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

2006 Final Season Summary

This 2006 Final Season Summary has been prepared for the Bonneville Power
Administration and the U.S. Army Corps of Engineers for the purpose
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EXECUTIVE SUMMARY

This study investigates predation by piscivorous waterbirds on juvenile salmonids (*Oncorhynchus* spp.) from throughout the Columbia River Basin. During 2006, study objectives in the Columbia River estuary, work funded by the Bonneville Power Administration, were to (1) monitor and evaluate previous management initiatives to reduce Caspian tern (*Hydroprogne caspia*) predation on juvenile salmonids (smolts); (2) measure the impact of double-crested cormorant (*Phalacrocorax auritus*) predation on smolt survival, and assess potential management options to reduce cormorant predation; and (3) monitor large colonies of other piscivorous waterbirds in the estuary (i.e., glaucous-winged/western gulls [*Larus glaucescens/occidentalis*]) to determine the potential impacts on smolt survival. Study objectives on the mid-Columbia River, work funded by the Walla Walla District of the U.S. Army Corps of Engineers, were to (1) measure the impact of predation by Caspian terns and double-crested cormorants on smolt survival; and (2) monitor large nesting colonies of other piscivorous waterbirds (i.e., California gulls (*L. californicus*], ring-billed gulls [*L. delawarensis*], American white pelicans [*Pelecanus erythrorhynchos*]) on the mid-Columbia River to determine the potential for significant impacts on smolt survival.

Our efforts to evaluate system-wide losses of juvenile salmonids to avian predation indicated that Caspian terns and double-crested cormorants were responsible for the vast majority of smolt losses to avian predators in the Columbia Basin, with most losses occurring in the Columbia River estuary. In 2006, East Sand Island in the Columbia River estuary supported the largest known breeding colonies of Caspian terns and double-crested cormorants in the world. The Caspian tern colony on East Sand Island consisted of about 9,200 breeding pairs in 2006, up slightly (but not significantly so) from the estimate of colony size in 2005 (8,820 pairs). There has not been a statistically significant change in the size of the Caspian tern colony on East Sand Island since 2000. Tern nesting success averaged 0.72 fledglings per breeding pair in 2006, significantly higher than in 2005 (0.37 fledglings per breeding pair), a year of poor ocean conditions. Despite the presumably higher availability of marine forage fishes in 2006, the proportion of juvenile salmonids in diets of Caspian terns (32% of prey items) averaged higher than in 2005 (23% of prey items) and 2004 (18% of prey items).

Steelhead smolts were particular vulnerable to predation by East Sand Island terns in 2006, with predation rates as high as 20% on particular groups of PIT-tagged fish reaching the estuary. Consumption of juvenile salmonids by terns nesting at the East Sand Island colony in 2006 was approximately 5.3 million smolts (95% c.i. = 4.4 – 6.2 million), significantly higher than the estimated 3.6 million smolts consumed in 2005, but still roughly 7 million fewer smolts consumed compared to 1998 (when all terns nested on Rice Island in the upper estuary). Caspian terns nesting on East Sand Island continue to rely primarily on marine forage fishes as a food supply, even in 2005 when availability of marine forage fishes declined due to poor ocean conditions. Further management of Caspian terns to reduce losses of juvenile salmonids would be implemented under the Caspian Tern Management Plan for the Columbia River Estuary; the Records of Decision (RODs) authorizing implementation of the plan were signed in November 2006. The ROD lists as the management goal the redistribution of approximately half of the East

Sand Island Caspian tern colony to alternative colony sites in interior Oregon and San Francisco Bay, California (USFWS 2006). Implementation of the management plan is stalled, however, because of the lack of appropriated funds.

The double-crested cormorant colony on East Sand Island consisted of about 13,740 breeding pairs in 2006, a record high estimate for size of this colony, up about 10% from the estimate in 2005 (12,290 pairs) and 2004 (12,480 pairs). Since our monitoring began in 1997, this cormorant colony has increased by about 275%. Nesting success in 2006 (1.92 fledglings per breeding pair) was up considerably from 2005 (1.38 fledglings per breeding pair), when it was comparatively low due to poor ocean conditions. Despite relatively low availability of marine forage fish in 2005, juvenile salmonids represented only ca. 2% of cormorant diets, compared with 23% of Caspian tern diets in the same year. Because of the low proportion of salmonids in the diet of East Sand Island cormorants during 2005, the estimate of total smolt consumption by cormorants (3.0 ± 1.0 million) was similar to that of East Sand Island Caspian terns (3.6 ± 0.3 million) in the same year; in 2004 the estimate of salmonid smolt consumption by East Sand Island cormorants (6.4 ± 2.0 million) exceeded the estimated consumption by East Sand Island terns (3.5 ± 0.3 million). In 2005, estimated losses of spring/summer (yearling) Chinook salmon, coho salmon, and steelhead smolts due to cormorant predation in the estuary were significantly less than losses due to Caspian tern predation, but losses of fall (sub-yearling) Chinook salmon due to cormorant predation were much greater than losses due to tern predation.

Data on diet composition and smolt consumption of double-crested cormorants nesting on East Sand Island (based on analysis of adult foregut samples) in 2006 are pending. A relative comparison of predation rates on juvenile salmonids between terns and cormorants in 2006 was, however, calculated based on smolt PIT tag recoveries on the two colonies. These data indicated that East Sand Island cormorants consumed more PIT-tagged salmonid smolts than did East Sand Island terns in 2006. PIT tags from all species of anadromous salmonids (i.e., Chinook salmon, coho salmon, sockeye salmon, steelhead, and sea-run cutthroat trout), from all run-types (fall, winter, summer, and spring), and from all ESUs were recovered on the East Sand Island cormorant colony in 2006. The numbers of PIT tags from the various salmonid species that were recovered on the cormorant colony were mostly proportional to the relative availability of PIT-tagged salmonids, suggesting that cormorant predation on salmonids was less selective than tern predation. In contrast, PIT tag recoveries on the East Sand Island tern colony indicated that steelhead were far more vulnerable to Caspian tern predation as compared to other salmonid species in the estuary.

If the cormorant breeding colony on East Sand Island continues to expand and/or the proportion of salmonids in cormorant diets increases, cormorant predation rates on juvenile salmonids may far exceed those of Caspian terns nesting in the estuary. Resource management agencies have not decided whether management of the large and expanding colony of double-crested cormorants on East Sand Island is warranted. Elsewhere in North America, management of double-crested cormorants has consisted primarily of lethal control (i.e., shooting of adults, egg oiling, and destruction of nests in trees). Nonlethal management approaches, such as relocating a portion of the colony to alternative colony sites along the coast of Oregon and Washington, seem more appropriate in the context of the cormorant colony on East Sand Island, which constitutes nearly 50% of the entire breeding population of the Pacific Coast subspecies *P. auritus albociliatus*. Pilot studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., decoys, audio playback systems) to relocate nesting cormorants have shown some promise; cormorants were attracted to nest and nested successfully (raised young to fledging) on Miller Sands Spit and Rice Island, two islands in the upper estuary where no successful cormorant nesting attempts have been recorded recently. In order to reduce cormorant predation on juvenile salmonids from the Columbia Basin, however, it will be necessary to relocate nesting cormorants to suitable habitat outside the Columbia River estuary. As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses will likely require additional research and NEPA analysis, including assessments of (1) population status of the Pacific Coast subspecies of double-crested cormorant, (2) available suitable nesting habitat for the subspecies outside the Columbia River estuary, and (3) the potential enhancement of salmonid recovery rates in the Columbia River Basin due to management of cormorants in the estuary.

The Caspian tern colony on Crescent Island in the mid-Columbia River has received comparatively little attention from salmon management agencies because of its relatively small size (ca. 500 nesting pairs, ca. 1/20th the size of the tern colony in the estuary) and low annual consumption of juvenile salmonids (ca. 500,000 smolts, ca. 1/10th the consumption of the tern colony in the estuary). In 2006, there were two breeding colonies of Caspian terns on the mid-Columbia River; about 448 pairs nested on Crescent Island (Rkm 510 in the McNary Pool), and about 110 pairs nested at a new colony site on Rock Island (Rkm 445 in the John Day Pool). The Crescent Island tern colony declined by 6% from 2005, but is still the largest Caspian tern colony on the Columbia Plateau and the third largest colony in the Pacific Northwest. The Rock Island Caspian tern colony increased dramatically from 2005, the first year that Caspian terns were known to nest there, when only 6 pairs nested. Nesting success at the Crescent Island tern colony was only 0.43 young fledged per breeding pair, down 22% from 2005, and the lowest nesting success so far recorded at this colony. The Rock Island Caspian tern colony completely failed in 2006 due to mink predation on eggs and chicks. At Crescent Island, salmonid smolts represented 63% of prey items in tern diets during 2006, similar to 2005. Although no diet data were collected at the Rock Island tern colony prior to nesting failure, 731 smolt PIT tags were recovered on the colony, indicating that salmonids were a significant part of the diet. A comparison of smolt PIT tags recovered from the Crescent Island and Rock Island tern colonies suggests that Rock Island terns consumed roughly 1/6th as many PIT-tagged salmonid smolts as Crescent Island terns. Total salmonid consumption by Crescent Island terns in 2006 was ca. 402,000 smolts, about 9% lower than in 2005 (ca. 442,000 smolts). However, the estimate of steelhead consumption by Crescent Island terns in 2006 was 56,000 smolts, up 22% from the 2005 estimate.

Based on smolt PIT tag recoveries on the Crescent Island Caspian tern colony, the predation rate on in-river migrants from the Snake River (all species and run types) was about 3.8% in 2006, down substantially from 7.5% in 2005. These predation rates were corrected for both the detection efficiency of PIT tags on-colony and the proportion of PIT tags ingested by terns that were subsequently deposited on-colony. As in previous years, predation rates on PIT-tagged steelhead smolts were greater than for other salmonid species. In 2006, ca. 12.3% of hatchery-reared, in-river steelhead smolts from the Snake River were consumed by Crescent Island terns, compared to about 7.5% of wild, in-river steelhead smolts. The comparable predation rates in 2005 were 18.6% and 14.5%, respectively (these predation rates are based on the number of PIT-tagged fish interrogated passing Lower Monumental Dam between 1 April and 31 July that were subsequently detected on the Crescent Island tern colony). Because fewer Snake River steelhead were transported around McNary Pool in 2006 compared to 2005, however, a larger proportion of the Snake River steelhead population was susceptible to predation from Crescent Island terns in 2006, which corresponds with the higher total consumption of steelhead by Crescent Island terns in 2006 compared to 2005.

In 2006, the double-crested cormorant colony on Foundation Island in the mid-Columbia River consisted of > 360 nesting pairs, about 14% larger than in 2005. The largest cormorant colony on the Columbia Plateau, however, was on Potholes Reservoir, where about 1,160 pairs nested in trees at the north end of the reservoir, also an increase over 2005. Colony counts suggest that both the number of cormorant colonies and the size of the cormorant breeding population on the Columbia Plateau are increasing. The limited diet data for Foundation Island cormorants suggest that juvenile salmonids represent 10-20% of the diet. Predation rates on smolts by cormorants nesting on Foundation Island, based on smolt PIT tags recovered on-colony, were roughly 1/3rd of those by Crescent Island terns, an increase compared to 2005, when cormorant predation rates were about 1/4th those of terns. Similar to predation by Crescent Island terns, Snake River steelhead were particular vulnerability to predation by Foundation Island cormorants in 2006. Unlike terns, however, Foundation Island cormorants also keyed in on groups of Chinook salmon (both yearlings and sub-yearlings) from the Walla Walla and Yakima rivers. Currently, there is very little evidence to suggest that cormorants nesting at the colony on Potholes Reservoir are affecting the survival of juvenile salmonids from the Columbia and Snake rivers, based on the paucity of PIT tags from Columbia Basin salmonid smolts recovered at the colony in recent years.

Compared to Caspian terns and double-crested cormorants, other piscivorous colonial waterbirds (i.e., California gulls, ring-billed gulls, American white pelicans) that nest on the Columbia Plateau are having little impact on the survival of juvenile salmonids from the Columbia and Snake rivers. Previous research indicated that fish, and salmonids in particular, constituted a very small proportion of the diet of California and ring-billed gulls nesting at up-river colonies in 1997 and 1998 (Collis et al. 2002). PIT tag recoveries during 2006 indicated that gulls nesting at up-river colonies on Miller Rocks and Three Mile Canyon Island, plus American white pelicans nesting on Badger Island, consumed between 0.04 and 0.61 PIT-tagged smolts per nesting adult. In contrast, Caspian terns and double-crested cormorants nesting at Crescent Island and Foundation Island consumed between 7.2 and 15.1 PIT-tagged smolts per adult. The size of some up-river gull colonies (> 10,000 breeding pairs on several islands) and the Badger Island pelican colony (> 500 pairs), however, exceeds that of the up-river tern and cormorant colonies and should be taken into account when evaluating over-all impacts on salmonid survival. Furthermore, the high variability in per-capita PIT tag consumption rates suggests that certain gull colonies (i.e., Miller Rocks) may pose a greater threat to survival of juvenile salmonids than others (i.e., Three Mile Canyon Island), and continued monitoring of certain gull colonies may be warranted.

In contrast to the gulls and pelicans nesting at up-river locations, previous research on glaucous-winged/western gulls nesting in the Columbia River estuary indicated that these birds consumed primarily fish (Collis et al. 2002). Gulls nesting on Rice Island (river km 34) also ate mostly riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice Island/Miller Sands Spit and East Sand Island, respectively. PIT tag studies have not been conducted on these colonies, nor have diet data been collected since 1998. As such, the current impact of gulls nesting at these estuary colonies on survival of salmonid smolts is unknown.

A system-wide assessment of avian predation on juvenile salmonids using the available data from recent years indicates that the most significant impact to smolt survival occurs in the estuary, with Caspian terns and double-crested cormorants nesting on East Sand Island combining to consume ca. 7-10 million smolts in 2004 and 2005. Although estimates of smolt consumption for East Sand Island cormorants in 2006 are not yet available, combined smolt losses to terns and cormorants nesting on East Sand Island in 2006 are in this range, if not higher. The PIT tag recovery data from 2006 corroborates this prediction. Estimated smolt losses to piscivorous birds that nest in the estuary are more than an order of magnitude greater than what has been observed on the mid-Columbia River. Additionally, when compared to the impact of avian predation on the mid-Columbia, avian predation in the estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids belonging to every ESA-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 to reach the ocean. For these reasons, management of terns and cormorants nesting on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other bird populations. The Caspian tern colony on Crescent Island may be an exception to this rule; management of this small, up-river colony may benefit certain salmonid stocks, particularly steelhead in low flow years.

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Table 9. Estimated predation rates on PIT-tagged salmonid smolts traveling through the McNary Pool by Crescent Island Caspian terns in 2006. Predation rates are based on the number of fish interrogated/tagged at Lower Monumental Dam (Snake River), Rock Island Dam (Upper Columbia River), and in the Middle Columbia River (fish released below the confluence of the Snake and Columbia rivers and upstream of McNary Dam). Predation rates on hatchery (H) and wild (W) smolts are listed separately. Sample sizes of interrogated/tagged fish less than 100 were not included. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (see Table 3) and deposition (see Table 5).

Table 10. Estimated predation rates (PR) on juvenile salmonids from the Snake River based on PIT-tagged smolts that were interrogated passing Lower Monumental Dam (N) from 1 April to 31 July, 2006 and subsequently detected on either the Crescent Island Caspian tern colony (CI te), the Rock Island Caspian tern colony (RI te), the Foundation Island double-crested cormorant colony (FI co), or the Badger Island American white pelican colony (BI pe). The number of PIT tags recovered from each bird colony is provided in parentheses. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (all colonies) and proportion of ingested PIT tags that are deposited on-colony (tern colonies only). Direct measures of detection efficiency and deposition rate were not available for the Rock Island tern colony and results obtained from the Crescent Island tern colony were used for calibration purposes. In all other cases, predation rate estimates are minimums.

Table 11. Estimated per capita consumption of 2006 migration year PIT-tagged salmonid smolts by Caspian terns (CATE), double-crested cormorants (DCCO), American white pelicans (AWPE), and California gulls (CAGU) nesting at various locations in the Columbia River basin. Tagged juvenile salmonids include steelhead, yearling Chinook salmon (Chin 1), sub-yearling Chinook salmon (Chin 0), unknown run Chinook salmon (Chin U), coho salmon, and sockeye salmon. Per capita values are corrected for PIT tag detection efficiency, but not deposition proportion, and are therefore minimums. In the case of the Rock Island tern colony and the Rice Island cormorant colony, detection efficiency data from a similar study location and bird colony were used, as no direct measures of detection efficiency were available for these two colonies in 2006. PIT tags were

recovered (R) from nesting colonies using different approaches; recoveries from the entire colony (C) or from plots within the colony (P). Estimates of per capita PIT tag consumption were estimated by dividing the total number of tags recovered (corrected for detection efficiency) by the number of breeding adults on the colony or in plots.

Table 12. Estimated predation rates (PR) on PIT-tagged salmonid smolts by East Sand Island Caspian terns in 2006. Predation rates are based on the number of PIT-tagged fish interrogated (I) passing the Juvenile Bypass Facility at Bonneville Dam (In-river) or released (Rel) from transportation barges below Bonneville Dam (Transported). Predation rates on hatchery-raised and wild smolts are listed separately. Sample sizes of interrogated/released fish less than 100 were not included. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (Table 4), but not for the proportion of ingested PIT tags that were deposited on-colony, and are therefore minimums.

Table 13. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants nesting on East Sand Island in the Columbia River estuary, 1999-2005. Data from 1999-2004 are based on the analysis of soft tissue and bones recovered from samples of stomach contents from adults. Data from 2005 are preliminary and include only the analysis of soft tissue. The data from 2006 are currently being analyzed and will be provided in a subsequent report.

Table 14. Percent biomass of identifiable prey in samples of regurgitated food from double-crested cormorants nesting on Foundation Island in the mid-Columbia River during 2-week sampling periods over the 2006 breeding season. All samples were regurgitations collected from beneath nesting trees.

Table 15. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants nesting on Foundation Island in the mid-Columbia River on three different sampling days in 2006. Data from 2006 are preliminary and include only the analysis of soft tissue.

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 [*Hydroprogne caspia*] nesting) and Rice Island (to discourage tern nesting), and allowed limited hazing of terns (i.e., prior to egg laying) attempting to nest on dredge spoil islands in the upper estuary during 2002–2006 (Map 1).

In September 2005, the tern colony area on East Sand Island was treated with herbicide, which helped suppress encroaching European beach grass and other invasive vegetation on the colony site over the winter. During 21-22 March 2006, habitat restoration on the Caspian tern colony site was accomplished by the U.S. Army Corps of Engineers. Similar to the previous four years, approximately 6.5 acres of bare sand nesting habitat was prepared at the eastern end of East Sand Island by disking and harrowing the colony site, and mechanical removal of encroaching grass and other invasive plants. Tern decoys (50) were deployed on the colony site and the entire colony site was marked off with wooden stacks to assist in efforts to census and monitor the colony. Severe winter storms destroyed all three of our observations blinds used to collect data at the tern colony during the 2005-2006 non-breeding season. These blinds were rebuilt and were in place at the north, southeast, and southwest ends of the colony by 1 April. On 7 April, a camp was set up on East Sand Island and was continuously occupied by two colony monitors throughout the tern breeding season. Limited gull (*Larus* spp.) control activities that were performed during the 1999 and 2000 nesting seasons to enhance prospects for tern colony restoration at East Sand Island were discontinued and have not been conducted during 2001-2006.

In previous years, work crews from NOAA Fisheries, Oregon Department of Fish and Wildlife, and USACE carried out various habitat modifications on the former tern colony site on Rice Island (e.g., fencing and flagging) prior to the breeding season to discourage terns from nesting there. This was not necessary in 2006 because the former colony site on Rice Island (ca. 7 acres) has become completely vegetated and was consequently unsuitable for tern nesting. In 2006, no hazing of terns to discourage nesting was conducted on Rice Island, but some passive measures (i.e., flagging) were deployed to discourage tern nesting at Miller Sands Spit and Pillar Rocks Sands (Map 1; see below).

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 2006 was estimated using aerial photographs of the colony taken near the end of the incubation period. The average of 2 direct counts of adult terns in aerial photos was corrected to estimate the number of breeding pairs on the colony using ground counts of incubating and non-incubating terns on 12 different plots within the colony area.

Nesting success (number of young raised per breeding pair) at the East Sand Island tern colony was estimated using aerial photos taken of the colony just prior to the fledging period. The average of 2 direct counts of all terns (adults and juveniles) in aerial photos was corrected to estimate the number of fledglings on the colony using ground counts of adults and fledglings on 12 different plots within the colony area. The confidence intervals for the number of breeding pairs and nesting success were calculated using a Monte Carlo simulation procedure to incorporate the variance of the multiple counts from the aerial photos and the plot counts used to generate these estimates.

In 2006, periodic boat-based and aerial surveys were conducted of the dredged material disposal islands in the upper estuary (i.e., Rice Island, Miller Sands Spit, Pillar Rock Sands; Map 1) to look for early signs of nesting by Caspian terns.

Results and Discussion: As was the case during 2001–2005, all nesting by Caspian terns in the Columbia River estuary occurred on East Sand Island in 2006. Figure 1 presents weekly average counts from the ground of adult Caspian terns on the East Sand Island colony during the 2006 breeding season. Based on the results from an aerial photo census, we estimate that 9,201 breeding pairs (95% c.i. = 8,460–9,942 breeding pairs) attempted to nest at East Sand Island in 2006. This estimate is 4% more than our best estimate of colony size at East Sand Island in 2005 (8,822 breeding pairs, 95% c.i. = 8,324–9,319 breeding pairs), but this change was not statistically significant. The East Sand Island tern colony represents the largest known breeding colony of Caspian terns in the world.

We estimate that 6,628 fledglings (95% c.i. = 5,963–7292 fledglings) were produced at the East Sand Island tern colony in 2006. This corresponds to an average nesting success of 0.72 young raised per breeding pair (95% c.i. = 0.63–0.81 fledglings/breeding pair), which was considerably higher than the estimate of nesting success for the East Sand Island tern colony in 2005 (0.37 fledglings/breeding pair, 95% c.i. = 0.31–0.44 fledglings/breeding pair), a year of poor ocean conditions.

On 27 April, 148 and 116 Caspian terns were observed loafing on upland areas of Miller Sands Spit and Pillar Rock Sands, respectively. As was observed in previous years, the behavior of these birds indicated an intention to nest at these two dredged material disposal islands, as evidenced by courtship displays, exchange of courtship meals, copulations, and digging of nest scrapes. Resource managers were informed of the situation and on 29 and 30 April a USACE contractor (Ken Larson) deployed stakes fixed with brightly colored flagging to dissuade terns from nesting at these incipient colony sites. These efforts were effective in dissuading terns from roosting or nesting at these two sites throughout the remainder of the 2006 nesting season. No other aggregations of Caspian terns were observed in upland areas at other dredged material disposal sites in the upper estuary (i.e., Rice Island, Puget Island) in 2006.

1.2.2. Columbia Plateau

Methods: The number of Caspian tern breeding pairs at Crescent Island (Map 2) was estimated by averaging 6 independent ground counts of all incubating terns on the colony 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 or aerial surveys of former Caspian tern breeding colony sites (i.e., Three Mile Canyon Island, Rock Island, Miller Rocks, Cabin Island, Sprague Lake, Banks Lake) were conducted during the 2006 nesting season to determine whether these colony sites had been re-occupied (Map 2). We also flew aerial surveys of the lower and middle Columbia River from The Dalles Dam to Rock Island Dam, the lower Snake River from the confluence to Lower Granite Dam, and Potholes Reservoir searching for new or incipient Caspian tern colonies.

In 2006, Caspian tern colonies in Potholes Reservoir (Map 2) were monitored by NOAA Fisheries (POC: Tom Good); the results from this separately funded study are provided in an appendix to this report.

Results and Discussion: Figure 2 presents weekly average counts of all adult Caspian terns on the Crescent Island colony during the 2006 breeding season. About 448 breeding pairs of Caspian terns attempted to nest at the Crescent Island colony in 2006, about 6% fewer pairs than in 2005. Similar to the East Sand Island tern colony, the number of Caspian terns nesting on Crescent Island has remained relatively constant since 1997 (Figure 3). We estimated that 191 young were fledged from the Crescent Island tern colony in 2006, or 0.43 young raised per breeding pair, the lowest nesting success ever recorded at the Crescent Island tern colony.

On 30 May an aerial survey of Rock Island (Map 2), one of the Blalock Islands in John Day Pool, revealed that about 110 pairs of Caspian terns were nesting on the island, along with about 200 pairs of ring-billed gulls. At that time the nesting Caspian terns were attending either eggs or chicks. This was a major increase in the size of this Caspian tern colony compared to 2005, when only about 6 pairs of Caspian terns attempted to nest on Rock Island (2005 was the first year when nesting Caspian terns were detected on Rock Island). On 18 June, however, when Rock Island was revisited, the Caspian tern colony had experienced complete nesting failure. There were no adult terns attending either eggs or chicks. The carcasses of tern and gull chicks that had died at least 10 days earlier were scattered over the colony. Although 35 dead adult ring-billed gulls were counted on the colony, no dead adult Caspian terns were found. One ring-billed gull carcass and 56 Caspian tern eggs were found cached in a hollow log located near the colony. This evidence suggests that the colony failure was caused by an American mink (*Mustela vision*). The mink nearly caused complete nesting failure for the ring-billed gull colony as well; only one chick survived and 5-10 pairs of ring-billed gulls had renested on the island and were sitting on eggs on 18 June.

With the exception of Rock Island, we found no evidence of Caspian terns attempting to nest at other potential colony sites along the lower and mid-Columbia River or the lower Snake River in 2006. An American mink disrupted tern nesting at Three Mile Canyon Island (Map 2) in 2000 and 2001, causing the colony to fail in both years. In 2001, Caspian terns were found nesting on Miller Rocks on the lower Columbia River just upstream of the mouth of the Deschutes River (Map 2); up to 20 breeding pairs attempted to nest on the edge of a large gull colony. We suspect that terns nesting on Miller Rocks in 2001 were failed breeders from the Three Mile Canyon Island colony. Cabin Island above Priest Rapids Dam (Map 2), where nesting Caspian terns have been previously recorded, was the site of a large ring-billed gull colony until the late 1990s, when USDA-Wildlife Services dispersed the colony by oiling eggs and disturbing nesting birds.

Caspian terns nested on Harper Island in Sprague Lake (approximately 50 miles east of Moses Lake on I-90; Map 2) in 2006. In late June, 12 adult terns and 7 one-egg nests were counted on colony. Based on surveys conducted at Harper Island earlier in the season, we suspect these were renesting attempts by failed breeders. In 2005, terns attempted to nest on Harper Island but failed.

During a survey of Banks Lake (just above Dry Falls Dam near Coulee City; Map 2) in late June, 38 adult terns were counted on Dry Falls Island. A total of 21 tern chicks and some nests with eggs were counted on Dry Fall Island during this survey. In 2005, terns were successful in hatching young on islands in Banks Lake. In 2006, we do not know whether any of the Caspian tern nesting attempts on Sprague Lake or Banks Lake were successful (i.e., resulting in fledged young).

Total numbers of Caspian terns nesting throughout the Columbia Plateau Region (including colonies in Potholes Reservoir) in 2006 was approximately 930 pairs (Table 1). This suggests that the number of Caspian terns nesting throughout the Columbia Plateau has remained about the same since 1997, when the number of breeding Caspian terns was estimated at ca. 1,000 breeding pairs (Collis et al. 2002; Figure 4).

1.2.3. Coastal Washington

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

Results and Discussion: Although Caspian terns were commonly observed foraging and roosting in Willapa Bay and Grays Harbor throughout the 2006 breeding season, no nesting attempts by terns were detected in either area. This suggests that suitable tern nesting sites (i.e., island sites that are unvegetated, above high high tide levels, 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 Caspian terns transport whole fish in their bills to their mates (courtship meals) and young (chick meals) at the breeding colony, taxonomic composition of the diet can be determined by direct observation of adults as they return to the colony with fish (i.e., bill load observations). Observation blinds were set up at the periphery of the tern colony on East Sand Island so that prey items could be identified with the aid of binoculars and spotting scopes. The target sample size was 350 bill load identifications per week. Fish watches at the East Sand Island tern colony were conducted twice each day, at high tide and low tide, to control for potential tidal and time of day effects on diet composition. Prey items were identified to the taxonomic level of family. We were confident in our ability to distinguish salmonids from non-salmonids and to distinguish among most non-salmonid taxa based on direct observations from blinds, but we did not attempt to distinguish the various salmonid species. The percent of the identifiable prey items in tern diets was calculated for each 2-week period throughout the nesting season. The diet composition of terns over the entire breeding season was based on the average of the percentages for the 2-week periods.

To assess the relative proportion of the various salmonid species in tern diets, we collected bill load fish near the East Sand Island tern colony by shooting Caspian terns returning to the colony with whole fish carried in their bills (referred to hereafter as "collected bill loads"). Salmonid bill loads were identified as either Chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), steelhead (*O. mykiss*), or unknown based on soft tissue or morphometric analysis. J. Fisher at the College of Oceanic and Atmospheric Sciences at Oregon State University provided verifications of salmonids collected as bill loads that were difficult to identify.

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

Results and Discussion: Of the bill load fish identified at the East Sand Island Caspian tern colony, on average 31% were juvenile salmonids (n = 5,549 bill loads). As in previous years, marine forage fishes (i.e., sardine, herring, and shad [Clupeidae], anchovies [Engraulidae], smelt [Osmeridae], and surfperch [Embiotocidae]) were prevalent (averaging 62% of all identified bill loads) in the diets of terns nesting on East Sand Island (Figure 5; Table 2). The proportion of the diet that was salmonids peaked at ca. 75% during the second week of May (Figure 6), approximately the same time as peak salmonid consumption was observed the previous two years. We estimate that Caspian terns nesting on East Sand Island consumed a total of 5.3 million juvenile salmonids in 2006 (95% c.i. = 4.4 – 6.2 million), a ca. 47% increase in smolt consumption compared to 2005 (best estimate = 3.6 million smolts, 95% c.i. = 3.0 – 4.2 million). Of the juvenile salmonids consumed in 2006, we estimate that 39% were coho salmon (best estimate = 2.1 million, 95% c.i. = 1.7 – 2.4 million), 26% were yearling Chinook salmon (best estimate = 1.4 million, 95% c.i. = 1.1 – 1.6 million), 18% were steelhead (best estimate = 1.0 million, 95% c.i. = 0.8 – 1.2 million), 16% were sub-yearling Chinook salmon (best estimate = 0.8 million, 95% c.i. = 0.7 – 1.0 million), and 1% were sockeye salmon (best estimate = 38,000, 95% c.i. = 30,000 – 45,000).

1.3.2. Columbia Plateau

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

Estimates of annual smolt consumption for the Crescent Island Caspian tern colony were calculated using a bioenergetics modeling approach (see Antolos et al. [2005] for a detailed description of model construction and input variables). We used a Monte Carlo simulation procedure to calculate reliable 95% confidence intervals for estimates of smolt consumption by terns at Crescent Island.

Results and Discussion: Juvenile salmonids were the most prevalent prey type for Caspian terns nesting on Crescent Island (63% of identifiable bill loads), followed by centrarchids (bass and sunfish, 16%) and cyprinids (carp and minnows, 14%; n = 3,199 bill loads; Figure 7). The proportion of salmonids in the diet was higher and with more short-term variability over the breeding season compared to that of terns nesting on East Sand Island in 2006. The salmonid portion of the diet peaked in late April and early May at more than 90% of identifiable prey items (Figure 8). Seasonal changes in the proportion of salmonids in the diet probably reflected changes in availability of hatchery-reared smolts near the colony in April and early May. We estimated that Caspian terns nesting on Crescent Island consumed 402,000 juvenile salmonids in 2006 (95% c.i. = 310,000 – 500,000), a ca. 9% decline in smolt consumption compared to 2005 (best estimate = 442,000, 95% c.i. = 340,000–550,000; Figure 9). Steelhead comprised an estimated 13.7% of the identifiable salmonid smolts, or roughly 56,000 fish. Per capita smolt consumption in 2006 (446 smolts per nesting tern across the breeding season) was similar to the previous year (464 smolts per nesting tern across the breeding season; Figure 10).

1.4. Salmonid Predation Rates: PIT Tag Studies

Each spring millions of downstream migrating juvenile salmonids are tagged with Passive Integrated Transponder (PIT) tags to gather information on their survival and behavior. Each tag contains a unique 14 digit alphanumeric code that provides data on the species of fish, run of fish (if known), release date, and release location, among other information. Each year, thousands of these PIT-tagged fish are consumed by colonial waterbirds and many of the ingested tags are subsequently deposited on piscivorous waterbird colonies throughout the Columbia River basin. The recovery of PIT tags on bird colonies can be used as a direct measure of predation rates on salmonid species listed under the Endangered Species Act (ESA) (Collis et al. 2001, Ryan et al. 2003, Antolos et al. 2005), and these data can be used to assess the relative vulnerability of various salmonid species, stocks, and rearing types to avian predators.

Previous estimates of predation rates based on PIT tag recoveries were considered minimums because not all tags consumed by birds are deposited on the nesting colony and not all tags deposited on the colony are detected. From 2004 to 2006, we have worked collaboratively with NOAA Fisheries (the agency responsible for PIT tag recoveries on bird colonies) to generate more accurate and defensible predation rate estimates based on PIT tag recoveries. This was accomplished by (1) physically removing tags from the Crescent Island tern colony, where PIT tag collision is believed to significantly reduce PIT tag detection efficiency; (2) systematically sowing test PIT tags with known tag codes on various bird colonies in order to directly measure PIT tag detection efficiencies; and (3) conduct experiments to measure on-colony deposition rates of ingested PIT tags by Caspian terns nesting on Crescent Island.

1.4.1. PIT Tag Collision

Methods: Throughout the course of each nesting season, PIT tags accumulate on the Crescent Island tern colony and their close proximity to one another causes tag signals to collide; this phenomenon renders some of the tags unreadable via electronic recovery methods, thereby decreasing on-colony tag recovery. One method of minimizing collision is to physically remove PIT tags from the tern colony (hereafter referred to as “hand removal”). To accomplish this, a six-person crew manually removed PIT tags from the Crescent Island tern colony on 9-11 August 2006. 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 across the colony were marked out and each transect was swept and raked twice. Once recovered, PIT tags were scanned using a handheld transceiver to determined tag functionality and all tag codes were recorded. Following the hand removal of tags from the colony, NOAA Fisheries used electronic equipment to detect tags (*in situ*) that were not removed by hand from the colony (see Ryan et al. 2003 for detailed description of NOAA Fisheries' PIT tag recovery methods).

Results and Discussion: We physically removed 6,679 PIT tags, 281 radio tags, 166 hydro-acoustic tags, and 24 floy tags – all tags that had been implanted in out-migrating juvenile salmonids – from the Crescent Island tern colony in 2006. Of the 6,679 PIT tags collected from the colony, 6,153 (92.1%) were still functional or readable. Tag codes were uploaded to the regional smolt PIT tag database (PTAGIS) and the owners of other fish tags (i.e., radio, hydro-acoustic, and floy tags) were notified, whenever possible. Using specially designed electronic equipment, NOAA Fisheries detected an additional 6,280 functional PIT tags on the tern colony following the hand removal effort. In total, 12,433 functional PIT tags were removed from or detected on (hereafter referred to as "recovered" tags) the Crescent Island tern colony following the 2006 tern breeding season. Of these functional tags, 6,855 were unique or newly recovered (i.e., tags not detected in past recovery efforts). Of these newly detected, functional tags, 5,189 (75.7%) were from smolts tagged and released during the 2006 migration year.

The number of functional PIT tags recovered at the Crescent Island tern colony in 2006 (n = 12,433) was the lowest number of tags recovered at that colony since collaborative tag recovery efforts began in 2004. In 2004 and 2005, a total of 29,438 and 22,856 functional tags were recovered from the Crescent Island tern colony, respectively. A combination of lower detection efficiency (see Section 1.4.2), a smaller tern colony (see Section 1.2.2), and a reduction in the number steelhead (a species of fish particularly vulnerable to tern predation) that were PIT-tagged and released into the Columbia River Basin in 2006 (see Section 1.4.4) likely account for reduced numbers of tags recovered at the Crescent island tern colony in 2006 relative to the previous two years.

1.4.2. Detection Efficiency

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

In 2006, we continued this approach by systematically sowing a total of 962 PIT tags on the Crescent Island tern colony on four discrete plots during four different occasions: (1) prior to the birds arrival on colony (24 March), (2) during egg incubation (13 May), (3) during chick fledging (29 June), and (4) once the birds had left the colony following the nesting season (26 July). Each discrete plot measured 5 m x 10 m and plots were located within the core colony area. Detection efficiency estimates were then analyzed relative to the release date and the release plot, thereby describing both temporal and spatial variation in detection efficiency.

At the East Sand Island tern colony we sowed 1,200 test PIT tags on three discrete plots (10 m x 10 m) on four different occasions: (1) prior to the birds arrival on colony (6 April), (2) during incubation (12 May), (3) during fledging (11 July), and (4) once the birds had left the colony following the nesting season (7 September).

Results and Discussion: Of the 962 test tags sown on the Crescent Island tern colony, 440 or 45.7% were subsequently detected on-colony in 2006 (Table 3). Detection efficiency ranged from as low as 12.1% for tags sown pre-season to as high as 96.7% for the tags sown post-season (Table 3). Average detection efficiency was estimated to be 42.9% (linear fit) during the nesting season (i.e., during the period when terns were observed on the colony and were ingesting PIT tags). Similar to data collected in 2004 and 2005, there was a positive association between the date when test tags were sown and detection efficiency ($R^2 = 0.6505$, $P = 0.002$), with those tags sown later in the nesting season more likely to be detected than tags sown earlier in the nesting season. Detection efficiency results suggest that PIT tags from early-migrating smolts that were deposited on the Crescent Island colony by terns are less likely to be detected on-colony as compared to PIT tags from late-migrating smolts.

Of the 1,200 test tags sown on the East Sand Island tern colony, 769 or 64.1% were subsequently detected on-colony. Detection efficiency ranged from 52.7% for tags sown during the incubation period to 75.3% for tags sown post-season (Table 4). Unlike Crescent Island, however, there was no evidence that detection efficiency increased as a function of when the tags were sown on the colony ($R^2 = 0.0693$, $P = 0.4084$). This result is similar to those described on East Sand Island in 2004 and 2005 (CBR 2005, 2006); suggesting that differences in detection efficiency are not related to when tags are deposited on the East Sand Island tern colony.

Detection efficiency on both the Crescent Island and East Sand Island tern colonies were the lowest recorded since 2004, when the project started using the strategy of sowing test PIT tags multiple times. Several factors may have contributed to the low detection efficiency values obtained in 2006: (1) severe storms that passed through the region during the 2006 breeding season removed (via wind and rain) an anomalously high number of tags, (2) NOAA Fisheries new electronic transceiver (new equipment for

2006) was less efficient than the older, previously used transceiver, (3) the presence of new, higher reader range PIT tags in the Columbia Basin (Biomark TX1400SST) resulted in higher collision rates, and (4) PIT tags are now accumulating on the East Sand Island tern colony to such an extent that collision problems similar to those formerly observed on the Crescent Island tern colony are causing lower detectability. Finally, with regard to Crescent Island, it is possible that someone else (researchers or even individuals seeking a profit) may have physically removed tags before our crews collected PIT tags on the island in early August. Measures will be taken in 2007 to address many of these possible factors. For example, a proportion of the test tags used to measure detection efficiency in 2007 will be the new, higher read range tags. Additionally, NOAA Fisheries is planning on modifying their antenna to increase detection efficiency. We will also search regional PIT tag databases in the unlikely event that someone else is removing tags from the Crescent Island colony without our knowledge and reusing them in other studies. Finally, we are working with NOAA Fisheries and the Corps of Engineers to find innovative ways to reduce PIT tag density on the East Sand Island tern colony by physically removing tags prior to the 2007 nesting season.

1.4.3. Deposition Rates

Methods: Not all smolt PIT tags consumed by terns are deposited on the nesting colony. Some proportion of the consumed PIT tags is regurgitated by terns while they are not on-colony, for example during flight or at off-colony loafing areas. Therefore, predation rate estimates based on on-colony PIT tag recoveries are still minimums, even after accounting for detection efficiency. From 2004 to 2006, we conducted experiments to measure on-colony deposition rates of PIT tags ingested by terns. First, we allowed terns to forage on PIT-tagged fish confined to net pen enclosures and then scanned for those tag codes at the colony following the nesting season. Secondly, we captured nesting adult terns on-colony and force fed them PIT-tagged fish and then scanned for those tag codes following the nesting season.

Two circular net pens (roughly 6 meters in diameter) were anchored in backwater areas of the Columbia River in 2006; one in Burbank Slough (approximately 11 kilometers northeast of Crescent Island) and one in Peninsula Slough (approximately 8 kilometers northeast of Crescent Island; Map 3). Two net pens were deployed in 2006 to investigate whether deposition rate of PIT tags is related to foraging location (i.e., distance from the colony). On 26 April, a total of 796 juvenile rainbow trout (*O. mykiss*) of two different size classes (small: mean = 10.5 cm fork length, SD = 1.26, n = 398; large: mean = 17.8 cm, SD = 1.29, n = 398) were PIT-tagged and placed in the Burbank Slough net pen. On 27 April, a total of 799 juvenile rainbow trout (*O. mykiss*) of two different size classes (small: mean = 11.4 cm fork length, SD = 0.97, n = 399; large: mean = 17.7 cm, SD = 0.96, n = 400) were PIT-tagged and placed in the Peninsula Slough net pen. All trout were certified disease free, triploids (sterile as adults) and were obtained from the Trout Lodge Hatchery, WA. After stocking, the net pens were monitored daily (8 to 15 hrs/day) to determine tern foraging behavior (i.e., arrival times, number of foraging attempts per bird, and duration of foraging bout) and foraging success (i.e., number of fish captured, size class of fish captured) from 28 April to 28 June 2006. Each net pen was covered with nylon mesh to prevent terns from foraging when observers were not present. The number of fish removed from each net pen was then recorded throughout the 62-day observation period. At the conclusion of the net pen study, all fish remaining in the net pen were rescanned to determine PIT tag retention rates (i.e., proportion of tagged trout that retained tags throughout the study period), a parameter needed to correct for the total number of PIT-tagged fish captured by terns. A deposition rate (DR) of PIT tags from fish removed by terns from the net pen was then calculated by dividing the number of net pen PIT tags recovered on Crescent Island (adjusted for detection efficiency) by the total number of net pen fish removed by adult terns (adjusted for retention rate).

Deposition rates were also estimated at the Crescent Island and East Sand Island tern colonies by force-feeding PIT-tagged trout to adult terns that were nesting at each colony. Breeding adult terns were captured near the peak of incubation (13-14 May and 28-29 May at Crescent Island and East Sand Island, respectively) by placing noose mats around active nests. Following capture, adult terns were force-fed one PIT-tagged juvenile rainbow trout by opening the bill, inserting the fish head-first into the esophagus, and gently massaging the fish down the esophagus. Each adult tern used in the experiment was then weighed, measured, color-banded, marked with bright pink dye on the breast (for easy on-colony identification) and immediately released back onto the colony. Following release, the presence/absence of each marked bird and the birds post-release behavior (e.g., actively attending a nest site) was observed from a blind until nightfall or until all of the force-fed birds were observed on the colony. A deposition rate (DR) of PIT tags from force-fed fish at each colony was then calculated by dividing the number of force-fed tags recovered on the colony (adjusted for detection efficiency) by the total number of force-fed tags used in the experiment.

