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

2007 Final Season Summary

This 2007 Final Season Summary has been prepared for the Bonneville Power Administration and the U.S. Army Corps of Engineers for the purpose of assessing project accomplishments. This report is not for citation without permission of the authors.

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EXECUTIVE SUMMARY

This study investigates predation by piscivorous colonial waterbirds on juvenile salmonids (*Oncorhynchus* spp.) from throughout the Columbia River Basin. The study objectives for the Columbia River estuary in 2007, 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; (3) assess potential management options to reduce cormorant predation; and (4) monitor large colonies of other piscivorous waterbirds in the estuary (i.e., glaucous-winged/western gulls [*Larus glaucescens/occidentalis*]) to determine potential impacts on smolt survival. The study objectives for the middle Columbia River in 2007, 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 in the mid-Columbia River; and (2) monitor large nesting colonies of other piscivorous waterbirds (i.e., California gulls (*L. californicus*], ring-billed gulls [*L. delawarensis*], and American white pelicans [*Pelecanus erythrorhynchos*]) on the mid-Columbia River to determine the potential for significant impacts on smolt survival.

Our previous studies to evaluate system-wide losses of juvenile salmonids to avian predation indicated that Caspian terns and double-crested cormorants nesting in the Columbia River estuary were responsible for the vast majority of smolt losses to avian predators in the Columbia Basin. Again in 2007, 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 ca. 9,900 breeding pairs in 2007, not significantly different than in 2006 (ca. 9,200 pairs). The size of the Caspian tern colony at East Sand Island has remained nearly stable since 2000. Tern nesting success averaged 0.64 fledglings per breeding pair in 2007, similar to 2006 (0.72 fledglings per breeding pair). Nesting success during 2005-2007 has been lower than during 2001-2004, when nesting success averaged 1.12 fledglings per breeding pair.

The proportion of juvenile salmonids in the diet of East Sand Island Caspian terns during the 2007 nesting season averaged 30% of prey items, similar to 2006 (31% of prey items), but higher than in 2004 (17% of prey items) or 2005 (23% of prey items). Consumption of juvenile salmonids by terns nesting at the East Sand Island colony in 2007 was approximately 5.5 million smolts (95% c.i. = 4.8 – 6.2 million), similar to smolt consumption the previous year (best estimate = 5.4 million smolts; 95% c.i. = 4.6 – 6.1 million). This is less than half the annual consumption of juvenile salmonids by Caspian terns in the estuary prior to 2000, when their breeding colony was located on Rice Island in the upper estuary. Caspian terns nesting on East Sand Island continued to rely primarily on marine forage fishes (i.e., northern anchovy, shiner perch, Pacific herring) as a food supply. Based on smolt PIT tag recoveries on the East Sand Island Caspian tern colony, predation rates on steelhead smolts were particularly high during 2007, at about 14.1% for in-river migrant smolts and 7.7% for transported smolts. Predation rates on steelhead were 2-12 times higher than those for other salmonid species and run-types.

In 2008, the U.S. Army Corps of Engineers will begin implementing the plan "Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary," outlined in the Final Environmental Impact Statement (FEIS) and Records of Decision (RODs) signed in November 2006. This management plan seeks to redistribute a portion of the East Sand Island tern colony to alternative colony sites in Oregon and California by 2015. The plan calls for the creation of up to 7 acres of new or enhanced tern nesting habitat in interior Oregon (i.e., Fern Ridge Lake, Crump Lake, and Summer Lake) and coastal California (i.e., the San Francisco Bay Area) and to actively attract terns to nest there. As alternative tern nesting habitat is created or enhanced, the available tern nesting habitat on East Sand Island will be reduced from its current size (6 acres) to 1.5 – 2 acres. Habitat enhancement at alternative sites will be accomplished in stages and the reduction of tern nesting habitat at East Sand Island will occur at a ratio of one acre reduced for each 2 acres of habitat created elsewhere. Once fully implemented, the plan would reduce the East Sand Island Caspian tern colony from its current size (approximately 9,500 nesting pairs) to approximately 3,100 – 4,400 nesting pairs. This reduction in the size of the East Sand Island tern colony is intended to reduce tern predation on smolts in the Columbia River estuary by an estimated 2.4 – 3.1 million smolts annually.

The double-crested cormorant colony on East Sand Island consisted of about 13,770 breeding pairs in 2007, similar to the estimate of colony size last year (13,740 pairs). Since our monitoring began in 1997, this cormorant colony has increased by about 275%. Nesting success in 2007 (2.78 fledglings per breeding pair) was the highest ever recorded for this colony, and up considerably from 2006 (1.92 fledglings per breeding pair). As in previous years, salmonids made up a small portion (9%) of the cormorant diet in 2007, while marine forage fish (i.e., northern anchovy) and estuarine resident fish (i.e., sculpin, flounder) made up over 50% of the diet. Despite the lower reliance on salmonids as a food source by cormorants compared to terns, total smolt consumption by cormorants was similar to or greater than that by terns. This is because double-crested cormorants are about four times larger than Caspian terns and the cormorant colony consists of about 40% more nesting pairs than the tern colony. In 2006, cormorants nesting on East Sand Island consumed an estimated 10.3 million juvenile salmonids (95% c.i. = 4.7 – 15.9 million), compared to an estimated 5.4 million juvenile salmonids (95% c.i. = 4.6 – 6.1 million) consumed by terns nesting on East Sand Island (estimates of cormorant consumption of salmonid smolts in 2007 are pending further analyses).

An analysis of salmonid PIT tags detected at the double-crested cormorant colony on East Sand Island indicated that 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 tagged ESUs were susceptible to cormorant predation in 2007. The numbers of PIT tags from the various salmonid species and run-types that were recovered on the cormorant colony were roughly proportional to the relative availability of PIT-tagged salmonids released in the basin, suggesting that cormorant predation on salmonid smolts in the estuary 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. An analysis of salmonid predation rates, based on the proportion of available PIT-tagged fish subsequently deposited on the cormorant colony, indicated that both hatchery and wild smolts were consumed, with rates averaging between 2 and 5% for most species and run-types of PIT-tagged fish originating upstream of Bonneville Dam. Predation rates in excess of 20% were observed for some groups of hatchery fall Chinook salmon released in or near 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. The discrepancy in predation rates for the two colonies will be even greater if the Caspian tern colony is reduced in size by >50% by 2015, as intended under the management plan now being implemented. 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, oiling of eggs, and destruction of nests in trees). Non-lethal 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*. Studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., old tires with nest material, decoys, audio playback systems) to relocate nesting cormorants have shown some promise; cormorants were previously 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 2007, habitat enhancement and social attraction were retained at Miller Sands Spit, but removed from Rice Island; the cormorant colony on Miller Sands Spit was again successful in raising young, while there was no cormorant nesting on Rice Island.

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. In 2007, we conducted a pilot study to test the feasibility of attracting double-crested cormorants to nest at a site remote from the Columbia River estuary and where cormorants had not previously been known to nest. We placed old tires with nest material, cormorant decoys, and audio playbacks of cormorant colony sounds on a floating platform in the Fern Ridge Wildlife Area, adjacent to Fern Ridge Lake near Eugene, Oregon. While double-crested cormorants were repeatedly seen in the area, no cormorants were seen on the platform and no nesting attempts occurred there. This pilot study will be repeated in 2008. While studies of the use of habitat enhancement and social attraction in the Columbia River estuary have been promising, results to date indicate that double-crested cormorants are not as responsive to these techniques as Caspian terns.

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 analysis under NEPA, including assessments of (1) the population status of the Pacific Coast subspecies of double-crested cormorant, (2) the availability of 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. These and other related studies are planned for 2008 and beyond.

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 Caspian tern colony in the estuary) and low annual consumption of juvenile salmonids (ca. 0.5 million smolts, ca. 1/10th the consumption of the tern colony in the estuary). In 2007, there were two breeding colonies of Caspian terns on the mid-Columbia River; about 355 pairs nested on Crescent Island in the McNary Pool and about 40 pairs nested at a relatively new colony site on Rock Island in the John Day Pool. The Crescent Island tern colony declined by 21% from 2006, when 448 breeding pairs nested at the colony; this colony is now smaller than in any year since 1997. It is still the largest Caspian tern colony on the Columbia Plateau, however, and the third largest Caspian tern colony in the Pacific Northwest. The Rock Island Caspian tern colony in 2007 was substantially smaller than in 2006, when 110 breeding pairs attempted to nest there, but was larger than in 2005 (6 breeding pairs), the first year that Caspian terns were known to nest on Rock Island. Nesting success at the Crescent Island tern colony was 0.68 young fledged per breeding pair, up 58% from 2006 (0.43 young fledged per breeding pair). Tern productivity at the Crescent Island colony in 2006 was the lowest recorded at this colony since monitoring began in 2000. In 2007, the Rock Island Caspian tern colony failed to produce any young, apparently due to avian predation on all tern eggs and chicks. In 2006, the Rock Island Caspian tern colony also failed, apparently due to mink predation.

At Crescent Island in 2007, salmonid smolts represented 69% of prey items in tern diets, up slightly from 2006 (63%). We estimated that Caspian terns nesting on Crescent Island in 2007 consumed 360,000 juvenile salmonids (95% c.i. = 250,000 – 460,000), a ca. 10% decline in smolt consumption compared to 2006 (best estimate = 402,000, 95% c.i. = 310,000–500,000). Steelhead comprised an estimated 20.5% of the identifiable salmonid smolts, or roughly 74,000 fish, an increase over the previous year (56,000 fish). Per capita smolt consumption by Crescent Island terns in 2007 (507 smolts per nesting tern across the breeding season) was also greater compared to 2006 (446 smolts per nesting tern). Although no data on diet composition were collected at the Rock Island tern colony, we estimate that 677 smolt PIT tags were deposited on the colony during the 2007 nesting season, indicating that salmonids were a significant part of the diet before the colony failed. A comparison of smolt PIT tags recovered from the Crescent Island and Rock Island tern colonies suggests that Rock Island terns consumed about 1/8th as many PIT-tagged salmonid smolts as did Crescent Island terns, or roughly 45,000 smolts.

Based on smolt PIT tag recoveries on the Caspian tern colony at Crescent Island, the predation rate on in-river migrants from the Snake River (all species and run types) was about 1.1% in 2007, down substantially from 7.5% and 3.8% in 2005 and 2006, respectively. These predation rates have been 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. Although predation rates were dramatically down in 2007, the numbers of Snake River smolts available to terns foraging in McNary Pool were substantially up, as fewer fish were collected for transportation at Snake River dams. As in previous years, predation rates on PIT-tagged steelhead smolts were greater than for other salmonid species. In 2007, ca. 4.9% of the hatchery and 4.8% the wild steelhead smolts from the Snake River were consumed by Crescent Island terns (these predation rates are based on the proportion 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 2007 compared to 2006, a larger proportion of the Snake River steelhead population was susceptible to predation from Crescent Island terns in 2007. Consequently, the total predation rate by Crescent Island terns on the Snake River steelhead ESU in 2007 was the highest observed since 2004. Predation rates on wild steelhead vs. hatchery steelhead from the Snake River were similar and not statistically different when pooled over the entire 2007 out-migration; this finding differs from results during 2004 – 2006, when predation rates on hatchery smolts were consistently higher than on wild smolts.

In 2007, the double-crested cormorant colony on Foundation Island in the mid-Columbia River consisted of at least 330 nesting pairs, and was somewhat smaller than in 2006. The largest cormorant colony on the Columbia Plateau in 2007 was again on Potholes Reservoir, where about 1,015 pairs nested in trees at the north end of the reservoir. The size of this colony was also somewhat lower than in 2006. The limited diet data for Foundation Island cormorants suggest that juvenile salmonids represented 16-18% of the diet. For the first time since this research was initiated in 2004, smolt PIT tag recoveries, and in some cases reach and stock-specific salmonid predation rates, were higher for the Foundation Island cormorant colony than for the Crescent Island tern colony. In fact, of all the piscivorous waterbird colonies studied on the Columbia River in 2007, the Foundation Island cormorant colony had the highest per capita consumption rate of PIT-tagged juvenile salmonids (ca. 11.3 PIT-tagged fish per breeding adult), followed by the Rock Island tern colony (7.87) and the Crescent Island tern colony (7.24). These results suggest that predation rates on salmonid smolts by Foundation Island cormorants are increasing and may now be similar to or greater than that of Caspian terns nesting on nearby Crescent Island. Similar to predation by Crescent Island terns, steelhead were particular vulnerability to predation by Foundation Island cormorants in 2007. Unlike terns, however, Foundation Island cormorants also keyed in on groups of Chinook salmon (both yearlings and sub-yearlings) migrating through McNary Pool. In contrast to the Foundation Island cormorant colony, there is little evidence to suggest that cormorants nesting at the larger colony on Potholes Reservoir are affecting the survival of juvenile salmonids from the Columbia and Snake rivers during the nesting season, based on the paucity of PIT tags from Columbia Basin salmonid smolts recovered at the colony in 2007 (n = 6 smolt PIT tags).

Unlike Caspian terns, which depart the Columbia Basin during the non-breeding season, some double-crested cormorants over-winter on the Columbia and Snake rivers. Over-wintering cormorants could potentially affect the survival of hold-over fall Chinook salmon smolts, particularly near Snake River dams. A pilot study to investigate this potential impact suggested that small numbers of cormorants (< 100) over-winter near two lower Snake River dams (Little Goose and Lower Granite) and that salmonids make up a significant, although not predominant, proportion of their diet. Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 11.8% by mass of the diet of double-crested cormorants foraging at Little Goose and Lower Granite dams in 2007 (n = 40 fore-gut samples). Juvenile shad were the most abundant fish found in fore-gut contents, representing 47.7% of prey biomass, followed by centrarchids (22.0%). It should be noted, however, that these diet composition results are based on a small sample size and the counts of cormorants at two dams on the Snake River tell us little about the system-wide abundance and distribution of over-wintering cormorants on the Snake River and their potential impact on survival of juvenile salmonids. In 2008, we plan to conduct more comprehensive surveys of the distribution and abundance of over-wintering cormorants along the Snake River from the confluence with the Columbia River to Lewiston, Idaho. Additionally, we will increase our sampling efforts to measure diet composition in order to better assess the impacts on ESA-listed salmonid stocks, particularly hold-over fall Chinook salmon smolts, of double-crested cormorants over-wintering along the lower Snake River.

Compared to Caspian terns and double-crested cormorants, other piscivorous colonial waterbirds that nest along the mid-Columbia River (i.e., California gulls, ring-billed gulls, American white pelicans) are having less impact on the survival of juvenile salmonids from the Columbia and Snake rivers. One gull colony that may be having a significant impact on salmonid smolt survival, however, is the large California gull colony (ca. 3,500 nesting pairs) on Miller Rocks in The Dalles Pool, where 2,653 smolt PIT tags were recovered in 2007. Previous research in 1997 and 1998 indicated that salmonid smolts, and fish in general, constituted a very small proportion of the diet of California and ring-billed gulls nesting at up-river colonies (Collis et al. 2002a). At the American white pelican colony on Badger Island 1,160 smolt PIT tags were recovered in 2007; this represents about 0.64 PIT-tagged smolts consumed per nesting adult at this growing colony. In comparison, double-crested cormorants nesting at Foundation Island and Caspian terns nesting on Crescent Island consumed 11.3 and 7.2 PIT-tagged smolts per nesting adult, respectively. The size of some up-river gull colonies (= 7,000 breeding pairs on several islands) and the Badger Island white pelican colony (> 900 pairs), however, exceeds that of the up-river tern and cormorant colonies and should be taken into account when evaluating overall impacts of avian predation on salmonid smolt survival on the Columbia Plateau. Further research and monitoring is necessary to determine whether particular gull and pelican colonies might be having a significant effect on survival of juvenile salmonids in the lower and mid-Columbia River.