Results and Discussion: Terns began foraging on fish within the Burbank and Peninsula slough net pens 10 and 14 days after stocking, respectively. During the 62-day study period, 41 and 39 PIT-tagged trout were removed by Caspian terns from the Burbank Slough net pen and the Peninsula Slough net pen, respectively. Caspian terns made a total of 62 attempts to capture fish (i.e., plunge dives into the net pen) at the Burbank Slough net pen and 101 attempts at the Peninsula Slough net pen. Of the 41 fish captured at Burbank Slough, 16 were immediately consumed and 25 were observed in the tern’s bill as it flew back toward the Crescent Island colony. Of the 39 fish captured at Peninsula Slough, 8 were immediately consumed and 31 were observed in the tern’s bill as it flew back toward the Crescent Island colony. In total, 80 PIT-tagged fish (50 large and 30 small) were successfully removed by terns from the Burbank and Peninsula slough net pens in 2006.

Of the 41 PIT-tagged trout captured by Caspian terns at the Burbank Slough net pen, 8 were detected on the Crescent Island tern colony (Table 5). Of the 39 PIT-tagged trout captured at the Peninsula Slough net pen, 8 were detected on the Crescent Island tern colony (Table 5). The estimated deposition rate for PIT tags from the net pen fish was 60.0% (Table 5), after accounting for PIT tag retention (98.4%) and on-colony detection efficiency (33.9%; based on a weighted linear fit of detection efficiency estimates during the time period when PIT-tagged fish were removed from the net pens). No statistical difference in deposition rates was detected between fish removed from the Burbank Slough (59.4%) and Peninsula Slough (60.6%) net pens in 2006 (P = 0.9272, based on results of a Chi-square test).

Fifty-nine adult terns from Crescent Island were captured and force-fed PIT-tagged trout in 2006. Of the 59 terns, 58 (98%) successfully ingested the PIT-tagged fish and six of these terns (10.0%) already had a PIT-tagged fish in their digestive tract at the time of capture (i.e., from a PIT-tagged salmonid caught in the wild by the tern prior to our capture of the tern). The capture and handling of terns at Crescent Island resulted in some tern egg loss. In total, 28 eggs were damaged during this research activity, the majority due to depredation by California gulls (n = 11 eggs) or by terns crushing eggs while in the noose mats (n = 11 eggs). No adult terns were injured during this experiment. Of the 58 successfully force-fed terns, 16 PIT tags (27.6%) were recovered on-colony following the breeding season. On-colony detection efficiency was estimated to be 34.6% during this time period, based on a sample of test tags (n = 240) released on-colony that same day. Based on this DE, we estimated that 79.7% of the force-fed PIT tags were deposited on the Crescent Island tern colony (Table 6).

Forty-five terns from East Sand Island were captured and subsequently force-fed PIT-tagged trout in 2006. In total, 43 (96%) successfully ingested the fish and were released. A total of 48 tern eggs were lost as a result of this research activity, the majority (n = 39 eggs) due to depredation by glaucous-winged/western gulls. One of the adult terns captured on East Sand Island was injured and was retained for rehabilitation and later successfully released. Of the 43 successfully force-fed terns, 26 PIT tags (60.5%) were recovered on-colony following the breeding season. On-colony detection efficiency was estimated to be 64.1% during the breeding season. Based on this DE, we estimated that 94.3% of the force-fed PIT tags were deposited on the East Sand Island tern colony (Table 6).

Summary: We have completed three consecutive years (2004-2006) of deposition rate studies on Crescent Island terns. In total, 265 trout were used to calculate deposition rates from net pen experiments (Table 5). Results of net pen trials suggest that Crescent Island terns deposit an average of 63.4% (± 4.9%, 95% confidence interval) of consumed tags on-colony. There was no evidence to suggest deposition rates obtained via net pen studies differ significantly among years (P = 0.9217, based on a Chi-square test) or between locations (P = 0.9272, based on a Chi-square test). A total of 117 trout were used in force-feeding experiments on Crescent Island in 2005 and 2006. Results indicated that terns deposited an average of 76.4% (SD = 4.6) of force-fed PIT tags on-colony (Table 6). Here, too, no statistical difference between years was detected (P = 0.7638, based on a Chi-square test). Pooled comparisons between net pen derived DR and force-fed derived DR were also not statistically different (P = 0.2885, based on Chi-square test). Finally, an additional 74 fish were force-fed to terns nesting on East Sand Island in 2005 and 2006. On average, 90.0% (SD = 6.1) of the PIT tags were deposited on-colony. Similar to terns on Crescent Island, no statistical difference between years was detected (P = 0.7639, based on a Chi-square test).

Although no statistical difference was evident between estimates of deposition rates derived from net pen vs. force-feeding experiments, we are inclined to use results from the net pen studies alone to calibrate current and future predation rate estimates for off-colony deposition. This is because PIT-tagged fish captured by terns at net pens more closely mimic the natural process of a tern capturing and depositing a PIT tag on-colony. Furthermore, results obtained via force-feeding trials do not account for gull kleptoparasitism (gulls stealing fish from terns) – a known cause of off-colony PIT tag depositions – because force-fed PIT-tagged trout can not be stolen by a gull. Conversely, net pen captured trout are presumably exposed to the full range of on- and off-colony deposition scenarios. Finally, we have no way of determining how the capturing and handling of adult terns influences the subsequent deposition process; although post-release behavioral data suggest that force-fed birds return to the colony and resume normal breeding behavior following release, the stress of capture and handling may cause them to remain on the colony more than is typical.

Despite the advantages to using deposition rates obtained from net pen generated data, we acknowledge that some assumptions (or unknowns) remain regarding how representative net pen derived deposition rates are relative to the naturally consumed PIT-tagged fish they aim to mimic. For example, (1) net pen fish were not consumed throughout the entire tern nesting season, (2) there is no way to determine how many individual terns used the net pen(s) in a given year or location (a possible bias if deposition rates vary among individual terns and only a few utilized the net pen), and (3) net pen data is available from only two different foraging locations in McNary Pool. Regardless of these unknowns and assumptions, we feel little additional benefit can be realized by continuing these studies in the future. Data obtained throughout this three year study produced consistent, repeatable results from fish of the same family (i.e., salmonids) and size range (100 to 190 mm) as those that Caspian terns consume in the wild. We are convinced that the results of the net pen experiments yield the most reliable correction factor for PIT tag derived estimates of tern predation rates.

1.4.4. Predation Rate Estimates

Methods: In collaboration with NOAA Fisheries (POC, Brad Ryan), we have been using PIT tag recoveries on bird colonies to evaluate the relative vulnerability of various salmonid species and stocks to bird predation. Preliminary analyses of the tags recovered from the Crescent Island and East Sand Island Caspian tern colonies in 2006 are presented here. These data will be analyzed in greater depth – including a multi-year synthesis – in the project's Final Report, in NOAA Fisheries' Annual Reports, and in articles published in peer-reviewed scientific journals that are currently in preparation in collaboration with NOAA Fisheries.

We queried the regional PIT tag database (PTAGIS) on 8 November 2006 to acquire data on the species of fish, run of fish (if known), origin of fish (hatchery, wild, or unknown), tagging date, tagging location, and in-river interrogations for all PIT-tagged fish released into the Columbia River Basin in 2006. We measured predation rates on different salmonid species, run types, and stocks (as defined by NOAA Fisheries' Evolutionarily Significant Units or ESUs). For Caspian terns nesting on Crescent Island, ESU or stock-specific predation rates were generated for PIT-tagged fish migrating in-river past Crescent Island (i.e., excludes all PIT-tagged smolts captured at dams on the lower Snake River and transported around Crescent Island). Predation rate estimates do not account for mortality that took place between the fish's release location and the detection site (i.e., the tern colony) and, as such, under-estimate predation rates because the numbers of smolts susceptible to tern predation are inflated to an unknown degree.

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

All predation rate estimates presented here for Crescent Island and East Sand Island terns were corrected for on-colony PIT tag detection efficiency, based on the results of PIT tag detection efficiency studies presented above (see Section 1.4.2). Results for Crescent Island terns are also corrected for PIT tag deposition rates based on net pen studies (see Section 1.4.2). We used the weighted monthly average derived from the passage timing of smolts at each interrogation site to calculate on-colony detection efficiency based on the linear fit of detection efficiency as a function of deposition date. This approach ensured that the detection efficiencies used to correct PIT tag recovery rates for particular smolt runs were adjusted for the differences in timing of peak out-migration among various runs. Because no temporal trend was evident from test tags sown on East Sand Island, we used the average detection efficiency estimate of 64.1% for all runs, regardless of timing.

Results and Discussion: Approximately 2 million PIT-tagged fish were released into the Columbia River Basin in 2006. The majority of these fish were released into the lower Snake River (1.57 million), followed by the Middle Columbia River (0.24 million) and Upper Columbia River (0.16 million). The smallest numbers of PIT-tagged fish were released into the lower Columbia River (0.01 million) and the Willamette River (0.01 million), which limits the usefulness of PIT tag recoveries on bird colonies for determining the relative vulnerability of fish originating from these two river systems. Of the 2 million PIT-tagged fish released in the basin, 77.8% were Chinook salmon, 17.8% steelhead, 3.8% coho salmon, 0.5% sockeye salmon, and the remaining 0.1% other salmonid species (e.g., sea-run cutthroat). Most of the PIT-tagged fish were of hatchery origin (83.6%), although wild origin smolts of many different species and run-types were present. Interestingly, steelhead made up a much smaller proportion of the tagged population in 2006 (ca. 17.8% or 0.36 million) relative to 2005 (ca. 40.9% or 0.76 million), a result that may have contributed to the smaller numbers of tags deposited on tern colonies in 2006 (see Section 1.4.2).

Crescent Island Caspian terns – We estimate that 1.4% (n = 21,273) of the in-river migrating PIT-tagged juvenile salmonids released upstream of McNary Dam were deposited on the Crescent Island tern colony in 2006. Similar to data collected in 2004 and 2005, Snake River steelhead were the most vulnerable species to predation by Crescent Island terns in 2006, with estimated predation rates of 7.3% and 2.2% for in-river steelhead of hatchery and wild origin, respectively (Table 7). Snake River steelhead were from five different spawning populations and predation rates on these populations ranged from 0.3% to 9.7%, indicating high stock-specific variability within this ESU (Table 8). Hatchery-raised steelhead from the Snake River were particular vulnerable to predation by Crescent Island terns, with predation rates on these fishing being more than double that of their wild counterparts (Tables 7 and 8). This marks the third consecutive year in which predation on hatchery-raised steelhead exceeded that of wild steelhead. The next most vulnerable ESU to predation by Crescent Island terns in 2006 was the Middle Columbia River and the Upper Columbia River steelhead ESUs, with estimated predation rates on wild steelhead of 1.0% and 1.9%, respectively (Table 7). Estimated predation rates by Crescent Island terns on all other listed/protected ESUs in 2006 were negligible (Table 7).

Reach-specific analysis of PIT tag data also indicate that steelhead from the Snake River, Middle Columbia River, and Upper Columbia River ESUs were the most vulnerable to Crescent Island terns in 2006, compared to other salmonid species and run-types in the Columbia River Plateau (Table 9). Reach-specific predation rates indicate that Crescent Island terns consumed 7.6%, 2.1%, 3.8% of the wild, in-river steelhead smolts belonging to the Snake River, Upper Columbia River, and Middle Columbia River ESUs, respectively (Table 9). After steelhead, Chinook and hatchery-raised sockeye smolts from the Snake River were the most vulnerable to predation by Crescent Island terns (Table 9), although the sample size for hatchery-raised sockeye passing Lower Monumental Dam was relatively small (n = 574).

Over-all, predation rates by Crescent Island terns on PIT-tagged smolts were considerably lower in 2006 relative to 2005 and, especially, 2004 (Figure 11). For example, estimated predation rates in 2004 were 35.5%, 6.2%, and 6.5% for steelhead (hatchery and wild combined) from the Snake River, Upper Columbia River, and Middle Columbia River, respectively (with corrections for detection efficiency and deposition rate). The smaller size of the Crescent Island tern colony in 2006 (ca. 6% reduction from 2005 and a 15% reduction from 2004) is one factor contributing to lower overall predation rates. In addition, evidence from the last three years of research suggests that predation on steelhead smolts is reduced in years of high river flows (Antolos et al. 2005; CBR 2005, 2006) and/or when large numbers of steelhead migrate past Crescent Island in a relatively short period of time (due to a predator swamping/prey density effects; CBR 2006). These and other potential factors affecting differences in predation rates will be investigated via new research approaches to be implemented in 2007-2009.

Compared to other piscivorous waterbirds that nest on the Columbia Plateau, Crescent Island terns had the greatest impact on survival of PIT-tagged smolts in 2006 (Table 10). Additionally, Crescent Island terns had the highest per-capita consumption rate of PIT-tagged juvenile salmonids among all the piscivorous waterbirds colonies investigated as part of this study (Table 11).

Some of the estimated predation rates by Crescent Island terns on certain salmonid ESUs are unexpectedly high and may be a cause for concern, especially for the Snake River steelhead ESU. It is important to consider, however, that these predation rates apply only to the in-river component of each ESU, and do not include the component that was transported past Crescent Island (Figure 12). For the Snake River ESUs, the in-river migrants were a small fraction of the overall ESU, because the majority of smolts were transported around McNary Pool in barges and therefore are unavailable to Crescent Island terns. For example, 75.6% of all juvenile steelhead and 60.9% of all juvenile yearling Chinook from the Snake River were transported around McNary Pool in 2006 (NOAA 2006). Unlike juvenile salmonids from the Snake River, smolts originating from the Upper Columbia River are not collected for transportation around McNary Pool, making the Upper Columbia River salmonid runs more susceptible to avian predators in McNary Pool. As such, the overall impact of predation by Crescent Island terns on survival of smolts from the Upper Columbia River steelhead ESU is likely similar to or greater than tern predation impacts on the Snake River steelhead ESU (Antolos et al. 2005; CBR 2005, 2006), contrary to reach-specific predation rates on in-river migrants.

Rock Island Caspian terns – Of the PIT-tagged fish released into the Columbia River basin upstream of John Day Dam (excluding transported fish) in 2006, < 0.1% (n = 731) were physically recovered on the Rock Island Caspian tern colony following the nesting season. No direct measure of detection efficiency was available for Rock Island in 2006, as test PIT tags were not sown on that colony. If one assumes, however, that both PIT tag detection efficiency and deposition rate of Rock Island terns was similar to that of Crescent Island terns, Rock Island terns consumed roughly 1/6 th as many PIT-tagged smolts (n = 3,517) as Crescent Island terns (n = 21,273) in 2006. This difference is associated with the difference in the size of the two colonies (110 pairs on Rock Island compared to 448 pairs of Crescent Island) and the fact that terns abandoned Rock Island (due to a mammalian predator) in early June (two months earlier than Crescent Island terns). Of the 731 tags detected on Rock Island, the majority (62.8% or 459 tags) were from steelhead, followed by yearling Chinook (15.0% or 111 PIT tags). PIT tags from sub-yearling Chinook were notably scarce on the Rock Island tern colony (6.4% or 47 tags), a finding consistent with the terns premature abandonment of the colony and the later migration timing of sub-yearling Chinook relative to other smolts. Regardless, Rock

Island terns had a similar impact on survival of PIT–tagged smolts as did double-crested cormorants nesting on Foundation Island (Table 10), and the second highest per-capita consumption rate of PIT-tagged smolts among all the piscivorous waterbirds colonies investigated as part of this study (Table11).

East Sand Island Caspian terns – Of the approximately 2 million PIT-tagged fish (this includes both in-river and transported fish) released into the Columbia River basin in 2006, 1.3% (n = 26,134) were recovered on the East Sand Island tern colony. This proportion increases to 2.0% (n = 40,771) once PIT tag detection efficiency corrections are made. Similar to the Crescent Island tern colony, steelhead were the most vulnerable to predation by terns nesting on East Sand Island in 2006 (Table 12). Predation rates as high as 20.0% were observed for hatchery steelhead interrogated passing Bonneville Dam; predation rates on wild steelhead were in excess of 10.0% for both transported and in-river migrants (Table 12). Hatchery-raised coho salmon smolts were the next most vulnerable to predation by East Sand Island terns (3.8%), followed by yearling Chinook salmon (ca. 2.9%; Table 12). Similar to predation by Crescent Island terns, hatchery-raised smolts were generally more vulnerable to predation by East Sand Island terns than their wild counterparts (Table 12).

The per-capita consumption rate of PIT-tagged juvenile salmonids by East Sand Island terns (2.21 tags per breeding adult) was less by a factor of 3 to 7 compared to terns and cormorants that nest on the Columbia Plateau (7.23 - 15.08 tags per breeding adult) and similar to the per-capita consumption of PIT-tagged smolts by East Sand Island cormorants (2.22 tags per breeding adult; Table11).

Finally, it is worth noting that estimates of predation rates based solely on PIT tag recovery data (i.e., the proportion of available PIT-tagged fish consumed by terns nesting at a particular colony) are not the same as estimates of the number of smolts belonging to a particular ESA-listed ESU that are taken by terns nesting at a particular colony. Accurate data on the abundance of smolts belonging to particular salmonid ESUs in a given river segment are needed to derive consumption estimates from predation rates based on PIT tag recoveries. We are currently working with NOAA Fisheries to generate abundance estimates for smolts in the Snake River and anticipate preliminary data will be available in 2007. Until such estimates are available, predation rates based on PIT tag recoveries on-colony indicate the relative vulnerability of various salmonid species and stocks within a given year, but do not provide precise estimates of the numbers of ESA-listed smolts that are annually consumed by populations of Caspian terns or other avian predators.

1.5. Dispersal and Survival

Methods: In 2006, adult Caspian terns were banded at two colonies in the Columbia Basin, East Sand Island and Crescent island; fledgling Caspian terns were banded at three breeding colonies in the Columbia Basin, East Sand Island, Crescent Island, and Goose Island. These banding efforts are part of our continuing objective to measure survival rates, post-breeding dispersal, and movements among colonies for Caspian terns in the

Pacific Coast population. Adult and fledgling terns were banded with a federal numbered metal leg band and two plastic, colored leg bands on one leg and a plastic leg band engraved with a unique alphanumeric code on the other.

As part of this study, tern chicks that were near fledging were banded at East Sand Island (n = 427), Crescent Island (n = 71), and Goose Island (n = 60) in Potholes Reservoir, Moses Lake, WA. Tern chicks were captured on-colony by herding flightless young into holding pens. Adult terns were captured at East Sand Island (n = 45) and Crescent Island (n = 59) for banding using noose mats placed around active nests. Once captured, terns were immediately transferred to holding crates until they were banded and released. Tern banding operations were conducted only during periods of moderate temperatures to reduce the risk of heat stress for captive terns.

Terns that were color-banded in previous years (2000–2005) were re-sighted on various breeding colonies by researchers throughout the 2006 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 2006, 173 and 103 previously-banded Caspian terns were re-sighted at the East Sand Island colony and the Crescent Island colony, respectively. All 276 banded terns were identified such that the banding year, age class when banded (i.e., adult or chick), and banding location were known. Of the 173 banded individuals that were re-sighted at East Sand Island, 143 (83%) were banded in the Columbia River estuary (61 as adults and 82 as chicks), 24 (14%) were banded at the former ASARCO colony in Commencement Bay, WA (19 as adults and 5 as chicks; Map 2), and 6 (3%) were banded at Crescent Island (3 as adults and 3 as chicks). Of the 103 banded terns that were re-sighted at the Crescent Island colony, 93 (90%) were banded at Crescent Island (78 as adults and 15 as chicks), 2 (2%) were banded at Solstice Island in Potholes Reservoir (both as chicks), 7 (7%) were banded at East Sand Island (all as chicks), and 1 (1%) was banded at the former ASARCO colony (as a chick).

In addition to these re-sightings, there were 45 banded terns that had been banded at either East Sand Island, Crescent Island, or Solstice Island that were resighted at Goose Island (30), at the colony in Naval Base Kitsap in Bremerton, WA (4; Map 2), and at Dungeness Spit, WA (11; Map 2). Of these, 6 were banded as adults and 39 were banded as chicks.

The age at first reproduction for Caspian terns was reported to be 3 years of age by Gill and Mewaldt (1983). The large cohorts of fledgling Caspian terns produced at the East Sand Island colony in 2001, 2002, and 2003 led to predictions that the East Sand Island colony would increase rapidly in size due to recruitment of these large cohorts into the breeding population within 3 - 4 years. Our observations indicate that the first breeding attempts by terns banded as chicks in 2001 and 2002 were confirmed at East Sand Island and Goose Island in 2006, suggesting that for this population the age of first reproduction may be 4 - 5 years of age. This delay in onset of breeding, compared to what has be reported in the literature (i.e., Gill and Mewaldt 1983), may be one of the reasons why the

East Sand Island tern colony has remained stable in size despite the large cohorts of fledglings produced at the colony during 2001-2003. Other potential factors responsible for the stable population size at the East Sand Island tern colony in recent years include (1) lower than expected survival rates for young terns prior to recruitment into the breeding population and (2) terns fledged from East Sand are nesting at locations other than their natal colony.

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

1.6. Monitoring and Evaluation of Management

1.6.1. Nesting Distribution

All Caspian terns that nested at the former colony site on Rice Island shifted to the restored colony site on East Sand Island during the three-year period 1999–2001. Because of active management, all Caspian terns nesting in the Columbia River estuary have used East Sand Island during 2001-2006 (Figure 13). Habitat restoration/improvement, social attraction (tern decoys and audio playback systems; see Kress 2000, Kress and Hall 2002, Roby et al. 2002), and gull control at the East Sand Island colony site were successful in attracting terns to breed there and provided suitable nesting habitat for all terns that formerly nested on Rice Island. Efforts to reduce available nesting habitat on Rice Island were successful in gradually reducing the area used by nesting terns (Figure 14). Furthermore, efforts to dissuade prospecting terns at other dredge disposal sites (e.g., Miller Sands Spit, Pillar Rock Sands) have prevented the formation of incipient tern colonies in the upper estuary, where predation impacts on smolts are known to be high. The number of Caspian terns nesting in the Columbia River estuary has remained relatively constant since 1998 (Figure 13).

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

1.6.2. Diet and Salmonid Consumption

Caspian terns nesting on East Sand Island continue to rely primarily on marine forage fishes as a food supply (Table 2, Figure 15), even in 2005 when availability of marine forage fishes declined due to poor ocean conditions. Caspian terns nesting on East Sand Island in 2004 had the lowest average percentage of salmonids in their diet (17%) and terns nesting on Rice Island in 2000 had the highest percentage of salmonids in their diet (90%; Table 2). From 2000-2004, we observed a decline in the percentage of the diet that was salmonids for terns nesting on East Sand Island, followed by an increase in the salmonid percentage in 2005 and 2006 (Figure 16). In general, juvenile salmonids were more prevalent in the diets of Caspian terns nesting in the Columbia River estuary during April and May, and salmonids declined in the diet during June and July. The one exception to this trend was at Rice Island in 2000, when the proportion of salmonids in the diet remained high (over 80%) for the entire breeding season.

The major difference in diets of Caspian terns nesting at colonies in the estuary separated by only 26 km (Table 2, Figure 15) suggests that the terns foraged primarily in proximity to their nesting colonies, instead of commuting longer distances to favored or traditional foraging sites. The success of tern colony relocation as a means to reduce consumption of juvenile salmonids was contingent on the terns foraging opportunistically and adapting their foraging behavior to local conditions near the colony.

Compared to the estimate of total consumption of juvenile salmonids by Caspian terns in the estuary during 1998 (12.4 million), when all Caspian terns nested on Rice Island, consumption of juvenile salmonids by all Caspian terns nesting in the Columbia River estuary was lower by approximately 34%, 53%, 48%, 66%, 72%, 71%, and 57% in 2000, 2001, 2002, 2003, 2004, 2005, and 2006, respectively (Figure 17). Per capita smolt consumption has also declined since the study began in 1997 (Figure 18); in 2006 per capita smolt consumption (288 smolts [nesting tern]$^{-1}$ [breeding season]$^{-1}$) declined 63% from the highest rate previously measured (777 smolts [nesting tern]$^{-1}$ [breeding season]$^{-1}$ in 1999). These declines in losses of juvenile salmonids to Caspian tern predation coincided with the shift of breeding terns from Rice Island to East Sand Island and improved ocean conditions, which enhanced the availability of marine forage fish near East Sand Island.

Caspian terns nesting on East Sand Island in 2006 still consumed an estimated 5.3 million juvenile salmonids (95% c.i. = 4.4 – 6.2 million smolts), with some ESA-listed stocks suffering significant losses to tern predation (Ryan et al. 2001a; Ryan et al. 2001b; Ryan et al. 2003). Nevertheless, a conservative estimate of the reduction in losses of juvenile salmonids to Caspian tern predation in the estuary due to this management action is on average 7.5 million smolts per year over the last 6 years, or ca. 45 million fewer smolts consumed by terns after the colony relaocation. This large reduction in smolt losses was primarily due to a reduction in the number of sub-yearling Chinook salmon consumed, although smaller reductions in the consumption of steelhead and coho salmon smolts also occurred (Figure 19). To achieve further reductions in consumption of juvenile salmonids by Caspian terns in the estuary, however, it will be necessary to reduce the size of the

East Sand Island tern colony by relocating a portion of the colony to alternative sites outside the estuary.

1.6.3. Nesting Success

Our results indicate that relocating the tern colony from Rice Island to East Sand Island enhanced the nesting success of Caspian terns nesting in the Columbia River estuary. Average nesting success of Caspian terns on East Sand Island in 1999–2006 (0.92 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 20). 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 sufficient to compensate for annual adult and subadult mortality. Average nest density, which ranged from 0.25 to 0.78 nests/m^2 on Rice Island, and from 0.26 to 0.62 nests/m^2 on East Sand Island (Figure 21), was not apparently related to nesting success at either colony.

The relatively high nesting success of Caspian terns on East Sand Island in 2001–2004 was reflected in similarly high nesting success among double-crested cormorants and glaucous-winged/western gulls nesting on East Sand Island. These piscivorous colonial waterbirds all benefited from strong coastal up-welling and associated high primary and secondary productivity along the coast of the Pacific Northwest, particularly in 2001 (Emmett et al. 2006). The favorable ocean conditions have been linked to the regime shift associated with the Pacific Decadal Oscillation (PDO), which was expected to ensure relatively high availability of marine forage fishes near the mouth of the Columbia River for at least the next decade. Other climatic events (e.g., El Nino/Southern Oscillation, global warming) also influence ocean conditions, however, and availability of marine forage fishes may not remain relatively high compared to the 1980s and 1990s (Brodeur et al.2003; Emmett 2003). Ocean conditions during 2004-2006 were not as good as during 2001-2003 (W. Peterson, pers, comm.), and this seems to be reflected in lower productivity at the East Sand Island Caspian tern colony. In 2005 in particular, East Sand Island terns experienced the lowest productivity we have measured since terns started nesting there in 1999; productivity was comparable to that observed on Rice Island in 1998 and 1999. This agrees with reports of poor ocean conditions and widespread seabird nesting failure along the coast of the Pacific Northwest in 2005.

SECTION 2: DOUBLE-CRESTED CORMORANTS

2.1. Nesting Distribution and Colony Size

2.1.1. Columbia River Estuary

Methods: In order to estimate the size of the double-crested cormorant colony on East Sand Island in 2006, high resolution aerial photography of the colony was taken late in the incubation period. Counts of the number of stick nests within delineated boundaries of the breeding colony were conducted by staff in the Survey, Mapping, and Photogrammetry Department at the Bonneville Power Administration. In addition, researchers from Oregon State University proofed the count of stick nests in the photography to confirm the estimate of numbers of breeding pairs in 2006. Counts from aerial photography also provided an assessment of habitat use and distribution of nesting cormorants on East Sand Island in 2006.

Boat-based surveys of eight navigational markers near Miller Sands Spit (river km 38; Map 1) were conducted 4 - 9 times monthly from early April through late July in 2006. Because nesting chronology varied among the different channel markers, the number of nesting pairs at each marker was estimated using the greatest number of attended nests observed on each of the markers throughout the season. Any well maintained nest structure attended by an adult and/or chicks was considered active. To minimize impacts to nesting cormorants (i.e., chicks sometimes jump from nests into the water when disturbed), we did not climb the navigational markers and check nests to estimate productivity.

Monthly boat-based surveys of the Astoria-Megler Bridge (Map 1) were conducted from May through July in 2006. Our vantage point on the water enabled us to get an exact count of the number of attended nests on the underside of the bridge; however, visual confirmation of eggs and very small chicks was not possible. Any well maintained nest structure that was attended by an adult was considered active, along with any nests containing visible nestlings.

In 2006, frequent boat-, land-, and air-based surveys were also conducted to monitor the cormorant social attraction sites at Miller Sands Spit and Rice Island, looking for indications of nesting activity by double-crested cormorants.

Results and Discussion: In 1989, fewer than 100 pairs of double-crested cormorants nested on East Sand Island. But growth in the breeding population since 1989 resulted in the East Sand Island colony becoming the largest known colony of double-crested cormorants in North America by 2004 (Anderson et al. 2004; L. Wires, University of Minnesota, pers. comm.). We estimate that 13,738 breeding pairs (95% c.i. = 12,914 – 14,562 breeding pairs) attempted to nest at East Sand Island in 2006, a ca. 12% increase in colony size compared to 2005 (12,287 breeding pairs, 95% c.i. = 11,550 – 13,024 breeding pairs). The East Sand Island cormorant colony was nearly three times larger in 2006 than when we first estimated the size of this colony in 1997 (Figure 22). The growth of the East Sand Island colony appears to be exceptional among colonies of double-crested cormorants along the coast of the Pacific Northwest, most of which are stable or declining. The available data suggest that much of the growth of the East Sand Island colony was caused by immigration from colonies outside the Columbia River estuary. More data are needed to assess the extent to which factors limiting the size and reproductive success of colonies throughout the Pacific Northwest are influencing population trends at the East Sand Island colony.

During 2001-2004, increases in the size of the East Sand Island cormorant colony were associated with increases in colony area (Figure 23), as opposed to increases in nest density (Figure 24). In 2005-2006, double-crested cormorants nesting on East Sand Island used less total area for nesting (Figure 23) and nested at higher densities (Figure 24) as compared to the previous years. The smaller area encompassed by the cormorant colony and the higher nesting density in 2005 and 2006 was apparently caused by increased disturbance and predation pressure from bald eagles (*Haliaeetus leucocephalus*). Prior to 1999, cormorants on East Sand Island nested exclusively amongst the boulder riprap and driftwood on the southwest shore of the island. After 1999 they began nesting in satellite colonies in the adjacent low-lying habitat (see Map 4 for distribution of nesting cormorants in 2006). Based on the apparent habitat preferences of nesting cormorants, there is currently ample unoccupied habitat on East Sand Island, which could support further expansion of the colony for the foreseeable future. Despite availability of habitat to support continued colony expansion, bald eagle disturbance may limit the size of the colony in the future.

In 2006, a total of 152 pairs of double-crested cormorants nested on eight channel markers located in the upper estuary near Miller Sands Spit. The previous year, 208 cormorant pairs nested on the same channel markers. Peak nest counts on individual markers were recorded during 8 May - 30 June in 2006. The asynchrony in nesting chronology among the different channel marker colonies was likely due to differences among channel marker colonies in the incidence of disturbance and predation by bald eagles.

In 2006, we again observed double-crested cormorants nesting on the Astoria-Megler Bridge, immediately south of the southernmost portion of the established pelagic cormorant (*Phalacrocorax pelagicus*) colony on the bridge. During boat-based censuses on 2 and 15 June, 7 and 6 nests were attended by double-crested cormorants, respectively. In 2005, 14 nests with attending double-crested cormorants were confirmed during boat surveys in June.

In 2006, double-crested cormorants were successfully attracted to artificial colonies created on the downstream ends of Miller Sands Spit and Rice Island in the upper estuary. Habitat and social attraction techniques (preparation of nest substrate; installation of cormorant decoys and audio playback systems) were employed. Forty-one and 35 pairs on breeding cormorants nested on Miller Sands Spit and Rice Island sites, respectively. Chicks were successfully fledged from both colonies (see Section 2.5 for further information on cormorant management feasibility studies).

2.1.2. Columbia Plateau

Methods: To estimate the size of the double-crested cormorant colony on Foundation Island in 2006 (Map 3), periodic boat-based and land-based counts of attended nest structures were conducted off the east shore of the island. To improve nest count accuracy and our ability to monitor individual nests, we constructed an observation blind in the water, approximately 25 m off the eastern shore of the island. Nest counts and observations of nest contents were conducted weekly from the observation blind in 2006.

Periodic boat- and land-based surveys were conducted at sites where cormorant nesting had been reported previously, such as the mouth of the Okanogan River (referred to as the “Okanogan colony”) and in Potholes Reservoir within the North Potholes Reserve (referred to as the “North Potholes colony;” Map 2). At each site we counted attended nests to obtain a rough estimate of the number of breeding pairs at each colony. We also flew aerial surveys of the lower and middle Columbia River from The Dalles Dam to Rock Island Dam, and of the lower Snake River from the confluence with the Clearwater River to its mouth, searching for new double-crested cormorant colonies.

Results and Discussion: In 2006, the double-crested cormorant colony on Foundation Island consisted of a minimum of 359 pairs, the largest cormorant colony on the mid-Columbia River. The estimated size of the colony was ca. 14% larger than our estimate in 2005 (315 pairs); this colony has more than tripled in size since 1998 (when the colony was first censused as part of this study; Figure 25). As was the case in previous years, all cormorant nests at this colony were in trees at the south end of the island.

In 2006, the largest cormorant colony in the entire Columbia Plateau Region was on Potholes Reservoir in the North Potholes Reserve (ca. 1,100 breeding pairs), a ca. 38% increase in colony size compared to 2005 (ca. 800 breeding pairs). Cormorants at this colony nest in trees that are flooded for much of the nesting season. This colony has also been increasing in size over the last decade. There is little evidence, however, that these birds commute to the Columbia River to forage on juvenile salmonids based on the lack of salmonid PIT tags found near the colony.

Based on our counts of cormorant nests at the Okanogan colony, we estimate that there was a minimum of 32 nesting pairs at that colony in 2006, down slightly from the previous year (38 nesting pairs).

Aerial and boat surveys of the lower and mid-Columbia River and lower Snake River revealed two new double-crested cormorant colonies in 2006; one on Miller Rocks (5 breeding pairs), an island on the Columbia River just upstream from the mouth of the Deschutes River, and one on a railroad trestle bridge (2 breeding pairs) on the Snake River near Lyons Ferry Hatchery. Cormorants nesting at Miller Rocks were successful in raising young (3 chicks were observed), whereas no chicks were observed at the railroad trestle colony. Our observations indicate that the double-crested cormorant population on the Columbia Plateau is growing in both the number of breeding pairs and number of colonies. Furthermore, there appears to be a fairly substantial non-breeding population of cormorants on the Columbia Plateau, with large roosts of breeding and non-breeding birds observed at the mouth of the Yakima River and at many of the mid-Columbia River and lower Snake River dams.

2.1.3. Coastal Washington

Methods: In 2006 we counted cormorant nests on channel markers in Grays Harbor, WA (Map 1) during three aerial surveys between late April and mid June. No boat-based surveys of nesting habitat were conducted in Grays Harbor in 2006.

Results and Discussion: In 2006, 156 pairs of double-crested cormorant nested on 7 different channel markers, located in the western and northeast portions of Grays Harbor. We counted a total of 121 double-crested cormorant nests on 8 channel markers in the same area during an aerial survey of Grays Harbor in May 2005.

We saw no evidence of cormorant nesting attempts on Sand Island in Grays Harbor in 2006, a site where double-crested cormorants have nested in previous years.

2.2. Nesting Chronology and Productivity

2.2.1. Columbia River Estuary

Methods: Two elevated blinds located at the periphery of the East Sand Island cormorant colony were used to observe nesting cormorants in 2006 (see Map 4 for blind locations). The blinds were accessed via above-ground tunnels to prevent disturbance to nesting cormorants and gulls, as well as roosting California brown pelicans (*Pelecanus occidentalis californicus*). In 2006, 373 individual cormorant nests in 11 separate plots were monitored for productivity. Visual observations of nest contents were recorded each week from mid-April through July to determine nesting chronology and monitor nesting success. Productivity was measured as the number of nestlings in each monitored nest 28 days post-hatching. Cormorant chicks older than 28 days are capable of leaving their nests.

Monitoring of nesting cormorants on channel markers in the upper estuary and on the Astoria-Megler Bridge was conducted periodically (1 – 9 times each month) from a boat.

Results and Discussion: The first cormorant eggs on East Sand Island were observed on 23 April 2006, 1 day later than in 2005. The first cormorant hatchlings were observed on the colony on 22 May in 2006, 1 day earlier than in 2005.

We estimate that 27,477 fledglings (95% c.i. = 25,167 - 29,787 fledglings) were produced at the East Sand Island colony in 2006. This corresponds to an average productivity of 1.93 young raised per breeding pair (95% c.i. = 1.81 - 2.05 fledglings/breeding pair), which was higher than the estimate of productivity for the East Sand Island cormorant colony in 2005 (1.38 fledglings/breeding pair, 95% c.i. = 1.28 – 1.48 fledglings/breeding pair; Figure 26). Productivity at the East Sand Island cormorant colony in 2006 falls towards the middle of the typical range (1.2–2.4 young per nest) reported for other North American colonies of this species (Hatch and Weseloh 1999).

Confirmation of eggs in nests on the channel markers in the upper Columbia River estuary was not possible from our vantage on the water, but small chicks (7-14 days) were observed on markers by mid-June in 2006, later than the nesting chronology of cormorants on East Sand Island. Nests on the Astoria-Megler Bridge were also likely initiated later than nests on East Sand Island or the upper estuary channel markers; no chicks were observed during our boat survey on 15 June. Due to our poor vantage and infrequent visits, we were unable to estimate nesting success for either the nests on the upper estuary channel markers or on the Astoria Bridge.

2.2.2. Columbia Plateau

Methods: In 2006, we monitored 55 nests on Foundation Island each week from the observation blind (see Map 3). Productivity was estimated from the number of chicks in monitored nests at 28 days post-hatching. Because of our distance from the colony and our vantage below the elevation of the nests, we assumed that chicks were approximately 10 days old when first observed.

Results and Discussion: In 2006, nest initiation was earlier at the Foundation Island cormorant colony compared to the cormorant colonies in the Columbia River estuary. The first cormorant chicks were observed on Foundation Island on 2 May, almost three weeks before the first chick was observed on East Sand Island. Productivity (measured 28 days post-hatch) on Foundation Island was significantly lower ($P < 0.001$) in 2006 (1.37 ± 0.17 fledglings/nest) than in 2005 (2.30 ± 0.13 fledglings/nest). Nest abandonment occurred throughout the chick-rearing period and some nests were blown down during a severe storm on 19 May. Even for successful nests, brood size in 2006 (1.90 ± 0.14 fledglings/nest at 36 days post-hatch) was smaller ($P = 0.04$) than in 2005 (2.28 ± 0.11 fledglings/nest) and similar to 2004 (1.86 ± 0.11 fledglings/nest).

2.2.3. Coastal Washington

Methods: In 2006 we counted cormorant nests on channel markers in Grays Harbor, WA during three aerial survey flights between late April and mid June (156 pairs nested on 7 channel markers). No boat-based surveys of cormorant nesting success were conducted in Grays Harbor during 2006.

Results and Discussion: Because we did not visit Grays Harbor by boat later in the breeding season (after hatch and near the fledging period), we were unable to assess nesting success for the nests on channel markers in Grays Harbor in 2006.

2.3. Diet Composition and Salmonid Consumption

2.3.1. Columbia River Estuary

Methods: Lethal sampling techniques were necessary to assess the diet composition of double-crested cormorants nesting on East Sand Island. The best method to obtain a random sample of the diet is to collect adult birds commuting toward the colony from foraging areas throughout the breeding season. The target sample size was 6-10 adult fore-gut (stomach and esophagus) samples collected 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, labeled, and stored frozen for later sorting and analysis in the laboratory.

Laboratory analysis of semi-digested diet samples was conducted at Oregon State University. Samples were partially thawed, removed from whirl-paks, re-weighed, and separated into identifiable and unidentifiable fish soft tissues. The diet composition results for 2005 are preliminary because they are based only on identifiable fish soft tissues, not diagnostic bones. Diet analysis of samples collected in 2006 is currently underway and the results from those analyses will be made available in a subsequent report.

Fish in fore-gut samples were identified to genus and species, whenever possible. Intact salmonids in fore-gut samples were identified as Chinook salmon, sockeye salmon, coho salmon, steelhead, or unknown based on otolith and/or genetic analyses. Unidentifiable fish soft tissue samples were artificially digested (work that is ongoing) according to the methods of Peterson et al. (1990, 1991). Once digested, diagnostic bones (i.e., otoliths, cleithra, dentaries, pharyngeal arches, and opercles) were removed from the sample and identified to species using a dissecting microscope (Hansel et al. 1988). Unidentified fish soft tissue samples that do not contain diagnostic bones and samples comprised of bones only (i.e., no soft tissue) were included in diet composition analysis. Taxonomic composition of double-crested cormorant diets was expressed as % of identifiable prey biomass. The prey composition of cormorant diets was calculated for each 2-week period throughout the nesting season. The diet composition of cormorants over the entire breeding season was based on the average of these 2-week percentages.

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

Results and Discussion: Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 2% of double-crested cormorant diets (by mass) at East Sand Island in 2005 (n = 133 adult fore-gut samples or 27,128 total grams of identifiable fish tissue; Figure 27), a lower percentage compared to 2004 (5%; Table 13). As in previous years, anchovy were the most abundant fish found in foregut contents, representing 22% of prey biomass in 2005 (Table 13). The proportion of the diet that was salmonids peaked at ca.

6% during the last half of June (Figure 28), roughly one month later than in 2004. We estimated that double-crested cormorants nesting on East Sand Island consumed 2.9 million juvenile salmonids in 2005 (95% c.i. = 0.9 – 4.9 million), a 55% decrease in smolt consumption compared to 2004 (best estimate = 6.4 million, 95% c.i. = 2.5 – 10.3 million; Figure 29). Similarly, per capita smolt consumption decreased ca. 54% in 2005 (118 smolts [nesting cormorant]$^{-1}$ [breeding season]$^{-1}$) compared to the previous year (256 smolts [nesting cormorant]$^{-1}$ [breeding season]$^{-1}$).

2.3.2. Columbia Plateau

Methods: During the 11-week period (late April to early July) when nestlings were being fed at the Foundation Island cormorant colony, we collected diet samples from the ground below active nests, samples that were spontaneously regurgitated by nesting adults and their young. In 2006, a total of 118 samples of regurgitations were collected from the ground during this period. Additionally, 27 adult cormorants were lethally collected on three different occasions (20 April [n = 8], 3 May [n = 12], and 16 June [n = 7]) and contents of their fore-gut were removed (as described above). All diet samples were analyzed in our laboratory at Oregon State University to investigate the diet composition of cormorants nesting on Foundation Island in 2006.

Diet samples were not collected early in the nesting season (March and most of April) in order to avoid disturbing the Foundation Island cormorant colony and potentially causing nest abandonment. Collection of diet samples was initiated around the time that the first eggs hatched on the Foundation Island colony.

Results and Discussion: In 2006, the regurgitation samples collected from late April through early July indicated that centrarchids (bass and sunfish), percids (perch), and cyprinids (minnows) were the most prevalent prey types in the diet of Foundation Island cormorants during chick-rearing (Table 14). Salmonids were a relatively minor component of the diet (4.3%) during this period, based on the percent biomass of identifiable prey in regurgitations. Salmonids were only detected in regurgitations collected on two dates, 20 April (20% salmonids, n = 5 regurgitations) and 25 June (5.9% salmonids, n = 11 regurgitations). Salmonids made up 13.9% of identifiable prey biomass in the fore-gut contents from the 27 collected adults (Table 15). These diet composition data suggest that, unlike Caspian terns nesting on nearby Crescent Island, double-crested cormorants nesting on Foundation Island do not rely on juvenile salmonids as a primary food source throughout the nesting season.