In contrast to the gull and pelican colonies on the Columbia Plateau, previous research on glaucous-winged/western gulls nesting in the Columbia River estuary indicated that these birds consumed significant numbers of juvenile salmonids (Collis et al. 2002a). Gulls nesting on Rice Island (river km 34) ate mostly riverine fishes, including out-migrating salmonids, 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 on salmonid smolt survival of predation from gulls nesting at these estuary colonies is unknown.

In 2007 we conducted a pilot study to investigate how smolt morphology, condition, and origin might be related to differences in smolt vulnerability to avian predation. We hypothesized that the probability of smolt mortality due to avian predation increases with the declining physical condition of the fish. We also hypothesized that river conditions and dam operational strategies may be associated with a smolt's vulnerability to avian predators. As part of this pilot study, we scored the condition of 7,088 steelhead smolts that were PIT-tagged and released at Lower Monumental and Ice Harbor dams. Subsequent recovery of some of these PIT tags on piscivorous waterbird colonies downstream indicated that avian predation is partially condition-dependent, with diseased steelhead or steelhead with severe external damage more likely to be consumed by birds than fish with little or no external damage or disease. For example, steelhead with severe external damage were 1.8 times more likely to be consumed by an avian predator than fish with no signs of external damage. Similarly, there was a positive relationship between the extent of de-scaling of smolts and their vulnerability to avian predation, slight to severely de-scaled fish were 1.2 to 2.4 times more likely to fall prey to birds than smolts with little to no de-scaling. Preliminary results indicate that at least some smolt mortality is compensatory, and that not all mortality due to avian predation is additive.

A system-wide assessment of avian predation on juvenile salmonids based on recent available data indicates that the most significant impacts to smolt survival occur in the estuary, with Caspian terns and double-crested cormorants nesting on East Sand Island combined to consume ca. 7 – 16 million smolts annually during 2003-2006. Although estimates of smolt consumption for East Sand Island cormorants in 2007 are not yet available, combined smolt losses to terns and cormorants nesting on East Sand Island in 2007 are expected to be within this range. Estimated smolt losses to piscivorous birds that nest in the estuary are more than an order of magnitude greater than those observed on the mid-Columbia River. Additionally, when compared to the impact of avian predation on the mid-Columbia River, avian predation in the Columbia 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 Caspian tern and double-crested cormorant colonies on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other colonies of other piscivorous waterbirds. The Caspian tern colony on Crescent Island and the double-crested cormorant colony on Foundation Island may be exceptions to this rule; management of these small, up-river colonies may benefit certain salmonid stocks, particularly steelhead.

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corrected for detection efficiency) by the number of breeding adults on the colony or in the plots.

Table 6. Estimated predation rates on wild, in-river PIT-tagged salmonid smolts by avian predators nesting in McNary Pool during 2007. Colonies include American white pelicans (AWPE) on Badger Island, Caspian terns (CATE) on Crescent Island, double-crested cormorants (DCCO) on Foundation Island, and California gulls (CAGU) on Crescent Island. 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 wild-origin that were released into the fish's natal river. Predation rates are corrected for bias due to PIT tag detection efficiency (Table 3), but not for deposition rates, and are therefore minimum estimates. Predation rates do not account for other mortality that took place between the fish's release location and McNary Pool. 95% confidence intervals (±) were based on variation derived from multiple release groups of PIT-tagged smolts within the corresponding ESU (Table 7).

Table 7. Stock-specific predation rates on in-river PIT-tagged salmonid smolts by Crescent Island Caspian terns (CATE), Foundation Island double-crested cormorants (DCCO), Badger Island American white pelicans (AWPE), and Crescent Island California gulls (CAGU) in 2007. 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 locations 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, but not deposition rates, and therefore are minimum estimates. Smolt mortality from the individual stock's release site to the vicinity of McNary Pool is not accounted for.

Table 8. Estimated predation rates on PIT-tagged salmonid smolts traveling through McNary Pool by avian predators nesting at colonies in McNary Pool during 2007. Colonies include American white pelicans (AWPE) on Badger Island, Caspian terns (CATE) on Crescent Island, double-crested cormorants (DCCO) on Foundation Island, and California gulls (CAGU) on Crescent Island. Predation rates are based on the proportions of fish interrogated/tagged at Lower Monumental Dam (LMO), Rock Island Dam (RIS), or in the McNary Pool (McP; fish tagged and released below Priest Rapids and Ice Harbor dams but upstream of McNary Dam) that were subsequently detected on-colony. Predation rates on hatchery (H), wild (W), and unknown (U) rear-type smolts are listed separately. Chinook are designated by run-type as spring/summer (Spr/Sum), fall, and unknown. Sample sizes (N) of interrogated/tagged fish less than 100 were excluded. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not deposition, and are therefore minimum estimates.

Table 9. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants nesting on East Sand Island in the Columbia River

estuary during 1999-2007. Data from 1999-2004 and 2006-2007 are based on the analysis of soft tissue and diagnostic bones recovered from samples of stomach contents from adults. Data from 2005 are preliminary and include only the analysis of soft tissue.

Table 10. Diet composition (% identifiable biomass in regurgitations) of double-crested cormorants nesting on Foundation Island in the mid-Columbia River during 2-week sampling periods in 2007. All samples are regurgitations collected from beneath nesting trees.

Table 11. Diet composition (% identifiable biomass in stomach contents samples) of adult double-crested cormorants nesting on Foundation Island in the mid-Columbia River on five different sampling dates in 2007.

Table 12. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants over-wintering on the Snake River. Cormorants were collected near Little Goose and Lower Granite dams on four different occasions during October–December 2007.

Table 13. Numbers and percentages of steelhead tagged and released at Lower Monumental Dam (n = 6,254) and Ice Harbor Dam (n = 834) in 2007 that were subsequently recovered on avian colonies throughout the Columbia River basin in 2007. Recovery percentages (percentage of tagged fish recovered) are corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not for deposition rates, and therefore are minimum estimates.

SECTION 1: CASPIAN TERNS

1.1. Preparation and Modification of Nesting Habitat

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 tern 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 pre-laying terns that attempted to nest on dredge spoil islands in the upper estuary (Map 1).

During 21-23 March 2007, habitat restoration at the Caspian tern colony site on East Sand Island was accomplished by the U.S. Army Corps of Engineers. Similar to the previous five years, approximately 6 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 European beach grass and other invasive plants. Tern decoys (50) were deployed on the colony site and the entire colony site was marked off with wooden stakes to assist in efforts to census and monitor the colony. To avoid damage from winter storms, two of the three observation blinds surrounding the tern colony had been removed in October 2006. These two blinds, at the southeast and southwest corners of the tern colony, were replaced in these locations on 28 March. The observation blind on the northern edge of the colony had been left in place throughout the winter. On 5 April, a camp was set up on East Sand Island and was continuously occupied by two colony monitors throughout the tern nesting season. Although limited control of glaucous-winged/western gulls (*Larus glaucescens/occidentalis*) was performed during the 1999 and 2000 nesting seasons to enhance prospects for tern colony restoration on East Sand Island, no gull control has been conducted since 2000.

In previous years, work crews from NOAA Fisheries, Oregon Department of Fish and Wildlife, and USACE carried out various habitat modifications on the former tern colony site on Rice Island (e.g., fencing and flagging) prior to the breeding season to discourage Caspian terns from nesting there. This has not been necessary since 2002 because the former colony site on Rice Island (ca. 7 acres) has become completely vegetated and consequently is unsuitable for tern nesting.

1.2. Colony Size and Productivity

<u>1.2.1. Columbia River Estuary</u>

Methods: The number of Caspian terns breeding on East Sand Island in the Columbia River estuary in 2007 was estimated using low-altitude, high-resolution 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, corrected for ground counts of the ratio of incubating and non-incubating terns on 12 different plots within the colony area, was used to estimate the number of breeding pairs on the colony.

Nesting success (average number of young raised per breeding pair) at the East Sand Island tern colony was estimated using aerial photographs taken of the colony just prior to the fledging period. The average of 2 direct counts of all terns (adults and juveniles) in aerial photos, corrected for ground counts of the ratio of fledglings to adults on 12 different plots within the colony area, was used to estimate the number of fledglings on the colony. The total number of fledglings on-colony was then divided by the number of breeding pairs estimated during late incubation. 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 from the plot counts used to generate these estimates.

In 2007, 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) in order to detect early signs of nesting by Caspian terns.

Results and Discussion: As was the case during 2001–2006, all nesting by Caspian terns in the Columbia River estuary occurred on East Sand Island in 2007. Figure 1 presents weekly average counts of adult Caspian terns on the East Sand Island colony during the 2007 breeding season, conducted by observers in blinds. Based on the results from an aerial photo census, we estimate that 9,900 breeding pairs (95% c.i. = 9,152–10,638 breeding pairs) attempted to nest at East Sand Island in 2007. This estimate is not significantly different from our best estimate of colony size at East Sand Island in 2006 (9,200 breeding pairs, 95% c.i. = 8,460–9,942 breeding pairs). There has not been a significant change in the size of the East Sand Island Caspian tern colony since 2001, the first year when all Caspian terns nesting in the Columbia River estuary used East Sand Island. The East Sand Island tern colony represents the largest known breeding colony of Caspian terns in the world.

We estimate that 6,320 fledglings (95% c.i. = 5,481–7,165 fledglings) were produced at the East Sand Island tern colony in 2007. This corresponds to an average nesting success of 0.64 young raised per breeding pair (95% c.i. = 0.54–0.74 fledglings/breeding pair), which is not significantly different from the estimate of nesting success for the East Sand Island tern colony in 2006 (0.72 fledglings/breeding pair, 95% c.i. = 0.63–0.81 fledglings/breeding pair).

No aggregations of Caspian terns were observed on upland areas of dredged material disposal sites in the upper estuary (i.e., Rice Island, Miller Sands Spit, Pillar Rock Sands, Puget Island) during 2007. Prior to this year, Caspian terns have attempted to nest in the upper estuary in every year since the tern colony was completely relocated from Rice Island to East Sand Island in 2001. During each breeding season from 2001-2006, resource managers employed both passive and active measures to dissuade terns from nesting at these incipient colony sites in the upper estuary; this was not necessary in 2007.

1.2.2. Columbia Plateau

Methods: The number of Caspian tern breeding pairs at Crescent Island (Maps 2 and 3) 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-based and aerial surveys of former Caspian tern breeding colony sites (i.e., Three Mile Canyon Island, Rock Island, Miller Rocks, Cabin Island, Sprague Lake, Banks Lake, and Potholes Reservoir) were conducted during the 2007 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 its mouth to the confluence with the Clearwater River, and Potholes Reservoir searching for new or incipient Caspian tern colonies.

Results and Discussion: Figure 2 presents weekly average counts of all adult Caspian terns on the Crescent Island colony during the 2007 breeding season, collected by observers in blinds. About 355 breeding pairs of Caspian terns attempted to nest at the Crescent Island colony in 2007, about 21% fewer pairs than in 2006. The number of Caspian terns nesting on Crescent Island has declined steadily over the past 6 years (Figure 3); in comparison the number of terns nesting on East Sand Island has remained relatively stable over this same period. We estimated that 241 young terns fledged from the Crescent Island colony in 2007, or 0.64 young raised per breeding pair, a 58% increase in productivity compared to 2006.

Rock Island (located on the mid-Columbia River in the John Day Pool) was visited on 16 July. No terns were observed on the island during this visit. Significant mortality of nesting terns and gulls was observed during a previous visit to the island on 7 July. We suspect that the mortality was caused by an avian predator, perhaps a great horned owl or peregrine falcon, and not a mammalian predator. During our visit to the colony on 7 July, 26 adult Caspian terns and five Caspian tern chicks remained on Rock Island. Based on our observations, it is uncertain whether any young terns successfully fledged from the Rock Island colony in 2007; at best, productivity was very low. In 2006, the Rock Island Caspian tern colony failed due to mink predation on all tern eggs and chicks produced at the colony. Nesting was first detected on Rock Island in 2005, when about 6 pairs of Caspian terns attempted to nest there.

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 2007. 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.

In 2007, Caspian terns nested at two sites located on the Columbia Plateau off the Columbia and Snake rivers. During surveys of Banks Lake (just above Dry Falls Dam near Coulee City; Map 2), as many as 48 adult terns were counted on Dry Falls Island. Caspian terns were successful in rearing young at this colony in 2007, with a total production of 15-20 fledglings. Caspian tern nesting was first confirmed at this site in 2005.

Caspian terns also nested successfully at Goose Island in Potholes Reservoir (Map 2) in 2007. We estimated that ca. 282 nesting pairs nested on Goose Island in 2007, slightly lower than our estimate in 2006 (323 nesting pairs). Nesting success on Goose Island was similar in 2007 (139 chicks near fledging age were banded on 2 July) and in 2006 (122 fledglings produced). Goose Island was first used by nesting Caspian terns in 2003; previously Caspian terns nested on another island in Potholes Reservoir (Solstice Island), where tern nesting was first confirmed in 2000.

Caspian tern nesting was not confirmed on Harper Island in Sprague Lake (approximately 50 miles east of Moses Lake on I-90; Map 2) in 2007. In late May, 50 Caspian terns were observed loafing on the island. During subsequent aerial surveys of Harper Island we did not see any terns there. Caspian tern nesting on Harper Island was first confirmed in 2000; in general, fewer Caspian terns have nested there in comparison to the other sites discussed here and nesting success has been sporadic (e.g., no nesting success in 2005).

Total numbers of Caspian terns nesting throughout the Columbia Plateau Region (including colonies in Potholes Reservoir) in 2007 was approximately 700 pairs (Table 1). This suggests that the number of Caspian terns nesting throughout the Columbia Plateau has declined since 1997 (Figure 4), when the number of breeding Caspian terns was estimated at ca. 1,000 breeding pairs (Collis et al. 2002a).

1.2.3. Coastal Washington

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

The numbers of Caspian terns breeding on Dungeness Spit (in Dungeness National Wildlife Refuge near the city of Sequim, WA; see Map 2) and on a rooftop at Naval Base Kitsap Bremerton (in Bremerton, WA) were estimated using aerial photographs of the colonies taken early during chick-rearing. The count of adult terns in aerial photos of Dungeness Spit was corrected to estimate the number of breeding pairs on the colony using ground counts of the ratio of brooding to non-brooding terns within the colony area. Counts of adult terns in aerial photographs of the rooftop at Naval Base Kitsap

Bremerton were not corrected with ground counts. The number of young produced at the Dungeness Spit Caspian tern colony was estimated using ground counts of black-capped chicks late in the chick-rearing period. Productivity estimates were not made for the rooftop tern colony in Bremerton.

Results and Discussion: Although Caspian terns were commonly observed foraging and roosting in Willapa Bay and Grays Harbor throughout the 2007 breeding season, no nesting attempts by terns were detected in either area. This suggests that suitable tern nesting sites (i.e., island sites that are unvegetated, above high high tide levels, not currently occupied by other colonial nesting birds, and free of mammalian predators) are not available in either Willapa Bay or Grays Harbor.

The Caspian tern colony on Dungeness Spit in Dungeness NWR during 2007 was located close to the colony site used during 2003-2006. Our best estimate of the peak size of the Caspian tern colony at Dungeness Spit in 2007 was 1,147 breeding pairs. This represents a 44% increase in colony size compared to 2006. This colony has been growing steadily in recent years (Roby et al. 2004, 2005, 2006) and is likely the second largest Caspian tern colony along the Pacific Coast (after the colony on East Sand Island). Based on resightings of banded Caspian terns in previous years, at least some of this growth is from immigration of birds banded at colonies in the Columbia Basin (i.e., East Sand and Crescent islands) and Commencement Bay (Roby et al. 2004, 2005, 2006). A maximum of 317 black-capped chicks were counted on the Dungeness Spit tern colony on 01 August, suggesting poor nesting success in 2007.

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

The Caspian tern colony located on a rooftop of a waterfront building at the Naval Base Kitsap in Bremerton was observed on only one occasion midway through the 2007 breeding season. Our best estimate for the size of this colony in 2007, based on counts of breeding pairs during the single visit, was 117 breeding pairs. Much larger numbers of Caspian terns (~ 900 individuals) were counted at this colony earlier in the breeding season; (S. Holton, USDA – Wildlife Services, pers. comm.); however, there was evidence of hundreds of abandoned tern eggs on the colony when it was visited in mid-

June. See Roby et al. (2007) for a full report on our observations at the Dungeness Spit and Naval Base Kitsap Caspian tern colonies in 2007.

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 with 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 30% were juvenile salmonids (n = 5,387 bill loads). As in previous years, marine forage fishes (i.e., anchovies [Engraulidae], herring [Clupeidae], shiner perch [Embiotocidae], and smelt [Osmeridae]) were prevalent, averaging 59% 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. 66% during the second week of May (Figure 6), approximately the same time as peak salmonid consumption was observed the previous three years. We estimate that Caspian terns nesting on East Sand

Island consumed a total of 5.5 million juvenile salmonids in 2007 (95% c.i. = 4.8 – 6.2 million), similar to smolt consumption the previous year (best estimate = 5.4 million smolts, 95% c.i. = 4.6 – 6.1 million). Of the juvenile salmonids consumed in 2007, we estimate that 47% were coho salmon (best estimate = 2.6 million, 95% c.i. = 2.3 – 3.0 million), 20% were yearling Chinook salmon (best estimate = 1.1 million, 95% c.i. = 1.0 – 1.3 million), 16% were steelhead (best estimate = 0.9 million, 95% c.i. = 0.8 – 1.0 million), 15% were sub-yearling Chinook salmon (best estimate = 0.8 million, 95% c.i. = 0.7 – 0.9 million), and 1% were sockeye salmon (best estimate = 33,000, 95% c.i. = 28,000 – 38,000). Most salmonids were consumed during the period from mid-April through mid-June, with the peak in smolt consumption occurring in mid-May (Figure 7). This period of high smolt consumption generally corresponds to the peak of the steelhead and yearling Chinook out-migration through the estuary.

1.3.2. Columbia Plateau

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

Estimates of annual smolt consumption 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. Temporal trends in steelhead consumption by Crescent Island terns were also investigated relative to the estimated fish passage index at McNary Dam (FPC 2007), a gross measure of smolt availability near Crescent Island.

Results and Discussion: Juvenile salmonids were the most prevalent prey type for Caspian terns nesting on Crescent Island (69% of identifiable bill loads), followed by centrarchids (bass and sunfish, 20%) and cyprinids (carp and minnows, 6%; n = 2,271 bill loads; Figure 8). The proportion of salmonids in the diet was consistently higher throughout the breeding season compared to that of terns nesting on East Sand Island in 2007. The proportion of salmonids in the diet peaked during late April and early May at more than 90% of identifiable prey items (Figure 9). Seasonal changes in the proportion of salmonids in the diet probably reflected changes in availability of hatchery smolts near the colony, which was presumably high in April and early May. We estimated that Caspian terns nesting on Crescent Island consumed 360,000 juvenile salmonids in 2007 (95% c.i. = 250,000 – 460,000), somewhat less but not significantly so compared to 2006 (best estimate = 402,000, 95% c.i. = 310,000–500,000; Figure 10). Steelhead comprised an estimated 20.5% of the identifiable salmonid smolts, or roughly 74,000 fish, the highest point estimate for steelhead consumption in the last four years (2004 – 2006 point estimates ranged from 48,000 – 58,000 fish), despite the colony being smaller in 2007 than in previous years (355 pairs vs. 448 – 530 pairs). Per capita smolt consumption also increased in 2007 (507 smolts per nesting tern across the breeding season) compared to 2006 (446 smolts per nesting tern across the breeding season; Figure 11). Within-season temporal patterns in consumption of all salmonids (all species/types) have been qualitatively similar over the past four years, but the pattern in 2007 was somewhat less peaked than in previous years (Figure 12). The within-season trend in steelhead consumption also was more protracted in 2007, more so than in any of the previous three years; significant steelhead consumption continued later into the season than previously observed (Figure 13). During the period 5/22 – 7/2, steelhead consumption was substantially greater in 2007 (roughly 36,000 smolts) than in 2004 – 2006 (18,000 – 20,000 smolts). This higher steelhead consumption by Crescent Island terns later in the 2007 nesting season (corresponding to the terns' chick-rearing period) was the main difference resulting in higher steelhead consumption for the entire season, and presumably contributed to the higher tern nesting success observed in 2007.

In general, during the years 2004 – 2007, the timing of peak steelhead consumption by Crescent Island Caspian terns corresponded to the peak of the steelhead out-migration through McNary Pool, as measured by the McNary Dam smolt passage index (Figure 13). Within each year, a significant correlation existed between the number of steelhead consumed during each two-week period and the smolt passage index for that same period (P = 0.01 for 2004 – 2006 and P = 0.05 for 2007). This correlation was weaker in 2007 because of prolonged consumption of steelhead into June, well after the decline in the passage index. Part of the correlation between the steelhead passage index and numbers of steelhead consumed by Crescent Island terns is a function of the synchrony between tern nesting and the steelhead out-migration. This is supported by the significant within-year correlation between the number of terns actively nesting on Crescent Island in each two-week period and the steelhead passage index at McNary Dam for that same period (P = 0.01, 0.03, 0.005, and 0.02 for 2004 – 2007, respectively). Consequently, a major reason for the higher consumption of steelhead when more steelhead were migrating in-river was because peak steelhead out-migration coincided with peak numbers of Caspian terns on Crescent Island. Nevertheless, Caspian tern consumption of steelhead smolts remained high even after the steelhead passage index dropped to very low rates, and this was especially pronounced in 2007.

1.4. Salmonid Predation Rates

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

Previous estimates of predation rates based on PIT tag recoveries were considered minimums because not all tags consumed by birds are deposited on their nesting colony and not all tags deposited on the colony are detected. From 2004 to 2007, we have worked collaboratively with NOAA Fisheries to generate more accurate and defensible estimates of avian predation rates based on PIT tag recoveries. This was accomplished by (1) physically removing tags from the Crescent Island and East Sand Island tern colonies, 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) conducting experiments to measure on-colony deposition rates of PIT tags ingested by Caspian terns.

<u>1.4.1. Smolt PIT Tag Recoveries</u>

Methods: Predation rate estimates based on PIT tag recoveries were corrected for the biases associated with PIT tag collision, detection efficiency, and deposition rate (for terns on Crescent Island only; see CBR 2005, CBR 2006, and CBR 2007 for detailed methods). Briefly, PIT tag collision (where tags in close proximity on a colony renders them unreadable by electronic equipment) was addressed by physically removing tags from the Crescent Island and East Sand Island tern colonies by passing large magnets (which gather the PIT tags) over the colony surface. Detection efficiency was estimated by systematically sowing PIT tags on tern colonies throughout the nesting season and then recovering tags after the nesting season. Sowing of test tags were conducted (1) prior to the birds' arrival on colony (March), (2) during egg incubation (May), (3) during chick fledging (June), and (4) once the birds had left the colony following the nesting season (July to August). Detection efficiency estimates were then analyzed relative to the sowing date, thereby describing temporal variation in detection efficiency. Finally, not all smolt PIT tags consumed by terns are deposited on the nesting colony; some proportion of consumed PIT tags is regurgitated by terns while they are not on-colony, for example during flight or at off-colony loafing areas. In 2004-2006, we conducted experiments to measure on-colony deposition rates of PIT tags ingested by terns nesting on Crescent Island. First, we allowed terns to forage on PIT-tagged fish confined to net pen enclosures and then scanned for those tag codes at the Crescent Island tern colony following the nesting season. Secondly, we captured nesting adult terns on the Crescent Island tern colony and force-fed them PIT-tagged fish and then scanned for those tag codes following the nesting season. Based on these previous studies (see CBR 2007), we estimate that the on-colony deposition rate of PIT tags consumed by Crescent Island terns is 63.4% (± 4.9%). Results from the current and previous years were used to correct our predation rate estimates for terns to account for these biases (where noted, corrections for deposition rate were applied to Crescent Island tern predation rates).

Following the 2007 nesting season, electronic PIT tag detection equipment (antennas and transceivers) were used to detect tags *in situ* that were not removed physically using magnets (see Ryan et al. [2003] for a detailed description of NOAA Fisheries' PIT tag recovery methods). Tag recovery efforts at avian colonies in the Columbia River estuary were conducted primarily by NOAA Fisheries, while recovery efforts on the Columbia Plateau (e.g., Crescent Island and Rock Island tern colonies) were conducted primarily by RTR/OSU.

Results and Discussion: Prior to the 2007 breeding season, NOAA Fisheries and U.S. Army Corps of Engineers physically removed 2,920 PIT tags, 89 radio tags, and 19 hydro-acoustic tags from the East Sand Island tern colony. Physical tag removal was done as part of pilot study to evaluate the efficacy of using large sweeper magnets towed behind a tractor to remove a large number of tags from the colony surface and reduce PIT tag collision, believed to be an emerging problem on the East Sand Island tern colony. Physical removal efforts on the East Sand Island tern colony were only marginally successful, with just 2.0% of the 144,254 functional tags (tags from all migration years) previously detected on-colony being physically removed. These results indicate that physical PIT tag removal is much more difficult to accomplish on East Sand Island compared to Crescent Island (see below). Not only is the tern colony area on East Sand Island nearly 20 times greater than on Crescent Island, but the substrate on the East Sand Island colony (i.e., loose silty sand) is less compacted than the substrate on the Crescent Island colony (i.e., hard packed dirt), making PIT tag recovery using magnets much less effective on East Sand Island.

Following the 2007 nesting season, NOAA Fisheries used specially designed electronics to detect 27,934 functional, previously undetected PIT tags on the East Sand Island Caspian tern colony. Of these, 22,903 or 81.9% were from smolts tagged and released during the 2007 migration year. All PIT tag codes were uploaded to the regional smolt PIT tag database (PTAGIS 2007) and the owners of other fish tags (i.e., radio, hydro-acoustic, and floy tags) that were physically recovered were notified, whenever possible.

Following the 2007 breeding season and before electronic detection, we physically removed 7,522 PIT tags, 310 radio tags, 59 hydro-acoustic tags, and 1 floy tag from the Crescent Island tern colony. Of the 7,552 PIT tags collected from the colony, 6,617 (86.3%) were still functional or readable. Following physical removal, we detected an additional 6,412 functional PIT tags on the tern colony using specially-designed electronics. In total, 13,029 functional PIT tags were removed from or detected on the

Crescent Island tern colony following the 2007 tern breeding season. Of these functional tags, 8,055 (61.8%) were unique or previously undetected (i.e., tags not detected in past recovery efforts). Of these newly detected, functional tags, 3,578 (44.4%) were from smolts tagged and released during the 2007 migration year. All PIT tag codes were uploaded to the regional smolt PIT tag database (PTAGIS 2007) and the owners of other fish tags were notified, whenever possible.

Of the test tags sown on the East Sand Island tern colony in 2007 (n = 600), 542 or 90.3% were subsequently detected on-colony (Table 3). Detection efficiency ranged from 79.0% for tags sown during the chick-rearing period to 95.0% for tags sown post-season. Unlike Crescent Island (see below), however, there was no evidence that detection efficiency increased as a function of when the tags were sown on-colony (R^2 = 0.0179, P = 0.7123). This result is similar to those described for East Sand Island in 2004 – 2006 (CBR 2005, 2006, 2007), suggesting that differences in detection efficiency are not related to when tags are deposited on the East Sand Island Caspian tern colony.

Of the test tags sown on the Crescent Island tern colony in 2007 (n = 800), 558 or 69.8% were subsequently detected on-colony (Table 3). Detection efficiency ranged from as low as 31.5% for tags sown pre-season to as high as 98.0% for tags sown post-season. Average detection efficiency during the nesting season (i.e., during the period when terns were observed on the colony and were ingesting PIT tags) was 68.1% (linear fit). Similar to data collected during 2004-2006, there was a positive correlation between the Julian date when test tags were sown and detection efficiency (R^2 = 0.8384, $P < 0.01$), with tags sown late in the nesting season more likely to be detected than tags sown early in the nesting season. Detection efficiency results suggest that PIT tags from early-migrating smolts that were deposited on the Crescent Island colony by terns are less likely to be detected on-colony as compared to PIT tags from late-migrating smolts.

Overall, detection efficiencies at both the Crescent Island and East Sand Island tern colonies were up markedly in 2007 compared to the record lows observed in 2006 (CBR 2007). On East Sand Island, average detection efficiency increased from 64.1% to 90.3%. The observed increase in detection efficiency on East Sand Island was likely due to the use of newer electronic equipment (S. Sebring, NOAA Fisheries, pers. comm.), the tilling of the tern colony surface by the U.S. Army Corps of Engineers prior to the 2007 nesting season (a process that can displace and bury old tags, thereby reducing PIT tag collision), and, to a lesser degree, the physical removal of 2,920 tags prior to the breeding season. On Crescent Island, average detection efficiency increased from just 31.5% in 2006 to 69.8% in 2007. Although it is not clear exactly why detection efficiency was higher on Crescent Island in 2007, we suspect a combination of newer electronic equipment and a reduced number of severe wind/rain storms (which can remove tags from the colony) compared to 2006. Finally, we suspect that someone may have removed PIT tags from the Crescent Island tern colony in 2006, prior to our crew's removal and detection efforts in August of that year. If true, this would also help explain the between-year discrepancy in detection efficiency. Perhaps our installation of a video camera on the Crescent Island tern colony in 2007 dissuaded others from attempting to remove PIT tags from that colony.