2.4. Salmonid Predation Rates: PIT Tag Studies

2.4.1. Columbia River Estuary

Methods: In comparison to Caspian tern colonies, the recovery/detection of smolt PIT tags on cormorant colonies is more difficult. Unlike Caspian terns, which nest primarily on bare sand, cormorants nest in a wide array of habitat types (i.e., in trees, on the ground amongst vegetation and woody debris, on rip-rap). This poses significant challenges for the on-colony recovery or detection of PIT tags egested by nesting cormorants, with previous measures of detection efficiency at the East Sand Island cormorant colony at less than 40% (B. Ryan, NOAA Fisheries, unpublished data). To improve our ability to recover PIT tags from the cormorant colony on East Sand Island, we prepared cormorant nesting plots within the boundaries of the colony and used social attraction techniques to encourage cormorants to nest in the plots (see Section 2.5 for details regarding social attraction). We hypothesized that if we could attract cormorants to nest in the plots, we would improve the detection efficiency of smolt PIT tags at the East Sand Island colony. Furthermore, if we knew how many cormorant breeding pairs nested in each plot, we could calculate an accurate per-capita PIT tag consumption rate for East Sand Island cormorants, which could be used, along with our estimate of colony size, to estimate total consumption of PIT-tagged smolts by cormorants nesting on East Sand Island.

Prior to the 2006 nesting season, we set up six cormorant nesting plots (each measuring 5 m x 5 m) near the observation tower at the west end of East Sand Island (Map 4). A 4-m wide trench was dug around each plot to discourage birds from nesting immediately adjacent to the plots. Four of the six plots consisted of wooden platforms elevated less than a meter above the surrounding substrate. Each platform was top-dressed with sand and 36 truck and car tires were placed on the sand. In the case of the two plots that were on the ground, 36 truck and car tires were used, as in the wooden platform plots. Old cormorant stick nests from the 2005 nesting season or fine woody debris was then placed on each truck tire, providing nest sites for up to 36 nesting pairs of cormorants in each plot. Cormorant decoys and audio playback systems broadcasting sounds of a cormorant colony were placed on both ground plots and two of the four platform plots to further encourage nesting. In addition to the plots on East Sand Island, social plots that consisted of 36 truck and car tires, decoys and audio playback systems were placed at the downstream ends of Rice Island (Rkm 34) and Miller Sands Spit (Rkm 37), both to recover PIT tags and to test social attraction methods (see Section 2.5 for further information on cormorant management feasibility studies).

Nesting chronology, number of breeding pairs, and nesting success of cormorants on each platform was recorded throughout the nesting seasoning (April to September). Detection efficiency for PIT tags on the platforms (a parameter needed to adjust/correct PIT tag recovery results) was measured by sowing test PIT tags (n = 100 per plot per release) on three of the six East Sand Island plots at two different times: before nest building (6 April) and immediately following fledging (7 September). Fifty PIT tags were also sown on the Miller Sands Spit social attraction plot during a single, early season sowing on 6 May. PIT tags were not sown on the Rice Island social attraction plot due to concerns that sowing tags would result in nesting cormorants abandoning the site. PIT tags were recovered from each cormorant nesting plot following the nesting season by NOAA Fisheries.

Results and Discussion: In total, 11,978 salmonid PIT tags from 2006 migration year smolts were recovered from the double-crested cormorant colony on East Sand Island by NOAA Fisheries in 2006. Of these tags, 65.3% were from Chinook salmon (includes sub-yearlings and yearlings), 31.8% from steelhead, 2.2% from coho, 0.5% from sockeye, and 0.2% from sea-run cutthroat trout. With the exception of steelhead, the relative proportion of salmonid tags recovered on the East Sand Island cormorant colony was similar to the proportion of PIT-tagged fish released in the basin in 2006 (76.8% Chinook, 18.8% steelhead, 3.8% coho, 0.5% sockeye, and 0.1% sea-run cutthroats), suggesting that cormorants consume salmonids in similar proportions to their relative availability. Steelhead smolts were consumed in greater portion to their availability in 2006, which was not the case the previous year (i.e., the proportion of steelhead tags recovered on the cormorant colony [ca. 39.1%] was very similar to the proportion presumed available [ca. 40.9%; Figure 30]. Due to uncertainties regarding the survival of various species and groups of PIT-tagged fish to the estuary, these calculations are rough estimates of fish availability. Nonetheless, the data suggest that cormorants are less selective and more generalists in their foraging as compared to Caspian terns, which consume steelhead smolts in much greater proportion to their relative availability.

In 2006, detection efficiency of sown test PIT tags on the experimental cormorant nesting plots averaged 75.8%, significantly greater than previous colony-wide detection efficiency estimates (see above). Per-capita PIT tag consumption was estimated to be 2.22 tags per breeding adult cormorant based on the total number PIT tags recovered from the plots (n = 839), the number of breeding birds counted in the plots (n = 489), and a PIT tag detection efficiency of 75.8% (Table 11). Based on our estimate of the per-capita PIT tag consumption by East Sand Island cormorants (2.22 tags per breeding adult) and our estimate of colony size (27,476 breeding adults), we estimate that cormorants deposited ca. 60,997 tags on the colony during the 2006 breeding season. This suggests that the colony-wide detection efficiency was only 19.6% (11,978 / 60,997) in 2006.

Per-capita consumption of PIT-tagged juvenile salmonids was greater for cormorants nesting in the upper estuary (Miller Sands Spit and Rice Island) compared to cormorants nesting on East Sand Island (Table 11). On Rice Island, 70 breeding adult cormorants were counted on the experimental plot and 221 salmonid PIT tags were recovered after the nesting season. No direct measure of detection efficiency was available for the Rice Island plot; thus, the detection efficiency of PIT tags on the East Sand Island platforms (75.8% detection efficiency) was used to estimate per-capita PIT tag consumption at the Rice Island cormorant colony (4.17 tags per breeding adult; Table 11). Per-capita PIT tag consumption for cormorants nesting on Miller Sands Spit was 3.18 tags per breeding adult based on the total number PIT tags recovered from the plot (n = 120), the number of breeding birds counted on the plot (n = 82), and a detection efficiency for sown test PIT tags of 46.0% on the Miller Sand Spit plot (Table 11). These results corroborate our earlier finding that cormorants nesting in the upper estuary are my reliant on juvenile salmonids as a food source compared to cormorants nesting on East Sand Island (Collis et al. 2002).

2.4.2. Columbia Plateau

Methods: In 2006, PIT tags were recovered at the Foundation Island double-crested cormorant colony in order to calculate smolt predation rates. The methods used to generate these estimates are similar to those described for Crescent Island terns (see

Section 1.4). Unlike the Crescent Island tern colony, however, test tags used to evaluate detection efficiency were not sown on discrete plots because double-crested cormorants nest in trees on Foundation Island. Instead, test tags (n = 100 per release) were sown haphazardly under nesting trees on four different occasions: prior to arrival of birds on the colony (24 March), early in the chick-rearing period (14 May), during fledging (6 June), and after the birds had left the colony following nesting (27 July). Predation rates were corrected for detection efficiency (but not deposition rate); consequently, all predation rates reported here are minimums. Furthermore, an unknown proportion of smolt PIT tags are likely retained within the arboreal cormorant nests (primarily from chicks too small to regurgitate castings outside the nest), a phenomenon that further reduces tag recovery and thus underestimates predation rates.

Results and Discussion: Of the 400 test PIT tags sown on Foundation Island in 2006, 269 or 67.3% were subsequently recovered on-colony after the nesting season. Detection efficiency ranged from as low as 58.0% for tags spread during the chick-rearing period to 79.0% for tags spread before the nesting season. There was no evidence of an association between test tag release date and detection efficiency ($R^2 = 0.2897$, $P = 0.4617$), indicating that test tags sown early in the nesting season were just as likely to be recovered as test tags sown late in the nesting season.

A total of 3,505 PIT tags from 2006 migration year smolts were recovered by NOAA Fisheries on the Foundation Island cormorant colony following the nesting season. These tags represent 0.2% of the in-river PIT-tagged fish released upstream of McNary Dam. The proportion increases to 0.3% (n = 5,208) once an adjustment is made for PIT tag detection efficiency. Foundation Island cormorants consumed an estimated 0.89% of all the PIT-tagged smolts interrogated passing Lower Monumental Dam from 1 April to 31 July. Like Crescent Island terns, predation rates were relatively high for hatchery-reared Snake River steelhead smolts (2.8%) and wild Snake River steelhead smolts (1.4%; Table 10). Similar to results from 2005, Foundation Island cormorants consumed relatively large proportions of PIT-tagged fall Chinook from the Yakima River (ca. 2.0%), unknown run Chinook from the Walla Walla River (ca. 5.8%), and wild steelhead from the Walla Walla River (ca. 4.0%). Predation rates on all other salmonid species and run-types from the Snake River were negligible (Table 10).

Foundation Island cormorants consumed about 1/3th as many PIT-tagged smolts as did Crescent Island terns in 2006. A similar comparison in 2005 indicated Foundation Island cormorants consumed approximately 1/4th as many PIT-tagged smolts as Crescent Island terns. Increases in Foundation Island cormorant predation rates relative to those of Crescent Island terns in 2006 are likely associated with the increase in the size of the Foundation Island cormorant colony and the decrease in size of the Crescent Island tern colony in 2006 relative to 2005. Of all the piscivorous waterbirds studied on the Columbia Plateau in 2006, Foundation Island cormorants appear to have the second highest impact on smolt survival (after Crescent Island terns), but similar to Rock Island terns (Table 10). Rock Island terns, however, had a higher per-capita consumption rate of PIT-tagged smolts than did Foundation Island cormorants (9.68 and 7.23 tags per breeding adult, respectively), and the Rock Island tern colony failed and was abandoned well before the end of the nesting season (Table 11).

2.5. Management Feasibility Studies

Methods: In 2006, we continued studies designed to test the feasibility of potential management techniques for reducing losses of juvenile salmonids to cormorant predation. These studies sought to determine whether habitat and social attraction techniques can be used to induce double-crested cormorants to nest in areas where they have not previously nested and, if so, whether these techniques can be used to redistribute some of the double-crested cormorants nesting in the Columbia River estuary to alternative colony sites outside the estuary. We employed social attraction techniques (decoys and audio playbacks; Kress 2000, Kress 2002, Roby et al. 2002) and enhanced nesting habitat on three different islands in the Columbia River estuary in 2006: (1) East Sand Island in areas within and adjacent to previously established nesting areas; (2) Miller Sands Spit at the west (downstream) end, approximately 24 km east of the East Sand Island cormorant colony; and (3) Rice Island at the west (downstream) end, approximately 16 km east of the East Sand Island cormorant colony.

Six experimental plots were set up on East Sand Island within the active cormorant breeding colony to evaluate relative efficacy of three types of artificial satellite colonies (treatments; Map 4). Four plots were set up by constructing elevated wooden platforms (5 m x 5 m), and two other plots (5 m x 5 m) were set up on the ground near platforms. Three types of treatments were prepared: (1) decoys, audio playbacks, and tires on the ground; (2) decoys, audio playbacks, and tires on elevated platforms, and (3) tires only on elevated platforms. Two plots were assigned to each treatment type. Thirty-six truck and car tires were placed in each experimental plot. In three of the plots, each tire was filled with either old cormorant nest material or fine woody debris collected near the plots in order to evaluate whether cormorants prefer old cormorant nests over woody debris. Fifty-four truck and car tires in three plots (n = 18 in each plot) were randomly selected and filled with old cormorant nests, and the rest of tires in those plots were filled with fine woody debris. All the tires in the other three plots were filled with fine woody debris only. A total of 12 cormorant decoys and one speaker broadcasting audio playbacks of the cormorant colony were placed in each of the plots assigned to treatments 1 and 2. These six experimental plots were also designed to facilitate recovery of smolt PIT tags from cormorant nesting areas in order to generate better estimates of cormorant predation rates based on PIT tag recoveries on-colony (see above).

Nesting chronology and productivity data for cormorants nesting in the experimental plots were collected by direct observation from the nearby observation tower. Visual observations of nest contents were recorded each week from mid-April through July. Productivity was expressed as the number of nestlings in each monitored nest 28 days post-hatch.

Habitat and social attraction techniques were also tested on Miller Sands Spit, a dredged material disposal site in the upper Columbia River estuary (river km 34). Approximately

10 pairs of double-crested cormorants attempted to nest at the west (downstream) end of Miller Sands Spit in 2001, but all nests were abandoned prior to eggs hatching. Nest depredation by gulls, perhaps facilitated by human disturbance, was the most likely cause of abandonment at this site. In April of 2004, we set up an experimental plot on the western tip of the upland portion of the island, near the area where cormorants had attempted to nest in 2001. On a number of occasions, aggregations of cormorants were observed roosting on the beach below the experimental plot, but only once were cormorants observed in the upland area near the experimental plot. In 2005, we repeated our efforts to attract cormorants to nest on Miller Sands Spit by creating a similar experimental plot. Double-crested cormorants attempted to nest in the experimental plot and there were a total of 21 partially or completely built nests on the plot, and a total of six eggs were laid in four of the nests. However, all nests subsequently failed prior to hatching, presumably due to gull depredation. In 2006, we set up a similar experimental plot with a total of 41 decoys and 36 truck and car tires placed throughout the plot. Each tire was filled with fine woody debris as nesting material, and some of the decoys were placed on the tires. Four speakers broadcasting audio playbacks of a cormorant colony were also placed in the plot. Boat-based or aerial surveys of the island were conducted 1-3 times each week from mid-April through July in order to monitor nesting activity at the site.

An experimental social attraction plot for double-crested cormorants was also set up on Rice Island, another dredged material disposal site in the upper Columbia River estuary (river km 26). Over 1,100 breeding pairs nested at the west (downstream) end of Rice Island in 1997; however, double-crested cormorants have not nested at that site since 2003. An experimental tire plot was set up on Rice Island with 40 decoys and two audio playback systems at the site where cormorants previously nested. Nesting chronology and productivity data from the Rice Island experimental plot were collected by direct observation from a nearby observation blind.

Results and Discussion: On East Sand Island, cormorants were observed in all the experimental plots within a day of completing construction. Nest initiation in the plots was synchronous with the rest of the East Sand Island cormorant colony. A total of 31 to 39 breeding pairs nested in each experimental plot. Productivity was similar in the experimental plots (1.97 fledglings/breeding pair, 95% CI: 1.81 - 2.13, n = 236 nesting attempts) compared with elsewhere on the East Sand Island cormorant colony (2.08 fledglings/breeding pair, 95% CI: 1.89 – 2.27, n = 153 nesting attempts). The average productivity of nests in the experimental plots would have been higher if not for a disturbance caused by a bald eagle that landed immediately adjacent to one of the plots, which resulted in several nests failing within that plot.

We expected that cormorants would colonize the elevated wooden platforms with decoys, audio playbacks, and tires before the ground plots or the wooden platforms without social attraction; however, the ground experimental plots were occupied first and had the highest density of active nests. Cormorants might have preferred ground plots because they are more similar to the natural habitat used by cormorants on East Sand Island as compared to the wooden platforms. The numbers of active nests on platforms with decoys and audio playback systems vs. those without were not significantly different. Also, there was no difference in cormorant productivity among the three treatments. The comparison between tires with old cormorant nests and tires with fine woody debris showed no significant difference in the timing of nest initiation at the two types of artificial nests. Consequently, cormorants showed no preference for old cormorant nests over fine woody debris.

In 2006, nesting cormorants were attracted and chicks successfully fledged at artificial colonies on both Miller Sands Spit and Rice Island. This marks the first time that double-crested cormorants have nested successfully at habitat and social attraction plots on islands other than East Sand Island. At the social attraction site on Miller Sands Spit, cormorants were first observed carrying nesting material on 10 May, 26 days after completion of the experimental plot (13 April). First chicks (approximately 2 weeks old) were observed on 13 July. The best estimate of the productivity of the colony was 2.18 fledglings/breeding pair (n = 33 nests) based on a single nest/chick count conducted at the colony on 27 July. Cormorants were first observed in courtship display at the experimental site on Rice Island on 27 April, one day after completion of setting up the experimental plot. The first cormorant egg on the site was confirmed on 19 May, when an egg was taken by a gull while cormorants were disturbed and flushed off their nests by a bald eagle. The first chick (1-2 days old) was observed on 16 June. Productivity at the colony was estimated at 2.61 fledglings/breeding pair (n = 33 nests) from a single nest/chick count performed at the colony on 13 July.

These results from the two experimental habitat and social attraction plots set up on two islands at some distance from the large colony on East Sand Island suggest that social attraction/habitat enhancement techniques may be effective for establishing new double-crested cormorant colonies outside the Columbia River estuary. A combination of placing at least 36 tires filled with fine woody debris on the ground on islands where mammalian nest predators are absent and placing several dozen cormorant decoys and at least two audio playback systems amongst the tires should be effective at attracting double-crested cormorants to establish new breeding colonies. These new colonies could support part of the population of cormorants that currently nests on East Sand Island, thereby reducing cormorant predation rates on juvenile salmonids in the Columbia River estuary. The efficacy of this approach, however, is likely to be limited by human disturbance, bald eagle disturbance, and nest predation by glaucous-winged/western gulls, to the extent that these factors cause cormorant nest failure at newly-established alternative colony sites.

SECTION 3: OTHER COLONIAL WATERBIRDS

3.1. Distribution

3.1.1. Columbia River Estuary

Gulls: During land-based, boat-based, and aerial surveys in 2006, breeding colonies of glaucous-winged/western gulls (*Larus glaucescens/occidentalis*) and ring-billed gulls (*L.*

delawarensis) were confirmed at several sites in the Columbia River estuary (Table 1). Glaucous-winged/western gulls nested on three islands in 2006: East Sand Island, Rice Island, and Miller Sands Spit, with the East Sand Island gull colony being by far the largest of the three (over 8,500 counted; Table 1). Ring-billed gulls, which previously nested on Miller Sands Spit (Collis et al. 2002), now nest solely on East Sand Island within the Columbia River estuary (over 1,300 counted; Table 1).

California Brown Pelicans: East Sand Island has been identified as the largest known post-breeding roost site for California brown pelicans, and is the only known night roost for this ESA-listed endangered species in the Columbia River estuary (Wright 2005). In 2006, California brown pelicans were observed for the first time off East Sand Island on 11 April; 3,514 pelicans were counted on the island during the last island-wide census of the season on 10 October. The number of brown pelicans roosting on East Sand Island in 2006 peaked at 8,862 on 25 July, the second highest annual peak count of pelicans since counts were initiated in 2000. We observed limited breeding behavior by brown pelicans roosting on East Sand Island (i.e., courtship displays, nest-building, attempted copulations), but there was no evidence of egg-laying, and the incidence of these behaviors seems to have waned since 2002. The numbers of brown pelicans roosting on East Sand Island was more evenly distributed across the island in 2006; formerly, pelicans roosted primarily at the western end of the island, near the large double-crested cormorant colony. For the first time, brown pelicans were observed in the Caspian tern colony at the eastern end of the island. Brown pelicans were also observed destroying Caspian tern eggs and young chicks on the tern colony for the first time. Researcher disturbance to roosting brown pelicans (numbers of individuals flushed) was higher than in previous years, mostly because of the larger numbers of pelicans roosting adjacent to the Caspian tern colony. Bald eagle disturbance, however, remained the most common cause of brown pelican flushes from the roost on East Sand Island in 2006.

Brandt's and Pelagic Cormorants: A small colony of Brandt's cormorants (*P. penicillatus*) consisting of 44 nesting pairs became established on East Sand Island amidst the double-crested cormorant colony in 2006 (Table 1). This was the only site in the Columbia River estuary where Brandt's cormorants were known to nest. Formerly, a small breeding colony of Brandt's cormorants existed on a pile dike at the western end of East Sand Island, but this site was abandoned in 2006 because of storm damage to the pile dike during the winter of 2005-2006. Brandt's cormorants were first documented to nest on that pile dike in 1997, when a few pairs were found nesting there (Couch and Lance 2004). Pelagic cormorants (*P. pelagicus*) nested again on the Astoria–Megler Bridge in 2006 (124 nesting pairs), the only site in the Columbia River estuary where this species is known to nest (Table 1). Pelagic cormorants have been observed nesting on the underside of the southern portion of the Astoria-Megler Bridge since we began surveying the structure in 1999.

3.1.2. Columbia Plateau

Gulls: Based on aerial, boat-based, and land-based surveys along the Columbia and Snake rivers, gulls, primarily California and ring-billed gulls, were confirmed to be nesting on six different islands on the Columbia River between The Dalles Dam and Rock Island Dam in 2006: Miller Rocks (river km 333), Three Mile Canyon Island (river km 413), Rock Island (river km 445), Crescent Island (river km 510), and on two islands near Richland, Washington (Fencepost Island [river km 545] and Island 18 [river km 553]; see Map 2 and Table 1). The gull colonies on Miller Rocks, Three Mile Canyon Island, Crescent Island, Fencepost Island, and Island 18 were the largest colonies identified along the mid-Columbia River in 2006 (Table 1). The California gull colony on Little Memaloose Island on the lower Columbia River (river km 315), which was active in 1998 (Collis et al. 2002), has not been active for several years (Map 2). No gull colonies were observed on the lower Snake River in 2006, nor has there been any confirmed breeding by gulls on the lower Snake River since our research began in 1997 (Collis et al. 2002).

An unknown number of ring-billed and California gulls were also confirmed to be nesting in Potholes Reservoir, Sprague Lake, and Banks Lake in 2006 (see Map 2 and Table 1).

American White Pelicans: We conducted boat-based counts of American white pelicans (*Pelecanus erythrorhynchos*) at the colony on Badger Island each week during the 2006 nesting season (Map 3). Badger Island is the site of the only known nesting colony of American white pelicans in the State of Washington, and the species is listed as endangered by the State. Consequently, the island is closed to both the public and researchers in order to avoid human disturbance to nesting pelicans that might cause pelicans to abandon the colony. Aerial photography was taken of the colony on 25 May during the incubation period in order to estimate colony size. Complete counts of the number of active pelican nests on Badger Island were not possible from the water because most nests were concealed amidst the thick, brushy vegetation on the island. Most, but probably not all, pelicans present on the island were visible in the aerial photography; however, we could not correct aerial photo counts to estimate the number of breeding pairs (as with Caspian terns) because we were unable to obtain representative counts of incubating and non-incubating pelicans from the water. Thus counts of adult pelicans from the aerial photos are an index to the number of breeding pairs utilizing Badger Island, rather than a count of nesting pairs. 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 1,310 adult American white pelicans were counted in the aerial photography taken on 25 May. This is a minimum count of adults present on the colony at the time of the photograph. The pelicans were divided between three nesting areas on the island: 583 pelicans were counted near the middle of the eastern shore of the island, 280 pelicans were counted in the interior of the middle of the island, and 447 pelicans were counted in an area near the northern (upriver) end of the island. Counts from aerial photography have increased significantly in the years since 2001 (Figure 31), when only 263 pelicans were counted on Badger Island, suggesting a corresponding increase in the number of breeding pairs. The average annual growth rate (lamda) in the number of pelicans counted in aerial photography during 2001-2006 was 1.39. Our boat-based counts resulted in a maximum count of 444 adults on 3 July, and a maximum count of 151 juveniles on 3 July. Maximum counts of juvenile pelicans during boat-based surveys were 238 in 2002, 141 in 2003, 329 in 2004, and 296 in 2005.

Other species: In addition to gulls and pelicans, other colonies of piscivorous waterbirds were recorded by our field crews in 2006, including colonies of great blue herons, black-crowned night-herons, great egrets, and Forster's terns (Table 1).

3.2. Diet Composition

3.2.1. Columbia River Estuary

Gulls: As part of the current study, we have not collected diet composition data from gulls nesting in the Columbia River estuary for several years. Our previous research indicated that, in contrast to the gulls nesting at up-river locations (see below), glaucous-winged/western gulls nesting in the Columbia River estuary consumed primarily fish (Collis et al. 2002). In general, gulls nesting on Rice Island (river km 34) ate mostly riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice Island/Miller Sands Spit and East Sand Island, respectively. At least some of these fish had been kleptoparasitized from Caspian terns, which nested at the nearby colony on Rice Island (Collis et al. 2002). Kleptoparasitism rates (proportion of fish delivered by terns to the colony that were subsequently stolen by gulls) for salmonids smolts averaged 12.7% during 2004-2006; indicating gulls nesting in close proximity to East Sand Island terns have an impact on survival of juvenile salmonids by reducing the number of salmonid smolts successfully delivered the tern colony. PIT tags were not recovered from gull colonies in the estuary in 2006; we intend to carry out this work in future years.

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

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

3.2.2. Columbia Plateau

Gulls: As part of the current study, we have not collected diet composition data from gulls nesting on islands in the lower and middle Columbia River for several years. Our previous research indicated that there were small amounts of fish in general, and salmonids in particular, in the diets of California and ring-billed gulls nesting at up-river colonies in 1997 and 1998. The only up-river gull colonies where juvenile salmonids were found in diet samples were the California gull colonies on Little Memaloose Island (15% of total diet mass; this colony is no longer active) and Miller Rocks (3% of total diet mass). Gulls from these colonies were known to prey on juvenile salmonids in the tailrace of The Dalles Dam (J. Snelling, OSU, pers. comm.). Gulls from other up-river colonies may occasionally prey on juvenile salmonids when available in shallow pools or near dams (Ruggerone 1986; Jones et al 1996), but our previous data suggest that at the level of the breeding colony, juvenile salmonids were a minor component of the diet. Similar to gulls nesting in close proximity to terns in the estuary, however, gulls on Crescent Island may also have a negative effect on survival of juvenile salmonids. Kleptoparasitism rates on salmonid smolts delivered to by terns to Crescent Island have averaged 14.9% during 2004-2006. Smolt PIT tags were recovered from a few selected gull colonies on the Columbia Plateau in 2006 (Table 11; see Section 3.3), data that corroborate an earlier study suggesting that the majority of gulls nesting at up-river locations pose little risk to salmonid survival (Collis et al. 2002).

American White Pelicans: We do not collect diet composition data for American White Pelicans nesting on Badger Island because of the conservation concerns for this colony. Based on smolt PIT tag detections on the pelican colony by NOAA Fisheries, pelicans do not appear to be a source of significant smolt mortality (Table 11; see Section 3.3). Despite this, there appears to be a growing number of non-breeding white pelicans 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 these non-breeding pelicans on survival of juvenile salmonids are not well understood.

3.3. Salmonid Predation Rates: PIT Tag Studies

3.3.1 Columbia Plateau

Gulls: PIT tags were recovered from plots set up on two gull colonies in the mid-Columbia River during 2006; Three Mile Canyon Island (Rkm 413 in the John Day pool) and Miller Rocks Island (Rkm 333 in The Dalles pool). These gull colonies were selected because prior research indicated they were relative large, stable breeding colonies, known to consume juvenile salmonids (albeit in small proportions compared to tern and cormorant colonies in the region). The same general PIT tag removal and detection efficiency methods described for terns (see Section 1.4) were used for gulls. One notable difference, however, was that PIT tag recovery was limited to several discrete nesting areas/plots located on each of the gull colonies. This approach was used to minimize the cost of tag removal efforts and analysis, while still allowing us to generate estimates of per-capita PIT-tag consumption rates for gulls nesting at these colonies.

In total, five 5 m x 5 m nesting plots were selected on Three Mile Canyon Island (n = 3) and Miller Rocks (n = 2) gull colonies. Plots were delineated using ground stakes and rope and were selected prior to the breeding season based on the location and density of nesting gulls seen in aerial photos from previous years. Detection efficiency for PIT tags was measured by sowing test PIT tags (n = 50 per plot per release) within each nesting colony prior to the nesting season (4 April) and during the chick-rearing period (20 June). The numbers of active gull nests were counted within each plot, along with counts of eggs and chicks within each nest, on 10 May and 20 June 2006. PIT tags were recovered from these plots by NOAA Fisheries using hand-held electronic equipment during August 2006.

Results and Discussion: In 2006, counts of active gull nests indicated that 46 breeding pairs and 23 breeding pairs were nesting in the experimental plots on Three Mile Canyon Island and Miller Rocks, respectively. Following the breeding season, 2 and 22 salmonid PIT tags (from 2006 migration year smolts) were recovered from 3 plots on Three Mile Canyon Island and the 2 plots on Miller Rocks, respectively (Table 11). Per-capita consumption rates were 0.04 tags per breeding adult on Three Mile Canyon Island and 0.61 tags per breeding adult on Miller Rocks (Table 11). Steelhead and yearling Chinook salmon were the most common species recovered, although other species and run-types were detected on Miller Rocks (Table 11). Comparisons of per capita consumption rates by gulls at up-river colonies compared to other piscivorous waterbirds in the region (e.g., terns and cormorants; Table 11) suggest that gulls consume far fewer PIT-tagged fish per individual. The over-all number of nesting gulls, however, on the Columbia Plateau far exceeds that of terns and cormorants (Table 1) and should be taken into account when evaluating impacts on survival of juvenile salmonids. PIT tag data collected from these two gull colonies in 2006 also indicate that gull predation rates on salmonids varies substantially by location, with gulls nesting on Miller Rocks consuming considerably more salmonid smolts than gulls nesting on Three Mile Canyon Island (Table 11). Similar variation may exist for other gull colonies in the region; however, recent (post 1998) empirical data are not available.

American White Pelicans: Smolt PIT tags were also recovered from the Badger Island American white pelican colony in order to estimate their impact on survival of juvenile salmonids in 2006. The methods used to generate these estimates were similar to those described for Crescent Island terns (see Section 1.4). One notable difference was that test tags used to determine detection efficiency could not be sown on Badger Island during the nesting season, as white pelicans are very sensitive to human disturbance on the colony. Test PIT tags (n = 100 per release) were sown on the southern nesting area (the larger of the two nesting areas on Badger Island) on 24 March (prior to the nesting season) and on 7 November (when pelicans had completely abandoned the island). PIT tags were recovered by NOAA Fisheries in November 2006. Similar to the analytical approach used for Foundation Island cormorants, predation rate estimates from the Badger Island pelican colony were adjusted for bias due to PIT tag detection efficiency, but not for deposition rate. As such, predation rate estimates presented here are minimums.

Results and Discussion: Of the 200 test tags sown on the Badger Island pelican colony in 2006, 64.5% were subsequently recovered on-colony by NOAA Fisheries. There was no difference between detection rates of tags spread pre-season (ca. 64%) and post-season (ca. 65%) and detection efficiency in 2006 was slightly higher than in 2005 (ca. 58.0%).

A total of 448 PIT tags from 2006 migration year smolts were recovered from the Badger Island pelican colony following the 2006 nesting season. These tags represent < 0.1% of all the PIT-tagged fish released into the Columbia River basin upstream of McNary Dam (excluding transported fish) in 2006. Of the 448 tags recovered, 46% (n = 208) were from sub-yearling Chinook salmon, 21% (n = 184) were from yearling Chinook salmon, 15% (n = 65) from steelhead, 11% (n = 51) from unknown run-type Chinook, and 7% from coho (n = 32). Overall, Badger Island pelicans consumed only 36 (0.03%) of the PIT-tagged smolts interrogated passing Lower Monumental Dam from 1 April to 31 July (Table 10). Data suggest that sub-yearling Chinook salmon (presumably fall run) from the Upper and Middle Columbia rivers (not listed) were the most vulnerable to white pelicans nesting on Badger Island, with these two ESUs comprising 38% of all PIT-tagged smolts recovered on-colony, yet comprising only 12% of all in-river PIT-tagged smolts released upstream of McNary Dam. Taken as whole, however, the 448 PIT tags recovered from the Badger Island pelican colony provides evidence that the overall impact of white pelicans on survival of juvenile salmonids smolts in the McNary Pool is negligible, especially when compared to that of Caspian terns and double-crested cormorants. The estimated per-capita consumption rate for Badger Island pelicans also suggested that pelican effects on survival of juvenile salmonids are minimal compared to other piscivorous waterbirds investigated as part of this study (Table 11). Similar results and conclusions were drawn from the analysis of PIT tag recovery data from the white pelican colony in 2005 (CBR 2006), although a larger proportion of the PIT tags found on Badger Island in 2005 were from steelhead smolts.

SECTION 4: SYSTEM-WIDE OVERVIEW

4.1. Avian Predator Population Trajectories

Although numbers of Caspian terns nesting in the Columbia River basin have remained fairly stable over the past 8 years, the numbers of double-crested cormorants nesting on East Sand Island have more than doubled during the same period to ca. 13,700 pairs, the largest known breeding colony of double-crested cormorants in the world (Figure 32). Based on the habitat preferences of nesting cormorants, there currently exists ample unused habitat on East Sand Island and at up-river locations to support continued expansion of the population of double-crested cormorants in the Columbia Basin in the future. Productivity at the East Sand Island and Foundation Island cormorant colonies has also been consistently higher than productivity for Caspian terns nesting in the estuary and up-river (Figure 33). Further management of Caspian terns to reduce losses of juvenile salmonids in the estuary is planned but currently stalled due to lack of funding. The Final EIS and Record of Decision (ROD) for Caspian tern management in the Columbia River estuary seeks to implement the redistribution of approximately half of the East Sand Island colony to alternative colony sites in interior Oregon and San Francisco Bay, California (USFWS 2006). Substantial increases in the numbers of nesting Caspian terns along the mid-Columbia River are unlikely due to the paucity of suitable nesting habitat for terns in that region. Based on these results, it is possible that the cormorant breeding population will continue to expand for the foreseeable future, while numbers of Caspian terns nesting in the estuary and up-river will remain stable or may decline as the ROD is implemented. The trajectories of other colonial waterbird populations along the Columbia River (e.g., gulls and pelicans) is less clear, but monitoring of these colonies has not been deemed a priority by the agencies funding this work because of the relatively low impact of these avian predators on survival of juvenile salmonids from the Columbia River basin (see below).

4.2. Relative Impact of Predation

A system-wide assessment of avian predation using the available data from recent years indicates that the most significant impact to survival of juvenile salmonids occurs in the estuary, with Caspian terns and double-crested cormorants nesting on East Sand Island combining to consume ca. 7-10 million smolts in 2004 and 2005 (Figure 34). Although consumption estimates for East Sand Island cormorants in 2006 are not yet available, combined smolt losses to terns and cormorants nesting on East Sand Island in 2006 are within this range, if not higher. The PIT tag data from 2006 corroborates this conclusion. Estimated smolt losses to piscivorous birds that nest further up-river are more than an order of magnitude less than what has been observed in the estuary. Additionally, when compared to the impact of avian predation on smolt survival further up-river, avian predation in the estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids from every listed stock in the Columbia River basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary. For these reasons, management of terns and cormorants nesting on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other populations of piscivorous birds. The Caspian tern colony on Crescent Island may be an exception to this rule; management of this small, up-river colony may benefit certain salmonid stocks, particularly steelhead in low flow years. Finally, although the current impact of double-crested cormorants nesting on the Columbia Plateau on smolt survival seem to be relatively small, the cormorant population on the Columbia Plateau is growing in both number of breeding pairs and number of colonies. Furthermore, there appears to be ample unoccupied nesting habitat for cormorants on the Columbia Plateau, which could support further expansion of that population for the foreseeable future. Monitoring of double-crested cormorants on the Columbia Plateau into the future will be necessary to determine if they pose an increasing risk to salmonid survival, perhaps necessitating management to reduce their impacts.

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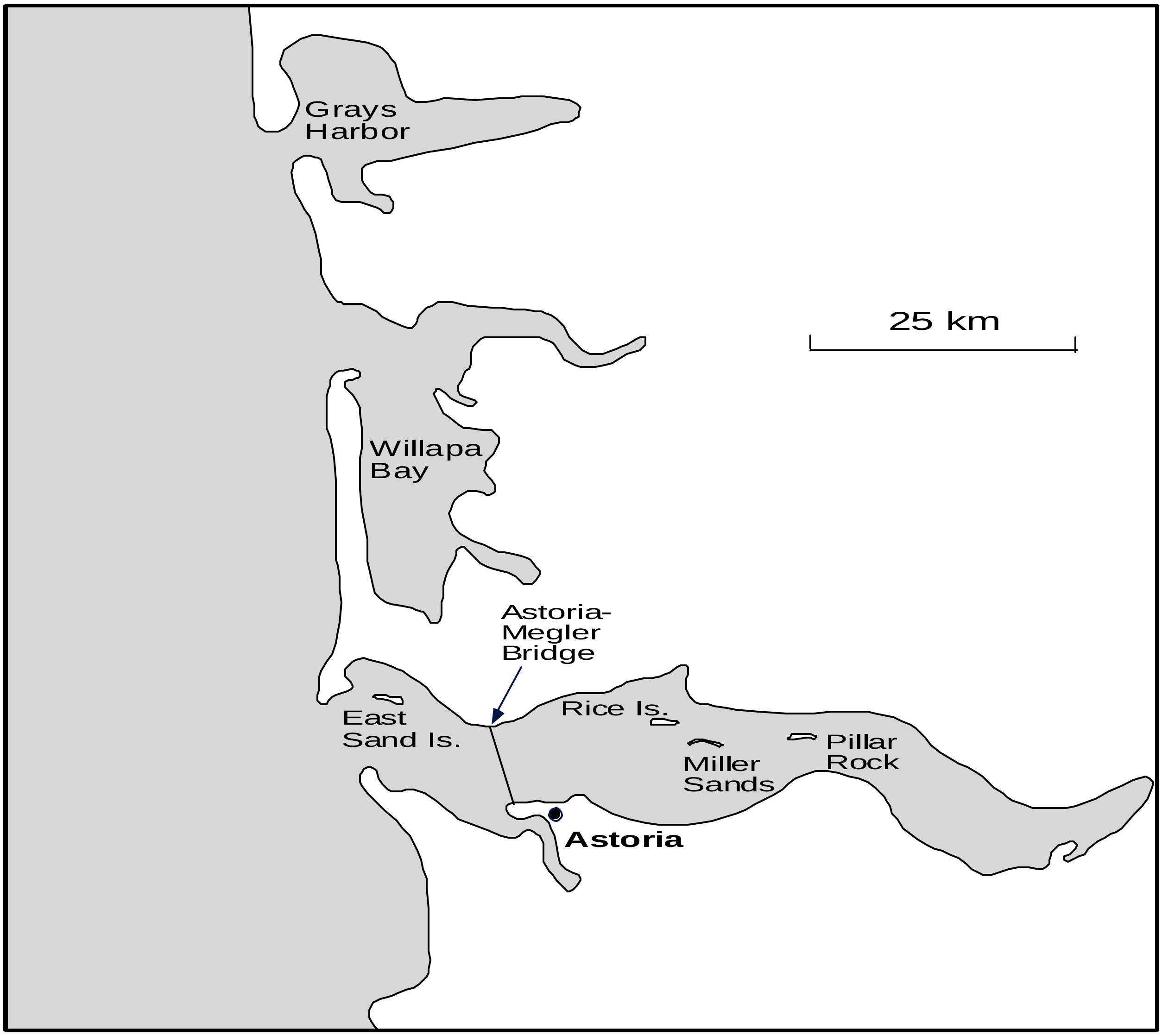
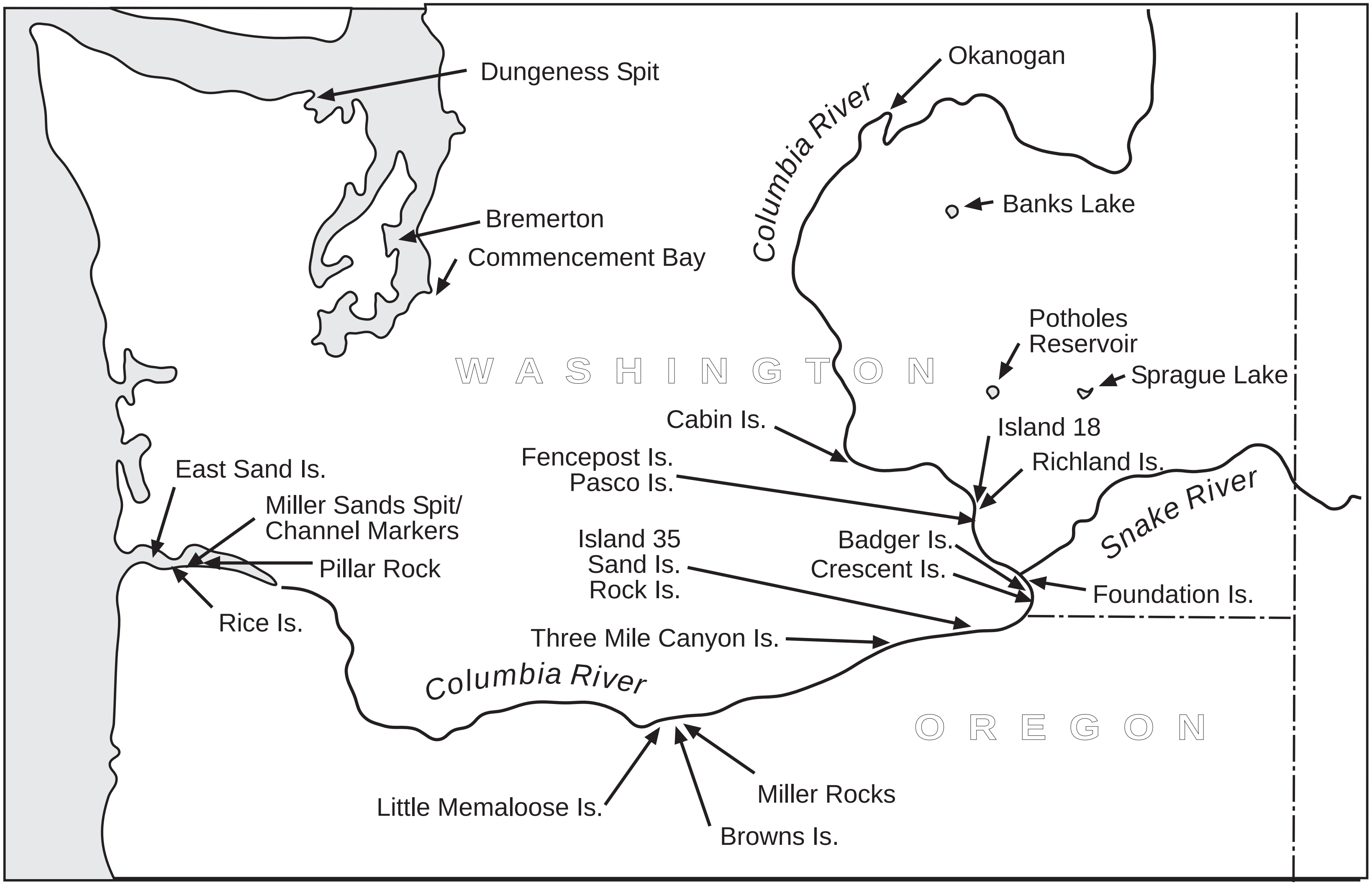
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Caspian terns			
1.1. Preparation and Modification of Nesting Habitat			
1.1.1. Columbia River Estuary		x	
1.2. Colony Size and Productivity			
1.2.1. Columbia River Estuary	x	x	
1.2.2. Columbia Plateau	x		x
1.2.3.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

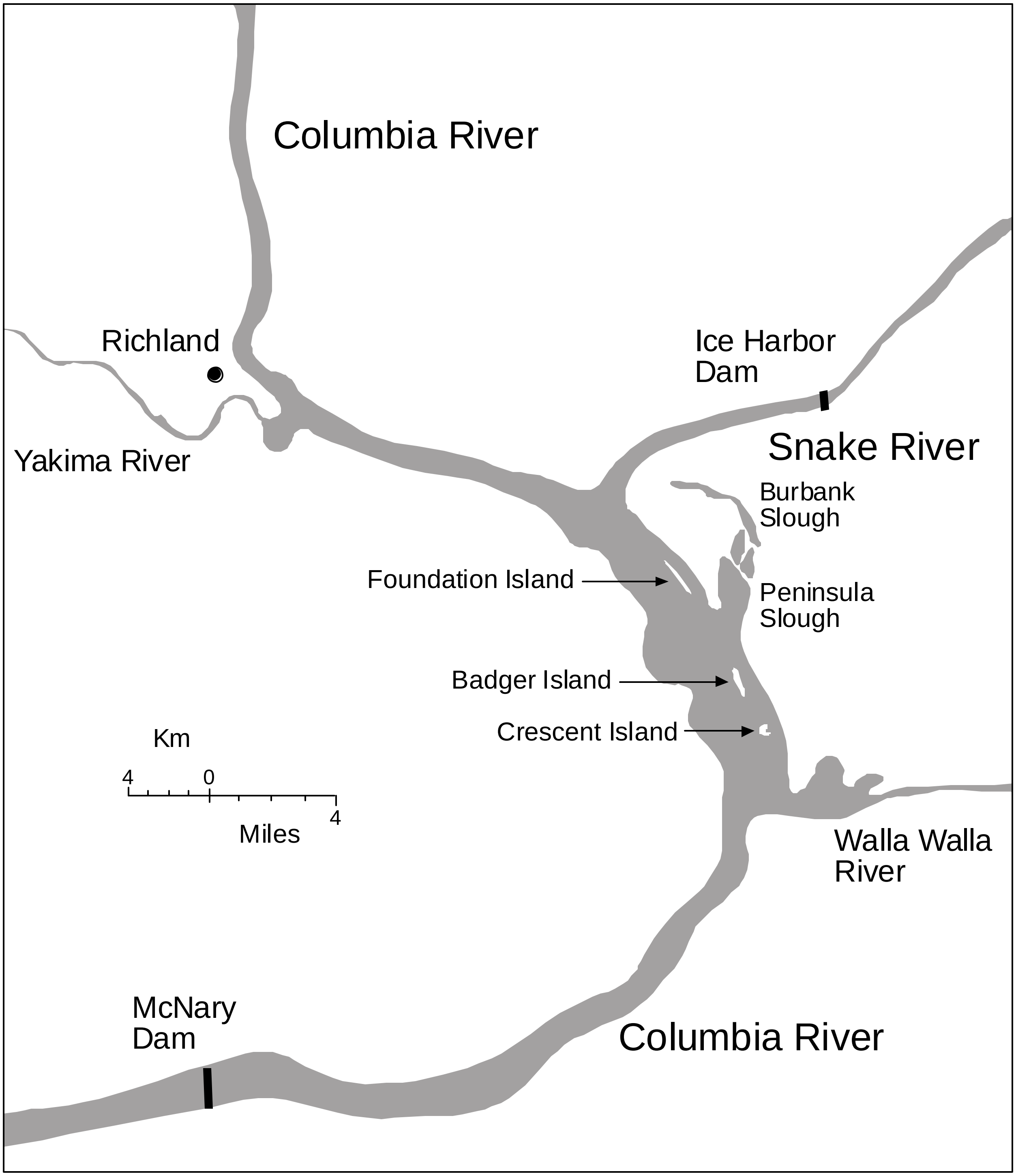
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Double-crested Cormorants			
2.1. Nesting Distribution and Colony Size			
2.1.1. Columbia River Estuary	x		
2.1.2. Columbia Plateau			x
2.1.3. Coastal Washington			
2.2. Nesting Chronology and Productivity			
2.2.1.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



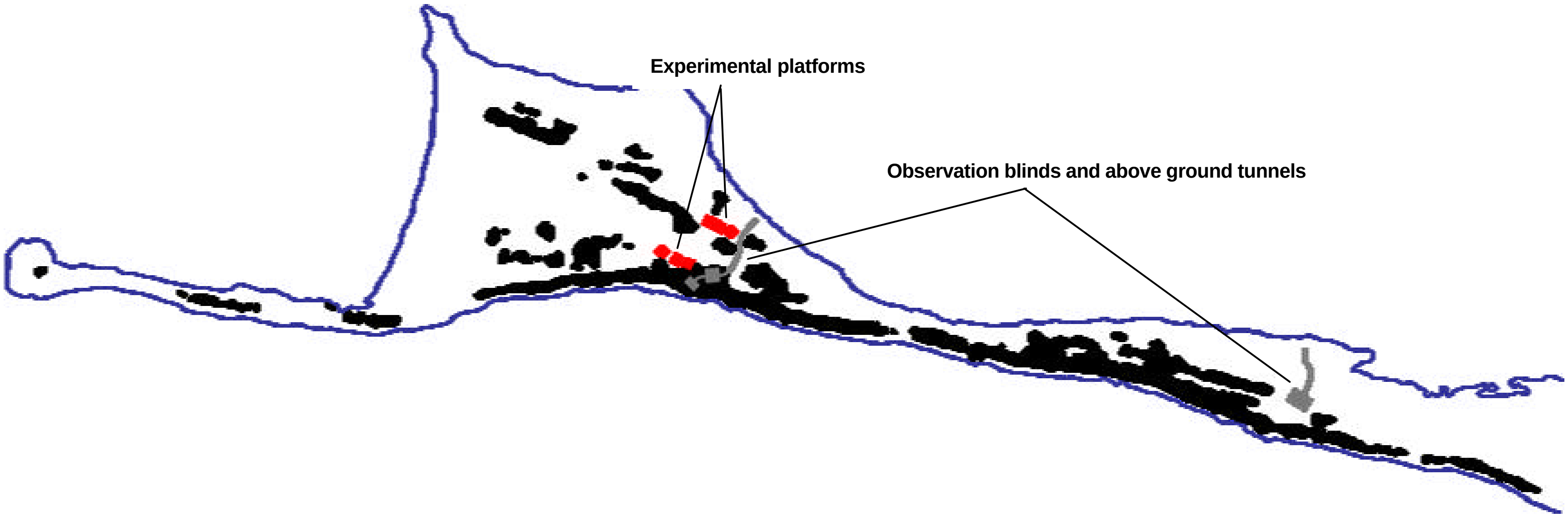
Map 1. Study area in the Columbia River estuary and along the southwest coast of Washington in 2006.