1.4.2. Avian Predation Rates on Smolts

Methods: In collaboration with NOAA Fisheries, we used PIT tag recoveries on bird colonies to evaluate the relative vulnerability of various salmonid species and stocks to bird predation. PIT tag data were also used to estimate predation rates on threatened and endangered salmonid populations, when sample sizes allowed. Preliminary analyses of tags recovered from Caspian tern colonies in 2007, with comparisons to data collected from 2004-2006, are presented here. These data will be analyzed in greater depth – including a multi-year synthesis – in this project's Final Report, in NOAA Fisheries' Annual Reports, and in articles published in refereed scientific journals.

We queried the regional PIT tag database (PTAGIS 2007) on 22 October 2007 to acquire data on the species of fish, run of fish (if known), origin of fish (hatchery, wild, or unknown), tagging date, tagging location, and in-river interrogation history for all PIT-tagged fish released into the Columbia River Basin in 2007. We calculated predation rates on different salmonid species, run types, and stocks (as defined by NOAA Fisheries' Evolutionarily Significant Units or ESUs) based on the total number of released fish that were subsequently recovered on tern colonies (referred to as ESU or stock-specific predation rates). 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 relative to a given river reach because the numbers of smolts susceptible to tern predation are inflated to an unknown degree.

A more accurate reach-specific measure of tern predation rate was calculated by limiting the analysis to actively-migrating smolts that were last detected within the general foraging range of the East Sand Island or the Crescent Island tern colonies (referred to as reach-specific predation rate estimates) during the bird's nesting season. For the East Sand Island tern colony, this was done by calculating a predation rate for just those PIT-tagged smolts that were interrogated while passing Bonneville Dam' (located 227 Rkm up-river from East Sand Island), plus those PIT-tagged smolts that were transported and released into the Bonneville Dam tailrace. 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 up-river from Crescent Island), Rock Island Dam (located on the Upper Columbia River; 210 Rkm up-river from Crescent Island), and PIT-tagged smolts released on the mid-Columbia River between McNary Dam (located on the Columbia River, 39 Rkm down-river from Crescent Island) and the confluence of the Snake and Columbia rivers. 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, a distance of upwards of 200 Rkm for particular ESUs and the corresponding avian colony. Reach-specific estimates also assume that predation rates on smolts using the juvenile bypass are reflective of other PIT-tagged smolts that use alternative routes to pass any particular dam (i.e., spillway, powerhouse).

We investigated temporal trends in predation on steelhead by using the interrogation date of PIT-tagged steelhead at Lower Monumental Dam (for Crescent Island terns) and Rock Island Dam (for Potholes terns) relative to the recovery of PIT tags at these two colonies. Non-parametric tests (e.g., Chi-square, Fisher Exact, and odds ratio comparisons based on the z-statistic; Ramsey and Schafer 1997) were used to compare weekly (week = Sunday to Saturday) predation rates among steelhead of different origins (hatchery versus wild). Temporal trends in steelhead predation by Crescent Island terns were also investigated relative to the estimated fish passage index at Lower Monumental Dam (FPC 2007), intended to be a gross measure of availability of Snake River smolts near Crescent Island. In addition, simple modeling techniques (e.g., regression analysis) were used to evaluate temporal trends in predation on Snake River steelhead by Crescent Island terns.

All predation rate estimates presented here were corrected for on-colony PIT tag detection efficiency, based on the results of PIT tag detection efficiency studies described above (see Section 1.4.1). When noted, results for Crescent Island terns are also corrected for PIT tag deposition rates, based on results from a previous study (see CBR 2007). 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 out-migration timing among various runs. Because no temporal trend was evident from test tags sown on East Sand Island, we used the average detection efficiency of 90.3% to estimate detection for all runs, regardless of timing. Confidence intervals for predation rate estimates were derived using variation (in this case, the standard error of the mean) obtained from multiple release groups of PIT-tagged fish of the same species, origin, and run-type.

We are working collaboratively with NOAA Fisheries to convert predation rate estimates based on PIT tag recoveries to consumption estimates (i.e., number of fish consumed) for particular salmonid ESUs. This requires that we have good data on the availability (i.e., abundance) of smolts in the vicinity of bird colonies. Until such estimates are available (we anticipate preliminary results by the Summer of 2008), predation rates based on PIT tag recoveries on-colony can measure the relative vulnerability of various salmonid species and stocks within a given year, but can not provide precise estimates of the numbers of ESA-listed smolts that are annually consumed by populations of Caspian terns or other avian predators.

Results and Discussion: Approximately 1.5 million PIT-tagged juvenile salmonids were released into the Columbia River Basin in 2007 (PTAGIS 2007). The majority of these fish were released into the lower Snake River (1.0 million), followed by the Columbia River (0.3 million) and upper Columbia River (0.2 million). As in previous years, the smallest numbers of PIT-tagged fish were released into the lower Columbia River (0.01 million) and the Willamette River (0.01 million; PTAGIS 2007), which limits the usefulness of PIT tag recoveries on bird colonies for determining the relative vulnerability of fish originating from these two major river systems. Of the 1.5 million PIT-tagged juvenile salmonids released in the basin, 68.9% were Chinook salmon, 22.2% were steelhead, 5.4% were coho salmon, 2.8% were sockeye salmon, and the remaining 0.7% were other salmonid species (e.g., sea-run cutthroat) or unknowns (PTAGIS 2007). Most of the PIT-tagged fish were of hatchery (75.9%), although wild smolts of many different species and run-types were tagged in 2007 (PTAGIS 2007). Some important exceptions to this were wild steelhead and Chinook salmon from the Willamette River (n = 0), wild sockeye salmon from the Snake (n = 917), and wild coho and Chinook salmon from the lower Columbia River (n = 0); these stocks and species are listed as threatened or endangered and information regarding predation by piscivorous waterbirds is lacking. Overall, the total number of PIT-tagged fish released in 2007 was lower than that of the previous three years, when approximately 2.0 million fish were released annually into the basin (PTAGIS 2007).

East Sand Island Caspian terns – Of the approximately 1.5 million PIT-tagged fish that were released into the Columbia River basin in 2007, 1.5% (n = 22,903) were recovered on the East Sand Island tern colony. This proportion increases to 1.7% (n = 25,362) once PIT tag detection efficiency corrections are made. As in previous years, steelhead were the most vulnerable salmonid species to predation by terns nesting on East Sand Island in 2007, with predation rates in excess of 13% for steelhead last interrogated passing Bonneville Dam (Table 4). Predation rates on wild up-river populations of steelhead (in-river migrants originating upstream of Bonneville Dam) in 2007 (ca. 14.1%) were similar than those observed in 2006 (ca. 13.3%; CBR 2007). Hatchery coho salmon smolts that migrated in-river were the next most vulnerable to predation (ca. 5.8% of PIT-tagged smolts), followed by in-river migrating fall Chinook salmon of unknown origin (ca. 3.2%; Table 4). Predation by East Sand Island terns on all salmonid species and run-types that were either interrogated at Bonneville Dam or released from barges below Bonneville averaged 2.2% in 2007. As was the case in previous years, there was evidence that predation rates differed between hatchery and wild smolts, with rates generally higher among hatchery fish (Table 4). Also similar to previous years, predation rates on transported fish, particularly steelhead, were lower than that of fish with in-river migration histories (Table 4). Comparisons of predation rates between in-river and transported groups of fish assume equal survival of each group from below Bonneville Dam to the estuary. This assumption has not been tested and is therefore an unknown, and perhaps important, unaccounted for factor in this comparison.

Per-capita consumption rates of PIT-tagged juvenile salmonids by East Sand Island terns (1.31 tags per breeding adult) was less by a factor of 4 to 8 compared to terns and cormorants that nested on the Columbia Plateau (7.24 – 11.31 tags per breeding adult; Table 5). This was also the case in 2006, when per-capita consumption of East Sand Island terns was 3 to 7 times less than for terns and cormorants nesting further upriver (CBR 2007). This suggests that salmonid smolts comprise a larger proportion of the diet for terns and cormorants nesting up-river relative to the same two species nesting on East Sand Island; a result supported by diet composition results presented for the two species (see Sections 1.3 and 2.3).

Crescent Island Caspian terns – We estimate that 0.67% (n = 8,074; adjusted for detection efficiency and deposition) of the in-river migrating PIT-tagged juvenile salmonids released upstream of McNary Dam (1,197,627 PIT-tagged fish) in 2007 were consumed by Crescent Island terns. Similar to data collected in 2004-2006, steelhead were by far the most vulnerable species to predation by Crescent Island terns, with ESU-specific predation rate estimates ranging between 0.5% – 1.7% (Table 6; see Table 7 for individual stocks and hatchery fish). Predation rates on other wild, ESA-listed species and stocks were comparatively low (ranging from <0.1% – 0.6%; Table 6; see Table 7 for individual stocks and hatchery fish). Within-species differences were noted, with predation rates highest on steelhead originating from the Snake and Columbia rivers (Table 7), although survival differences to McNary Pool were not considered in this analysis and likely contributed to these relative differences in vulnerability. Reach-specific analysis of PIT tag data also indicated that steelhead from the Snake River, middle Columbia River, and upper Columbia River ESUs were the most vulnerable to predation by Crescent Island terns in 2007, compared to other salmonid species and run-types in the Columbia Plateau (Table 8). Reach-specific predation rates indicated that Crescent Island terns consumed a minimum of 3.04%, 2.12%, and 1.01% of the wild, in-river steelhead smolts belonging to the Snake River, upper Columbia River, and middle Columbia River ESUs, respectively (Table 8). These predation rates increased to 4.79%, 3.34%, 1.59%, respectively, for each listed ESU, once adjusted for PIT tag deposition.

Predation rates on steelhead smolts from the Snake River (based on interrogation histories at Lower Monumental Dam; FPC 2007) differed with both the abundance of steelhead available in-river and passage timing. There was a negative, statistically significant association between predation rates and the Lower Monumental Fish Passage Index for steelhead ($p = 0.0079$, based on a simple regression), with predation rates by Crescent Island terns decreasing as the number of available fish increased. There was also evidence that predation rates changed throughout the season, with predation rates being higher during the later portion of the steelhead run for both hatchery and wild smolts (Figure 14). The number of steelhead available, however, is a covariate with passage timing, as fish numbers were also lowest during the later portion of the run (Figure 14). Although predation rates decreased as fish abundance increased, this should not be interpreted as a decrease in the number of smolts consumed. In fact, consumption estimates in 2004-2007 derived from bioenergetics modeling indicated that within a given season the Crescent Island tern colony consumes steelhead in proportion to their availability in-river, with peak consumption coinciding with the peak passage period (Figure 13). In other words, within a given year, evidence suggests that as more steelhead become available, more are consumed by terns nesting on Crescent Island (see Section 1.3.2). These data, particularly those involving passage indices, will be analyzed in greater detail once more precise smolt abundance numbers are made available through our collaborative work with NOAA Fisheries.

There were temporal trends in the relative vulnerability between hatchery and wild smolts to predation by terns nesting on Crescent Island. During the peak passage period of 13 May to 27 May 2007, hatchery smolts were significantly more vulnerable to tern predation relative to their wild counterparts (Figure 14). This trend, however, reversed as the run progressed, with predation on wild steelhead being significantly higher than on hatchery steelhead during the month of June (Figure 14). Overall (all weeks combined), however, there was no statistical difference in predation rates between hatchery and wild smolts, with average rates of 4.94% and 4.79% (adjusted for detection efficiency and deposition) for hatchery and wild smolts, respectively ($p = 0.9203$, based on z-statistic). The finding of no overall difference in relative vulnerability between hatchery and wild smolts in 2007 differs from results during 2004 – 2006, when hatchery smolts were consistently more vulnerable than wild smolts, both within and among study years (Figure 14). In total (all weeks and years combined), hatchery smolts were 1.4 times more likely to be consumed than wild smolts, a statistically significant difference ($p < 0.01$, based on z-statistic). Odds ratios were 1.3, 1.4, and 1.7 times more likely for hatchery smolts than wild smolts to be consumed in 2004, 2005, and 2006, respectively ($p < 0.01$ for each year, based on z-statistic).

Overall, predation rates by Crescent Island terns on PIT-tagged smolts were considerably lower in 2007 relative to 2004 – 2006 (Figure 15). For example, estimated reach-specific predation rates by terns in 2004 were 35.5%, 6.2%, and 6.5% for steelhead smolts (hatchery and wild combined) from the Snake River, upper Columbia River, and middle Columbia River, respectively (corrected for detection efficiency and deposition rate). Comparable rates from these three river segments in 2007 were just 4.9%, 3.1%, and 1.9%, respectively. Reduced predation rates in 2007 are likely a result of several factors. First, the size of the Crescent Island tern colony has been declining in every year since 2004 (ca. 33%, 25%, and 21% reduction in 2007 relative to 2004, 2005, and 2006, respectively). Second, evidence from research during the previous three years suggests that tern predation rates on steelhead smolts are lower in years of high river flows (Antolos et al. 2005; CBR 2005, 2006, 2007) and/or when large numbers of steelhead migrate past Crescent Island in a relatively short period of time (CBR 2006). Passage index data on steelhead from the Snake River in 2007 indicates that the majority of the run passed during a few weeks, compared to the more protracted, bimodal run timing observed in 2004 (Figure 14). Finally, although predation rates were lower for most species/run-types in 2007, this does not mean that the overall impact on salmonid ESUs was proportionally lower. This is because the estimates of predation rate apply only to the in-river component of each species/run-type and does not include the component of the run that was transported around McNary Pool in barges and therefore unavailable to Crescent Island terns. Since 2004, the number of steelhead originating from the Snake River that have been left to migrate in-river has steadily increased. For example, in 2004 an estimated 3.6% of the Snake River steelhead run remained in-river. This proportion increased to 58.9% in 2007 (NOAA Fisheries, unpublished data). This change in relative availability of smolts in the Snake River helps explains why predation rates fluctuate so much from one year to the next. An examination of predation rates on Snake River steelhead that have been adjusted for the proportion of the ESU that was transported helps to illustrate this point (Figure 16).

Unlike juvenile salmonids from the Snake River, smolts originating from the mid- and upper Columbia are not collected above McNary Dam and transported around McNary

Pool, making these salmonid runs more susceptible to avian predators in McNary Pool relative to Snake River smolts, especially in years of high transportation for Snake River stocks. Not surprisingly, predation rates on steelhead from these two non-transported ESUs have remained relatively constant compared to predation rates on Snake River stocks; average predation rates ranged from 2% to 5% for mid- and upper Columbia River stocks, compared to from 5% to 35% for Snake River stocks (CBR 2005, 2006, 2007).

Rock Island Caspian terns – Of the PIT-tagged fish released into the Columbia River basin upstream of John Day Dam in 2007 (excluding transported fish), < 0.1% (n = 677 tags; adjusted for detection efficiency) were deposited on the Rock Island Caspian tern colony during the nesting season. Similar to the Crescent Island Caspian tern colony, steelhead were the most vulnerable salmonid species, with the majority of tags (57.3%) from steelhead, followed by yearling Chinook (23.9%). Assuming that the proportion of ingested PIT tags deposited off-colony was similar between the Crescent Island and Rock Island tern colonies, Rock Island terns consumed roughly 1/8th as many PIT-tagged smolts as Crescent Island terns in 2007 (1,067 compared to 8,074). In 2006, we estimated Rock Island terns consumed roughly 1/6th as many PIT-tagged smolts as did Crescent Island terns. The difference in smolt predation between the Rock Island and Crescent Island tern colonies is likely associated with the difference in the size of the two colonies (43 pairs on Rock Island compared to 355 pairs of Crescent Island) and that the Rock Island colony may have completely failed prior to fledging due to predation by either a great horned owl or peregrine falcon in 2007. Finally, Rock Island terns ranked 2nd among Columbia Basin bird colonies in estimated per capita consumption of PIT-tagged smolts in 2007 (after the Foundation Island cormorant colony; Table 5), suggesting that the small size of the Rock Island colony, rather than the prevalence of salmonids in the diet, that limits its impact on salmonid smolt survival.

Potholes Caspian terns – Salmonid PIT tags were detected at the Potholes Reservoir tern colony on Goose Island (~45 km east of the Columbia River; Map 2). A total of 1,179 smolt PIT tags from the 2007 migration year were recovered. This number increases to 2,219 tags when adjusted for detection efficiency (Table 5). High variability in detection efficiency results, however, was observed in 2007, with detection efficiency estimates ranging from 14.0% during the pre-season (before terns arrived) to 92.0% in the post-season (after the nesting season). Such high variability in detection efficiency compromises the accuracy of estimated numbers of PIT tags deposited on this colony in 2007. Of the readable tags recovered, the vast majority were from steelhead smolts (n = 920 or 78%) and from smolts released into the Columbia River upstream of Wanapum Dam (ca. 1,162 or 98.6% of all tags recovered). Of the 920 steelhead tags recovered, 857 or 93.2% were from hatchery smolts, although this is not surprising given that the vast majority of tagged steelhead from this region were of hatchery origin (ca. 90.1% of all tagged steelhead released upstream of Priest Rapid Dam). Of the remaining 256 PIT tags recovered, 133, 109, and 14 were from Chinook salmon, coho salmon, and sockeye salmon smolts, respectively.

Reach-specific predation rates are available from the relatively small number of run-of-the-river smolts captured, tagged/interrogated, and released at Rock Island Dam each spring. It should be noted, however, that in addition to the high variability in detection efficiencies at Goose Island this year, Rock Island PIT-tagged smolts were released into the dam's tailrace during daylight hours only; how representative these fish were of the run at large (which migrates past the dam at all hours) is unknown. Because terns only forage during daylight hours, release timing may be important if terns from the Potholes Reservoir colony forage disproportionately on PIT-tagged steelhead released just below the Rock Island Dam as compared to other locations at other times. Similar to terns elsewhere in the region, predation rates by Potholes Reservoir terns on steelhead smolts were far greater than on other salmonid species, with estimated predation rates (adjusted for detection efficiency) of 9.0% and 8.2% for hatchery and wild steelhead, respectively. Predation rates were dramatically less for Chinook (ca. 0.13%) and sockeye smolts (ca. 0.55%). Reach-specific data for coho were not available because coho were not tagged and released at Rock Island Dam in 2007. Coho were, however, released from several hatcheries just upstream of Rock Island Dam (Wenatchee River and tributaries), and predation rates on these groups of PIT-tagged coho averaged 0.79% (adjusted for detection efficiency). A temporal analysis of predation rates indicated that steelhead smolts passing Rock Island Dam were consumed throughout the peak 6-week passage period of 29 April to 7 June, with average weekly rates ranging from an estimated 1.4% in week 2 to 15.1% in week 4. There was no evidence that rates (all weeks combined) differed significantly between hatchery and wild steelhead ($p = 0.6391$, based on chi-square). Sample sizes of both hatchery and wild smolts in the same week were generally less than 100, precluding meaningful weekly comparisons throughout the run. Similar to temporal trends documented for Snake River steelhead, there was some evidence that predation rates increased as the run progressed, although this finding should be viewed cautiously given uncertainties regarding on-colony detection efficiency in 2007.

The high estimated predation rate by Potholes Reservoir terns on steelhead that were tagged and released at Rock Island Dam in 2007 is alarming, especially because these smolts belong to an ESU that is listed as endangered under the ESA. Uncertainties and concerns regarding the on-colony detection efficiency of smolt PIT tags, the small number of steelhead tagged and released from Rock Island Dam annually, and questions about how representative tagged fish from Rock Island Dam are relative to the overall run, all warrant additional research. To address these uncertainties and concerns, we have proposed to expand our smolt PIT tag research regarding the Potholes Caspian tern colony in 2008. We will increase our efforts to measure on-colony PIT tag detection efficiency by spreading more tags on a more frequent basis and by increasing our tag recover efforts at the colony following the breeding season. We have also proposed increased efforts to tag run-of-river steelhead at Rock Island Dam in 2008 by tagging an additional 3,000 – 4,000 steelhead smolts annually for the next two years. Steelhead PIT-tagged as part of this study will be released at different times (day and night) to investigate diurnal predation patterns.

Banks Lake Caspian terns –Salmonid PIT tags were also detected at a small colony of Caspian terns (31 pairs) located in Banks Lake, WA (~70 km southeast of the Columbia

River; Map 2). A total of 31 smolt PIT tags from the 2007 migration year were recovered on-colony following the 2007 nesting season. No measure of detection efficiency was available for this colony. Of the 31 tags, 29 (94%) were from hatchery steelhead and the remaining two from hatchery yearling Chinook. All of the 31 tags were from smolts released in the Columbia River upstream of Wanapum Dam. In addition to PIT tags, 235 Floy tags and 5 hydro-acoustic tags were recovered on the Banks Lake tern colony. Floy tags were from hatchery rainbow trout released into Banks Lake and nearby streams by researchers from Eastern Washington University (Candace Hultberg, pers. comm.). An estimate of per capita consumption of PIT-tagged smolts by Banks Lake terns was 0.50, suggesting that Caspian terns nesting on Banks Lake had little impact on survival of salmonid smolts from the Columbia Basin relative to other tern colonies in the region (Table 5). This is likely a result of the distance of this colony to the Columbia River (~70 km) and the apparent abundance of forage fish within Banks Lake and the surrounding area.

1.5. Dispersal and Survival

Methods: In 2007, adult Caspian terns were banded at East Sand Island in the Columbia River estuary and fledgling Caspian terns were banded at three breeding colonies in the Columbia Basin (i.e., East Sand Island, Crescent Island, and Goose Island [Potholes Reservoir]). These banding efforts are part of our continuing objective to measure survival rates, post-breeding dispersal, and movements among colonies of 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 = 448), Crescent Island (n = 213), and Goose Island (n = 138) 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 = 57) 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 – 2006) were re-sighted on various breeding colonies by researchers throughout the 2007 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 2007, 300 previously-banded Caspian terns were re-sighted at the East Sand Island colony and 126 banded terns were re-sighted at the Crescent Island colony. All 426 resightings of 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 300 banded individuals that were re-sighted at East Sand Island, 269 (90%) were banded in the Columbia River estuary (90 as adults and 179 as chicks), 13 (4%) were banded at the former ASARCO colony in Commencement Bay, WA (12 as adults and 1 as a chick; Map 2), 14 (5%) were banded at Crescent Island (5 as adults and 9 as chicks), 1 (0.3%) was banded at Solstice Island in Potholes Reservoir (as a chick), and 3 (1%) were banded at Brooks Island in San Francisco Bay, CA (all as chicks). Of the 126 banded terns that were re-sighted at the Crescent Island colony, 124 (98%) were banded at Crescent Island (112 as adults and 12 as chicks), and 2 (2%) were banded at East Sand Island (both as chicks).

In addition to these re-sightings, 11 banded Caspian terns that had been banded at either East Sand Island, Crescent Island, or ASARCO were re-sighted at the colony on Dungeness Spit, WA (Map 2). Of these, 2 were banded as adults and 9 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. The first breeding attempts by terns banded as chicks in 2001 and 2002 were confirmed at East Sand Island and Goose Island in 2006, and the first breeding attempt by a tern banded as a chick in 2003 was confirmed at East Sand Island in 2007. A tern banded as a chick in 2002 at Crescent Island was also confirmed breeding at its natal colony in 2007, the first confirmation of breeding by a tern that was banded as a chick at Crescent Island. Our observations suggest that for this population the average age of first reproduction may be 5 years of age. This delay in onset of breeding, compared to what has been 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, (2) higher than expected adult mortality during the non-breeding season, and (3) terns fledged from the East Sand Island colony are recruiting to colonies other than their natal colony.

Analysis of the band re-sighting data is on-going and will allow us to estimate adult survival, juvenile survival, average age at first reproduction, colony site fidelity, and other factors important in determining the status of the Pacific Coast population of Caspian terns, and whether current nesting success is likely to result in an increasing, stable, or declining population. Moreover, by tracking movements of breeding adult terns 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 2001-2007 (Figure 17). 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 18). Furthermore, efforts to dissuade prospecting terns at other dredged material disposal sites (e.g., Miller Sands Spit, Pillar Rock Sands) have prevented the formation of incipient tern colonies in the upper estuary, where tern predation rates on smolts are known to be high. The number of Caspian terns nesting in the Columbia River estuary has remained nearly constant since 1998 (Figure 17).

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 19), 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 to 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 during 2005-2006 (Figure 20). 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 these two colonies in the Columbia River estuary, separated by only 26 km (Table 2, Figure 19), suggests that Caspian terns foraged primarily in proximity to their nesting colonies, instead of commuting longer distances to favored or traditional foraging sites. The success of Caspian 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 (11.4 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 more than 50% in each of the last seven years (range = 51% – 66% less; Figure 21). Per capita smolt consumption has also declined since the study began in 1997 (Figure 22); in 2007 per capita smolt consumption (278 smolts [nesting tern]$^{-1}$ [breeding season]$^{-1}$) was 59% less than in 1999 (679 smolts [nesting tern]$^{-1}$ [breeding season]$^{-1}$), the highest consumption rate recorded so far in the Columbia River estuary. These declines in smolt losses to Caspian tern predation in the estuary 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 2007 consumed an estimated 5.5 million juvenile salmonids (95% c.i. = 4.8 – 6.2 million smolts), or about 5% of juvenile salmonids that survive to the estuary on average. Some ESA-listed stocks continue to suffering significant losses to tern predation in the estuary (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 relocating the Caspian tern colony from Rice Island to East Sand Island is on average 6.5 million smolts per year over the last 7 years, or ca. 46 million fewer smolts consumed by terns following the colony relocation. 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 23). 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 breeding colony from Rice Island to East Sand Island enhanced the nesting success of Caspian terns breeding in the Columbia River estuary. Average nesting success of Caspian terns on East Sand Island during 1999–2007 (0.89 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 24). 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 0.72 nests/m^2 on East Sand Island (Figure 25), was not apparently related to nesting success at either colony.

The relatively high nesting success of Caspian terns on East Sand Island during 2001–2007 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 upwelling and associated high primary and secondary productivity along the coast of the Pacific Northwest, particularly during 2001-2003 (Emmett et al. 2006). Favorable ocean conditions have been linked to cold water regimes associated with the negative phase of the Pacific Decadal Oscillation (PDO), which is generally associated with greater availability of marine forage fishes near the mouth of the Columbia River. Other climatic events (e.g., El Nino/Southern Oscillation, timing of onset and strength of upwelling) also influence ocean conditions, however, and availability of marine forage fishes during this decade has not been consistently higher than in 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. In 2007, some measures of ocean conditions improved (early initiation of strong upwelling, etc.); however, our estimate of tern productivity did not reflect that. Cormorant productivity, however, was the highest we have seen at East Sand Island. Additionally, during July, after many young terns and cormorants had fledged, there was a two-week period when upwelling weakened substantially and conditions for foraging apparently worsened, negatively affecting the ability of adults to provision late hatching (not yet fledged) chicks and, potentially, on the foraging of already fledged young still residing in the estuary.

1.6.4. Future Management Actions

In 2008, the U.S. Army Corps of Engineers will begin implementing the Caspian tern management actions outlined in the Final EIS (FEIS) and Records of Decision (RODs) for Caspian tern management in the Columbia River estuary; a plan to redistribute a portion of the East Sand Island tern colony to alternative colony sites in interior Oregon and San Francisco Bay, California by 2015 (USFWS 2005, 2006). The management plan calls for the creation of up to 7 acres of new or enhanced tern nesting habitat in interior Oregon (i.e., Fern Ridge Lake, Crump Lake, and Summer Lake) and coastal California (i.e., the San Francisco Bay Area) and to actively attract Caspian terns to nest there. As alternative tern nesting habitat is created or enhanced, the available tern nesting habitat on East Sand Island will be reduced from its current size (6 acres) to 1.5 – 2 acres. Habitat enhancement at alternative sites and the reduction of habitat at East Sand Island will be accomplished in phases at a ratio of two new acres of habitat for each acre of habitat reduction on East Sand Island. Once fully implemented, the management plan is expected to reduce the East Sand Island Caspian tern colony from its current size (approximately 9,500 nesting pairs) to approximately 3,100 – 4,400 nesting pairs. This reduction in the East Sand Island tern colony is estimated to reduce tern consumption in the Columbia River estuary by 2.4 – 3.1 million smolts annually (USFWS 2005, 2006).

On 7 January 2008 the Corps initiated construction of a one-acre island specifically designed for Caspian tern nesting at Fern Ridge Lake near Eugene, Oregon. Island construction was completed on 12 February. Restoration of a one-acre tern nesting island in Crump Lake northeast of Lakeview, Oregon began in mid-February and is scheduled to be completed by 8 March 2008. The Corps will prepare 5 acres of nesting habitat for Caspian terns at East Sand Island in late March – early April 2008. As in previous years, the Corps will preclude Caspian terns from nesting on other dredged material disposal sites in the upper Columbia River estuary (e.g., Rice Island, Miller Sands Spit, and Pillar Rock Sands) in 2008 and beyond.

During late summer of 2008, the Corps plans to initiate construction of one or two half-acre islands in the Oregon Department of Fish and Wildlife's Summer Lake Wildlife Area, located northwest of Paisley, Oregon. Additionally, the San Francisco District of the U.S. Army Corps of Engineers will initiate efforts to develop alternative habitat sites in the San Francisco Bay area during winter of 2008-09. Upon the completion of habitat enhancements at alternative colony sites in interior Oregon and San Francisco Bay, tern nesting habitat at East Sand Island will be reduced as described above beginning in 2009.

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 2007, 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 Geospatial Services at the Bonneville Power Administration. In addition, researchers from Oregon State University proofed the counts of stick nests in the photography to confirm the estimate of numbers of breeding pairs in 2007. Counts from aerial photography also provided an assessment of habitat use and distribution of nesting cormorants on East Sand Island in 2007.