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



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



Map 4. The distribution of nesting double-crested cormorants (shown in black) on East Sand Island in 2006 and the location of the experimental nesting platforms (shown in red), observations blinds (shown in gray), and blind access tunnels (see text for details). Nesting cormorants were restricted to the western end on the island (shown here) and did not nest anywhere else on East Sand Island in 2006.

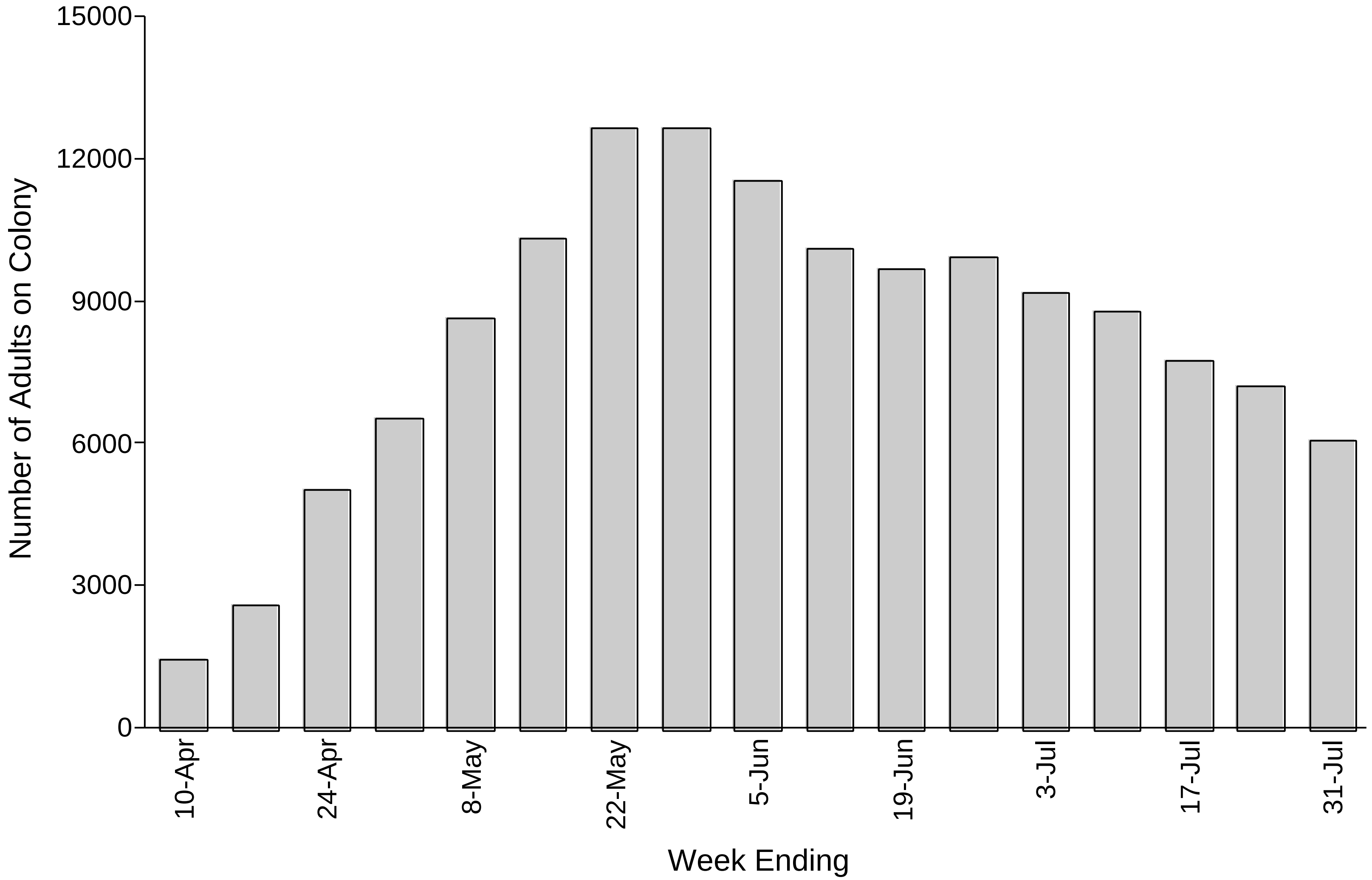


Figure 1. Weekly visual estimates of the number of adult Caspian terns on the East Sand Island colony in 2006.

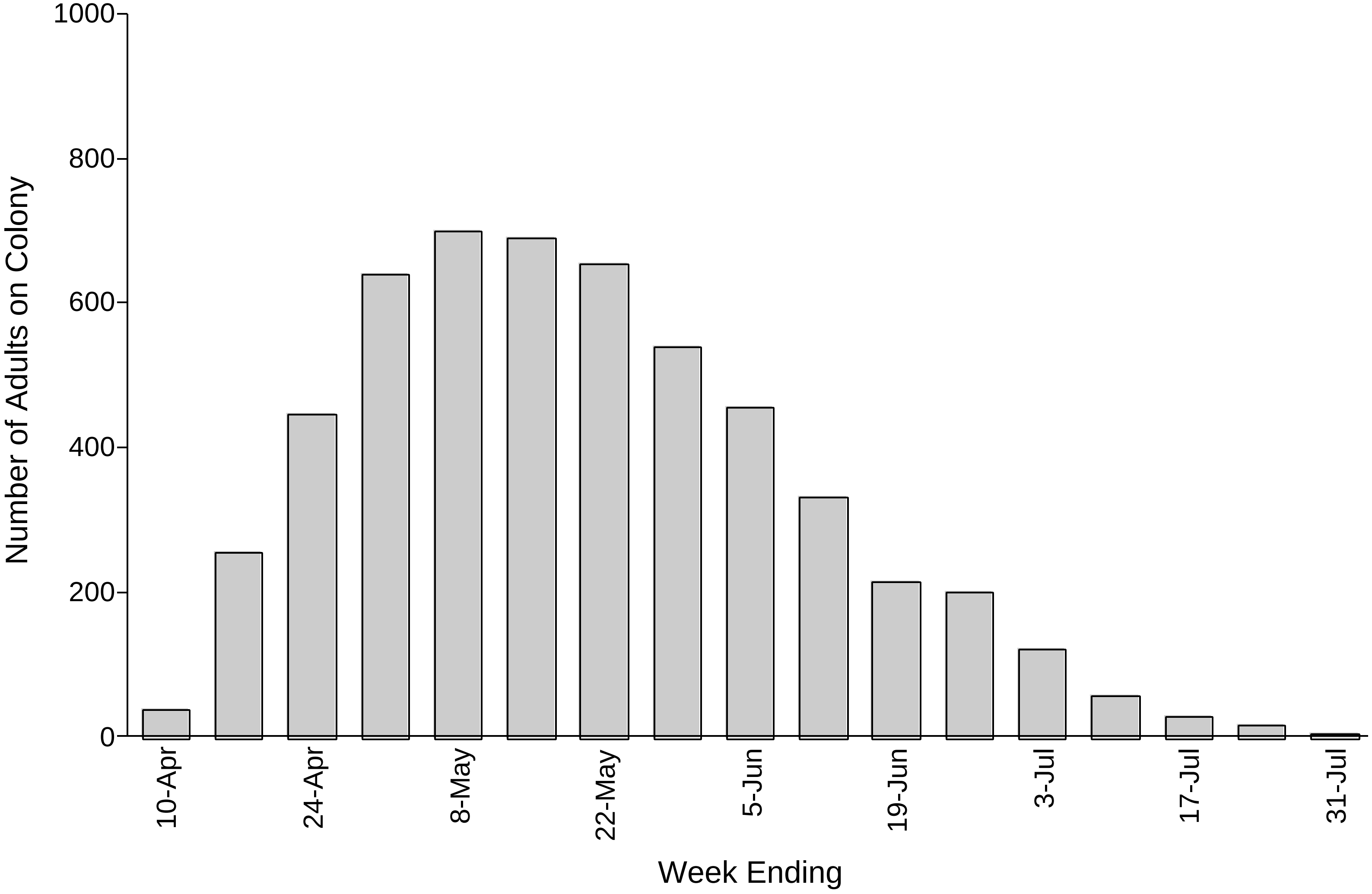


Figure 2. Weekly visual estimates of the number of adult Caspian terns on the Crescent Island colony in 2006.

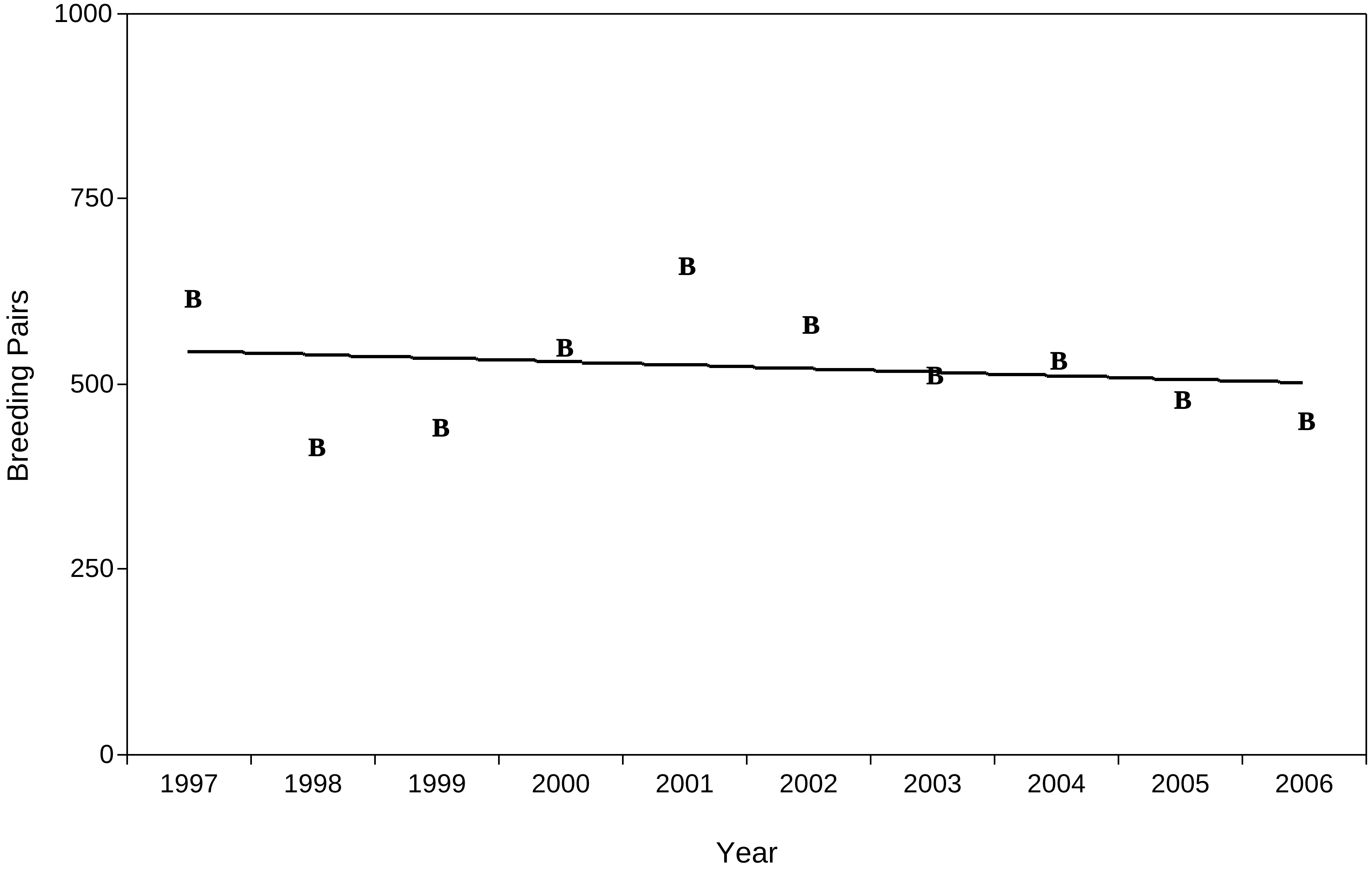


Figure 3. Population trends for Caspian terns nesting on Crescent Island, 1997-2006.

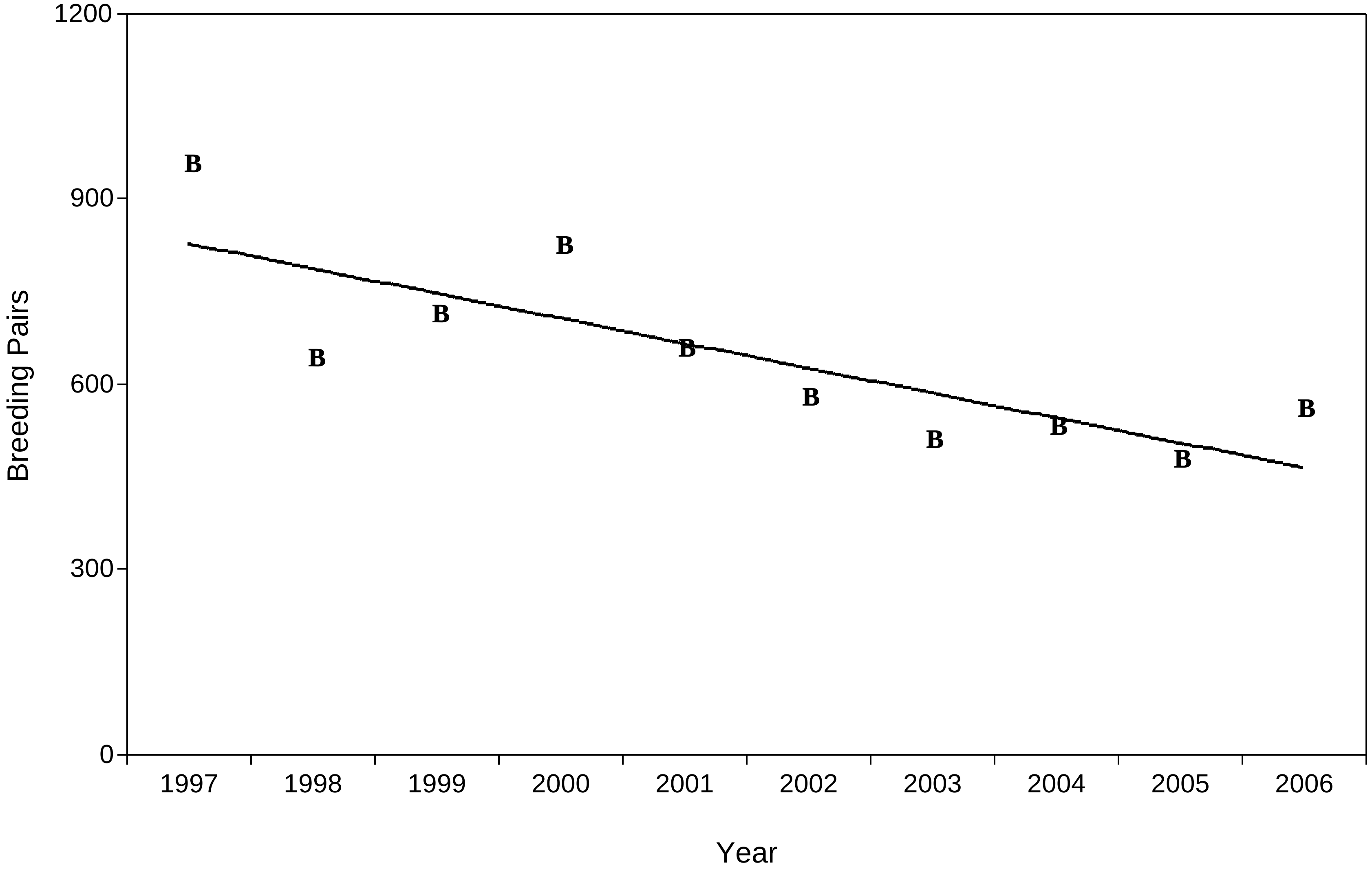
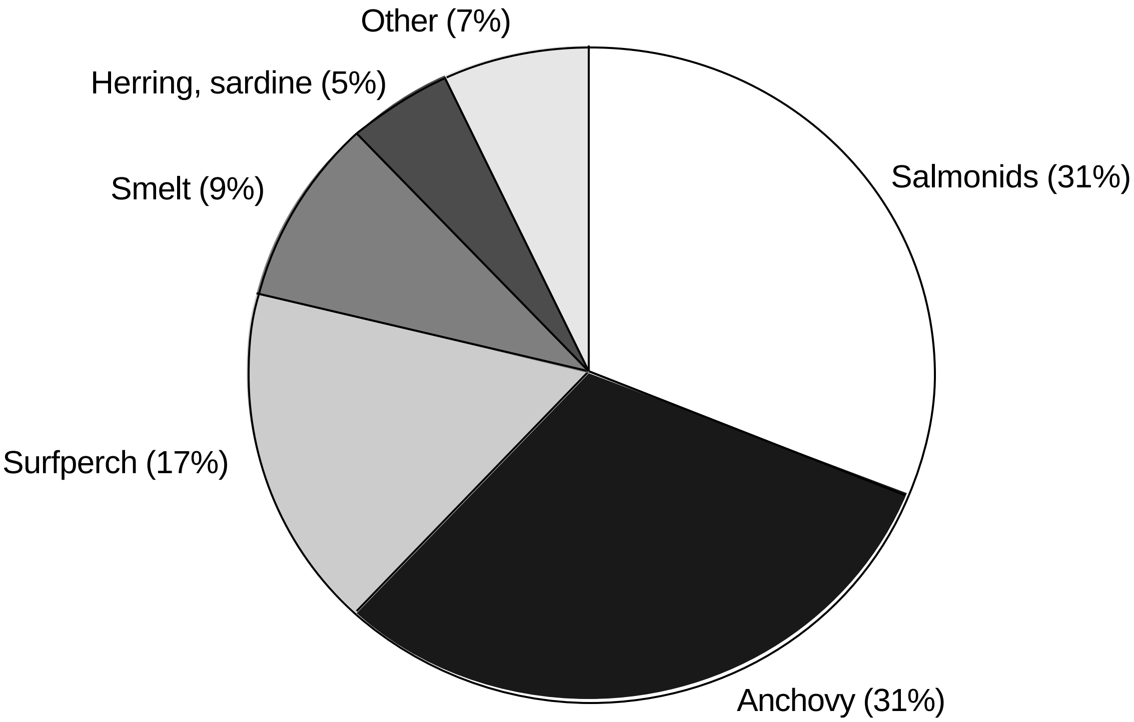


Figure 4. Population trends for Caspian terns nesting on the mid-Columbia River, 1997-2006.



N = 5,549 bill load fish

Figure 5. Diet composition of Caspian terns nesting on East Sand Island in 2006 (see text for methods of calculation).

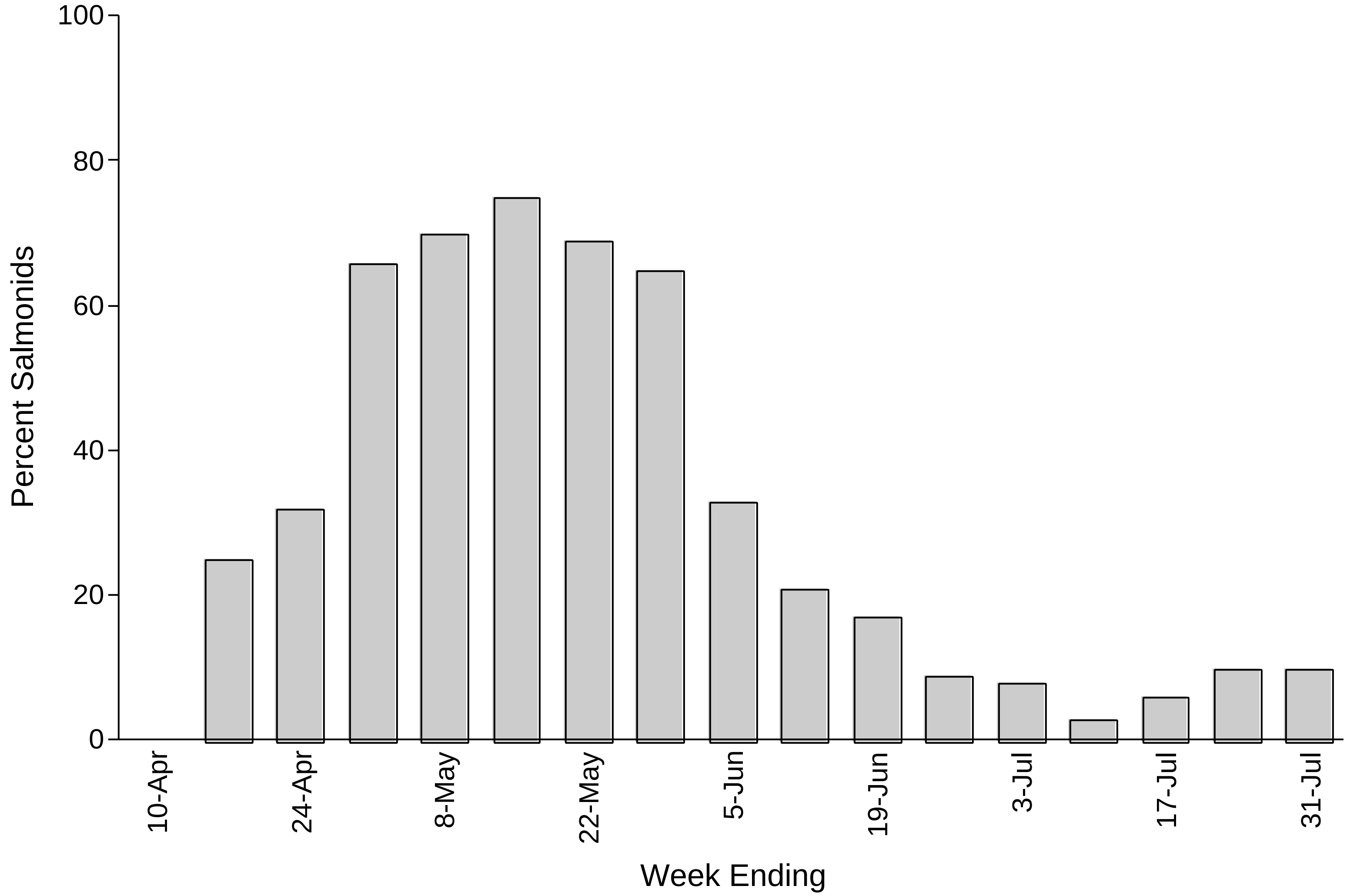


Figure 6. Weekly proportions of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island in 2006.

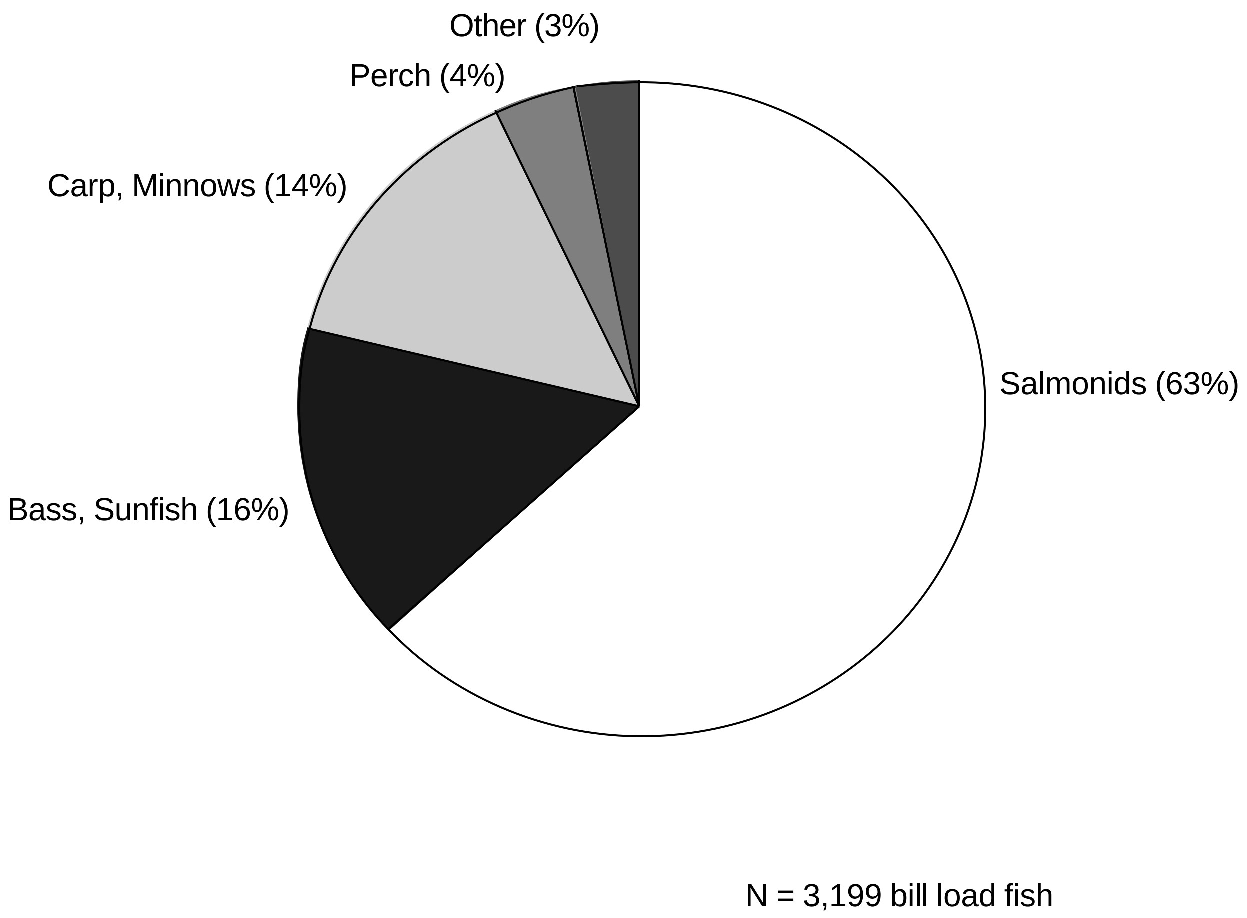


Figure 7. Diet composition of Caspian terns nesting on Crescent Island in 2006 (see text for methods of calculation).

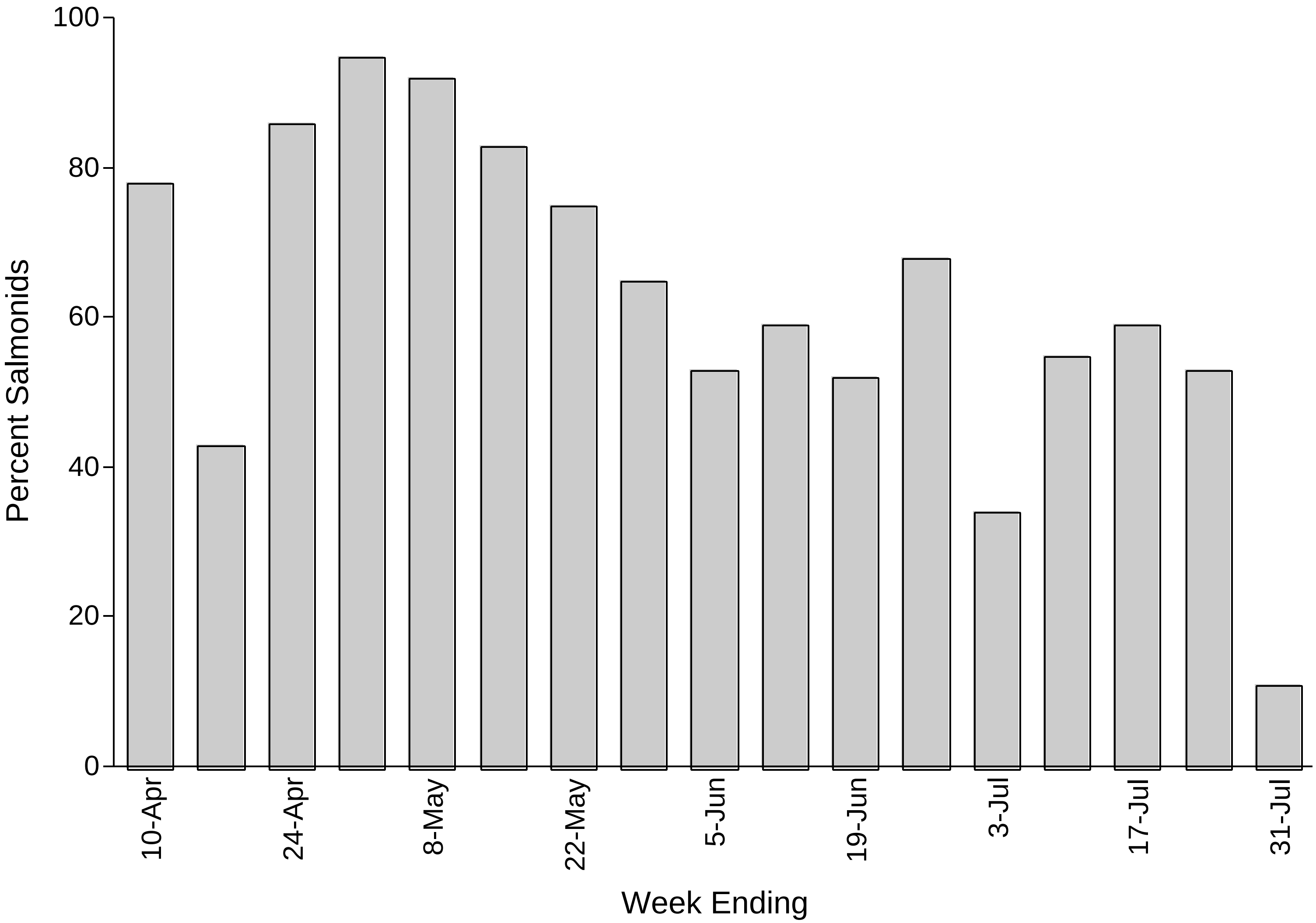


Figure 8. Weekly proportions of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island in 2006.

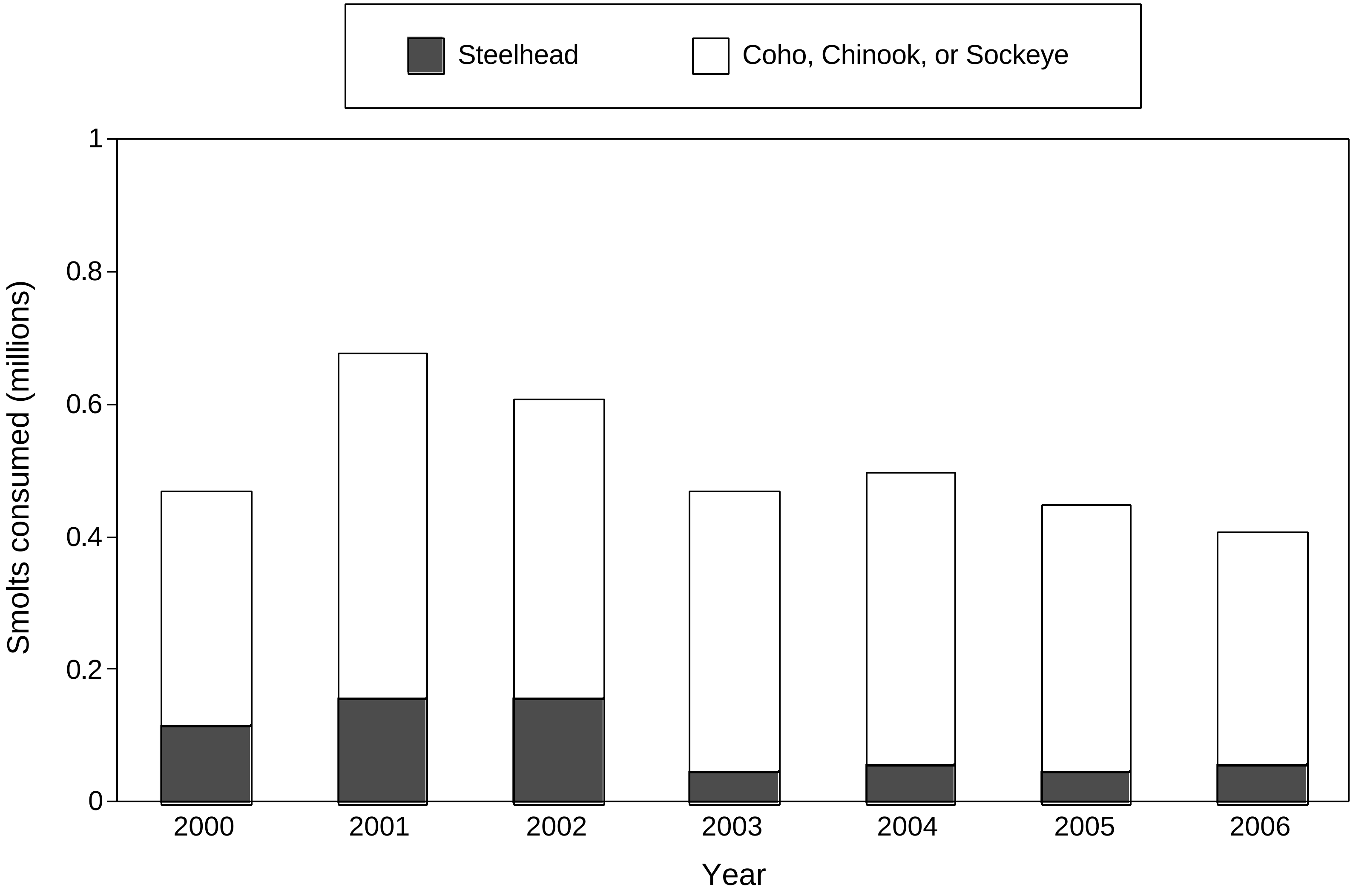


Figure 9. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting on Crescent Island, 2000-2006.

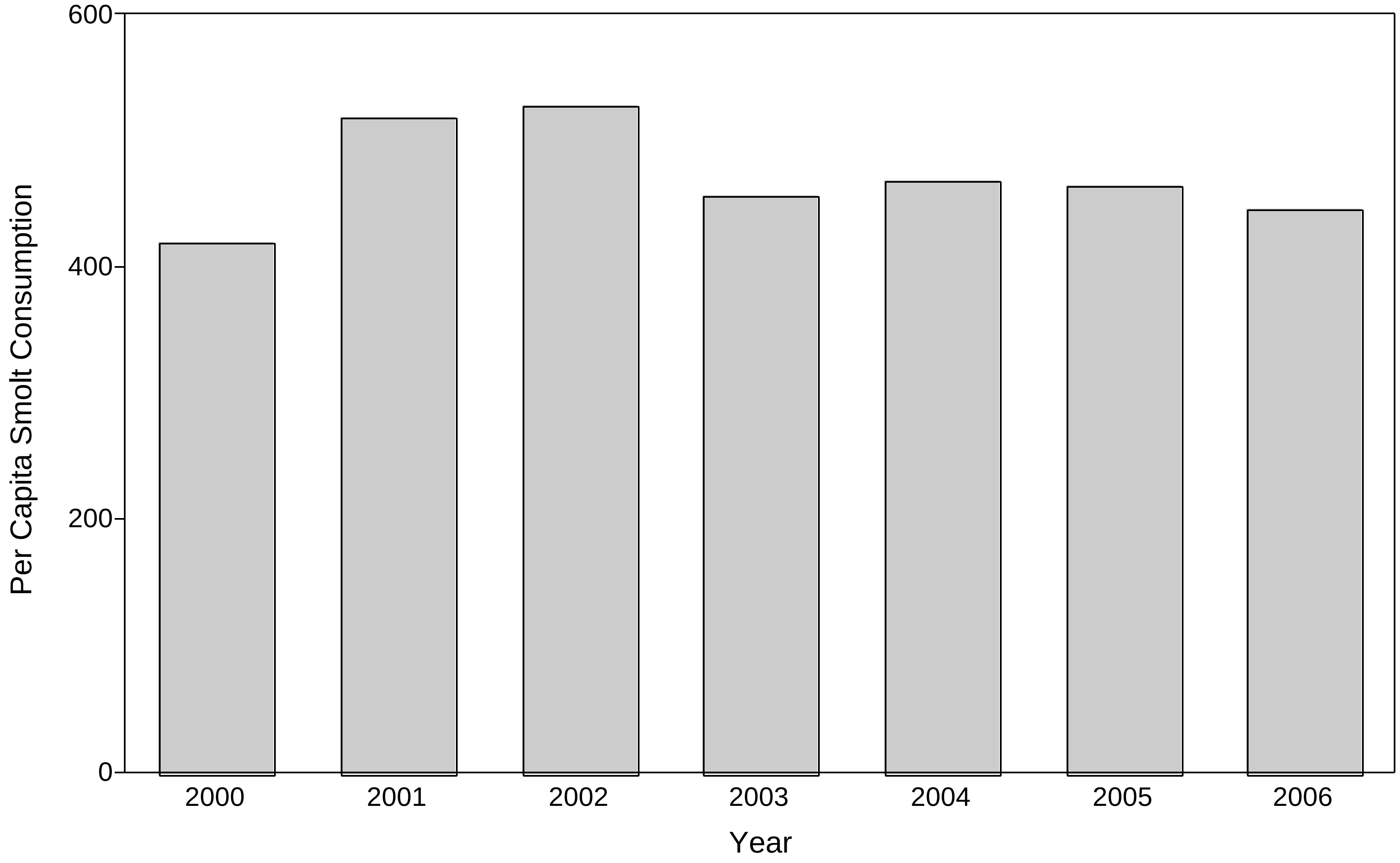


Figure 10. Estimated per capita annual consumption of juvenile salmonids by Caspian terns nesting on Crescent Island, 2000 - 2006.