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 2007. 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 jumping 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 2007. 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 2007, 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. Growth in the breeding population since 1989 has resulted in the East Sand Island colony becoming the largest known colony of double-crested cormorants in North America (Anderson et al. 2004; L. Wires, University of Minnesota, pers. comm.). We estimate that 13,770 breeding pairs (95% c.i. = 12,945 – 14,597 breeding pairs) attempted to nest at East Sand Island in 2007, very similar to our estimate of colony size in 2006 (13,738 breeding pairs, 95% c.i. = 12,914 – 14,562 breeding pairs). The East Sand Island cormorant colony was nearly three times larger in 2007 than when we first estimated the size of this colony in 1997 (Figure 26). 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 2003-2004, increases in the size of the East Sand Island cormorant colony were associated with increases in colony area (Figure 27), as opposed to increases in nest density (Figure 28). In 2005-2007, double-crested cormorants nesting on East Sand Island used less total area for nesting (Figure 27) and nested at higher densities (Figure 28) compared to previous years. The smaller area encompassed by the cormorant colony and the higher nesting density in 2005-2007 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 2007). 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 2007, a total of 155 pairs of double-crested cormorants nested on eight channel markers located in the upper estuary near Miller Sands Spit. The previous year, 152 cormorant pairs nested on the same channel markers. Peak nest counts on individual markers were recorded during 5 May - 22 June in 2007. 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 2007, 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 7 May and 13 June, 8 and 11 nests were attended by double-crested cormorants, respectively. A total of 18 chicks were observed in 7 out of 8 nests attended by double-crested cormorants during a boat-based survey on 8 July. In 2006, 7 nests with attending double-crested cormorants were confirmed during boat surveys in June.

In 2007, double-crested cormorants were successfully attracted to an experimental social attraction plot created on the downstream end of Miller Sands Spit in the upper estuary. Habitat enhancement and social attraction techniques (preparation of nest substrate; installation of cormorant decoys and audio playback systems) were employed. A total of 90 breeding pairs of double-crested cormorants nested on the Miller Sands Spit experimental plot site. Chicks were successfully fledged from the experimental plot (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 2007 (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 each week from the observation blind in 2007.

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 2007, the double-crested cormorant colony on Foundation Island consisted of a minimum of 334 pairs, the largest cormorant colony on the mid-Columbia River. The estimated size of the colony was ca. 7% smaller than our estimate in 2006 (359 pairs); this colony has more than tripled in size since 1998 (when the colony was first censused as part of this study; Figure 29). As was the case in previous years, all cormorant nests at this colony were in trees at the south end of the island.

In 2007, the largest cormorant colony in the entire Columbia Plateau Region was on Potholes Reservoir in the North Potholes Reserve (ca. 1,000 breeding pairs), a ca. 9% decrease in colony size compared to 2006 (ca. 1,100 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 scarcity of salmonid PIT tags near the colony.

Based on our counts of cormorant nests at the Okanogan colony, we estimate that there was a minimum of 10 nesting pairs at that colony in 2007, down from the previous year (32 nesting pairs).

Aerial surveys of the lower and mid-Columbia River and lower Snake River revealed one new double-crested cormorant colony in 2007; in a tree on the east bank of the Columbia River in the Wahluke Unit of the Hanford Reach National Monument. On 01 May, eight attended nests were observed; however, during the aerial survey on 01 June there were no attended nests and only two adult cormorants were observed in the nest tree. The two new cormorant colonies discovered in 2006 (Miller Rocks and the Lyons Ferry railroad trestle) were not active in 2007. There still appears to be a fairly sizable 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 and lower Snake River dams.

2.1.3. Coastal Washington

Methods: In 2007, we counted cormorant nests on channel markers in Grays Harbor, WA during three aerial survey flights between early June and early July. No boat-based surveys of cormorant nesting success were conducted in Grays Harbor during 2007.

Results and Discussion: During aerial surveys in Grays Harbor, we counted a total of 158 nests on 11 different channel markers. 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 2007.

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 2007 (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*), an endangered subspecies. In 2007, 333 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 at 28 days post-hatching. Cormorant chicks older than 28 days are capable of leaving their nests.

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

Results and Discussion: The first cormorant eggs on East Sand Island were observed on 26 April 2007, 3 days later than in 2006. The first cormorant hatchlings were observed on the colony on 26 May in 2007, 4 days later than in 2006.

We estimate that 38,283 fledglings (95% c.i. = 35,395 – 41,171 fledglings) were produced at the East Sand Island colony in 2007. This corresponds to an average productivity of 2.78 young raised per breeding pair (95% c.i. = 2.66 - 2.90 fledglings/breeding pair), which was the highest estimate of productivity for the East Sand Island cormorant colony since monitoring of the colony began in 1997 (Figure 30). Productivity at the East Sand Island cormorant colony in 2007 exceeded 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 post-hatch) were observed on markers by the end of May in 2007, approximately the same as or earlier than the nesting chronology of cormorants on East Sand Island. Nests on the Astoria-Megler Bridge were likely initiated later than nests on East Sand Island or the upper estuary channel markers; no chicks were observed during our boat survey on 13 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 2007, we monitored 50 cormorant 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 the distance of the blind from the colony and our vantage below the elevation of the nests, we assumed that chicks were approximately 10 days old when first observed.

Results and Discussion: In 2007, nest initiation was earlier at the Foundation Island cormorant colony compared to the cormorant colonies in the Columbia River estuary. The first chick was observed at the Foundation Island colony on 23 April, more than a month before the first cormorant chick was observed on East Sand Island. Productivity on Foundation Island (2.23 ± 0.16 fledglings/nest) was higher than in 2006 (1.37 ± 0.17 fledglings/nest) but similar to 2005 (2.30 ± 0.13 fledglings/nest). In successful nests, brood size on Foundation Island at 36 days post-hatch (2.69 ± 0.14 chicks/nest) was the highest we have seen (2006: 1.90 ± 0.14; 2005: 2.28 ± 0.11). During 2005-2007, cormorant productivity at Foundation Island and East Sand Island have varied over a similar range (1.37 – 2.30 and 1.38 – 2.78 fledglings/pair, respectively), although annual variations have not tracked one another.

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 for collections was 5-20 adult fore-gut (stomach and esophagus) samples per week. Immediately after collection, the abdominal cavity was opened, the fore-gut removed, and the contents of the fore-gut emptied into a whirl-pak. Each fore-gut sample was weighed, labeled, and stored frozen for later sorting and analysis in the laboratory.

Laboratory analysis of semi-digested diet samples was conducted at Oregon State University. Samples were partially thawed, removed from whirl-paks, re-weighed, and separated into identifiable and unidentifiable fish soft tissues. Fish in fore-gut samples were identified to genus and species, whenever possible. Intact salmonids in fore-gut samples were identified as Chinook salmon, sockeye salmon, coho salmon, steelhead, or unknown based on otolith[1] and/or genetic[2] 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, and pharyngeal arches) were removed from the sample and identified to species using a dissecting microscope (Hansel et al. 1988). Unidentified fish soft tissue samples that did not contain diagnostic bones and samples comprised of bones only (i.e., no soft tissue) were 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.

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

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

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

Results and Discussion: Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 9% of double-crested cormorant diets (by mass) at East Sand Island in 2007 (n = 137 adult fore-gut samples or a total of 21,834 grams of identifiable fish tissue; Figure 31), a lower percentage compared to 2006 (11%; Table 9). As in previous years, anchovy were the most abundant forage fish type found in fore-gut contents, representing 38% of prey biomass in 2007 (Table 9). The proportion of the diet that was salmonids peaked at ca. 31% during the first half of May (Figure 32).

Estimates of smolt consumption by double-crested cormorants nesting on East Sand Island during 2004-2006 have demonstrated substantial interannual variation (Figure 33). In 2004, we estimated that the cormorant colony consumed 6.4 million smolts (95% c.i. = 2.4 – 10.3 million). In 2005, a year of poor ocean conditions, poor nesting success, and low adult attendance at the colony, salmonid consumption dropped to an estimated 2.9 million smolts (95% c.i. = 0.9 – 4.9 million). In 2006, the size of the cormorant colony increased and colony attendance and productivity were good. The estimated smolt consumption by the cormorant colony in 2006 was 10.3 million juvenile salmonids (95% c.i. = 4.7 – 15.9 million). Analyses of 2007 data are ongoing.

Seventy-two individual salmonids, from the stomachs of 18 cormorants collected at East Sand Island during 2006, were identified to species and, for Chinook salmon, stock of origin. Steelhead were the most frequent salmonid in the cormorant stomach samples (43% of identified salmonids), followed by Chinook salmon and coho salmon (26% each). Two cutthroat trout (3%) and one sockeye salmon (1%) were also identified. While cormorants had previously been documented as predators on cutthroat trout using PIT tags recovered at the East Sand Island colony, this was the first documentation from the stomach contents of collected birds. Chinook salmon stocks that were identified as cormorant prey included Mid and Upper Columbia River spring Chinook, Upper Columbia River summer/fall Chinook, Snake River spring Chinook, Snake River fall Chinook, Spring Creek Group fall Chinook, West Cascade Tributaries spring Chinook, and West Cascade Tributaries fall Chinook. Ongoing collaboration with David Kuligowski, NOAA Fisheries, will allow us to more precisely break down the salmonid portion of the cormorant diet, both at East Sand Island (by processing samples from additional years and including samples with genetic materials extracted from bone) and at other cormorant colonies on the Columbia River (i.e., the Foundation Island colony on the Mid-Columbia River). These more precise breakdowns of the taxonomic composition of the salmonid portion of the diet will enhance our ability to estimate the numbers of salmonids consumed by species and type using the bioenergetics modeling approach.

2.3.2. Columbia Plateau

Methods: During the 11-week period (late April to early July) when nestlings were being fed by their parents at the Foundation Island cormorant colony, we collected diet samples from the ground below active nests, samples that were spontaneously regurgitated by nesting adults and their young. A total of 61 regurgitations were collected from the ground during this period. Additionally, a total of 45 adult cormorants were lethally sampled on five different occasions (n = 8 on 19 April, n = 9 on 2 May, n = 10 on 16 May, n = 8 on 30 May, and n = 10 on 15 June) and contents of their fore-gut and other tissues were sampled. All diet samples were analyzed in our laboratory at Oregon State University to investigate the diet composition of cormorants nesting on Foundation Island in 2007.

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

In 2007, using diet composition data from lethally-sampled adult cormorants, we were able to estimate salmonid consumption for the Foundation Island cormorant colony using a bioenergetics modeling approach (after the Caspian tern model described in Roby et al. 2003). At present, data to breakdown salmonid consumption into individual species and numbers of smolts consumed are not available, so we estimated consumption in units of salmonid biomass consumed and compared to salmonid biomass consumed by the Crescent Island Caspian tern colony.

Results and Discussion: In 2007, the regurgitation samples collected from late April through early July indicated that centrarchids (bass and sunfish), cyprinids (minnows) and salmonids (salmon and trout) were the most prevalent prey types in the diet of Foundation Island cormorants during chick-rearing (Table 10). Salmonids made up 16.0% of identifiable prey biomass in the fore-gut contents of the 45 collected adults (Table 11). 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 their primary food source during the nesting season.

Bioenergetics modeling suggested that cormorants nesting at Foundation Island consumed 10.9 Mg (million grams) of salmonids (95% CI: 7.6 – 14.3 Mg) in 2007. This was similar to that consumed by Crescent Island terns (point estimate: 12.0 Mg; 95% CI: 8.5 – 15.6 Mg). Despite salmonids making up a much smaller portion of the diet of Foundation Island cormorants (16%) compared with Crescent Island terns (69%), the larger body size and brood size of cormorants, and the consequent greater food requirements per breeding adult, caused smolt consumption by the cormorant colony to approach that of the tern colony (95% CI: 250,000 – 460,000 smolts).

2.4. Salmonid Predation Rates

2.4.1. Columbia River Estuary

Methods: The recovery/detection of smolt PIT tags on cormorant colonies is more difficult than on Caspian tern colonies. Unlike Caspian terns, which nest primarily on bare sand, cormorants nest in a wide array of habitat types, such as in trees, on the ground amongst vegetation and woody debris, on rip-rap, on bridges and channel markers. This poses significant challenges for the on-colony recovery or detection of PIT tags egested by nesting cormorants. Previous measures of detection efficiency at the East Sand Island cormorant colony have been less than 40% (B. Ryan, NOAA Fisheries, unpublished data). To improve the efficiency of PIT tag recovery at the East Sand Island cormorant colony, 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, the detection efficiency of smolt PIT tags within the plots would be considerably greater than the colony as a whole. 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 2007 breeding 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. Each plot contained 36 old truck and car tires containing cormorant stick nests from the 2006 nesting season or fine woody debris, 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 the plots to further encourage nesting. In addition to the plots on East Sand Island, a plot that consisted of 36 old tires, decoys, and audio playback systems was also set up at the downstream end of Miller Sands Spit (Rkm 37; Map 1) 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 plot were recorded throughout the nesting seasoning (April to September). Detection efficiency for PIT tags on the plots (a parameter needed to adjust/correct PIT tag recovery results) was measured by sowing test PIT tags (n = 400 for the plots and 200 for the trenches) at two different times: before nest building (5 April) and immediately following fledging (6 September), with equal numbers of tags sown during each time period. In addition to sowing test tags on the plots, test tags were also sown (n = 200) on the cormorant colony to test our hypothesis that detection efficiency is higher on the plots relative to the colony at large. Test tags were sown on two different habitat types used by nesting cormorants on East Sand Island; rip-rap and bare sand. Tags were sown in 15 x 5 m zones within the two different habitat types. Similar to tags sown on the plots, test tags spread on the colony were sown at two different times; before nest building (5 April) and immediately following fledging (6 September). Finally, PIT tags (n = 200) were sown on the Miller Sands Spit social attraction plot at two different times: before nest building (4 April) and immediately following fledging (5 September).

PIT tags were recovered following the nesting season by NOAA Fisheries using hand-held electronic scanners. Estimates of predation rates were adjusted for detection efficiency, but not deposition rate, and therefore are minimum estimates (see Section 1.4.2. for further details on these corrections).

Results and Discussion: The detection efficiency of sown test PIT tags on the cormorant nesting plots averaged 80.2% (± 8.4; Table 3). Detection efficiency was 40.3% (± 7.7) and 73.0% (± 2.2) from rip-rap and bare sand habit types, respectively; this confirmed our supposition that tag recovery from specially-designed nesting plots is greater than from the habitat types where cormorants typically nest on East Sand Island. Detection efficiency on the plots was statistically greater than on the rip-rap habitat ($p < 0.001$ for both pre-season and post-season releases, based on a chi-square test). No difference, however, in detection efficiency was noted between the plots and bare sand areas where cormorants nested within the East Sand Island cormorant colony ($p > 0.18$ for both the pre-season and post-season releases, based on a chi-square test).

A total of 4,482 salmonid PIT tags from 2007 migration year smolts were recovered from the double-crested cormorant colony on East Sand Island by NOAA Fisheries in 2007. Of these tags, 71.5% were from Chinook salmon (including sub-yearlings and yearlings), 25.2% from steelhead, 2.5% from coho salmon, and 0.8% from sockeye salmon. As in previous years, the relative proportions of PIT tags from different salmonid species recovered on the East Sand Island cormorant colony was very similar to the proportions of different salmonids PIT-tagged and released throughout the basin in 2007 (ca. 70.8% Chinook, 21.3% steelhead, 5.2% coho, and 2.7% sockeye), suggesting that cormorants consume salmonids in similar proportions to their relative abundance. Due to uncertainties regarding the relative survival of various species and groups of PIT-tagged smolts from their release location to the estuary, the relative proportions of PIT-tagged smolts at release are only rough approximations of relative abundance in the estuary. Nonetheless, the data suggest that cormorants are less selective and more generalist predators compared to Caspian terns, which consume steelhead smolts in much greater proportion to their relative abundance.

Per capita PIT tag consumption by East Sand Island cormorants was estimated to be 0.59 tags per breeding adult, based on the total number of PIT tags recovered from the plots (n = 272; corrected for detection efficiency) and the number of breeding birds in the plots (n = 464). Based on this estimate of the per capita PIT tag consumption by East Sand Island cormorants and our overall estimate of colony size (27,542 breeding adults), we estimate that cormorants deposited ca. 16,250 tags on the colony during the 2007 breeding season. This suggests that colony-wide detection efficiency was just 27.6% (4,482/16,250) in 2007. Per capita consumption of PIT-tagged juvenile salmonids was greater for cormorants nesting in the upper estuary (Miller Sands Spit) compared to cormorants nesting on East Sand Island (Table 5). On Miller Sand Spit, 106 breeding adult cormorants were counted on the experimental plot and 362 salmonid PIT tags were recovered after the nesting season. Detection efficiency was estimated at 58.0% (Table 3). Consequently, per capita PIT tag consumption for cormorants nesting on Miller Sands Spit was ca. 5.0 tags per breeding adult. These results corroborate our earlier finding that cormorants nesting in the upper estuary are more reliant on juvenile salmonids as a food source compared to cormorants nesting on East Sand Island (Collis et al. 2002a; CBR 2007).

Estimates of predation rates based on PIT-tagged smolts released from barges below Bonneville Dam or detected passing Bonneville Dam indicated that sub-yearling Chinook salmon smolts were the most vulnerable to predation from East Sand Island cormorants, following by steelhead (Table 4). Results for coho and sockeye salmon, particularly wild smolts, were unreliable and/or not available due to small sample sizes. Most of the coho smolts in the region originated below Bonneville Dam and were generally not PIT-tagged. Predation rates on steelhead smolts was similar to those for yearling Chinook smolts, with the exception of predation on wild steelhead last detected in-river passing Bonneville Dam (ca. 4.63%; Table 4). Finally, estimated predation rates for cormorants nesting on East Sand Island in 2007 should be viewed with caution because of the low overall detection efficiency of PIT tags on the colony (ca. 27.8%, based on per capita consumption and colony counts). Relative comparisons of vulnerability between difference salmonid species, run-types, and rear-types, however, are less prone to error given evidence that PIT tag detection efficiency is not positively or negatively associated with time since the tag was deposited on East Sand Island (CBR 2005; CBR 2006).

2.4.2. Columbia Plateau

Methods: In 2007, 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 were similar to those described for Crescent Island terns (see Section 1.4.2). 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: (1) prior to arrival of birds on the colony (14 March), (2) early in the chick-rearing period (2 May), (3) during fledging (7 June), and (4) after the birds had left the colony following nesting (25 July). Predation rates were corrected for detection efficiency (but not deposition rate); consequently, these estimated predation rates are minimums. Furthermore, an unknown proportion of smolt PIT tags are likely retained within the arboreal nests (primarily from small chicks being unable to regurgitate castings outside the nest), a phenomenon that further reduces tag recovery and thus underestimates predation rates.

To address the concern that tag recovery is reduced by tags being retained in arboreal nests, we initiated a pilot study whereby an artificial nesting platform was constructed on Foundation Island to improve our ability to recover PIT tags at this colony, similar to the plot approach used on East Sand Island (see Section 2.4.1). Prior to the 2007 nesting season, we constructed an elevated platform, measuring 6 m x 6 m x 3 m, at the north end of the Foundation Island cormorant colony. The platform, which was covered with sand, contained 30 old tires filled with fine woody debris, and was surrounded by a 10-cm high side wall to prevent tags from blowing or washing off the platform during the nesting season. Cormorant decoys and two audio playback systems broadcasting sounds of a cormorant colony were used to attempt to attract nesting pairs to the platform. As was done underneath the nesting trees on Foundation Island, PIT tags were spread on the platform to measure detection efficiency.

PIT tags (n = 50) were also sown at the double-crested cormorant colony in North Potholes Reservoir to measure detection efficiency at this, the largest known breeding colony of cormorants in the Columbia basin (see Section 2.1.2). Tags were sown only once on 2 June, during the chick-rearing period. Because the ground underneath this arboreal colony was flooded during the nesting season, tags were sown from a canoe directly into the water underneath trees containing active nests. The nesting area under which test tags were sown containing an estimated 167 nests (a sub-sample of the estimated 1,015 breeding pairs present in 2007), based on counts of nests made after the breeding season. Following the nesting season, PIT tags were recovered using hand-held electronic scanners and transceivers.

Results and Discussion: Of the 400 test PIT tags sown on Foundation Island in 2007, 271 or 67.8% were subsequently recovered on-colony after the nesting season (Table 3). Detection efficiency ranged from as low as 51.0% for tags sown during the chick-rearing period to 74.0% for tags sown before the nesting season. There was no evidence of a correlation between the date test tags were sown and detection efficiency ($R^2 = 0.0645$, $P = 0.8991$), 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.

No cormorants were attracted to nest on the artificial platform on Foundation Island in 2007. It is unclear why the platform was unsuccessful, but we speculate that the height and location of the platform relative to other nesting cormorants were key factors. Active nests surrounding the platform were nearly twice as high as those on the platform, with some nests up to 20 meters above the ground. Furthermore, similar experiments in the Columbia River estuary (see Section 2.5.1) have shown that cormorants may take several years before colonizing a new site where habitat enhancement and social attraction have been used. Based on these results, we will repeat the experiment on Foundation Island in 2008. We plan to raise the platform an additional 1.8 meters (total height of 4.8 meters) and move it closer to the core nesting area on Foundation Island to make the platform more attractive to nesting birds.

A total of 5,123 PIT tags from 2007 migration year smolts were recovered on the Foundation Island cormorant colony following the nesting season. These tags represent 0.43% of the in-river PIT-tagged smolts released upstream of McNary Dam. This proportion increased to 0.63% (n = 7,554) once a correction was made for PIT tag detection efficiency. Foundation Island cormorants consumed an estimated 1.29% of all the PIT-tagged smolts interrogated passing Lower Monumental Dam from 1 April to 31 July 2007. Like Crescent Island Caspian terns, predation rates were higher for Snake

River steelhead (ca. 2.4 and 2.3% for hatchery and wild smolts, respectively; Table 8) than for other species and run-types originating from the Snake River. Similar to results from 2004 – 2006, Foundation Island cormorants also consumed relatively large proportions of Chinook salmon (ca. 3.6%) and steelhead smolts (ca. 8.3%) tagged and released into the Walla Walla River (middle Columbia River ESU). Predation rates on all other salmonid species and run-types were negligible (Tables 6 and 7).

For the first time since this research was initiated in 2004, PIT tag recoveries (Table 5), and in some cases reach and stock-specific salmonid predation rates (see Tables 6, 7, and 8), were higher for the Foundation Island cormorant colony than for the Crescent Island tern colony. In fact, of all the piscivorous waterbird colonies studied on the Columbia River in 2007, the Foundation Island cormorant colony had the highest per capita consumption rate of PIT-tagged juvenile salmonids (ca. 11.3 PIT-tagged smolts per adult; Table 5). In 2006, Foundation Island cormorants had the third highest per capita PIT tag consumption rate (ca. 7.2 PIT-tagged fish per adult), behind Crescent Island terns (ca. 15.1 PIT-tagged fish per adult) and Rock Island terns (ca. 9.7 PIT-tagged fish per adult; CBR 2007). The increase in salmonid predation rates by Foundation Island cormorants relative to Crescent Island terns is likely associated with the decline in the size of the Crescent Island tern colony (Figure 3); in 2007 the two colonies were roughly equal in size (ca. 350 breeding pairs) while in 2006 the Crescent Island tern colony (ca. 450 pairs) was ca. 20% larger than the Foundation Island cormorant colony (ca. 350 pairs). It is also possible that cormorants are becoming more reliant on salmonids as a food source, but we currently have insufficient data on diet composition to adequately evaluate this. More research is necessary to carefully evaluate the cause(s) of this possible emergent trend.

At the cormorant colony on Potholes Reservoir (see Map 2) only 6 smolt PIT tags (corrected for detection efficiency; Table 5) were found underneath the trees where we estimated 167 pairs of double-crested cormorants nested. If tags deposited by these 167 pairs are representative of all breeding adults at the colony, just 36 PIT-tagged salmonid smolts were consumed by the cormorants at this colony in 2007, suggesting that Potholes Reservoir cormorants had very little impact on anadromous salmonids from the Columbia or Snake rivers during the breeding season. Estimated per capita consumption of PIT-tagged smolts by cormorants nesting in Potholes Reservoir was just 0.02 (Table 5), the lowest of any piscivorous waterbird colony monitored as part of this study in 2007. In comparison, Caspian terns nesting on Goose Island in Potholes Reservoir had an estimated per capita consumption rate of 3.93 PIT tags (Table 5). Interestingly, half of the PIT tags recovered beneath the cormorant colony were from smolts released into the Columbia River downstream of the confluence with the Snake River, a distance of more than 100 km from Potholes Reservoir. It is unlikely that these smolts were consumed during a daily foraging trip by actively-nesting cormorants at the North Pothole colony, but instead were presumably consumed by either non-breeders or breeding birds that were commuting to the colony from wintering areas.

2.5. Management Feasibility Studies

2.5.1. Techniques to Encourage Nesting

Methods: In 2007, we continued studies to test the feasibility of potential management techniques for reducing losses of juvenile salmonids to cormorant predation in the Columbia River estuary. These studies sought to determine whether habitat enhancement 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, if deemed necessary by the resource management agencies. In 2007, we employed habitat enhancement (i.e., placement of old tires filled with nesting material) and social attraction techniques (i.e., decoys and audio playback systems; Kress 2000, Kress 2002, Roby et al. 2002) on two different islands in the Columbia River estuary (East Sand Island and Miller Sands Spit; see Map 1) and on a floating platform in Fern Ridge Reservoir, near Eugene, OR (see Map 2). An experimental plot that was set up on Rice Island (see Map 1) in 2006 was not re-created in 2007 to evaluate whether cormorants that were attracted to nest there in 2006 would attempt to nest there again in 2007, despite the absence of habitat enhancement and social attraction at the site.

East Sand Island: In 2007, six experimental plots were re-created on East Sand Island within the active cormorant breeding colony to evaluate the relative efficacy of three different types of artificial plots (i.e., treatments; Map 4). Four plots were set up by re-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 the platforms. Three types of treatments were prepared: (1) tires only on the ground; (2) tires only on elevated platforms, and (3) decoys, audio playbacks, and tires on elevated platforms. Two plots were assigned to each treatment type. Thirty-six truck and car tires were placed in each experimental plot. Each tire was filled with old cormorant nest material. A total of 12 cormorant decoys and two speakers broadcasting audio playbacks of the cormorant colony were placed in each of the plots assigned to treatment 3. All 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.

Miller Sands Spit: In 2007, habitat enhancement and social attraction techniques were once again tested on Miller Sands Spit, a dredged material disposal site in the upper Columbia River estuary (river km 34; Map 1). We first set up an experimental attraction plot on Miller Sands Spit in 2004 at the western tip of the island, near the area where a few 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 2004. 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 in 2005; a total of 21 partially or completely built nests were counted in the plot, and a total of six eggs were laid in four different nests. All of these nests subsequently failed prior to hatching, presumably due to gull depredation. In 2006, we again created a similar experimental plot on Miller Sands Spit; cormorants were once again attracted to the site and chicks were successfully fledged. We repeated the experiment once again in 2007 to investigate whether these techniques could be used to attracted cormorants to nest successfully (i.e., nesting attempts resulting in fledged young) in consecutive years. Similar to previous years, 40 decoys, 36 truck and car tires filled with nesting material, and four speakers broadcasting audio recordings of a cormorant colony were placed in the experimental plot in 2007. 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.

Rice Island: In 2007, we did not re-build an experimental attraction plot on Rice Island (river km 26, see Map 1) to assess whether cormorants would come back to the same location where they had nested successfully the previous year without the use of habitat enhancement and social attraction. 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.

Fern Ridge Reservoir: We attempted to employ habitat enhancement and social attraction techniques to induce double-crested cormorants to nest at a site where cormorant nesting had not been previously recorded. We selected Fern Ridge Wildlife Area near Eugene, Oregon because it supported significant numbers of cormorants during the non-breeding season and we were able to obtain permission to launch a floating platform in one of the impoundments in the Fisher Butte Unit, where access by the public is restricted. A floating platform, about 30 feet long by 15 feet wide, was constructed from sections of floating dock material. Plywood sideboards about 1 foot high were attached to the sides of the floating platform to retain material on the platform. Forty-eight old tires were placed on the platform, and sticks and other fine woody debris were placed in each tire for nesting material. Forty hand-painted double-crested cormorant decoys were then secured on the platform. Finally, two audio playback systems, each with two speakers were placed on the platform, along with the solar panels and deep cycle batteries necessary to power the playback systems. The floating platform was then poled out into Fisher Butte cell #2 and anchored in about four feet of water, about 500 feet from the nearest dike, on 30 March 2007. The platform was checked from the dike 2-3 times each week from 9 April until 1 June for signs of cormorant nesting and to verify that the audio playback system was functioning.

Results and Discussion: Habitat improvements and social attraction (i.e., decoys, audio playback systems) have been shown to be highly effective in inducing Caspian terns to nest at sites where they have not nested previously (Kress 2000, Kress and Hall 2002, Roby et al. 2002, Collis et al. 2002b). These techniques were used to relocate Caspian terns nesting on Rice Island to East Sand Island over a three-year period. Pilot studies designed to test the feasibility of employing habitat enhancement and social attraction to relocate nesting cormorants have shown some promise; cormorants were attracted to nest and nested successfully (raised young to fledging) on Miller Sands Spit and Rice Island, two islands in the upper estuary where no successful cormorant nesting attempts have been recorded recently (CBR 2007). Presented here are further investigations into the efficacy of habitat enhancement and social attraction techniques in inducing cormorants to nest at both newly established sites within the Columbia River estuary and at new sites far removed from the estuary and outside the Columbia River Basin.