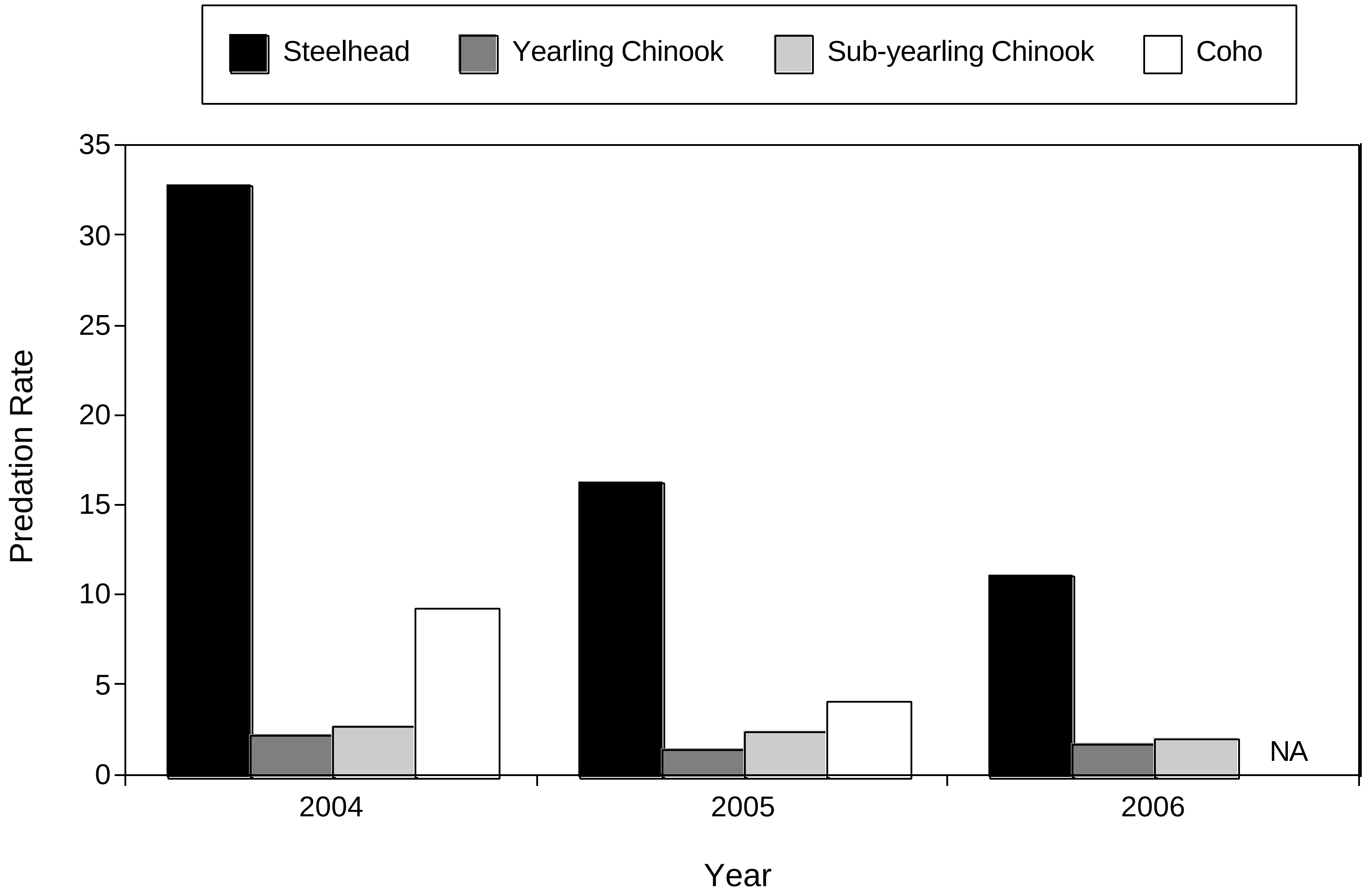


Figure 11. Predation rates on in-river PIT-tagged salmonid smolts from the Snake River by Caspian terns nesting on Crescent Island in 2004-2006. Adjusted predation rates (i.e., corrected for detection efficiency and deposition rate) are based on fish interrogated passing Lower Monumental Dam and subsequently detected on the tern colony.

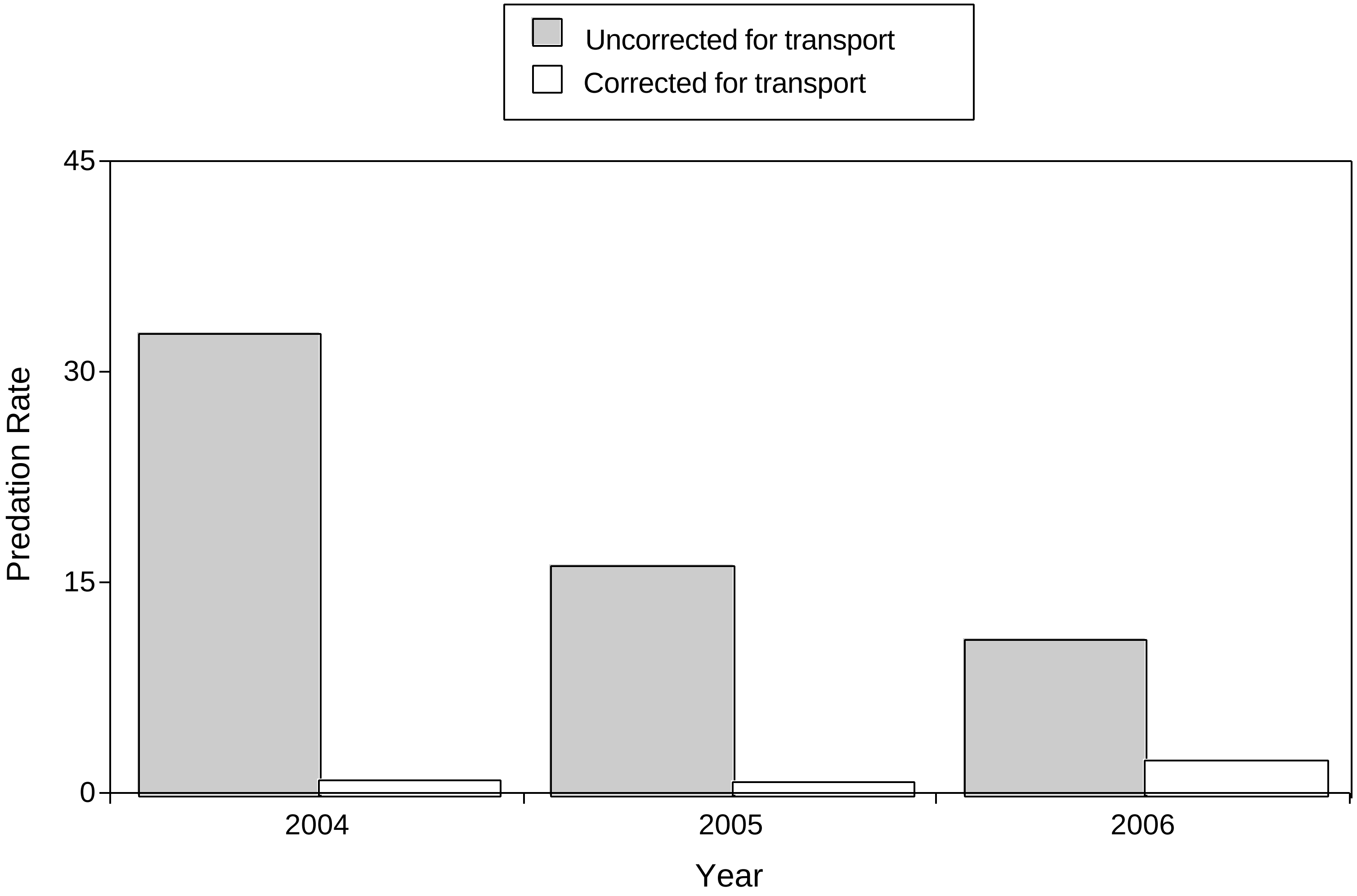


Figure 12. Transportation-adjusted predation rates (based on PIT tag recoveries) on Snake River steelhead by Caspian terns nesting on Crescent Island, 2004 - 2006. The proportion of the steelhead run that was not transported was 3.6%, 6.0%, and 24.7% in 2004-2006, respectively.

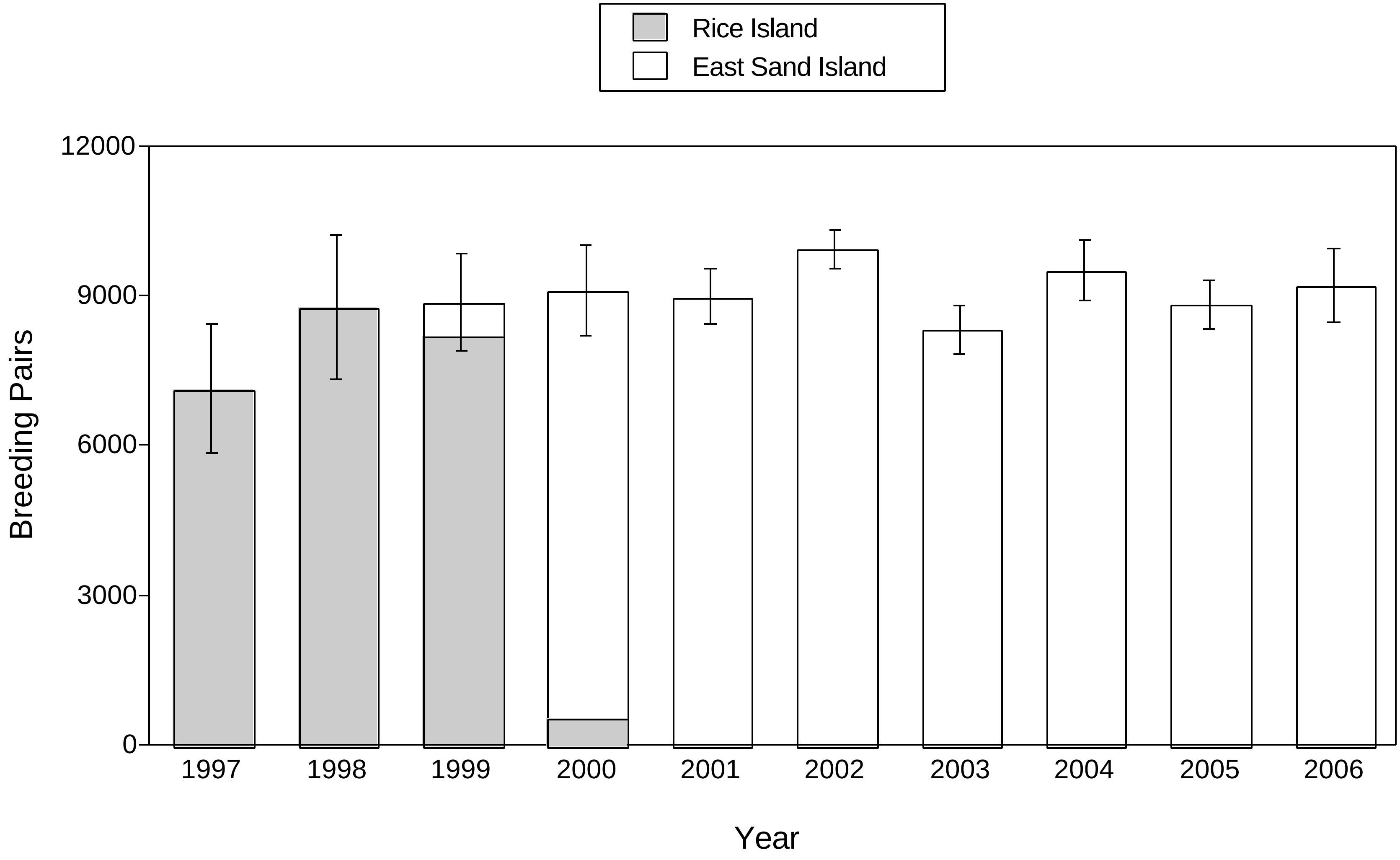


Figure 13. Caspian tern colony size in the Columbia River estuary, 1997 - 2006.

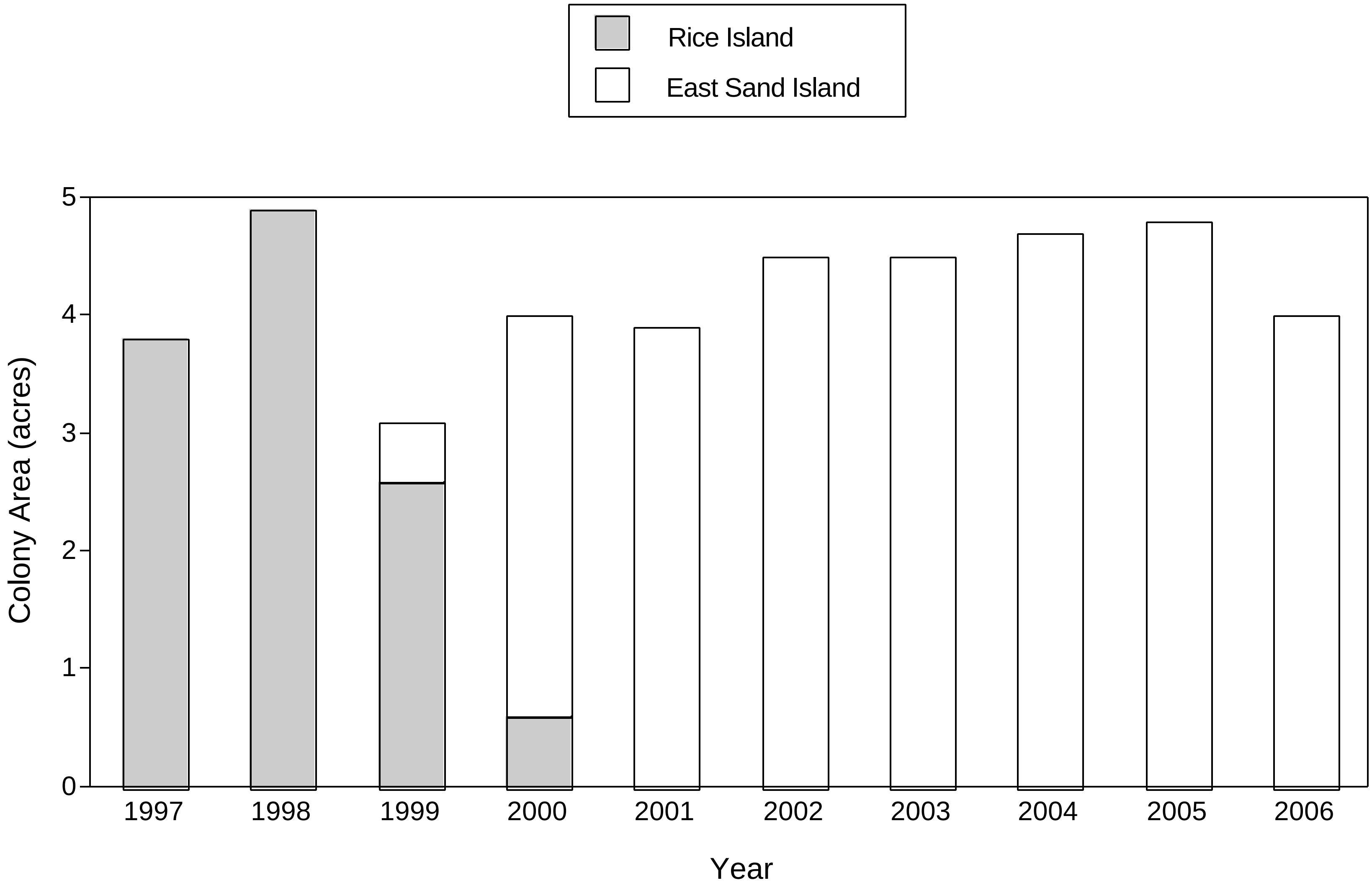


Figure 14. Area occupied by nesting Caspian terns at colonies in the Columbia River estuary, 1997 - 2006.

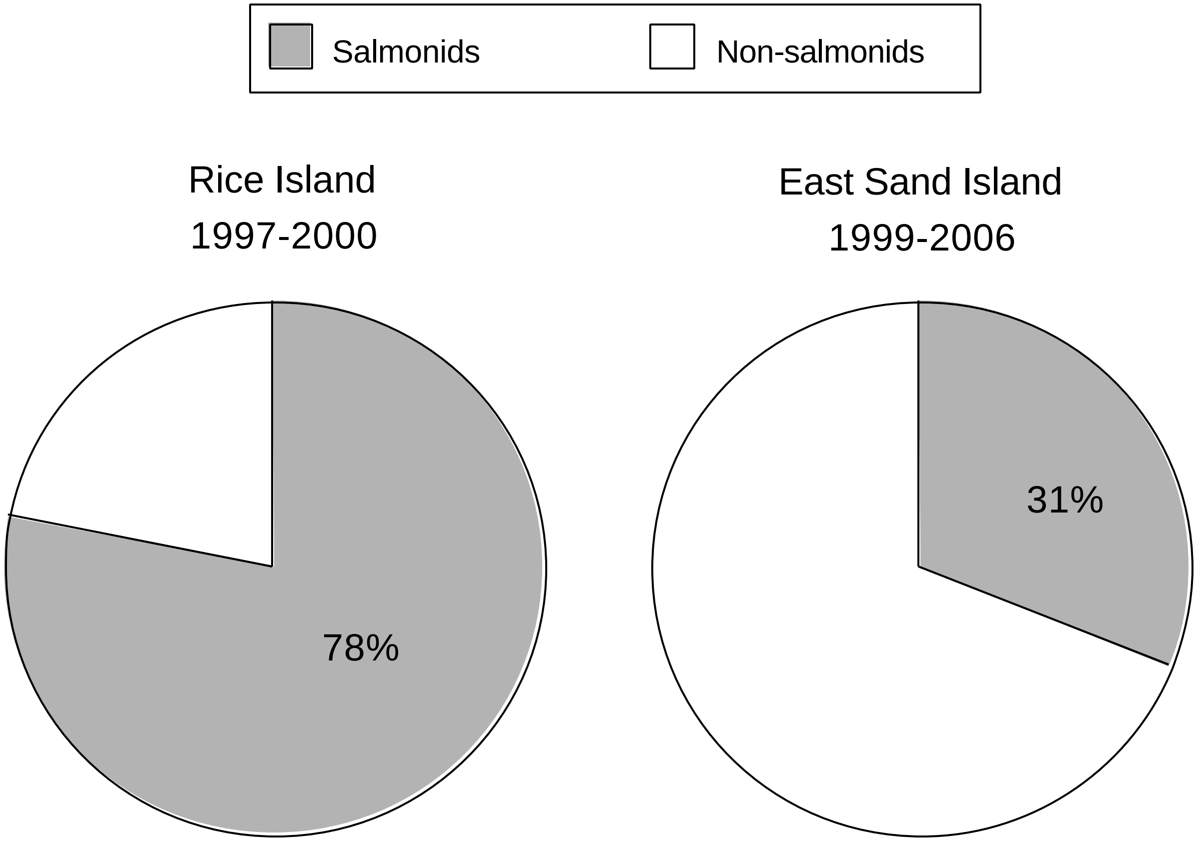


Figure 15. Mean annual proportion of juvenile salmonids in the diet of Caspian terns nesting on Rice Island (n = 4 years) and East Sand Island (n = 8 years) in the Columbia River estuary, 1997-2006.

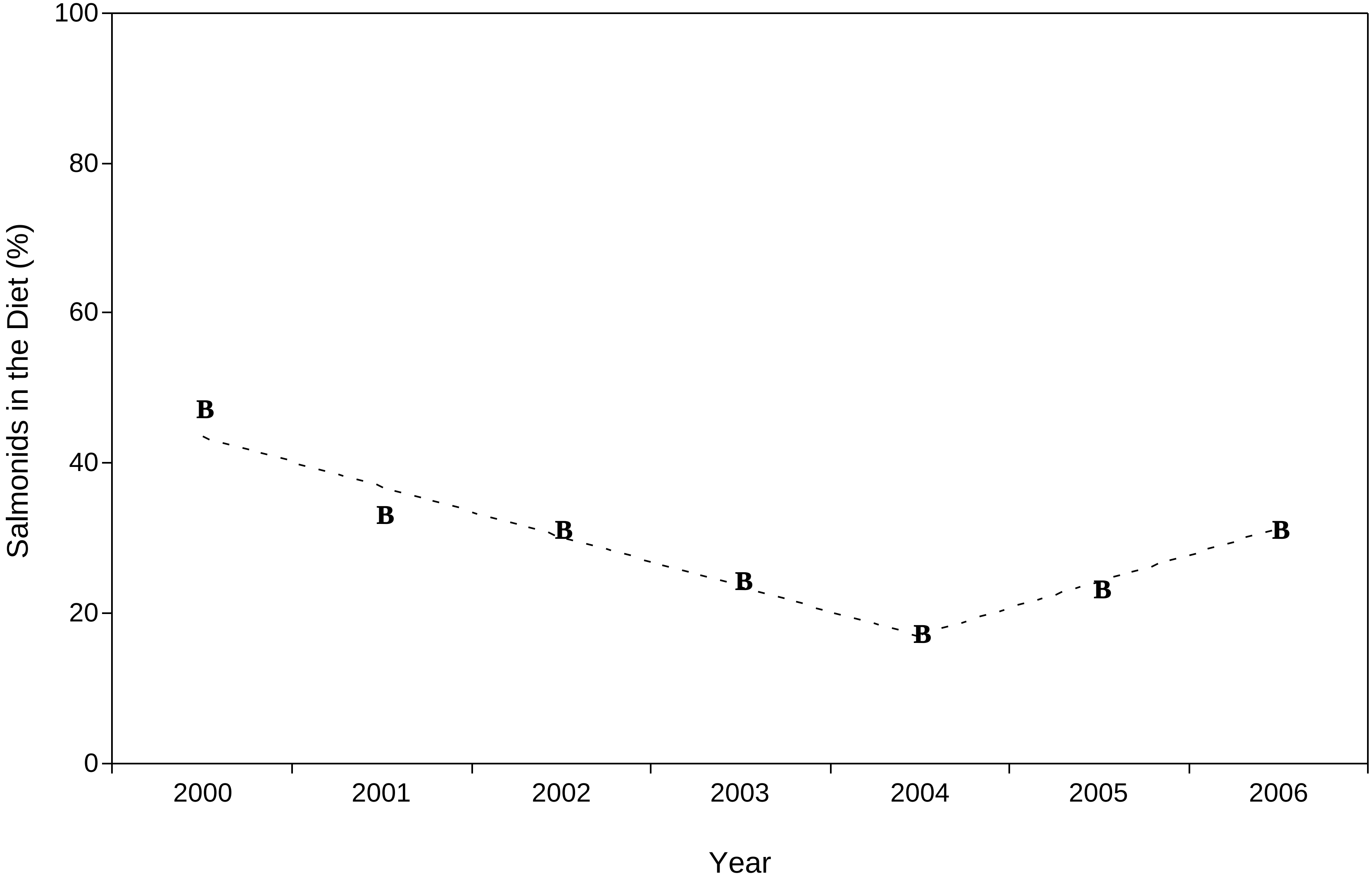


Figure 16. Proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island, 2000-2006.

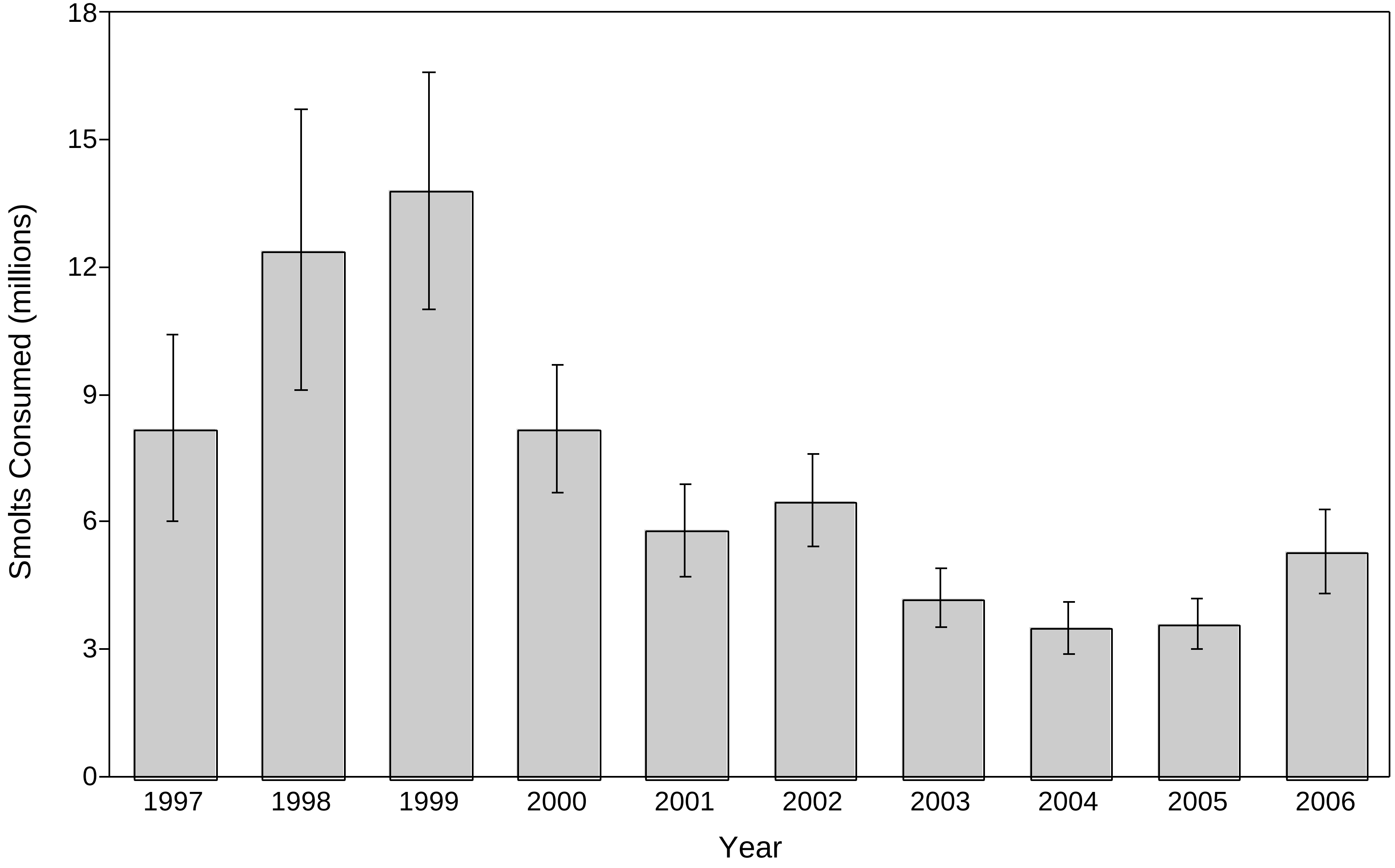


Figure 17. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting in the Columbia River estuary, 1997 - 2006.

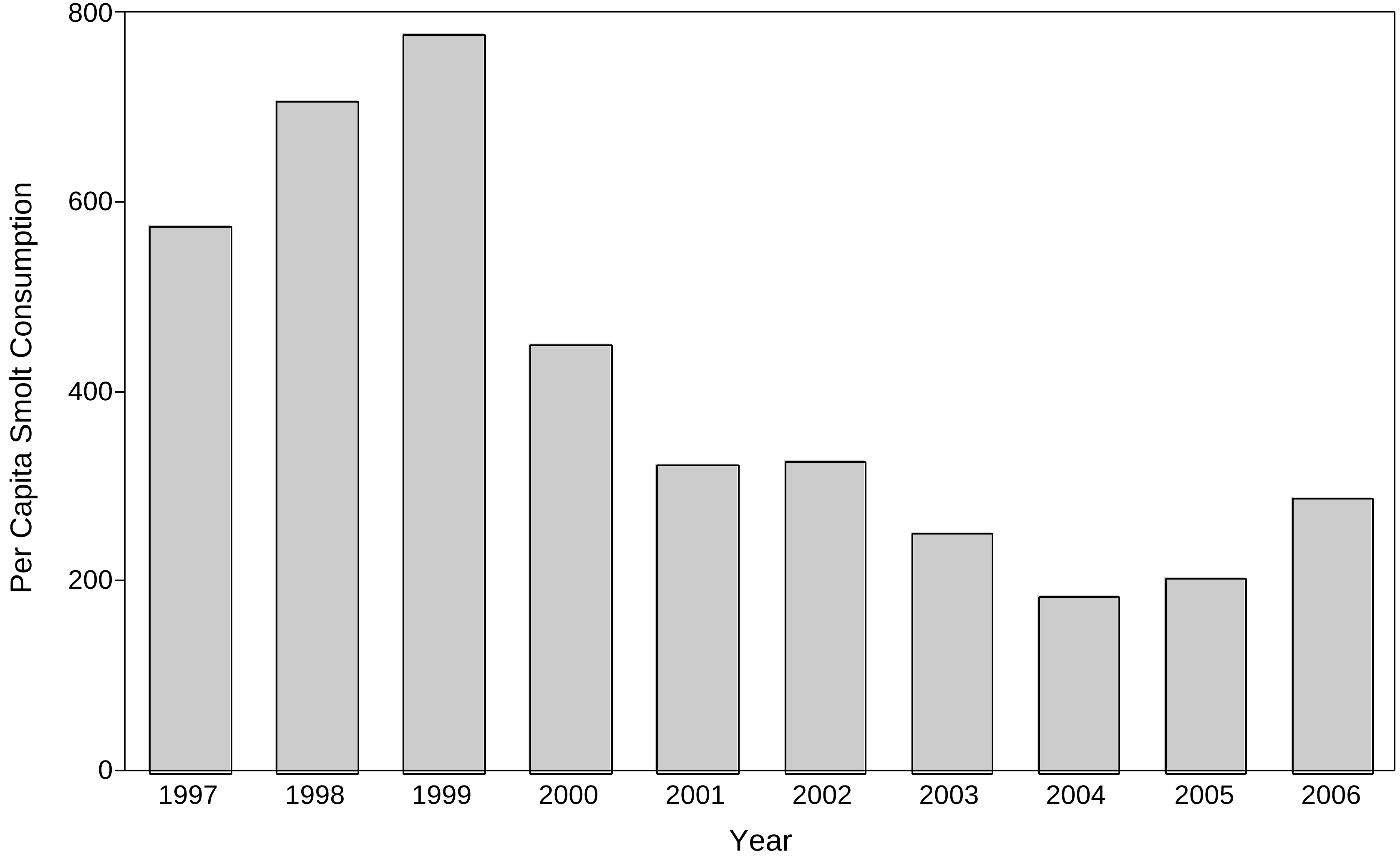


Figure 18. Estimated per capita annual consumption of juvenile salmonids by Caspian terns nesting in the Columbia River estuary, 1997 - 2006.

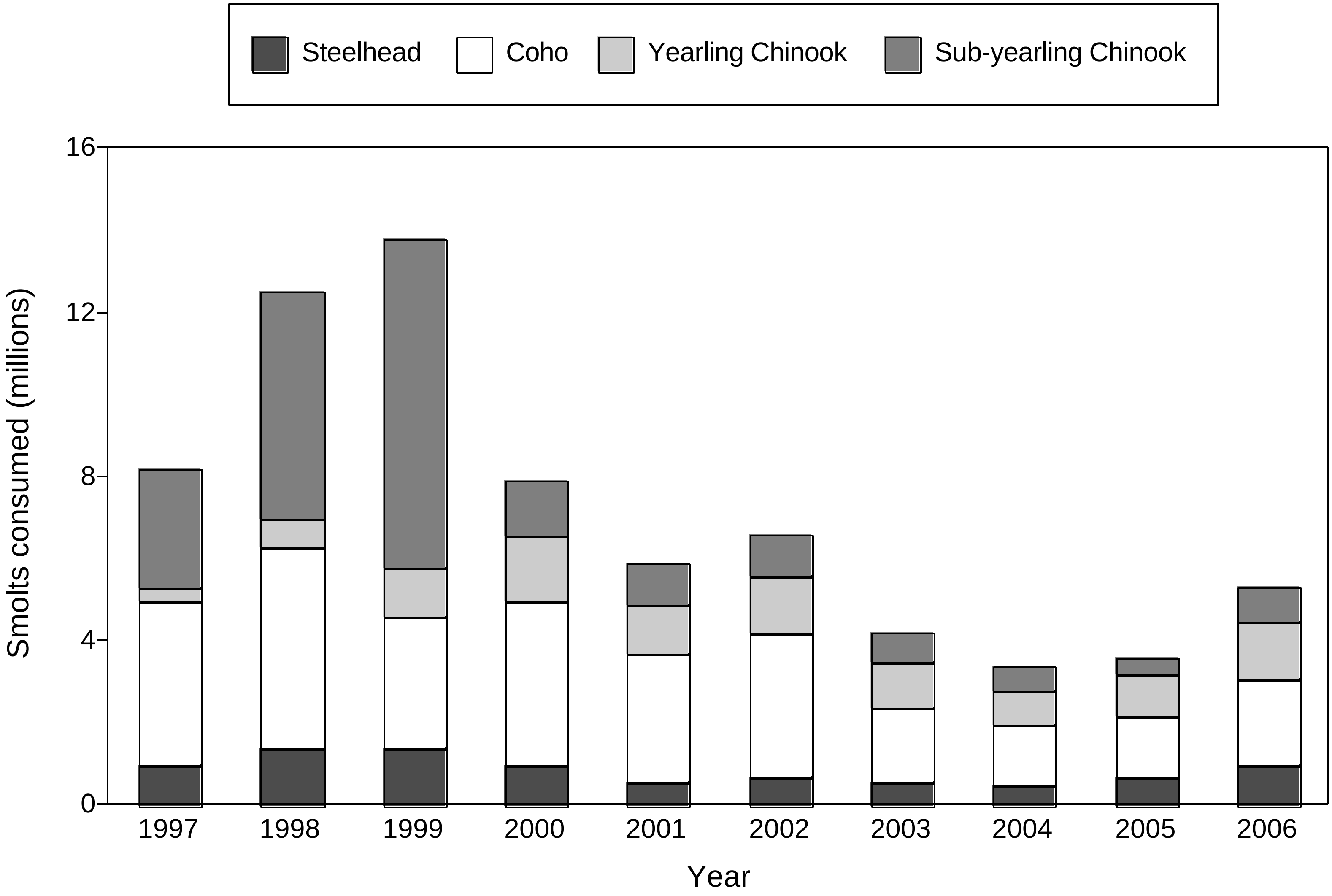


Figure 19. Estimated total annual consumption of four species of juvenile salmonids by Caspian terns nesting in the Columbia River estuary, 1997-2006.

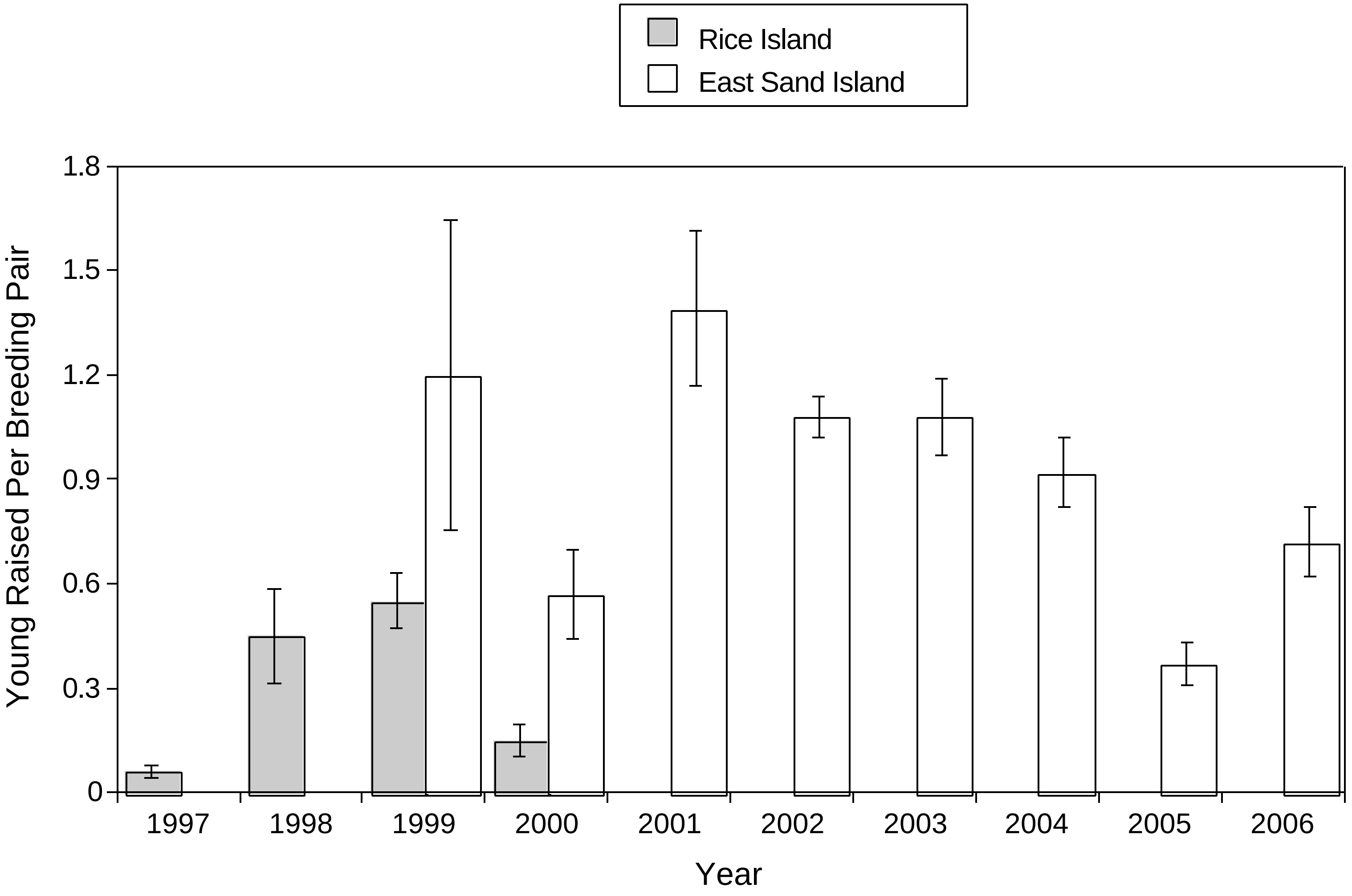


Figure 20. Average productivity (young fledged per breeding pair) of Caspian terns nesting at two colonies in the Columbia River estuary, 1997 - 2006.

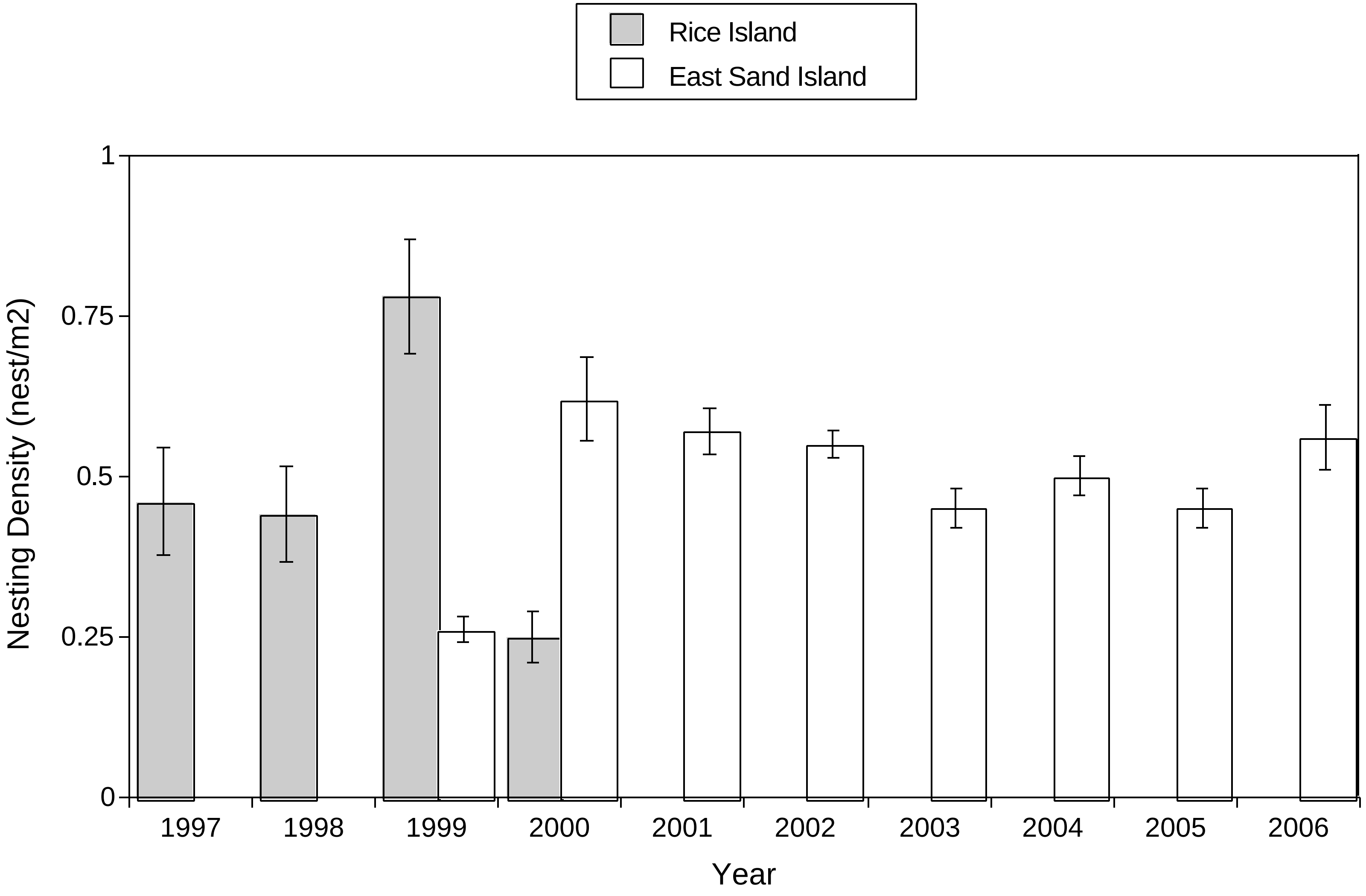


Figure 21. Average nest density for Caspian terns nesting at two colonies in the Columbia River estuary, 1997 - 2006.

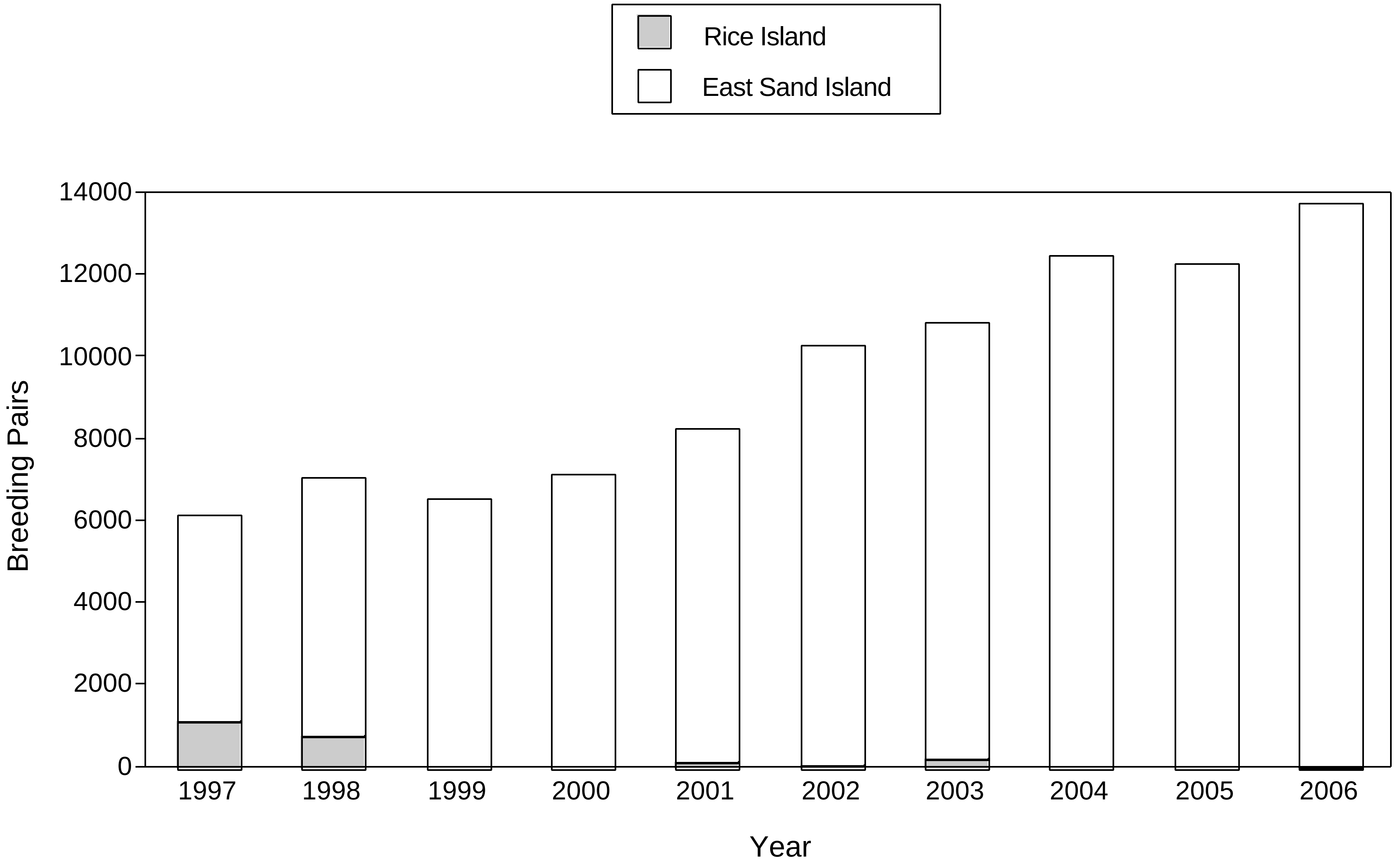


Figure 22. Numbers of breeding pairs of double-crested cormorants nesting at two colonies in the Columbia River estuary, 1997 - 2006.

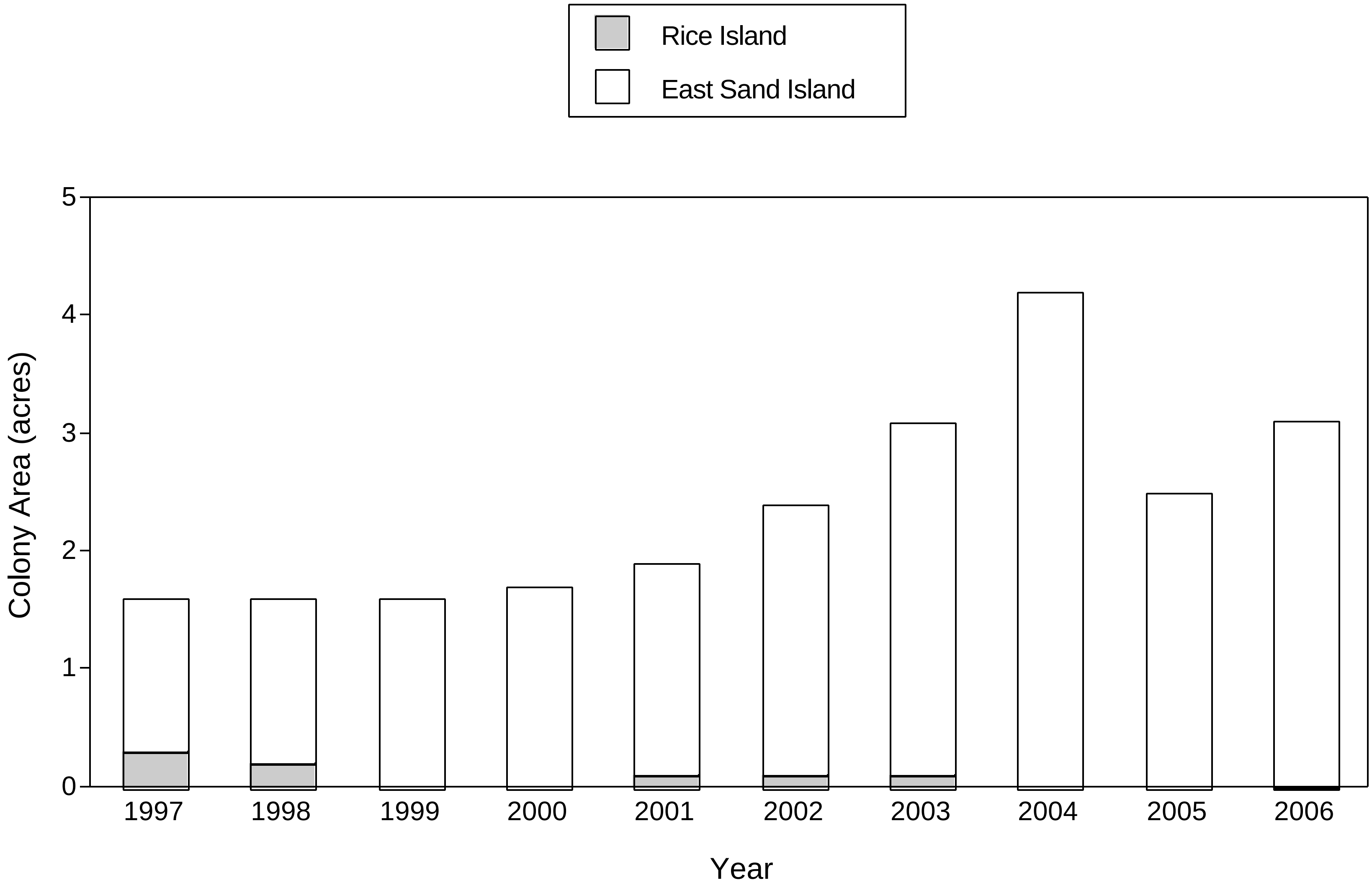


Figure 23. Area occupied by nesting double-crested cormorants at two colonies in the Columbia River estuary, 1997 - 2006.

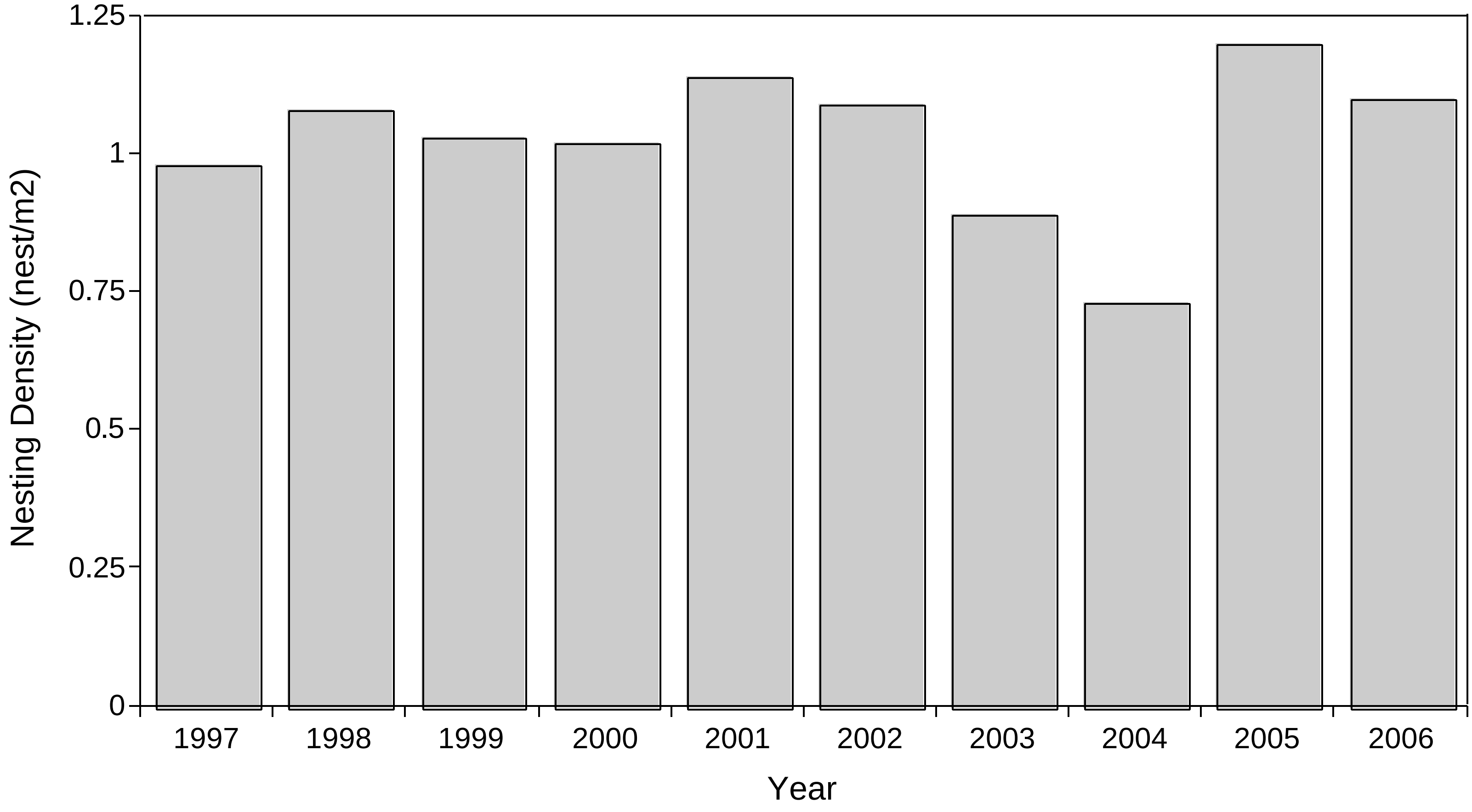


Figure 24. Average nest density for double-crested cormorants nesting on East Sand Island in the Columbia River estuary, 1997 - 2006.

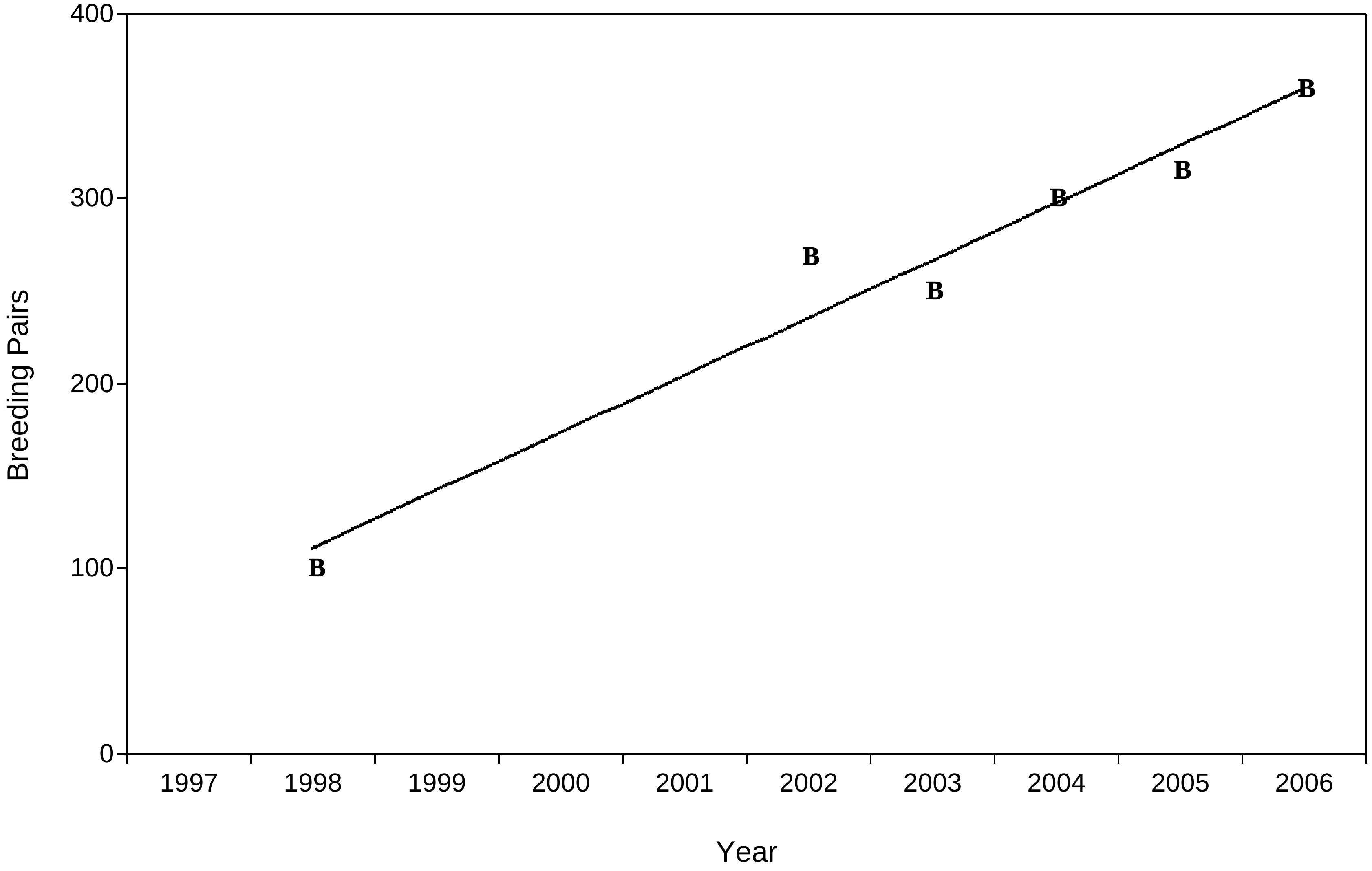


Figure 25. Population trends for double-crested cormorants nesting on Foundation Island, 1998-2006. Missing data points indicate that no colony count was conducted during that year.

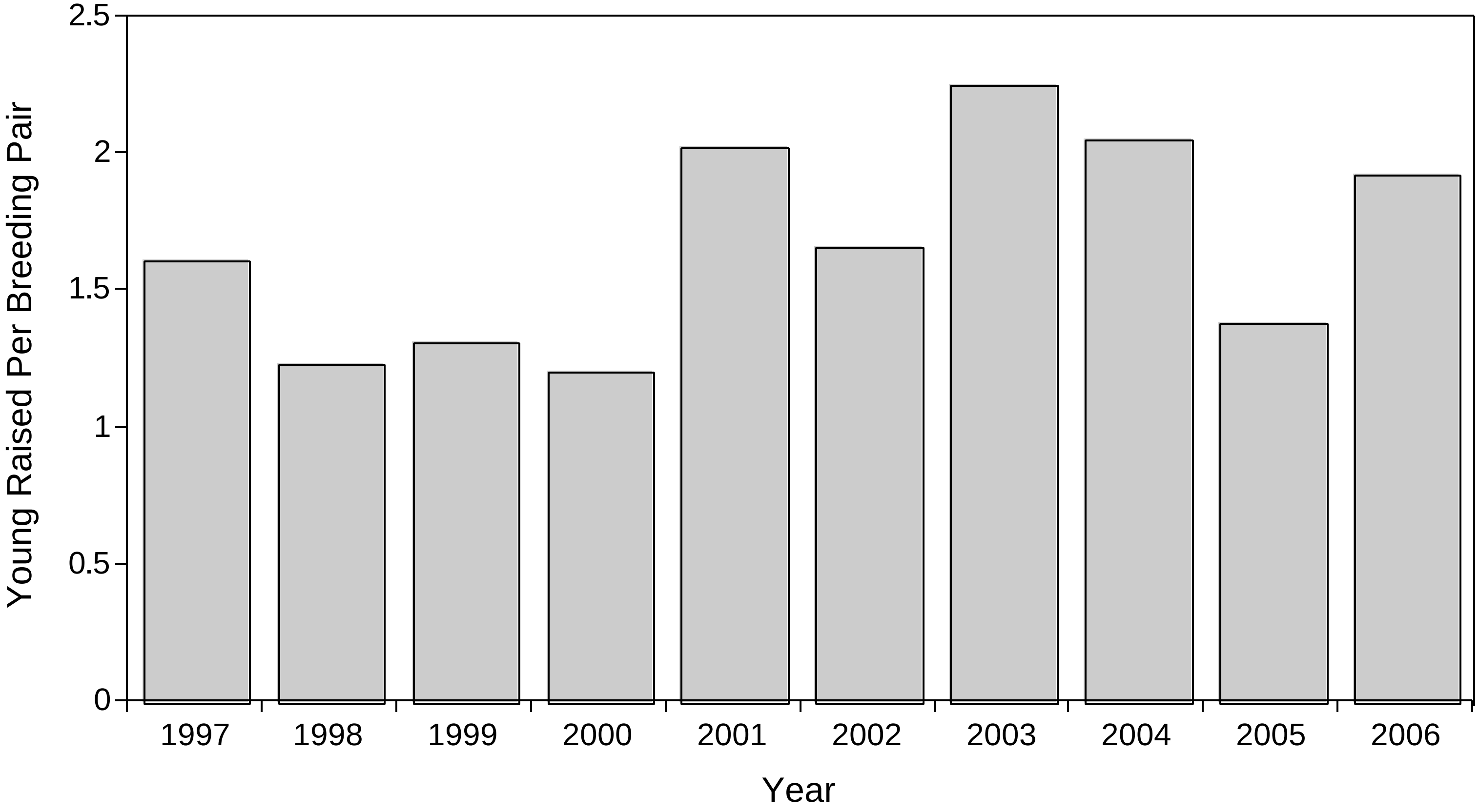
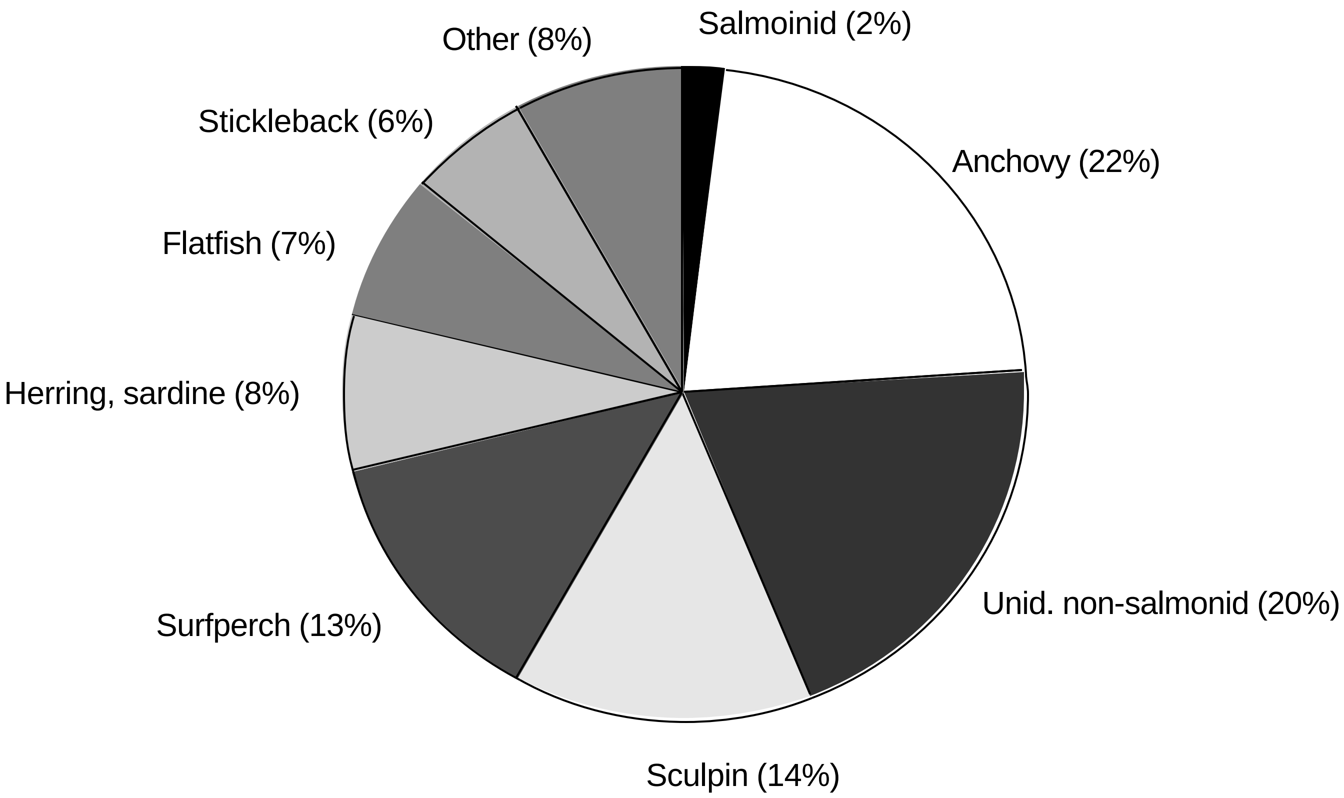


Figure 26. Average productivity (number of young fledged per breeding pair) of double-crested cormorants nesting on East Sand Island in the Columbia River estuary, 1997 - 2006.



N = 133 adult foregut samples

Figure 27. Preliminary diet composition (based on analysis of soft tissue only in stomach contents samples) of double-crested cormorants nesting on East Sand Island in 2005 (see text for methods of calculation).

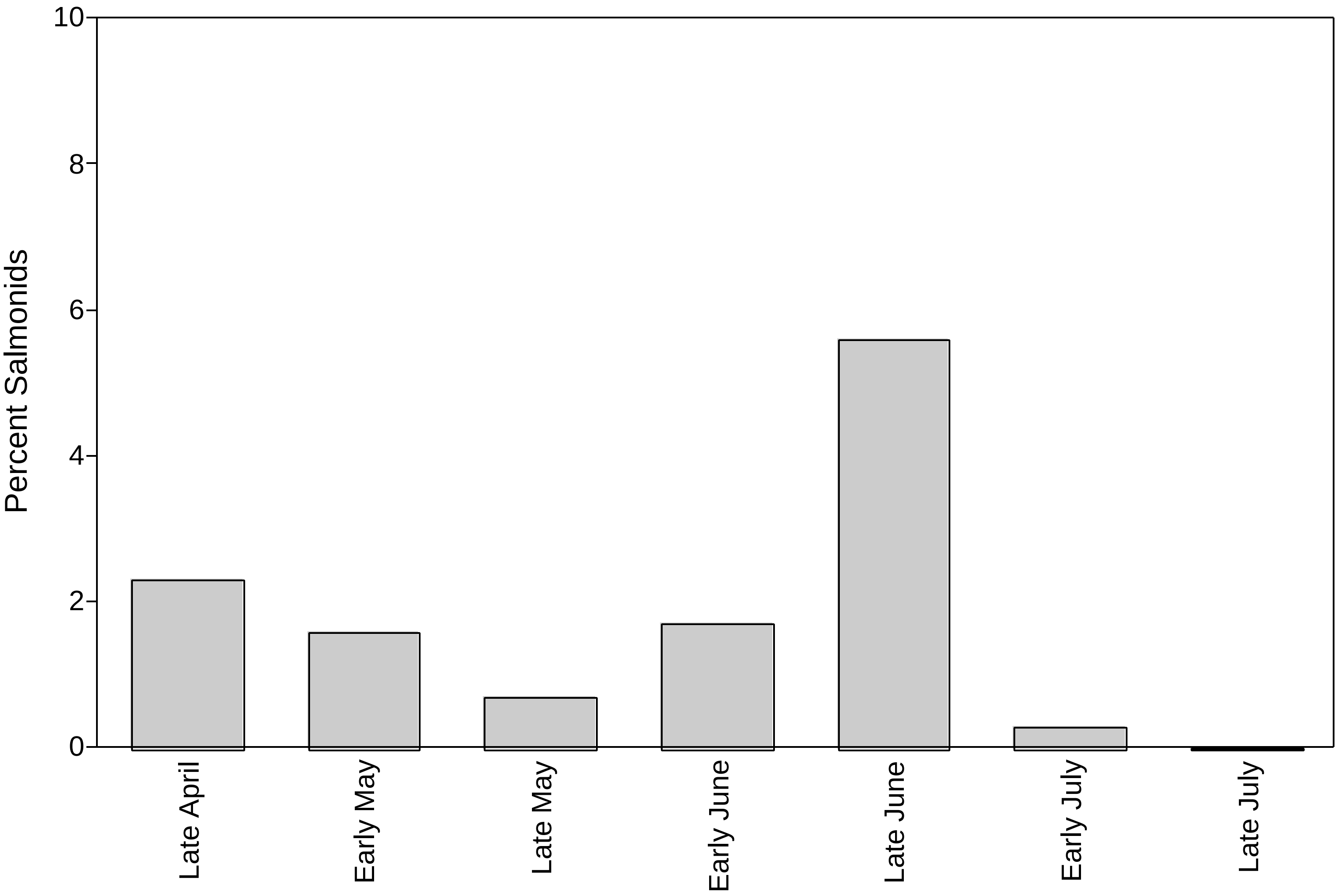


Figure 28. Bi-monthly proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island in the Columbia River estuary during 2005.

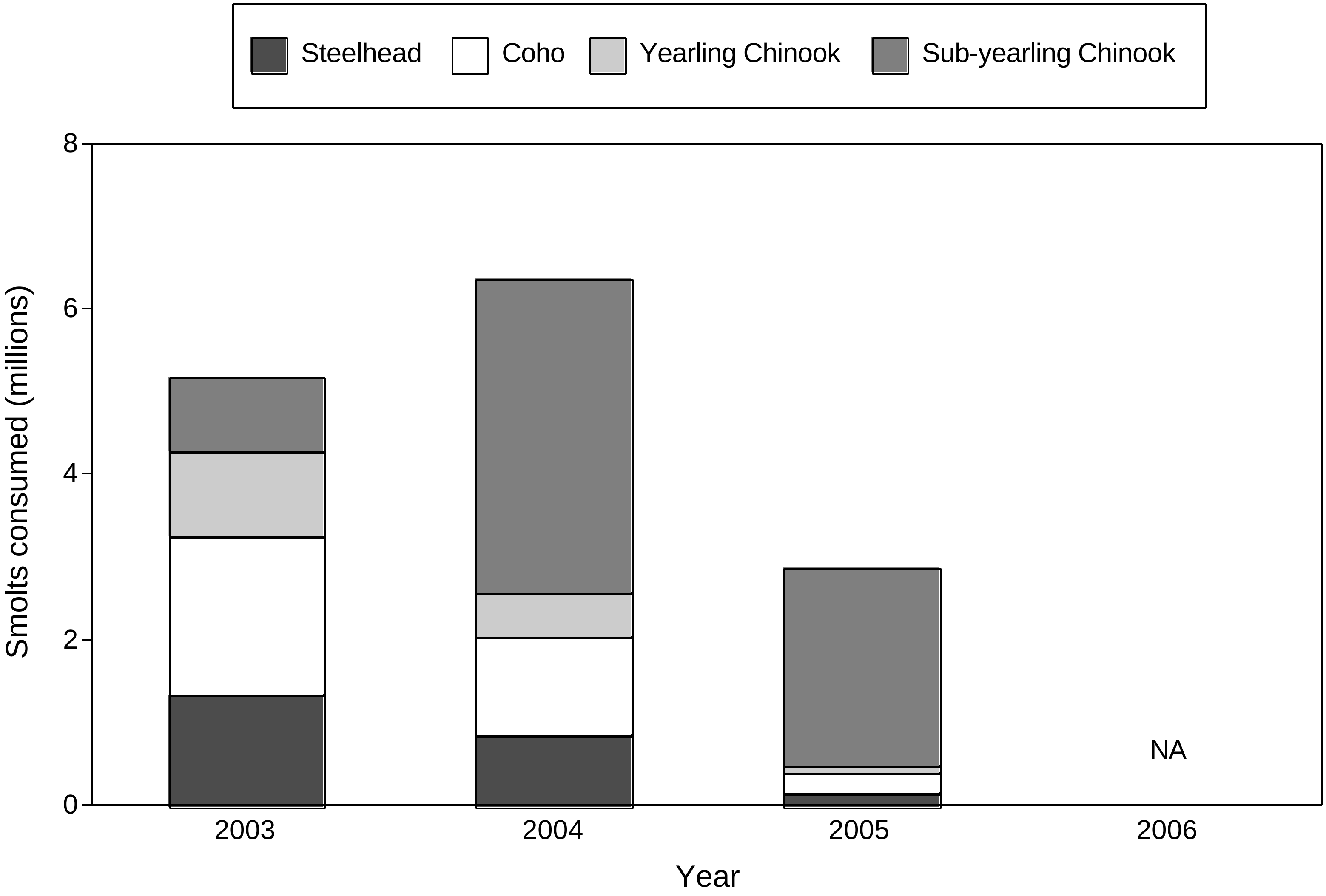


Figure 29. Estimated total annual consumption of four species of juvenile salmonids by double-crested cormorants nesting on East Sand Island in the Columbia River Estuary, 2003-2005. Data from 2006 are currently being analyzed and will be provided in a subsequent report.

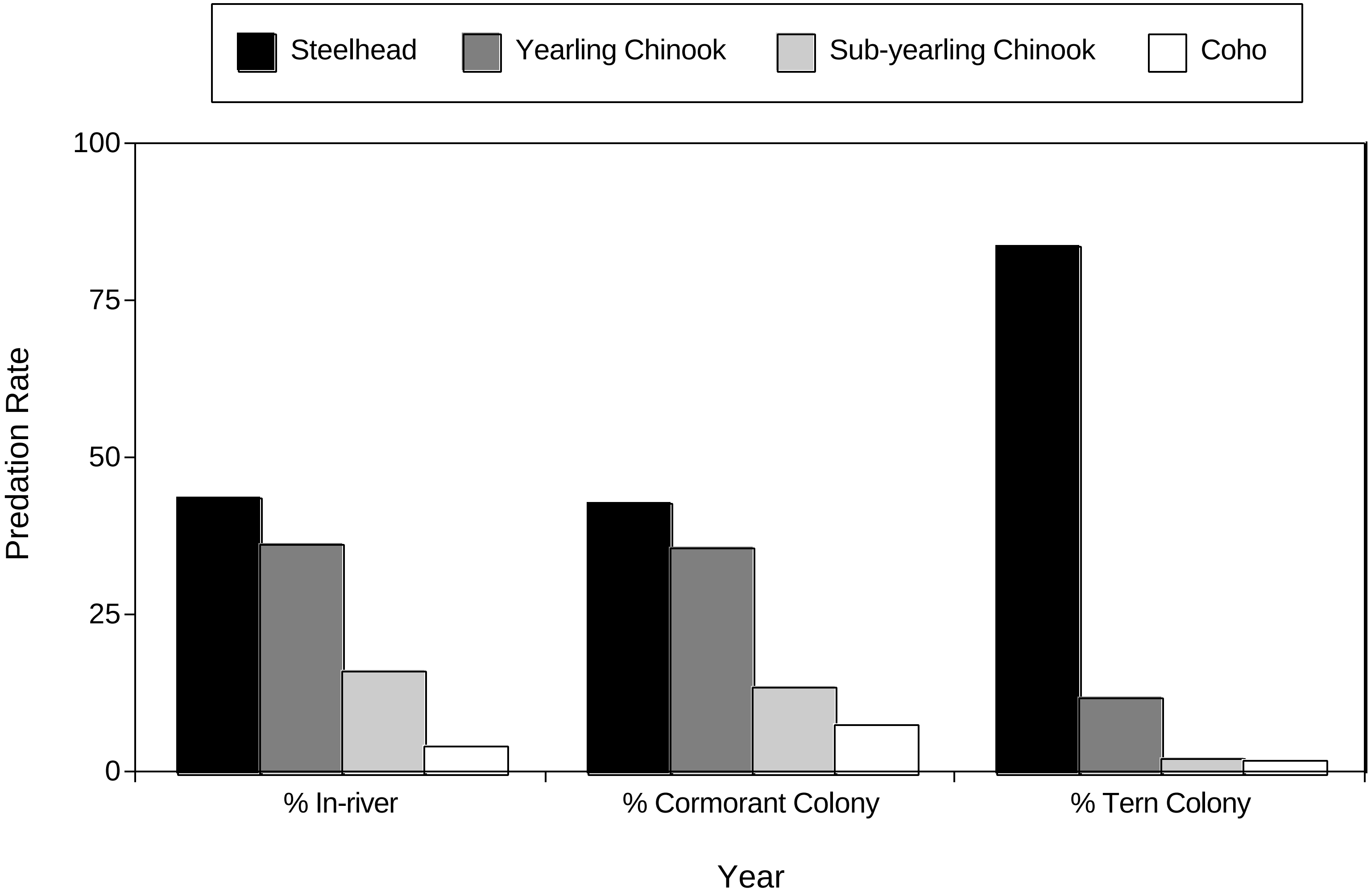


Figure 30. Relative availability and consumption of PIT-tagged salmonid smolts by Caspian terns and double-crested cormorants nesting on East Sand Island in the Columbia River estuary in 2005.

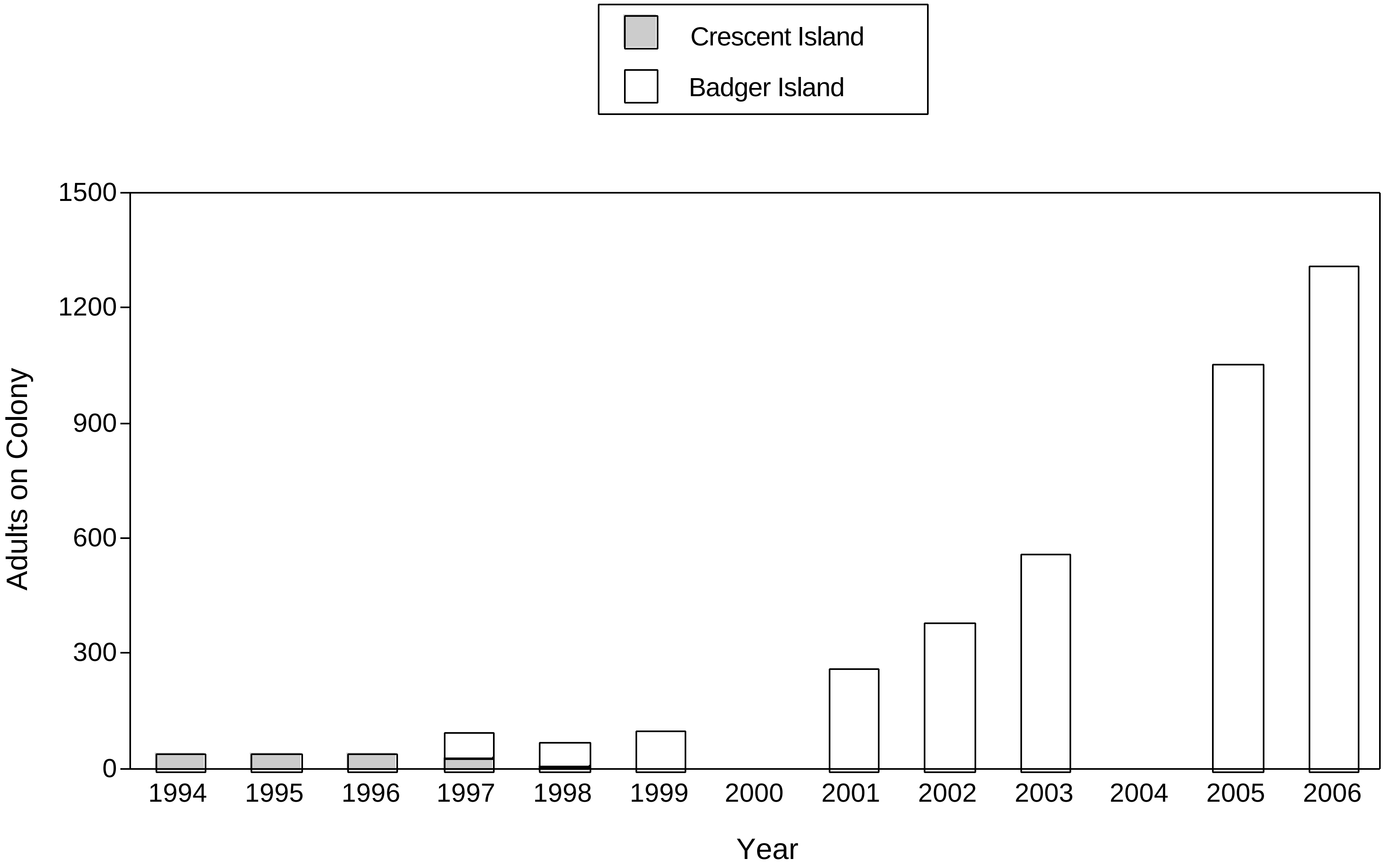


Figure 31. Population trends for American white pelicans nesting at two colonies on the mid-Columbia River, 1994-2006. Missing data points indicate that no colony counts were conducted during that year.

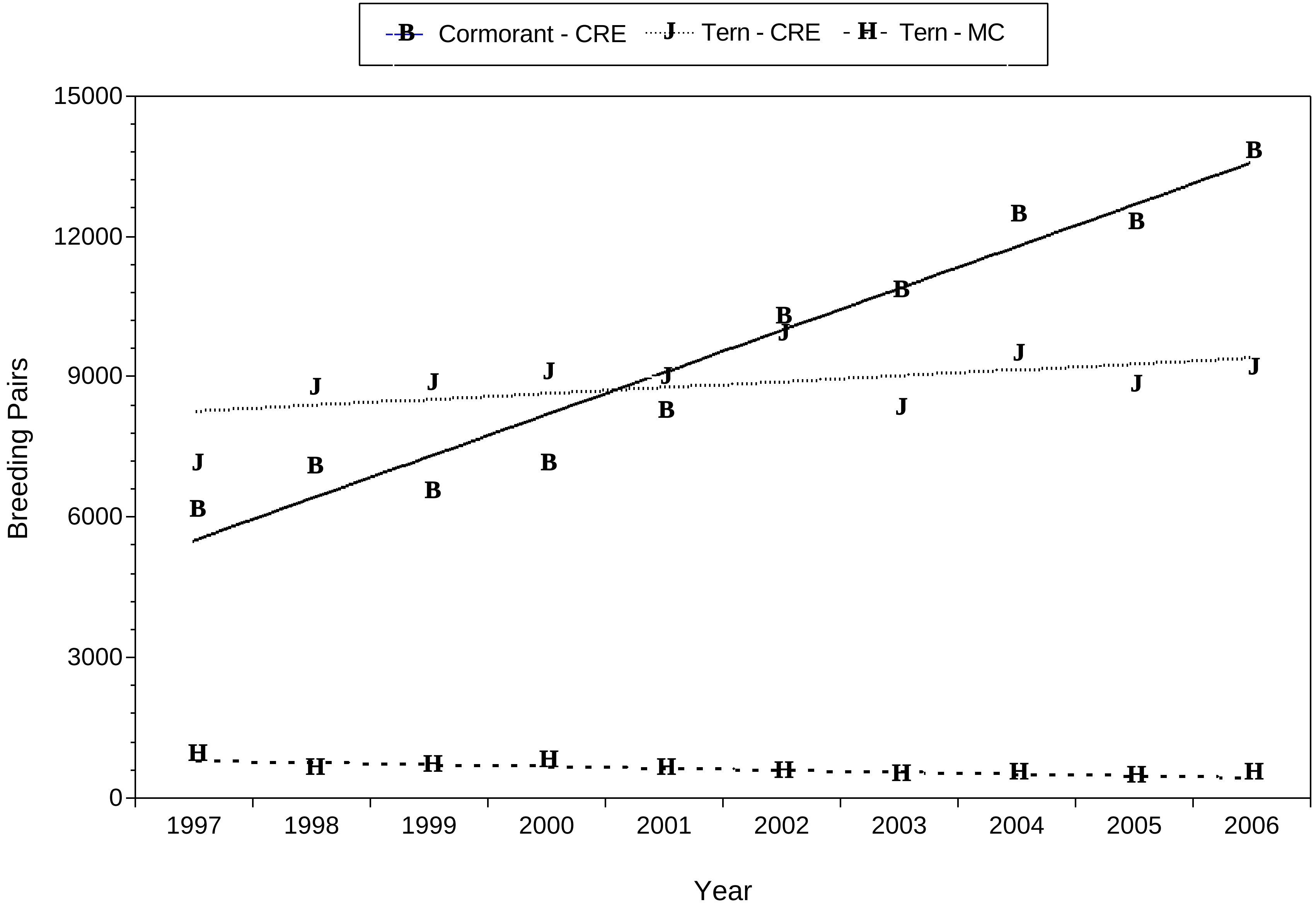


Figure 32. Trends in size of double-crested cormorant and Caspian tern colonies in the Columbia River estuary (CRE) and Caspian tern colonies on the mid-Columbia River (MC), 1997 - 2006.

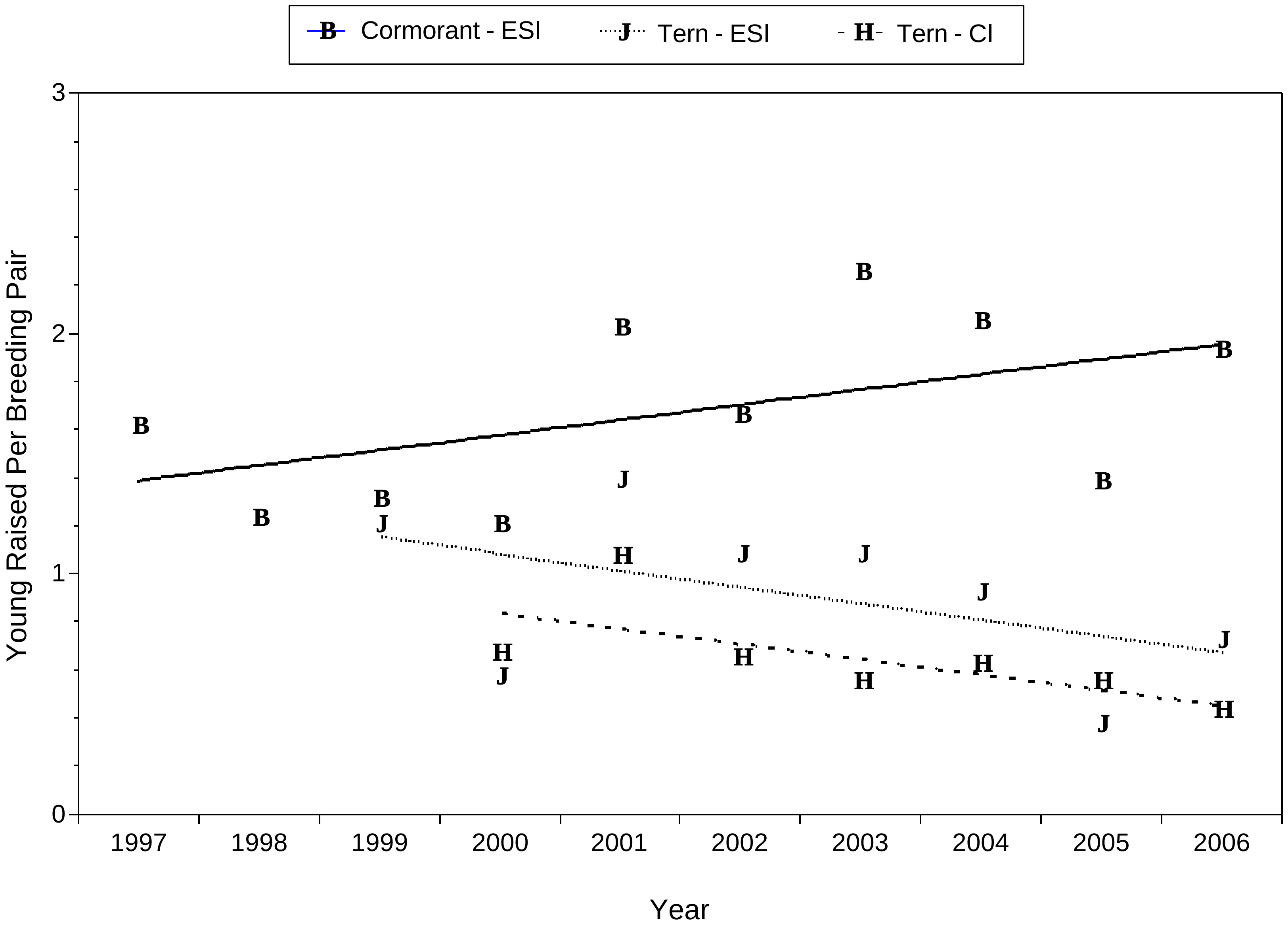


Figure 33. Trends in nesting success of double-crested cormorants and Caspian terns nesting on East Sand Island (ESI) and Caspian terns nesting on Crescent Island (CI), 1997 - 2006.

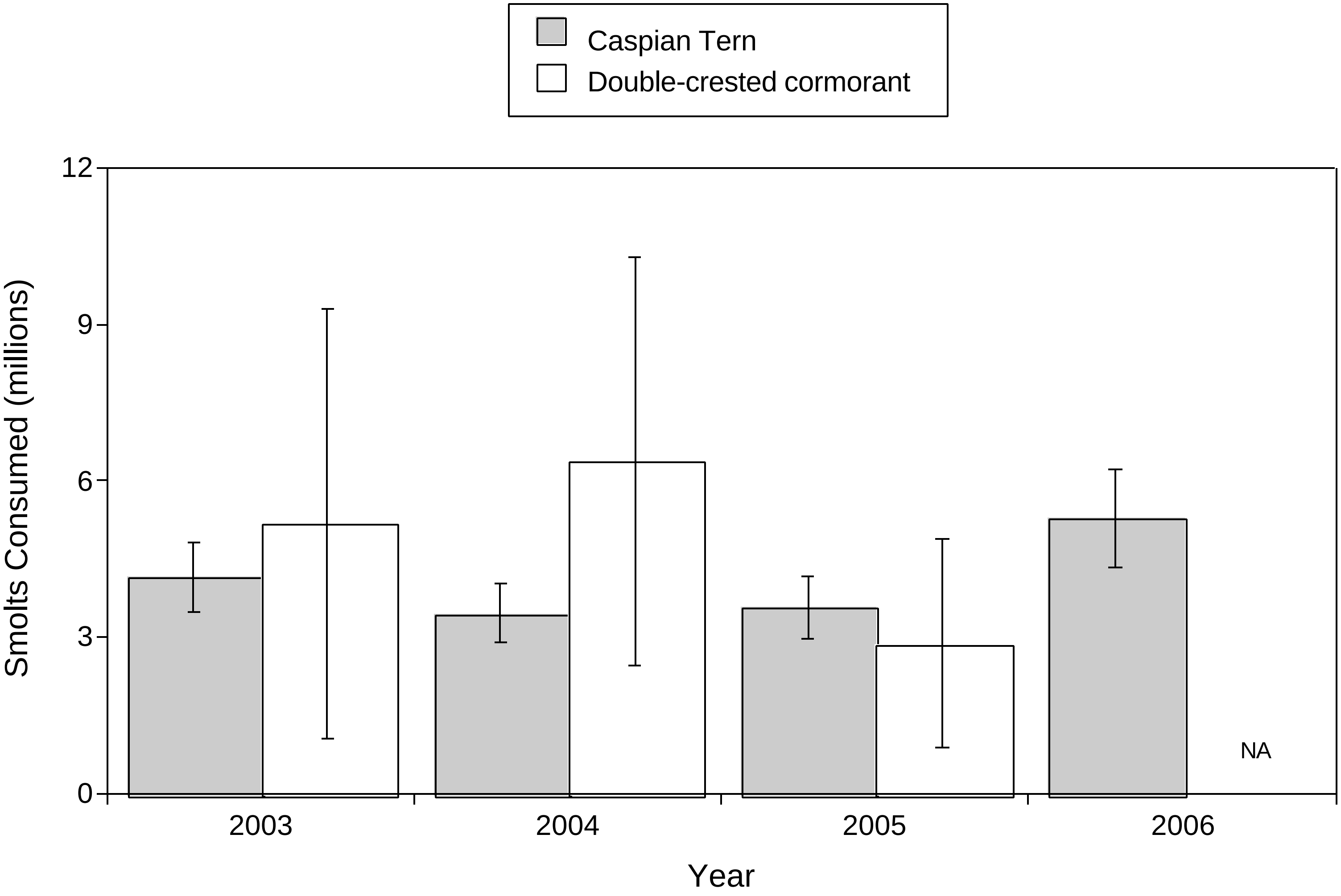


Figure 34. Estimated total annual consumption of juvenile salmonids by Caspian terns and double-crested cormorants nesting on East Sand Island in the Columbia River estuary, 2003 - 2006. Cormorant data from 2006 are currently being analyzed and will be provided in a subsequent report.

Table 1. Counts of nesting and roosting piscivorous waterbirds throughout the Columbia River basin in 2006. Species include American white pelicans (AWPE), brown pelicans (BRPE), Caspian terns (CATE), Forster's terns (FOTE), double-crested cormorants (DCCO), Brandt's cormorants (BRCO), pelagic cormorants (PECO), California gulls (CAGU), ring-billed gulls (RBGU), glaucous-winged/western gulls (GWGU/WEGU), great blue herons (GBHE), black-crowned night-herons (BCNH), and great egrets (GREG). Counts of terns and cormorants are of the number of breeding pairs; count of brown pelicans is the peak number of roosting individuals; all other counts are of the number of individuals on colony (an index to the number of breeding pairs).

Water Body	Location	River km	Species	Count
Columbia River estuary				
	East Sand Island	8	CATE	9,201
			DCCO	13,738
			BRCO	44
			GWGU/WEGU	8,587
			RBGU	1,389
			BRPE	8,862
	Astoria Bridge	16	PECO	124
	Rice Island	34	DCCO	35
			GWGU/WEGU	1,727
	Miller Sands Spit	37	DCCO	41
			GWGU/WEGU	704
Middle Columbia River				
	Browns Island	318	GBHE	unknown
	Miller Rocks	333	RBGU/CAGU	1,000-10,000
			DCCO	5
	Three Mile Canyon Island	413	RBGU/CAGU	1,000-10,000
	Sand Island	445	GBHE/GREG/BCNH	10-100
	Rock Island	445	RBGU	100-1,000
			CATE	110
	Crescent Island	510	CATE	448
			RBGU/CAGU	1,000-10,000
			GBHE/GREG	unknown
	Badger Island	511	AWPE	1,310
	Foundation Island	518	DCCO	> 359
Upper Columbia River				
	Fencepost Island	545	CAGU	1,000-10,000
	Island 18	553	RBGU/CAGU	1,000-10,000
			GBHE/GREG/BCNH	10-100
			FOTE	> 150
	Okanogan Island	858	DCCO	>32
Snake River				
	Lyons Ferry Railroad Tressle	59	DCCO	2
Yakima River				
	North of Selah	120	DCCO	10
Potholes Reservoir				
	Solstice Island	-	Unidentified gulls	0
	Goose Island	-	CATE	273
			RBGU/CAGU	unknown
	North Potholes		DCCO	1,156
Sprague Lake				
	Harper Island	-	CATE	7
			RBGU/CAGU	1,000-10,000
Banks Lake				
	Twining Island	-	CATE	20
			RBGU/CAGU	1,000-10,000
	Goose Island		RBGU/CAGU	unknown

Table 2. Diet composition (% identifiable prey items) of Caspian terns nesting on Rice Island and East Sand Island in the Columbia River estuary, 1997-2006.

	1997-98	1999		2000		2001	2002	2003	2004	2005	2006
Prey Type	Rice	Rice	East Sand	Rice	East Sand	East Sand	East Sand	East Sand	East Sand	East Sand	East Sand
Herring, sardine, shad	10.7	1.8	8.2	1.7	10.1	20.3	18.4	18.5	29.3	12.3	4.9
Anchovy	0.0	6.5	15.9	0.5	11.6	22.4	14.1	23.7	25.2	33.4	31.4
Peamouth, pike minnow	2.0	1.0	0.5	0.9	0.8	0.6	0.5	0.1	0.7	0.1	0.0
Smelt	6.2	0.9	3.8	0.7	5.6	5.1	7.3	17.6	9.3	8.8	8.5
Salmonid	**72.7**	**76.5**	**45.6**	**89.6**	**46.5**	**32.5**	**31.1**	**24.1**	**16.8**	**22.6**	**31.1**
Cod	0.0	0.0	0.0	0.0	0.0	2.2	0.1	0.3	2.4	0.0	0.0
Sculpin	1.2	1.3	3.3	1.9	5.1	3.6	2.4	3.0	3.1	2.8	3.0
Surfperch	5.5	2.8	10.7	1.2	10.0	5.9	11.6	6.7	11.5	16.4	16.5
Pacific sand lance	0.1	0.1	5.9	0.1	5.6	3.1	2.5	4.5	0.2	1.7	0.6
Flounder	0.2	0.3	0.2	1.8	0.6	0.2	0.1	0.0	0.2	0.2	0.1
Other	1.4	8.7	5.8	1.6	3.9	3.9	11.9	1.5	1.4	1.7	3.9
Total no. identified prey	1,448	5,305	5,486	5,023	5,387	6,007	5,661	5,476	5,854	5,536	5,549

Table 3. Detection efficiency (DE) of test PIT tags sown on the Crescent Island Caspian tern colony during four discrete time periods in 2006. Test tags were sown evenly over four study plots. R indicates the number of test tags recovered.

	Plot 1		Plot 2		Plot 3		Plot 4		
Date	R	DE	R	DE	R	DE	R	DE	Average
24 March	5	8.3%	4	6.7%	2	3.3%	18	30.0%	12.1%
13 May	14	23.3%	40	66.7%	6	10.0%	23	38.3%	34.6%
29 June	22	36.7%	36	60.0%	15	25.0%	23	37.3%	39.7%
26 July	58	96.7%	59	98.3%	59	98.3%	56	93.3%	96.7%
TOTAL	99	41.3%	139	57.9%	82	34.2%	120	49.6%	45.7%

Table 4. Detection efficiency (DE) of test PIT tags sown on the East Sand Island Caspian tern colony during four discrete time periods in 2006. Test tags were sown evenly over three study plots. R indicates the number of test tags recovered.

	Plot 1		Plot 2		Plot 3		
Date	R	DE	R	DE	R	DE	Average
6 April	70	70.0%	76	76.0%	64	64.0%	70.0%
22 May	49	49.0%	60	60.0%	59	49.0%	52.7%
11 July	69	69.0%	50	50.0%	56	56.0%	58.3%
7 September	73	73.0%	69	69.0%	84	84.0%	75.3%
TOTAL	261	65.3%	255	63.8%	253	63.3%	64.1%

Table 5. Estimated PIT tag deposition rates (DR) for net pen fish consumed by Crescent Island Caspian terns, 2004-2006. R indicates the number of tags recovered on-colony, which was corrected for PIT tag detection efficiency (DE). The average deposition rate is for 2004-2006, and combines results from two net pen locations in 2006.

Location	Year	Sample Size	R	DE	DR
Burbank Slough	2004	94	45	0.739	64.8%
Burbank Slough	2005	91	43	0.722	65.5%
Burbank Slough	2006	41	8	0.329	59.4%
Peninsula Slough	2006	39	8	0.339	60.6%
AVERAGE					63.4%

Table 6. Estimated PIT tag deposition rates (DR) for PIT-tagged fish force-fed to Crescent Island and East Sand Island Caspian terns, 2005-2006. R indicates the number of tags recovered on-colony, which was corrected for PIT tag detection efficiency (DE).

Location	Year	Sample Size	R	DE	DR
East Sand Island					
	2005	31	20	0.753	85.7%
	2006	43	26	0.641	94.3%
	AVERAGE				90.0%
Crescent Island					
	2005	59	32	0.742	73.1%
	2006	58	16	0.346	79.7%
	AVERAGE				76.4%

Table 7. Predation rates on in-river PIT-tagged salmonid smolts by Crescent Island Caspian terns in 2006. PIT-tagged smolts were from seven different ESA-listed Evolutionarily Significant Units (ESUs) of fish released upstream of McNary Dam. Analysis was limited to PIT-tagged fish of known origin. Predation rates are corrected for bias due to PIT tag detection efficiency (Table 3) and the proportion of ingested PIT tags that are deposited on-colony (Table 5). Predation rates do not account for other sources of mortality from release to the vicinity of Crescent Island and are therefore minimums. Confidence intervals (±) were based on variation derived from multiple release groups of PIT-tagged smolts within the corresponding ESU (Table 8).

	Released		Predation Rate	
ESU [a]	Hatchery	Wild	Hatchery	Wild
SR steelhead	37,740	37,312	7.3% (±1.0)	2.2% (±0.6)
UCR steelhead	52,852	4,669	1.9% (±0.2)	1.0% (±0.5)
MCR steelhead	10,555	2,626	1.9% (±1.1)	1.9% (±1.3)
SR Fall chinook	388,442	1,607	0.8%	0.0%
UCR Spring chinook	24,155	10,784	0.5% (±0.2)	0.4% (±0.1)
SR Spr/Sum chinook	303,810	77,238	0.9% (±0.2)	0.3% (±0.1)
SR sockeye	5,519	887	1.2%	0.0%

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

Table 8. Stock-specific predation rates on in-river PIT-tagged salmonid smolts by Crescent Island Caspian terns in 2006. Assignment of each stock to an Evolutionarily Significant Unit (ESU) is based on genetic and geographic criteria developed by NOAA Fisheries. Only fish of known rearing type, origin, and release location are included. Sample sizes and predation rates are listed separately for hatchery (H) and wild (W) fish. Predation rates are corrected for bias due to PIT tag detection efficiency on-colony (Table 3) and the proportion of ingested PIT tags that were depositied on-colony (Table 5). Predation rates do not account for other sources of mortality from release to the vicinity of Crescent Island and are therefore minimums.

			Released		Predation Rate		
Species	ESU[a]	Stock	H	W	H	W	Overall
Steelhead	SR						
		Imnaha River	1,978	898	7.3%	4.3%	6.4%
		Grande Ronde River	3,370	3,851	9.3%	1.8%	5.3%
		Clearwater River	11,854	17,000	9.7%	1.2%	4.7%
		Salmon River	7,176	13,804	7.9%	0.3%	2.9%
		Lower Snake	13,362	1,759	2.5%	3.3%	2.6%
	UCR						
		Okanogan River	19,887	-	2.0%	-	2.0%
		Methow River	2,907	1,537	1.5%	1.3%	1.4%
		Entiat River	-	1,223	-	1.6%	1.6%
		Wenatchee River	30,058	1,909	2.2%	0.3%	2.0%
	MCR						
		Walla Walla & Touchet	8,987	677	2.7%	2.8%	2.7%
		Yakima	-	1,147	-	0.8%	0.8%
		Umatilla	1,564	802	1.0%	0.0%	0.7%
Chinook	SR Fall						
		Mainstem Snake River	388,442	1,607	0.8%	0.0%	0.8%
	SR S/S						
		Salmon River	126,629	50,035	0.5%	0.3%	0.4%
		Grande Ronde/Imnaha	35,055	8,128	0.6%	0.1%	0.5%
		Lower Snake River	4,811	-	1.4%	-	1.4%
		Clearwater River	137,315	19,075	1.0%	0.5%	0.9%
	UCR S						
		Methow River	6,456	1,308	0.3%	0.3%	0.3%
		Entiat River	3,001	2,842	0.8%	0.2%	0.5%
		Wenatchee River	14,698	6,634	0.5%	0.5%	0.5%
Sockeye	SR						
		Redfish Lake	5,519	877	1.2%	0.0%	1.0%

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

Table 9. Estimated predation rates on PIT-tagged salmonid smolts traveling through the McNary Pool by Crescent Island Caspian terns in 2006. Predation rates are based on the number of fish interrogated/tagged at Lower Monumental Dam (Snake River), Rock Island Dam (Upper Columbia River), and in the Middle Columbia River (fish released below the confluence of the Snake and Columbia rivers and upstream of McNary Dam). Predation rates on hatchery (H) and wild (W) smolts are listed separately. Sample sizes of interrogated/tagged fish less than 100 were not included. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (see Table 3) and deposition (see Table 5).

	Snake R.		Upper Columbia R.		Mid-Columbia R.	
Species / Run Type	H	W	H	W	H	W
Steelhead	12.5%	7.6%	4.3%	2.1%	-	3.8%
Yearling Chinook	1.7%	2.2%	-	-	0.4%	0.5%
Sub-yearling Chinook	2.0%	-	-	-	0.5%	-
Unknown Run Chinook	1.6%	1.9%	-	-	-	-
Sockeye	6.0%	-	-	0.3%	-	-

Table 10. Estimated predation rates (PR) on juvenile salmonids from the Snake River based on PIT-tagged smolts that were interrogated passing Lower Monumental Dam (N) from 1 April to 31 July, 2006 and subsequently detected on either the Crescent Island Caspian tern colony (CI te), the Rock Island Caspian tern colony (RI te), the Foundation Island double-crested cormorant colony (FI co), or the Badger Island American white pelican colony (BI pe). The number of PIT tags recovered from each bird colony is provided in parentheses. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (all colonies) and the proportion of ingested PIT tags that are deposited on-colony (tern colonies only). Direct measures of detection efficiency and deposition rate were not available for the Rock Island tern colony and results obtained from the Crescent Island tern colony were used for calibration purposes. In all other cases, predation rate estimates are minimums.

		CI te	RI te	FI co [a]	BI pe [a]
Species / Run type	N	PR	PR	PR	PR
Hatchery Steelhead	22,475	12.5% (580)	2.6% (123)	2.8% (429)	< 0.1% (15)
Wild Steelhead	9,017	7.6% (142)	1.1% (20)	1.4% (87)	< 0.1% (4)
Hatchery Spring Chinook	38,494	1.7% (140)	< 0.1% (20)	0.6% (166)	< 0.1% (4)
Wild Spring Chinook	6,117	2.3% (30)	< 0.1% (2)	0.3% (12)	< 0.1% (1)
Hatchery Fall Chinook	18,341	2.0% (115)	<0.1% (16)	0.1% (14)	< 0.1% (4)
Unknown Fall Chinook	455	4.9% (7)	0.0% (0)	0.0% (0)	0.0% (0)
Unknown Run Chinook	51,098	1.6% (209)	< 0.1% (24)	0.5% (184)	< 0.1% (9)
Coho	47	9.1% (1)	0.0% (0)	0.0% (0)	0.0% (0)
Sockeye	697	5.0% (8)	0.0% (0)	0.9% (4)	0.0% (0)

[a] No PIT tag deposition data are available to correct the estimate.

Table 11. Estimated per capita consumption of 2006 migration year PIT-tagged salmonid smolts by Caspian terns (CATE), double-crested cormorants (DCCO), American white pelicans (AWPE), and California gulls (CAGU) nesting at various locations in the Columbia River basin. Tagged juvenile salmonids include steelhead, yearling Chinook salmon (Chin 1), sub-yearling Chinook salmon (Chin 0), unknown run Chinook salmon (Chin U), coho salmon, and sockeye salmon. Per capita values are corrected for PIT tag detection efficiency, but not deposition proportion, and are therefore minimums. In the case of the Rock Island tern colony and the Rice Island cormorant colony, detection efficiency data from a similar study location and bird colony were used, as no direct measures of detection efficiency were available for these two colonies in 2006. PIT tags were recovered (R) from nesting colonies using different approaches; recoveries from the entire colony (C) or from plots within the colony (P). Estimates of per capita PIT tag consumption were estimated by dividing the total number of tags recovered (corrected for detection efficiency) by the number of breeding adults on the colony or in plots.

River Segment / Bird Colony (est. number of breeding adults)	Method	R	Steelhead	Chin 1	Chin 0	Chin U	Coho	Sockeye	Total
McNary Pool									
Crescent Island CATE (896)	C	5,128	6.95	2.21	3.76	1.84	0.27	0.05	15.08
Foundation Island DCCO (720)	C	3,505	2.76	1.99	0.68	1.64	0.13	0.03	7.23
Badger Island AWPE (1,310)	C	448	0.08	0.11	0.25	0.06	0.04	0.00	0.53
John Day Pool									
Rock Island CATE (220)	C	731	6.39	1.48	0.44	1.12	0.21	0.04	9.68
Three Mile Canyon Is. CAGU (90)	P	2	0.02	0.02	0.00	0.00	0.00	0.00	0.04
The Dalles Pool									
Miller Rocks CAGU (42)	P	22	0.33	0.11	0.08	0.06	0.00	0.03	0.61
Columbia River Estuary									
East Sand Island CATE (18,402)	C	26,123	1.47	0.33	0.16	0.21	0.04	0.00	2.21
East Sand Island DCCO (498)	P	839	0.72	0.59	0.27	0.58	0.06	0.01	2.22
Rice Island DCCO (70)	C	221	1.55	1.11	0.43	0.94	0.09	0.02	4.17
Miller Sands DCCO (82)	C	120	1.11	0.85	0.51	0.53	0.13	0.03	3.18

Table 12. Estimated predation rates (PR) on PIT-tagged salmonid smolts by East Sand Island Caspian terns in 2006. Predation rates are based on the number of PIT-tagged fish interrogated (I) passing the Juvenile Bypass Facility at Bonneville Dam (In-river) or released (Rel) from transportation barges below Bonneville Dam (Transported). Predation rates on hatchery-raised and wild smolts are listed separately. Sample sizes of interrogated/released fish less than 100 were not included. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (Table 4), but not for the proportion of ingested PIT tags that were deposited on-colony, and are therefore minimums.

	In-river				Transported			
	Hatchery		Wild		Hatchery		Wild	
Species / Run Type	I	PR	I	PR	Rel	PR	Rel	PR
Steelhead	1,102	20.0%	667	13.3%	73,448	12.4%	35,302	10.4%
Yearling Chinook	7,703	2.5%	1,267	0.9%	84,027	2.9%	7,709	1.4%
Subyearling Chinook	4,517	1.6%	-	-	36,909	1.4%	-	-
Unknown Chinook	9,111	1.9%	838	0.9%	34,336	1.9%	24,327	1.7%
Coho	492	3.8%	-	-	-	-	-	-
Sockeye	-	-	115	0.0%	-	-	-	-

Table 13. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants nesting on East Sand Island in the Columbia River estuary, 1999-2005. Data from 1999-2004 are based on the analysis of soft tissue and bones recovered from samples of stomach contents from adults. Data from 2005 are preliminary and include only the analysis of soft tissue. The data from 2006 are currently being analyzed and will be provided in a subsequent report.

	1999	2000	2001	2002	2003	2004	2005
Prey Type	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is.	East Sand Is	East Sand Is
Herring, sardine, shad	4.6	9.8	13.4	27.8	6.5	11.2	8.1
Peamouth, pike minnow	8.4	5.2	2.6	4.5	3.9	4.5	5
Sucker	4.3	1	0	0	2.4	1.9	3.1
Smelt	0.8	0.49	0.7	6.1	1.7	1	0.2
Salmonid	**24.6**	**15.8**	**8.9**	**5.1**	**8.3**	**4.8**	**1.8**
Stickleback	1.6	4.3	0.1	0.8	0.3	3.2	5.7
Sculpin	4.2	14.1	11	6.9	4.6	3.9	13.8
Surfperch	7.6	6.8	5.5	5.1	6.5	4.7	12.8
Pacific sand lance	0	4.5	1.5	1.3	4.6	0.1	0
Flounder	8.5	17.4	12.7	9	9.3	10.5	7.1
Anchovy	27.8	15.1	17.9	17.4	20.6	39.3	21.7
Cod	0.1	2.8	10.9	1.1	5.6	1.3	0
Lamprey	1.4	1.2	0.6	0.1	0.4	0.2	0
Gunnel	0	0.2	0.1	0.1	1.1	0.1	0
Other	6.2	1.3	14.2	14.6	24.3	13.4	20.6
Total mass (g)	11,414	17,858	15,162	20,099	24,472	32,883	27,128

Table 14. Percent biomass of identifiable prey in samples of regurgitated food from double-crested cormorants nesting on Foundation Island in the mid-Columbia River during 2-week sampling periods over the 2006 breeding season. All samples were regurgitations collected from beneath nesting trees.

Sample period	N	Salmonids	Cyprinids	Catostomids	Centrarchids	Percids	Ictalurids
4/17 – 4/30	5	20.0%	0.0%	0.0%	0.0%	60.0%	20.0%
5/1 – 5/16	30	0.0%	37.5%	0.0%	37.5%	12.5%	6.5%
5/17 – 5/31	27	0.0%	25.0%	0.0%	18.7%	37.5%	6.5%
6/1 – 6/16	28	0.0%	4.0%	8.0%	80.0%	4.0%	0.0%
6/17 – 6/30	22	5.9%	3.1%	0.2%	25.0%	43.8%	4.1%
7/1 – 7/16	6	0.0%	60.0%	0.0%	0.0%	0.0%	40.0%
TOTAL[a]	118	3.9%	18.2%	2.6%	42.9%	24.7%	7.8%

[a] these percentages are the average percent biomass for all regurgitations (n = 118) collected on Foundation Island during 2006

Table 15. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants nesting on Foundation Island in the mid-Columbia River on three different sampling days in 2006. Data from 2006 are preliminary and include only the analysis of soft tissue.

Sample date	N	Salmonids	Cyprinids	Cottids	Centrarchids	Percids	Ictalurids	Unid. non-salmonids
4/20/06	8	20.0%	0.0%	0.0%	20.0%	20.0%	36.8%	3.2%
5/3/06	12	21.6%	11.1%	4.3%	28.0%	7.3%	11.1%	16.6%
6/16/06	7	0.3%	30.2%	3.5%	34.6%	0.0%	31.5%	0.0%
TOTAL[a]	27	13.9%	13.8%	2.6%	27.5%	9.1%	26.5%	6.6%

[a] these percentages are the average percent biomass for all stomach content samples (n = 27) collected from Foundation Island cormorants during 2006

Predation on juvenile salmonids by Caspian Terns nesting in Potholes Reservoir

DRAFT 2006 Season Summary

This Draft 2006 Season Summary has been prepared for the Bonneville Power Administration and the U.S. Army Corps of Engineers for the purpose of assessing project accomplishments. This report is not for citation without permission of the authors.

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Introduction

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

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

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

Study Sites

The field research was conducted on Caspian Tern breeding colonies located in the Potholes Reservoir in eastern Washington, ca. 50 km from the Columbia River (Fig. 1). Goose Island is in the lower (southern) reservoir, 1 km north of the O'Sullivan Dam. The island is composed of two hilltop islets (East Goose Island, West Goose Island) joined by a low-lying beach--the islet tops remain well above the waterline during the change in water level (5-6 m) over the course of the breeding season. Caspian Tern colonies lie atop both islets and are surrounded by nesting Ring-billed and California Gulls. The colony substrate is a hard-packed mix of soil, volcanic ash from the 1980 eruption of Mount St. Helens, guano, and fish bones.

Colony Size and Productivity

Methods:

Prior to the breeding season of 2006, an observation blind was placed on East Goose Island adjacent to the areas observed to have had Caspian Terns breeding in past years. The blind was located at the highest point of the islet, facing eastward and toward an area of previously known Caspian Tern breeding activity. A tunnel was constructed from the boat landing area to the entrance of the blind so that the terns would not be disturbed by researchers entering the blinds. Caspian Tern decoys were also placed on the colony prior to the breeding season to attract breeding pairs to the area in front of the observation blind.

Observation of the East Goose Island colony began 3 April, 2006 and spanned the Caspian Tern breeding season until early July. The number of adults breeding on East Goose Island was estimated from daily observations of adults observed on and around the breeding colony. Hourly counts were conducted of all adults observed on the colony and loafing on nearby shores or islets. The minimum number of chicks that reached the fledgling stage on the entire island was estimated from counting un-banded tern chicks along the shore of the island during a boat survey on the afternoon of July 6 and adding that number to the total number of chicks banded that morning.

Results and Discussion:

As in 2005, all breeding by Caspian Terns in the Potholes Reservoir in 2006 took place on Goose Island. Two breeding colonies were observed on Goose Island in 2006, one located on the eastern summit of the island (East Goose) and one located on the western summit (West Goose). Breeding activity has been documented on the East Goose colony since 2003 and on the West Goose colony since 2005. While the two sub-colonies were approximately the same size in 2005, breeding activity on West Goose Island surpassed that of East Goose Island in 2006. The maximum number of adult terns observed on the East Goose Island breeding colony was 149 during the week of 21 May (Fig. 2). The maximum number of adult terns on the West Goose Island breeding colony was unknown, but we estimated 326 Caspian Tern adults on that colony from an aerial photograph taken on 30 May. This photo was taken in the afternoon when nest attendance is low; thus, the maximum number on the West Goose Island colony may be substantially higher.

We estimate that there were 323 breeding pairs for all of Goose Island (and hence the Potholes Reservoir) in 2006. This estimate is based on the observed number of active nests during peak incubation on both East and West colonies. The East Goose colony estimate was from direct observation, while the West Goose colony estimate was from aerial photographs on 30 May. On the East Goose colony, a total of 114 pairs were engaged in breeding activity over the course of the breeding season Of these, six nests were not recorded as ever containing eggs, and 16 nests had an unknown egg status. On 27 May, the number of active nests on the East Goose Island colony peaked at 56. A major disturbance on the night of 27 May reduced the number of active to 46, and declined thereafter (Fig. 3). On 30 May, the number of active nests on the West Goose Island colony was estimated to be 277, including 34 that were counted in a satellite colony that formed on the eastern shoulder of the slope just down from the main West Goose Island colony. The overall estimate of breeding pairs on Goose Island was made difficult by repeated human disturbances, but it is likely conservative, as it ignores failed breeding attempts before 30 May or nesting attempts after 30 May.

We estimate the total number of Caspian Tern fledglings from both Goose Island colonies to be at least 122 (60 chicks were banded on the colony on July 6, and an additional 62 un-banded chicks were observed from a boat survey later in the same day that banded chicks were released). We estimate that only three fledglings were produced at the East Goose Island colony (Fig. 4), corresponding to a nesting success of 0.03 fledglings/active nest. This is a significant drop from the 53 fledglings and 0.32 fledglings/active nest estimated from the same colony in 2005. A total of 122 eggs were laid, for an average clutch size of 1.3 eggs/nest, which was down from the 1.8 eggs/nest in 2005. Although actual nesting success of the West Goose Island colony was not estimated directly, we estimate from the fledglings banded and the aerial photo nest estimate that nesting success was 0.4 fledglings/active nest.

Three major human caused disturbances are known to have occurred on East Goose during the 2006 breeding season. Two of these occurred early in the breeding season (8 April 8 & 23 April) prior to egg-laying. The first incident involved boaters stranded by bad weather and the second involved a boat that sank on the eastern edge of East Goose Island. In both instances, all the nesting Caspian Terns left the East Goose Island colony while boaters were present (one to two hours each). The third major disturbance occurred the evening of 27 May, during the peak of the egg-laying period. While we did not directly observe this disturbance, fresh boot prints and a beer bottle were observed in the middle of the East Goose Island colony on the morning of 28 May. Several nests had eggs on the afternoon of 27 May, but all of the eggs were gone and the nests were abandoned by the next morning observation period. As the East Goose Island colony is closer to the landing beach area, is lower in elevation, and is closer to water on all sides than the West Goose Island colony, the chances for human disturbance is high, and this may contribute to the observed shift of breeding activity to the West Goose Island colony. While the total number of breeding pairs estimated for all of Goose Island in 2006 was similar to that estimated for 2005, the majority of breeding pairs were on the upper West Goose Island colony.

Diet Composition and Salmonid Consumption

Methods:

During the field season of 2006, diet composition observations were made from blinds on the periphery of the Caspian Tern colony on East Goose Island. We visually identified all bill loads with binoculars and spotting scopes and collected data on taxonomic grouping and prey size (converted from tern bill length), along with date, time, nest number, recipient, and provider (if known). Males and females of many nests were identified early in the breeding season by observing courtship behaviors and noting distinctive plumage, bill and leg patterns, as well as colored and aluminum USFWS leg bands. From the observation blind, we could distinguish salmonids from non-salmonids; while we could identify the vast majority of non-salmonids to species, we did not identify all salmonids to species.

Results and Discussion:

All Bill Loads

Of the 1027 identifiable bill loads observed on the east Goose Island colony in 2006, 29.3% of these were salmonids (Fig. 5); this proportion was considerably greater than was observed in the Caspian tern diet on the East Goose Island colony in 2005 (Table 2). As was observed in 2005, the most prevalent family observed as prey at this breeding colony was the Centrarchidae

(62.7%). The family Percidae (primarily Yellow Perch) represented only 2.8% of prey items; this is in stark contrast to 2005, when they represented 14.4% of prey items identified. The remaining taxonomic groups were identified to three families: the Cyprinidae (2.0%), Ictaluridae (0.5%), and Petromyzontidae (0.1%). As in 2005, there were two peaks of salmonid consumption during the 2006 field season (Fig. 6). During the first week of observation (ending 9 April), 81% of identifiable observed prey brought back to the colony were salmonids; an unknown proportion of the smaller salmonids (<1.5 bill lengths) may have been rainbow trout obtained from stocked lakes in the vicinity of Potholes Reservoir. The second peak of salmonid consumption occurred during the week ending 14 May (69.2%), during the peak of colony building and egg-laying. This contrasts with 2005, when the second peak occurred later in the season during peak chick feeding; this is likely due to the low chick survival to this period on the East Goose Island colony.

Observed Adult Diet

In 2006, we detected an overall difference in diet composition between males and females on the East Goose Island colony; we observed males consuming twice the proportion of salmonids than did females (Fig. 7). Females also consumed far more Centrarchids than males (73 to 48%). This is in marked contrast to 2005, when males and females were observed to consume salmonid and centrarchid fish prey in similar proportions. This may have been due to a great many unsuccessful mate feedings, whereby males consume the prey item destined for their mate or potential mate or due to intraspecific kleptoparasitism of salmonids brought back to the colony.

Observed Chick Diet and Provisioning

Overall chick diets were generally similar to that observed in adults--centrarchids (72%), followed by salmonids (19%), percids (4%), unidentified non-salmonids (4%), and ictalurids (1%) (Fig. 8), although chicks consumed a proportion of salmonids closer to that observed in females. The proportion of salmonids consumed by chicks may have been higher if the chicks had survived better during the nestling period (chick survival averaged 10.5 days), as parents seem to select small, local fish for chick provisioning until chicks are large enough to consume bigger fish.

Observed chick provisioning by males and females also varied in the proportion of salmonids fed to chicks. Of the chick feedings where the provider could be identified, females delivered salmonids almost three times (34%) as often as males (12%; Fig. 9). This difference in chick provisioning by adults contrasts with the difference in observed adult consumption (female: 22%; male: 45%).

Estimates of the overall consumption of salmonid juveniles for the east Goose Island Caspian tern colony in 2006 are being calculated using a bioenergetics modeling approach.

Salmon Predation Rates: PIT Tag Studies

Methods:

On 28 August 2006, PIT tags were recovered from the East and West Goose Island colonies. After scanning the surface of the colony area using electronic PIT tag readers, the surface was raked to break up the crust, and PIT tags were physically removed from the surface using large rolling magnets and small magnets attached to rakes. We queried the PTAGIS website (Passive Integrated Transponder Tag Information System; http://www.ptagis.org) to get detailed information (tagging, release, dam, in-river passage, etc.) for the PIT tags deposited on the colonies.

Prior to the general scanning of the colonies on 28 August, we examined electronic interference among tags in nest cups on 21-22 August by individually scanning each nest cup using the PIT tag reader and then excavating and sieving the nest contents to retrieve tags deposited in the nest during the breeding season.

In order to estimate the detection efficiency of PIT tag deposition on the breeding colony in 2006, 600 test tags were distributed on the Goose Island colonies (400 test tags were spread over two 50 m^2 plots on East Goose Island 200 test tags were spread over one 50 m^2 plot on West Goose Island). Tags were spread over of the colony on four different occasions (50 tags each time) during the breeding season: prior to the birds arriving on the breeding colony (26 March), during peak incubation (West Goose Island colony: 19 May; East Goose Island colony: 30 May), during peak chick rearing (6 July), and after chicks had fledged (31 July).

Results and Discussion:

PIT Tag Data

In 2006, we recovered 2114 intact and unique PIT tags recovered from the East and West Goose Island Caspian Tern colonies, which is well below the 2005 total of 8,564 PIT tags. This data paints a very different picture than the observational data, which suggests that the proportion of salmonids in the observed diet doubled from last year. Additional tags recovered from the Goose Island colonies included 209 acoustic tags, 1 radio tag, and 6 spaghetti tags. The acoustic and radio tags were from studies of outmigration timing of juvenile salmonids in the Columbia and Snake rivers. The spaghetti tags originated from rainbow trout released in Lake Roosevelt, WA, over 70 km to the northeast of Potholes Reservoir; all of the six were released in May 2006. A majority of the rainbow trout were triploid (4/6), and the others were regular Spokane stock.

Of the 2114 PIT tags recovered from the Goose Island Caspian Tern colonies in 2006, information on 2095 tags could be retrieved from the PTAGIS database. Of these tags, 1248 were from migration year 2006, 641 from migration year 2005, 182 from migration year 2004, and 24 from migration year 2003. The number of tags from migration year 2005 was quite high (fully 1/3 of recovered tags), but it is unknown what proportion of those tags detected from previous migration years were newly deposited or were deposited in earlier years but went undetected until 2006. We are investigating to what extent this pattern was true for other colonies in the Columbia River basin. Of the newly recovered tags for 2006, the majority (79%) were steelhead, 15% were Chinook salmon, 6% were coho salmon, and 0.3% were sockeye salmon (Fig. 10). Of these tags, the vast majority (n=1997 or 95%) were hatchery-origin fish, and only 89 (5%) were wild-origin fish. These numbers are minimum estimates of salmonids depredated by Caspian Terns from the Goose Island colonies in 2006. The estimates are not corrected for detection efficiency, not all PIT tags deposited on the colony are detected, and not all PIT tags consumed by terns nesting at the colony are deposited on the colony.

Since 2000, thousands of PIT tags have been detected or physically recovered from Solstice and Goose islands in the Potholes Reservoir. Until 2006, the overall number of PIT tags found on these colonies had been increasing (Fig. 11) and has shifted from Solstice Island to Goose Island as the use of these islands by breeding Caspian Terns has shifted.

The vast majority of PIT tags originated from basins in the upper Columbia River, although a number of PIT tags from Snake River salmonids were recovered in 2006 (Table 3). The number and proportion of tags from Snake River fish went up in 2006, as did the proportion of tags represented by Chinook salmon (Table 4).

PIT tag electronic interference study

PIT tag electronic interference was examined for all nest cups used by Caspian Terns on the East Goose Island colony. Approximately 38% of all readable tags excavated from nest cups were detected by an electronic scan of each nest cup prior to nest excavation; this is dramatically higher than the 1% detection of tags from nest cups in 2005. Despite the higher detection overall, the percentage of tags in nests detected electronically declined as a function of increasing number of tags buried in the nest cup, just as it did in 2005 (Fig. 12). For the electronically-scanned and excavated nests, the number of PIT tags found in nest cups was low (n = 84; mean: 2.9; range: 0-14), which was considerably lower than in 2005 (n = 168; mean: 15 tags/nest cup; range: 0-68). The overall lower deposition of PIT tags in 2006 may have resulted in overall electronic detection of tags in the nest cup being far greater than in 2005.

PIT tag detection efficiency

Of the 400 test tags spread on the East Goose Island colony, 48% were subsequently recovered on the colony; detection efficiency ranged from a low of 30% for the 30 May PIT tag dispersal to a high of 89% for the 31 July PIT tag dispersal (Table 5). On the West Goose Island colony, overall test tag detection was 64% and ranged from 30% for the 6 July tag dispersal to a high of 90% for the 31 July tag dispersal (Table 5). As overall detections of the test tags ranged from 48% to 64% on the two colonies, PIT tags deposited on the colony by Caspian Terns may have gone equally undetected and un-recovered. The island is prone to much human disturbance after chicks fledge in July; thus, we have not applied detection efficiency corrections to our PIT tag recoveries. However, PIT tag recoveries are clearly underestimates of the number of PIT-tagged salmonids taken by Caspian Terns nesting on Goose Island.

Nest Predation and Kleptoparasitism

Interactions with other species breeding on Goose Island appear to be a major factor contributing to the low level of nesting success of Caspian Terns in 2006. California Gulls, which nest in close proximity to the observed Caspian Tern colony on East Goose Island, were significant predators on Caspian Tern nests. They stole eggs from 89% of all active Caspian Tern nests, accounting for the loss of 81% of all observed eggs laid during the 2006 breeding season, up from 48% of all observed eggs in 2005. California Gulls were also observed attacking and killing several Caspian Tern chicks; of these attacks, small chicks were usually eaten by the gulls. Approximately 15 chicks were observed to be attacked and/or eaten by California Gulls on the East Goose Island colony in 2006; one of the 15 chicks had been killed earlier by Caspian

Tern adults while its parents were away from the nest and was then eaten by a scavenging gull. The aggressive behavior of the gulls toward this shrinking breeding colony often resulted in the chicks being predated from their nest within the first days post hatching. On more than one occasion, we observed a California Gull pull a chick out of the nest while a parent was on the nest. No deaths could be attributed to or were known to have occurred due to starvation. The fledging success estimated for the West Goose Island colony suggests that nest depredation from California and Ring-billed Gulls nesting nearby must have been much less extensive than we observed on the East Goose Island colony.

Kleptoparasitism of Caspian Terns returning to the colony with fish may have affected individual and colony-wide breeding success. Moreover, kleptoparasitism may influence the juvenile salmonids on which the terns prey, if kleptoparasitized Caspian Terns returned to the Columbia River and harvested additional salmonids from the Columbia River to compensate for losses. In 2006, gulls stole an estimated 5.1% (n=62) of all bill loads observed from the observation blind on East Goose Island; as salmonids made up 49% of all identified thefts by gulls, about 10% of all salmonid bill loads may have been lost to gulls. Caspian Terns also pirated fish from each other (n=14); centrarchids made up 71.4% of their thefts, while salmonids accounted for 14.3% of their thefts. Moreover, larger fish appeared to be stolen more frequently. The average length of a fish stolen by a gull was 14.9 cm (SD = 3.9) whereas the average length of all other bill loads was 12.5 cm (SD = 3.9).

Kleptoparasitism of Caspian Terns may also have affected the overall impact that this breeding colony of Caspian Terns has on juvenile salmonid populations, if kleptoparasitized Caspian terns harvested additional salmonids from the Columbia River to compensate for losses. In 2006, we observed gulls stealing about 5% (n=62) of all bill loads brought to the colony on East Goose; as salmonids made up 50% of all thefts by gulls (Fig. 13), an estimated 10% of all salmonid bill loads were lost to gulls. Caspian Terns also kleptoparasitized each other, with centrarchids making up 72% of their thefts, and only 2% of all salmonid bill loads were stolen by other terns (Fig. 14). Larger fish appeared to be stolen by gulls more frequently (Fig. 15). This was true of most fish species; however, in contrast to 2005, the size of salmonids that were kleptoparasitized by gulls did not differ from all bill loads containing salmonid prey (Fig. 16).

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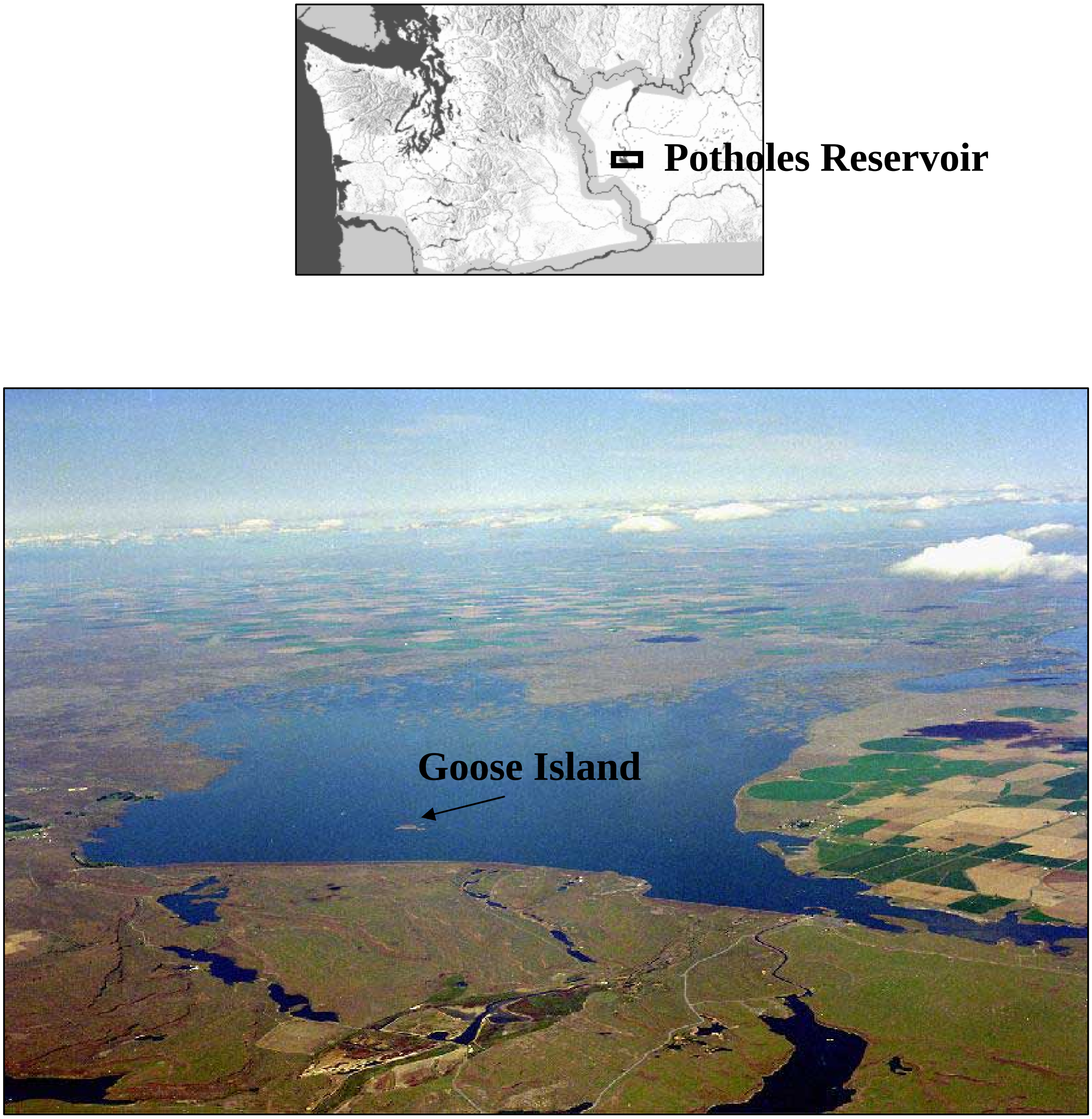

Figure 1. Study area on Potholes Reservoir in central Washington.

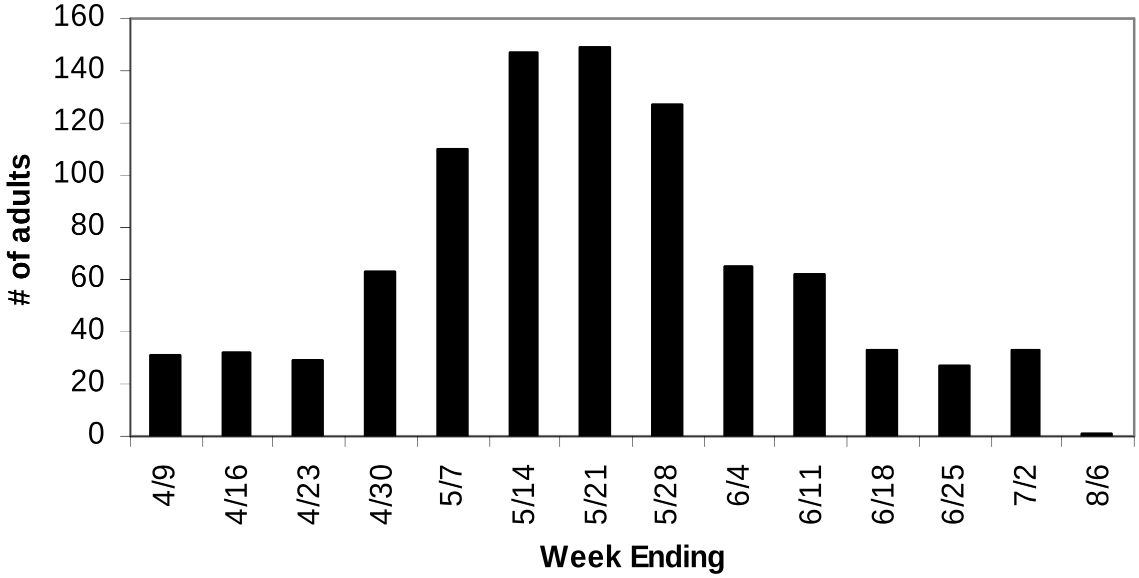

Figure 2. Visual estimate of the number of adult Caspian terns on the East Goose Island colony in 2006. Columns represent the maximum number of adults observed during each week. Estimate includes terns on breeding colony only (disturbances occurred on 4/8, 4/23 and 5/27).

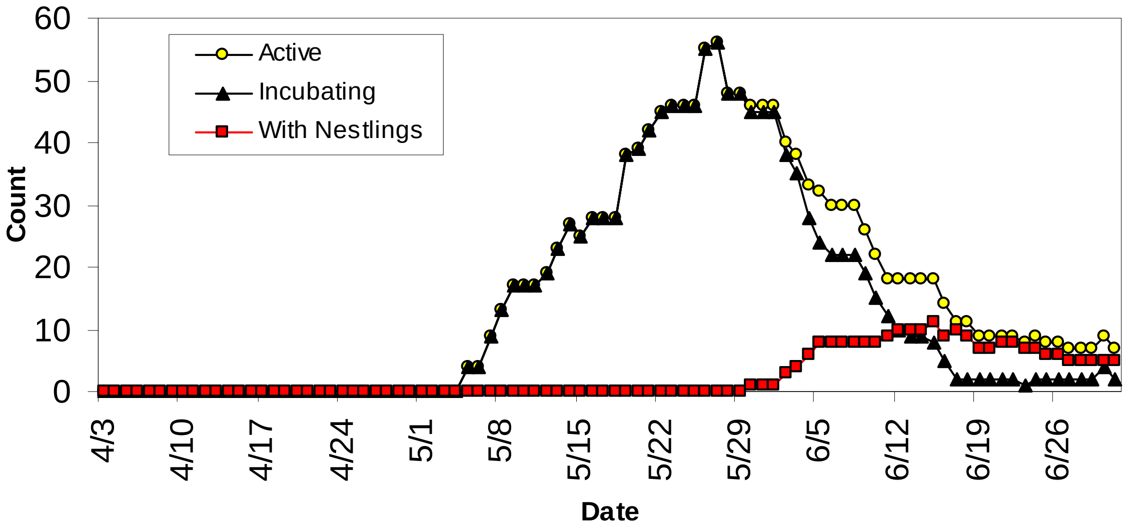

Figure 3. Visual estimate of the number of adult Caspian terns nesting on the East Goose Island colony in 2006. A major disturbance on 27 May led to almost reduced colony size and breeding attempts on this colony.

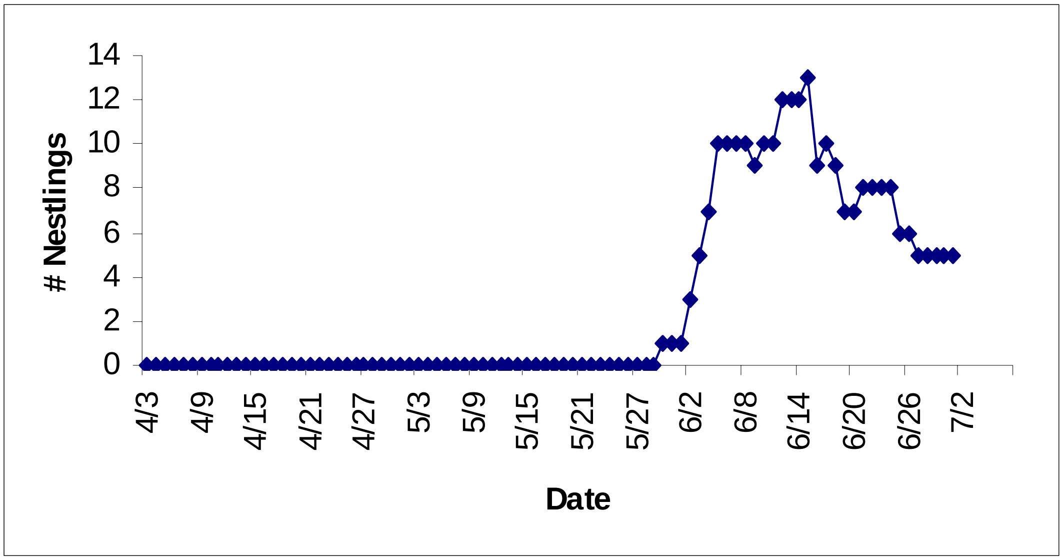

Figure 4. Numbers of Caspian Tern chicks on the East Goose Island colony in 2006 estimated using individual nest records.

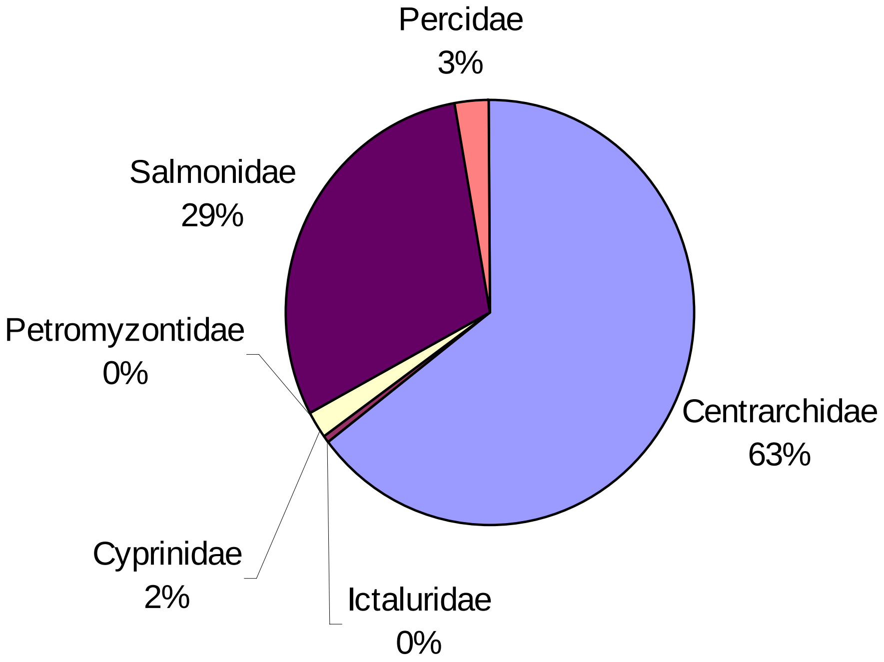

Figure 5. Observed bill-load composition of Caspian tern adults breeding on the East Goose Island colony in 2006 (n=1027 bill loads).

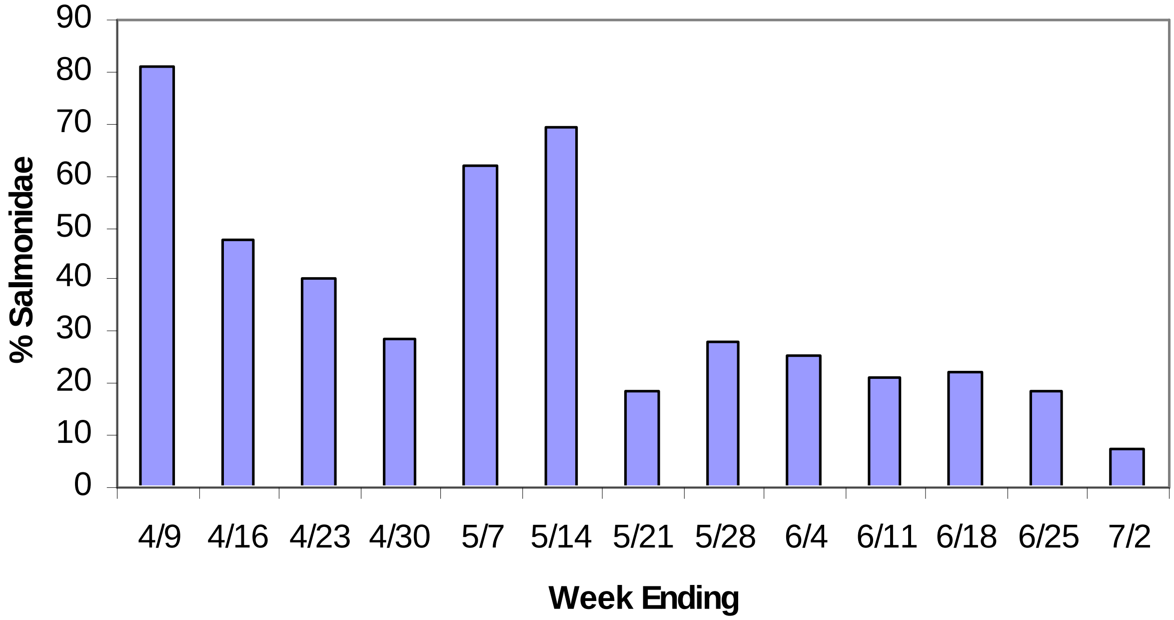

Figure 6. Percentage of observed diet composed of juvenile salmonids on the East Goose Island colony in 2006 (n=1027 bill loads; % is of identified prey items).

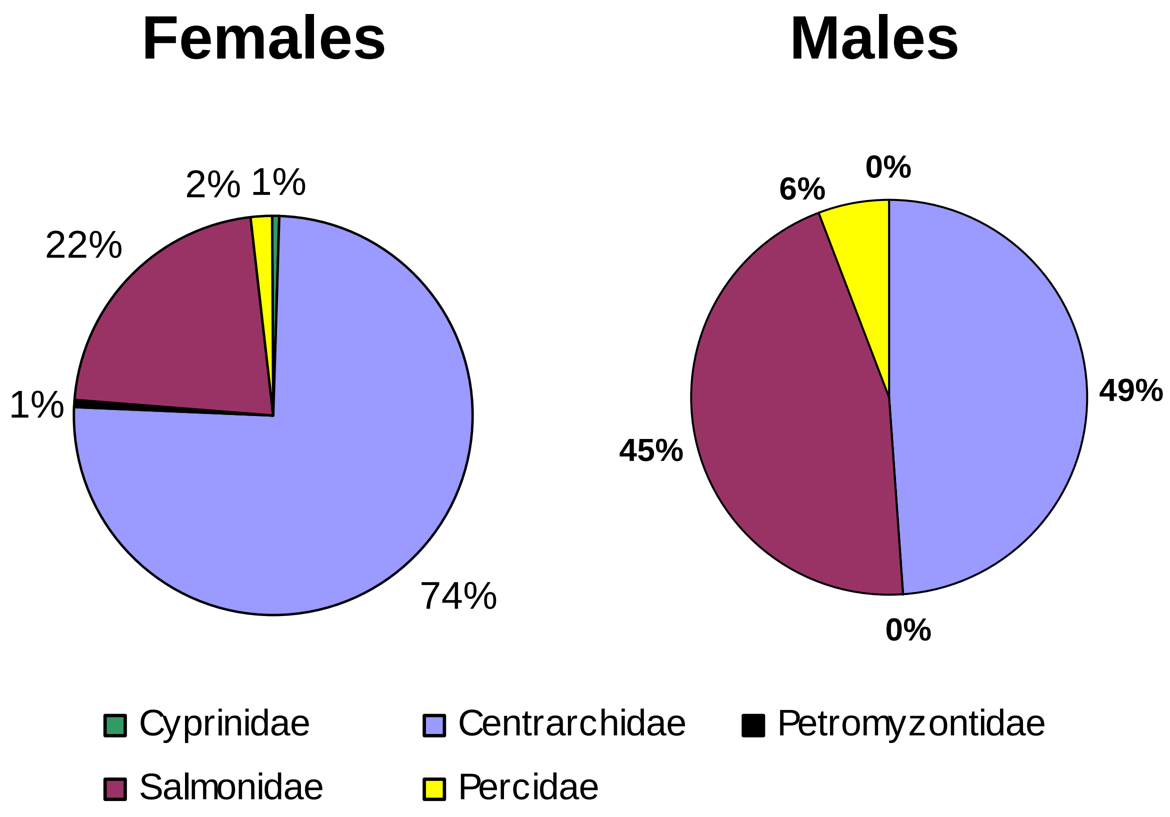

Figure 7. Prey types observed consumed by female (n=168) and male (n=87) Caspian Terns on the East Goose Island colony in 2006.

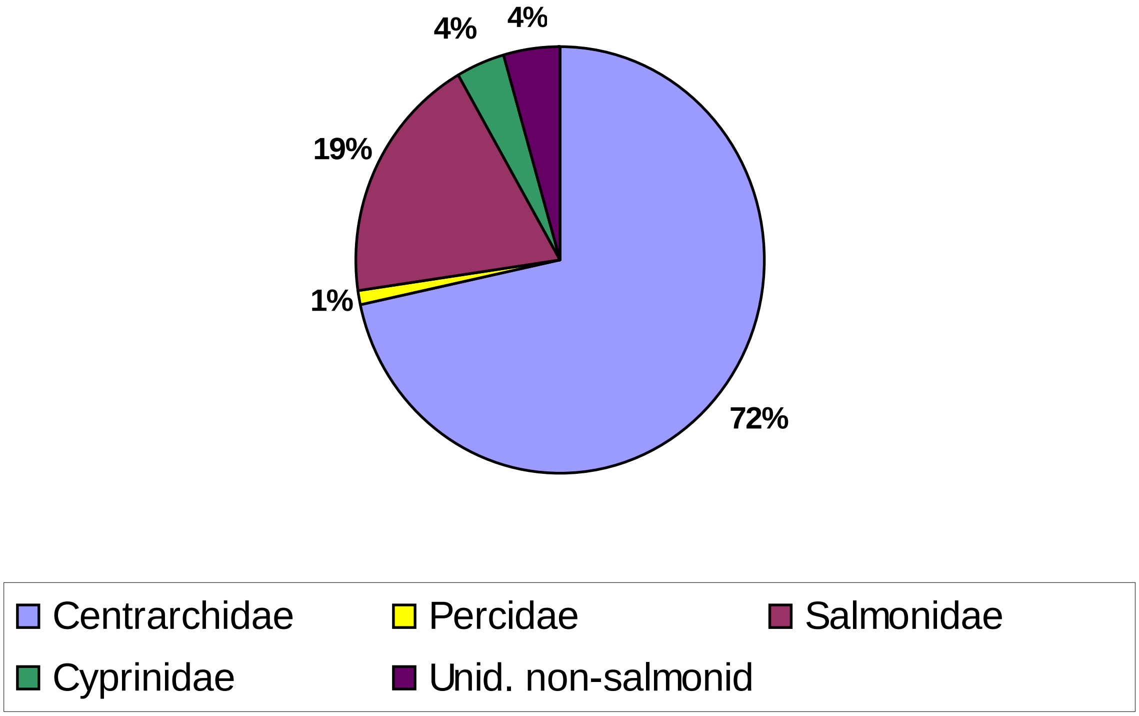

Figure 8. Diet composition of Caspian tern chicks observed on the East Goose Island colony in 2006.

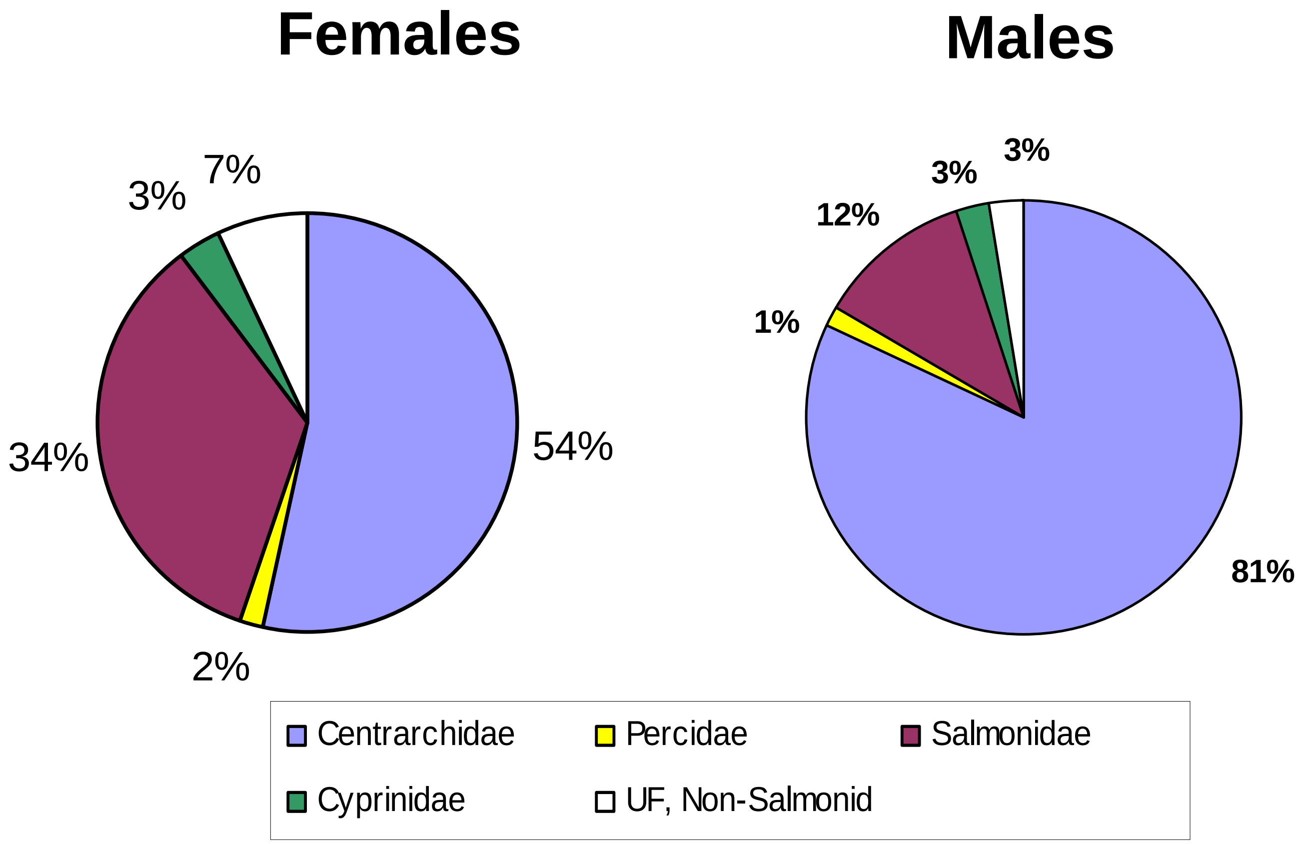

Figure 9. Comparison of chick provisioning by female (n=58) and male (n=78) Caspian Terns on the East Goose Island colony in 2006.

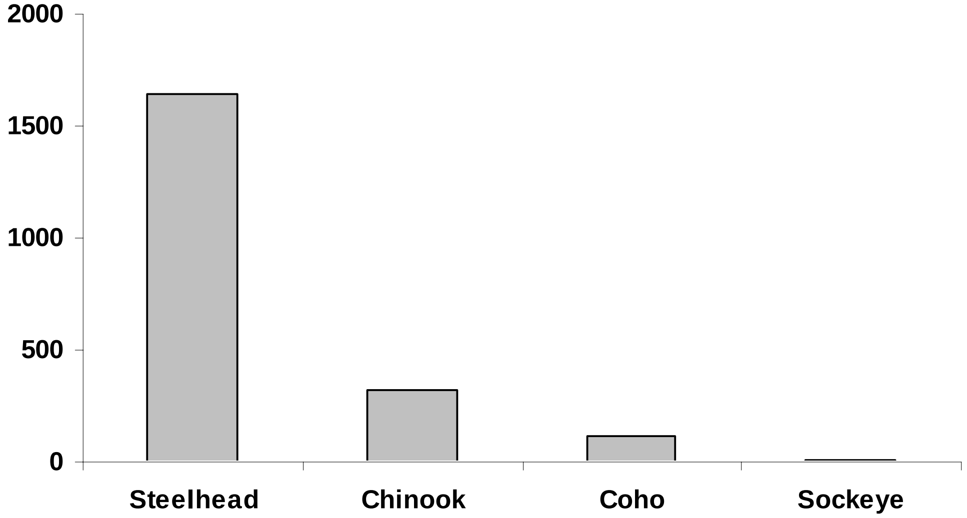

Figure 10. PIT tags detected on or recovered from the East Goose Island colony in 2006.

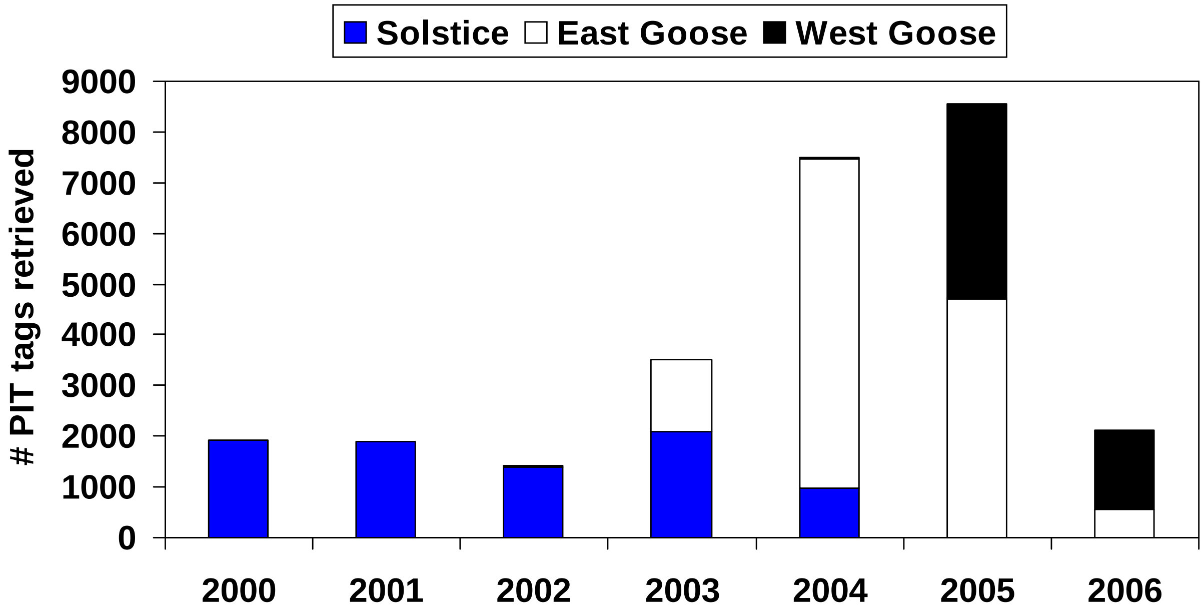

Figure 11. PIT tags detected on/recovered from colonies in the Potholes Reservoir from the years 2000-2006.

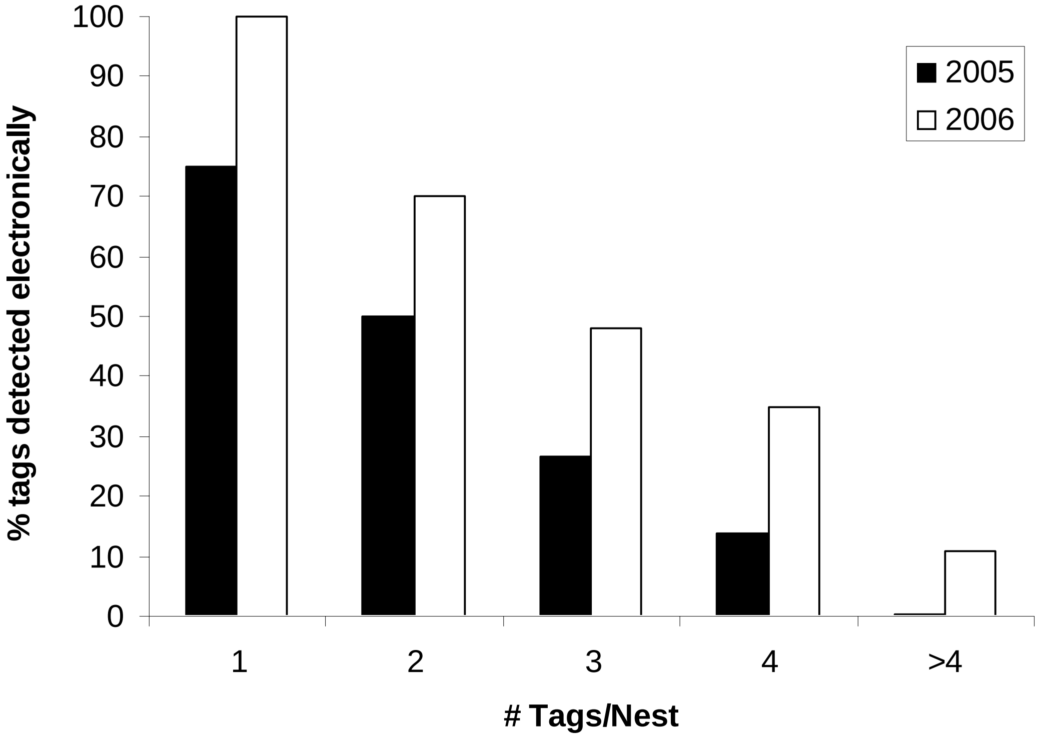

Figure 12. Percent detection of PIT tags in Caspian tern nest cups on the East Goose Island Caspian Tern colony in 2006 (# tags detected electronically/total number of tags recovered from each nest cup).

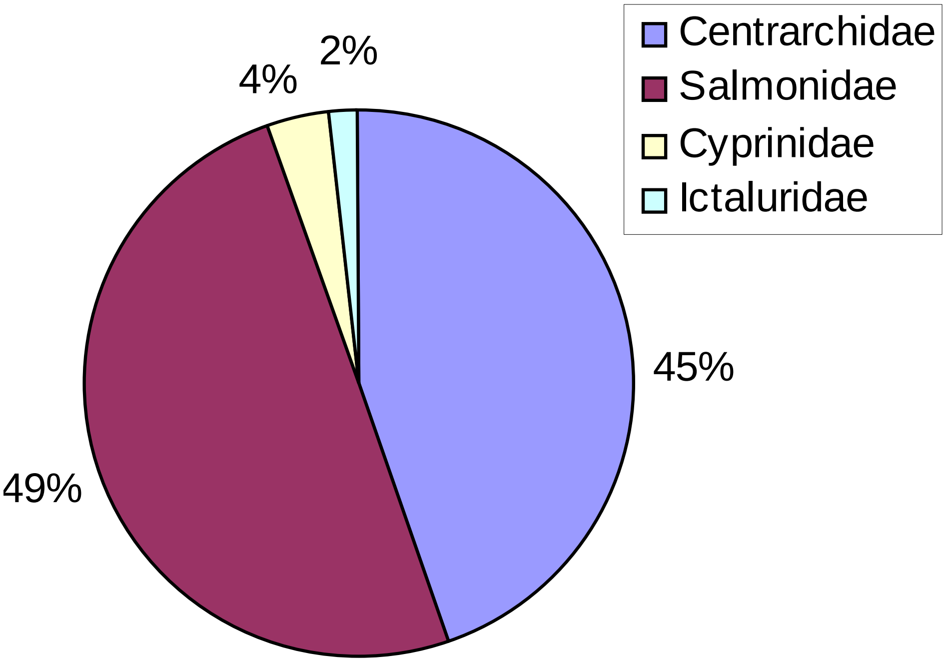

Figure 13. Composition of identified bill loads of Caspian Terns that were kleptoparasitized by gulls on the East Goose Island colony in 2006.

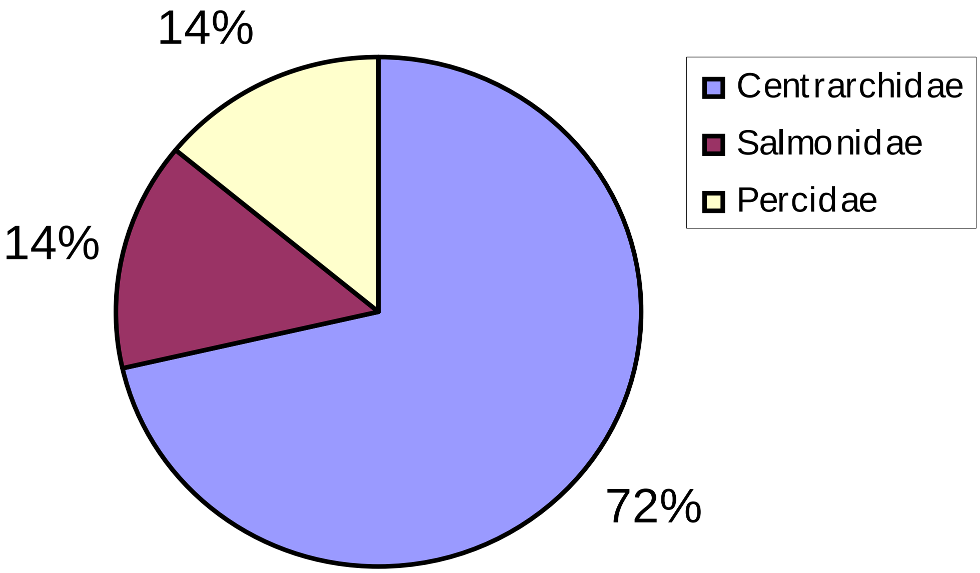

Figure 14. Composition of identified bill loads of Caspian Terns that were kleptoparasitized by Caspian Terns on the East Goose Island colony in 2006.

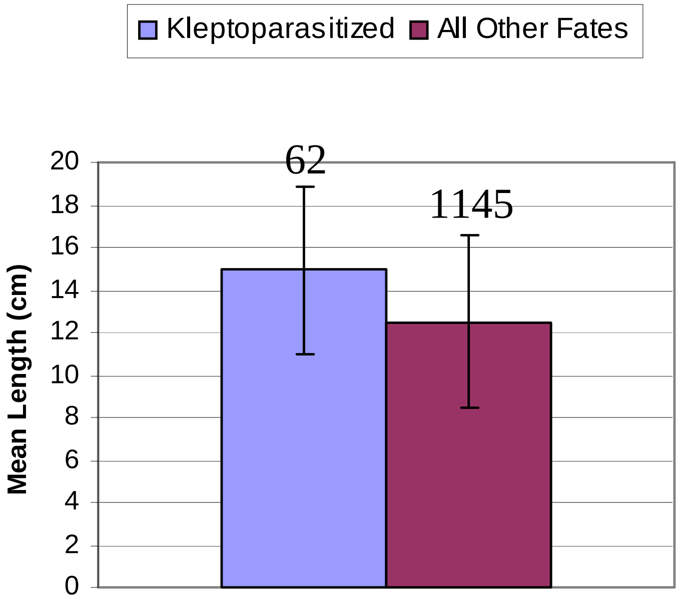

Figure 15. Size of fish kleptoparasitized by gulls as compared to all Caspian Tern bill loads on the East Goose Island colony in 2006 (error bars = 1 SD).

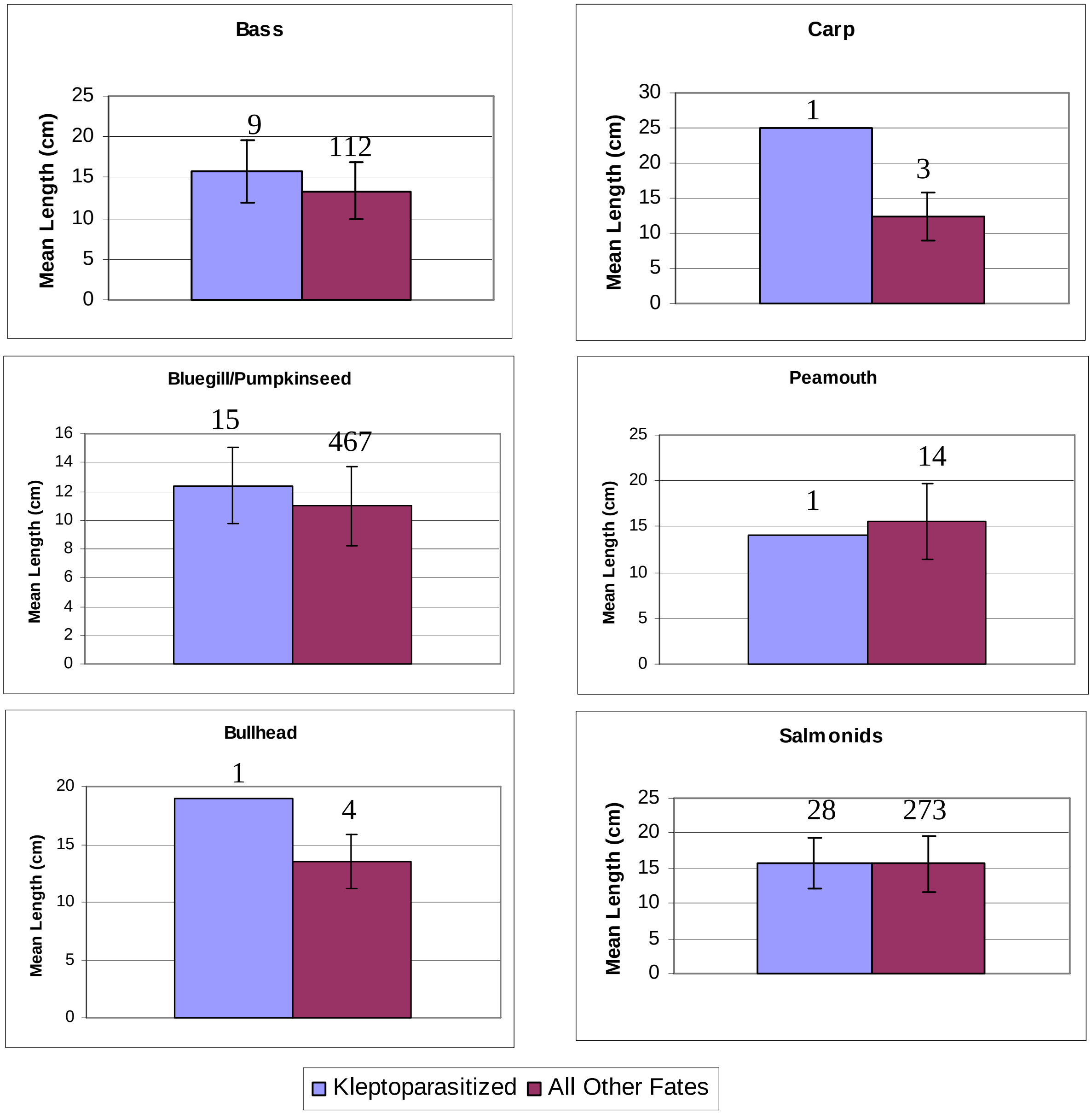

Figure 16. Size of fish kleptoparasitized by gulls as compared to all Caspian Tern bill loads on the East Goose Island colony in 2006 (error bars = 1 SD).

Table 1. Field chronology for Potholes Caspian Tern colonies in 2006.

Date	**Notes**
3/25-3/26	Colony preparation; sample PIT tags (#1) released on East and West Goose colonies for detection efficiency studies; no terns present on colony
4/3	1st Caspian Tern observed at Goose Island
4/8	Colony wide disturbance from humans; boatload of people stranded next to East Goose colony due to windy conditions for approximately 2 hours
4/23	Colony wide disturbance from humans; boaters stranded on Goose Island after boat sank during fishing tournament
5/5	1st egg observed on East Goose colony
5/19	Sample PIT tags (#2) released on West Goose colony
	1 to 2-day old chicks observed on West Goose during sample PIT tag release
5/27	Disturbance overnight; footprints and bottles on East Goose colony on 5/28
5/30	Sample PIT tags (#2) on East Goose colony
	1st chick observed on East Goose colony
	Aerial photo taken of West Goose colony
7/6	Chick banding on Goose Island
	Sample PIT tag releases on West Goose and East Goose colonies (#3)
7/31	Sample PIT tag releases on West Goose and East Goose colonies (#4)
8/21-8/22	PIT tag interference study on East Goose Island colony
8/28	PIT tag scanning/retrieval on East and West Goose colonies

Table 2. Diet composition (% identifiable prey items) of Caspian terns nesting on the east Goose Island colony in 2005 and 2006.

PREY TYPE		2005		2006	
Family	Species	Count	%	Count	%
Salmonidae	**All salmonids**	**641**	**17.0**	**301**	**29.3**
	Chinook salmon	0	0	30	2.9
	Rainbow trout/steelhead	46	1.2	17	1.7
	Unidentified salmonid	595	15.8	254	24.7
Centrarchidae	**All centrarchids**	**2558**	**68.0**	**644**	**62.7**
	Bluegill/Pumpkinseed	1730	46.0	482	46.9
	Crappie spp.	79	2.1	22	2.1
	Largemouth bass	633	16.8	63	6.1
	Smallmouth bass	96	2.6	13	1.3
	Unidentified bass	10	0.3	45	4.4
	Unidentified centrarchid	10	0.3	19	1.8
Ictaluridae	**Bullhead**	**15**	**0.4**	**5**	**0.5**
Percidae	**All percids**	**541**	**14.4**	**29**	**2.8**
	Yellow perch	538	14.3	29	2.8
	Walleye	3	0.1	0	0
Cyprinidae	**All cyprinids**	**0**	**0**	**20**	**2.0**
	Common carp	0	0	4	0.4
	Peamouth	0	0	15	1.5
	Unidentified cyprinid	0	0	1	0.1
Petromyzontidae	**Lamprey**	**6**	**0.17**	**1**	**0.1**
Catostomidae	**Sucker**	**1**	**0.03**	**-**	**-**
Unidentified (non-salmonid)				**27**	**2.6**
Total no. of prey		**3762**		**1027**	

Table 3. Number of PIT tags (H – hatchery; W – wild) from Columbia River and Snake River basin juvenile salmonids recovered from Goose Island colonies in 2006.

Species	ESU	Stock	Recovered	
Steelhead	**Snake River**		**H**	**W**
		Clearwater River	4	-
		Salmon River	3	1
		Lower Snake	28	7
	Upper Columbia River			
		Okanogan River	311	-
		Methow River	321	16
		Entiat River	174	31
		Wenatchee River	592	7
		Similkameen	59	-
		Priest Rapids	1	-
		Chief Joseph Dam	89	-
Chinook	**Snake River fall-run**			
		Clearwater River	4	-
		Lower Snake	31	-
	Snake River spring/summer run			
		Salmon River	6	1
		Lower Snake River	4	-
		Clearwater River	12	-
	Snake River unknown-run			
		Lower Snake	18	-
	Upper Columbia River spring-run			
		Methow River	10	5
		Entiat River	10	1
		Wenatchee River	127	11
		Priest Rapids Dam	10	-
	Upper Columbia River summer-run			
		Entiat River	35	-
		Chief Joseph Dam	22	-
		Priest Rapids Dam	4	-
	Upper Columbia River unknown-run			
		Methow River	1	-
		Entiat River	-	11
	Lower Columbia			
		Lower Columbia	1	-
Coho	**Upper Columbia**			
		Wenatchee River	120	-
Sockeye	**Upper Columbia**			
		Entiat River	-	6

Table 4. Number of PIT tags from Columbia River and Snake River basins recovered from all Potholes Reservoir colonies from 1999-2006.

Columbia River Basin (excl. Snake River)		**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
	Chinook	-	187	1475	1236	1192	1989	385	247
	Coho	-	145	161	71	30	142	61	120
	Steelhead	1	1557	234	78	2270	5316	8018	1602
	Sockeye	-	2	7	3	-	2	3	6
	Totals	1	1891	1877	1388	3492	7449	8467	1975
Snake River basin									
	Chinook	-	6	6	7	11	9	3	76
	Coho	-	-	1	-	-	-	-	-
	Steelhead	-	11	14	13	8	35	23	44
	Sockeye	-	1	-	1	1	-	-	-
	Totals	0	18	21	21	20	44	26	120

Table 5. Detection efficiency (DE) of test PIT tags dispersed on the East and West Goose Island Caspian Tern colonies during the breeding season of 2006 (R=recovered/dispersed).

Date	East Goose						West Goose	
	Plot 1		Plot 2		Total		Plot 1	
	R	DE	R	DE	R	DE	R	DE
3 March	24/50	0.48	13/50	0.26	37/100	0.37	35/50	0.70
19 May	-	-	-	-	-	-	34/50	0.68
30 May	14/50	0.28	16/50	0.32	30/100	0.30	-	-
6 July	21/50	0.42	15/50	0.30	36/100	0.36	15/50	0.30
31 July	49/50	0.98	40/50	0.80	89/100	0.89	45/50	0.90
	108/200	0.54	84/200	0.42	192/400	0.48	129/200	0.645