East Sand Island: On East Sand Island, cormorants were observed in all the experimental plots 7 days after completing the preparation of the plots. Nest initiation in the plots was synchronous with the rest of the East Sand Island cormorant colony. A total of 33 to 34 breeding pairs nested in each experimental plot. Productivity was similar in the experimental plots (2.78 fledglings/breeding pair, 95% CI: 2.62 - 2.94, n = 208 nesting attempts) compared with elsewhere on the East Sand Island cormorant colony (2.88 fledglings/breeding pair, 95% CI: 2.70-3.06, n = 135 nesting attempts).

As we expected, cormorants were first observed on the elevated wooden platforms with decoys and audio playbacks; however, cormorants were observed in plots not having social attraction only minutes (= 10) later. There was no significant difference in the timing of nest initiation among the three treatments. Furthermore, the numbers of active nests among plots were similar, and there was no difference in cormorant productivity among the treatments. Because the areas where cormorants nest within the colony have been similar in recent years (suggesting high nest site fidelity on East Sand Island), and because cormorants successfully nested in all the experimental plots in 2006, this insignificant difference in cormorant nesting preference among treatments could be explained by the previous nesting history of cormorants in all six experimental plots.

Miller Sands Spit: In 2007, cormorants nested again in and immediately outside of the social attraction plot on Miller Sands Spit. Cormorants were first observed within the plot on 2 May, 28 days after completion of the experimental plot (4 April). First chicks (approximately 3 weeks old) were observed on 9 July. The best estimate of the productivity of the colony was 1.68 fledglings/breeding pair (n = 81 nests) based on a single nest/chick count conducted at the site on 27 July. This marks the second consecutive year that cormorants were attracted to successfully nest on Miller Sands Spit using habitat enhancement and social attraction.

Rice Island: Although cormorants were observed on the beach near the experimental plot used by nesting cormorants in 2006, cormorants did not re-nest at the site in 2007. Although dog and human tracks were seen on Rice Island some distance from the experimental plot (> 300 m) on three different occasions, it is unlikely that potential disturbance caused by dogs or humans were the reason cormorants did not re-nest at the site, because gulls successfully nested in the area in 2007. These results suggest that habitat enhancement and social attraction continue to be important in maintaining an incipient cormorant colony from one year to the next, even after cormorants had successfully raised young at the site.

Fern Ridge: Cormorants did not attempt to nest on the floating platform and cormorants were never observed perched on the floating platform during the nesting season. Although small numbers of double-crested cormorants were observed in Fisher Butte cell #2 during April and May, the large numbers of cormorants that were observed foraging in Fern Ridge Lake in March were not present in April and May. Although we never observed any human disturbance of the platform, bald eagles were numerous in the vicinity of the platform, and may has served as a deterrence for prospecting adult cormorants. The platform with its tire nest structures, decoys, and audio playback systems should be deployed in Fisher Butte cell #2 again in 2008 to test the technique during a second nesting season.

Conclusions: Results from these studies suggest that: (1) habitat enhancement and social attraction techniques are effective in establishing double-crested cormorant breeding colonies at sites where nesting attempts have previously occurred, (2) cormorants take longer (i.e., 2 or more years) to colonize a new nesting site using these techniques compared to Caspian terns (i.e., in the first year; see Roby et al. 2002, Collis et al. 2002b), (3) newly established cormorant colonies can be maintained from one year to the next,through the continued use of habitat enhancement and social attraction methods, and (4) habitat enhancement and social attraction techniques used to attract cormorants to nest at new sites with no history of cormorant nesting and further removed from well-established colonies, such as Fern Ridge Lake, may require several years to be successful, if at all. The efficacy of habitat enhancement and social attraction techniques to establish new cormorant colonies outside of the Columbia River Basin as a means to reduce cormorant predation rates on juvenile salmonids in the Columbia River estuary remains uncertain and will require additional study to fully evaluate. Developing methodologies to enhance the size of existing double-crested cormorant colonies, along with establishing new colonies using habitat enhancement and social attraction techniques, may be necessary to shift cormorants from the large and growing colony on East Sand Island to alternative colony sites where ESA-listed salmonids are not as vulnerable to cormorant predation.

2.5.2. Techniques to Discourage Nesting

Methods: Efforts to attract Caspian terns to nest on East Sand Island involved creation of nesting habitat, use of social attraction techniques, and predator control, with concurrent efforts to discourage terns from nesting on Rice Island (Roby et al. 2002). If resource managers choose to manage cormorant predation on juvenile salmonids in the Columbia River estuary by relocating a portion of the cormorants currently nesting on East Sand Island to alternative sites outside the Basin, both techniques to attract (to new sites) and discourage (on East Sand) nesting cormorants will be important. In 2007, we tested the feasibility of two non-destructive methods to discourage nesting by cormorants on East Sand Island; erecting artificial perches for bald eagles and erecting visual barriers made of silt fencing within the cormorant colony (Map 4).

Bald eagles are known predators of adult double-crested cormorants nesting at the East Sand Island colony. Two artificial perches using driftwood (approximately 4-m high) were erected at the west and east ends of satellite colony next to the tidal pond, located in the northwest section of the cormorant colony (Map 4). Eagle use of these perches and other areas both within and near the colony were monitored every 30 minutes from the observation tower during extended observation periods. We also monitored the frequency, magnitude, and duration of all disturbances to nesting cormorants from eagles and other causes.

In order to assess whether silt fencing would deter cormorants from building nests between or near the fencing, silt fencing (10-m length x 1.2-m height) was erected in four parallel rows in two areas within the cormorant colony, on rock rip-rap and on bare ground in the colony interior (Map 4). In both areas, the silt fencing was erected in four rows from south to north, spaced at 5-m, 7.5-m, and 10-m intervals (intervals from west to east). A portion of the silt fencing on the rip-rap and all of the silt fencing in the colony interior blew down within a week due to a severe windstorm. Because this happened before many cormorants had started nesting, the silt fencing on the rip-rap was repaired and the silt fencing in the interior was replaced with fences of a different design. Ropes were used to create a net-like pattern between fence posts erected in the experimental plot in the interior. This alternative fencing technique did not catch the wind, but still provided a physical barrier to movements of nesting cormorants. The net-like fences were erected such that cormorants could easily free themselves if they flew into the fence. These areas were monitored for the presence of cormorants both between and immediately adjacent to the fences by direct observation from the nearby observation tower.

Results and Discussion: Bald eagles were attracted to the artificial perches when the number of eagles using the area in and around East Sand Island was relatively high, especially during the early part of the cormorant breeding season (April). Cormorants took off from the tidal pond satellite colony when eagles used the artificial perches; however, the use of the perches by bald eagles was not frequent enough to discourage cormorants from nesting in the tidal pond satellite colony. Cormorants nested and chicks were successfully fledged from this satellite colony, although nesting chronology was late compared to most other areas of the cormorant colony.

Because of the ample number of natural perches for eagles (e.g., other driftwood, pile dikes, etc.) on or near the East Sand Island cormorant colony, it was difficult to evaluate the effectiveness of the artificial eagle perches for discouraging cormorant nesting. If these other perches were not available, it is possible that eagles may have used the artificial perches more frequently, causing the cormorants in those areas to abandon their nests. However, because of the availability of suitable nesting habitat on much of East Sand Island, cormorants displaced from the vicinity of eagle perches may just relocate to another area of the colony where eagle disturbance is less frequent. Eagle perches might be effective in reducing the number of cormorants nesting on East Sand Island as one component of a larger effort to attract bald eagles to the vicinity of the cormorant colony throughout the cormorant nesting season, plus facilitate and enhance the natural predation on nesting cormorants by local bald eagles. This management approach is based on the premise that (1) bald eagles have disrupted other cormorant colonies and caused their abandonment, (2) bald eagle predation appears to have the potential to limit the expansion of the cormorant colony at East Sand Island, and (3) encouraging the functional and numerical response of bald eagles preying on nesting double-crested cormorants may hasten the time when eagle disturbance and depredation prevent the continued growth in the cormorant colony.

A portion of the repaired fence on the rip-rap came down by 16 April, three days after completion of repairs, once again due to strong winds. That same day, cormorants were seen on the rip-rap immediately to the north of the three western-most silt fences, towards the interior of the colony. Cormorants nesting in the area immediately north of the three western-most rows (5-m and 7.5-m intervals) gradually expanded into spaces between the fences; 5 cormorants were first observed on 20 April and these cormorants were confirmed to be nesting on 22 April. Other cormorants were also observed displaying immediately west and east of the experimental exclusion area on 22 April. Despite the larger space between the third and fourth rows from west (10-m interval), cormorants were not observed there until cormorants began nesting nearby on 28 April. By the end of April, the first and second rows from the west also partially blew down due to high winds, at which time a substantial number of cormorants started nesting in spaces between all the rows of fencing, and immediately outside of the fenced area. Cormorants initially avoided spaces between the net-like fences erected in the interior portion of the colony. Once cormorants started occupying areas immediately outside the net-like fenced area, however, cormorants began occupying the spaces between four rows of net-like fences (16 April), within three days of constructing the fences. By 20 April, the density of nesting cormorants between the net-like fences was approximately the same as in other parts of the colony.

Silt fencing erected in the colony was susceptible to high winds, while net-like fences lasted throughout the season. The silt fencing erected on the roip-rap did not discourage cormorants from nesting, although colonization of the area between and immediately outside the fencing by nesting cormorants appeared to be slightly slower than in other areas of the colony. We did not expect to see cormorants occupy the areas between the silt fences that were close together (5-m and 7.5-m intervals) before they occupied the areas between silt fences that were further apart (10-m interval). This was likely due to presence of other cormorants immediately north of the smaller spaces, between the three western-most rows. Because cormorants are gregarious, they may have chosen areas closer to the other cormorants nesting north of the experimental exclusion area, in spite of the short intervals between silt fencing, which would block their view on two sides. Cormorants colonized areas between the net-like fences in the interior portion of the colony much faster than the areas between silt fences on the rip-rap, presumably because the net-like fences did not provide a visual barrier between birds nesting on the colony, which seems to discourage nesting in colonial waterbirds (Roby et al. 2002). These results suggest that visual barriers (i.e., silt fencing) are more effective in discouraging cormorant nesting than physical barriers (i.e., net-like fencing), although neither technique ultimately prevented cormorants from nesting. More experiments will be necessary to determine what non-destructive methods are most effective in discouraging cormorant nesting on East Sand Island. In order to reduce the size of the East Sand Island cormorant colony, these methods need to not only be effective in deterring cormorants from nesting in certain areas, but also need to be cost-effective, capable of withstanding the extreme weather on the island, and durable enough to last several nesting seasons.

2.6. Post-breeding Distribution and Diet on the Columbia Plateau

Methods: Unlike Caspian terns, which migrate south of the Columbia Basin after the breeding season, some double-crested cormorants over-winter on the Columbia and Snake rivers, potentially reducing the survival of hold-over fall Chinook in the region, particularly near Snake River dams. To assess these impacts, weekly counts of double-crested cormorants were conducted at Little Goose and Lower Granite dams during September – December 2007. Opportunistic counts of roosting and foraging cormorants in the forebay and tailrace of each dam were conducted by staff with the U.S. Army Corps of Engineers several times a day for up to 3 days per week. Additionally, at the end of each month of the study period, approximately 10 cormorants were lethally collected by staff with the USDA–Wildlife Services at Little Goose and Lower Granite dams in order to assess diet composition. All fore-gut samples collected from birds were processed and analyzed as described in Sections 2.3.1 and 2.3.2 of this report.

Results and Discussion: Double-crested cormorants were observed at both dams throughout the study period (Figures 34 and 35). At both dams, cormorants used the navigation lock walls, log booms, trash-shear walls, and spillway guide walls to roost and stage before foraging. The maximum number of birds counted at each dam varied both spatially (i.e., forebay versus tailrace) and temporally (Figure 34 and 35). In general, there were more cormorants counted in the forebay of each dam early in the season; while late in the season greater numbers of cormorants were observed in the tailrace. Counts of cormorants in the forebay and tailrace at Little Goose dam ranged between 0 – 50 and 9 – 46 birds, respectively (Figure 34). At Lower Granite Dam, counts of cormorants in the forebay and tailrace ranged between 0 – 44 and 5 – 34 birds, respectively (Figure 35). At Lower Granite dam there was a general decline in the number of cormorants observed near the dam as the season progressed. This trend was less apparent at Little Goose dam, especially in the tailrace. Counts of cormorants in the forebay at Little Goose dam were highly variable, perhaps because of our monthly collection of cormorants for diet composition analysis at that location.

Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 11.8% of the double-crested cormorant diet (by mass) at Little Goose and Lower Granite dams in 2007; the percentage of salmonids in the diet was similar at the two dams (Table 12). Juvenile shad were the most prevalent prey type found in fore-gut contents, representing 47.7% of prey biomass, followed by centrarchids (22.0%; Table 12). Generally, centrarchids were the predominate prey type in the diet of cormorants collected during the first two sampling periods (4 October and 5 November), whereas shad were the most prevalent prey type during the last two sampling periods (7 December and 28 December; Table 12). Salmonids were found in the diets of cormorants throughout the sampling period (October through December), but appeared to be more prevalent in the diet during the earliest (4 October) and latest (28 December) sampling periods, compared to the two sampling periods in early November and early December. The salmonid samples collected from the fore-guts of over-wintering cormorants have been sent out for genetic analysis (see Section 2.3) to identify species and stock, and the results will be presented in a subsequent report.

These results suggest that moderate numbers of cormorants over-winter near Snake River dams and that salmonids make up a small proportion of their diet. It should be noted, however, that the diet composition results presented here are based on small sample sizes and the counts of birds at two dams on the Snake River tell us very little about the system-wide abundance and distribution of over-wintering cormorants on the Snake River and their potential impacts on juvenile salmonids. In 2008, we will conduct more comprehensive surveys on the distribution and abundance of over-wintering cormorants along the Snake River from the confluence with the Columbia River to the mouth of the Clearwater River. Additionally, we will increase our sampling efforts to measure diet composition in order to better assess the system-wide impacts of over-wintering double-crested cormorants on ESA-listed salmonid stocks, particularly hold-over fall Chinook smolts.

SECTION 3: OTHER PISCIVOROUS COLONIAL WATERBIRDS

3.1. Distribution

3.1.1. Columbia River Estuary

Gulls: During land-based, boat-based, and aerial surveys in 2007, 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 2007: East Sand Island, Rice Island, and Miller Sands Spit, with the East Sand Island gull colony being by far the largest of the three (Table 1). Ring-billed gulls, which previously nested on Miller Sands Spit (Collis et al. 2002a), now nest solely on East Sand Island within the Columbia River estuary (Table 1).

California Brown Pelicans: East Sand Island is 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 2007, the first California brown pelicans were observed roosting on East Sand Island on 8 April and = 600 pelicans were observed on the island during the last island-wide census of the season on 8 October. The number of brown pelicans roosting on East Sand Island peaked at about 7,660 on 5 September. We observed breeding behavior by brown pelicans roosting on East Sand Island (i.e., courtship displays, nest-building, attempted copulations), but there was no evidence of egg-laying. Bald eagle activity was the most common source of non-researcher caused disturbance to brown pelicans roosting on East Sand Island in 2007.

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. In 2007, this colony grew to 288 nesting pairs (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 2007 (133 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 2007: 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 2007 (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. 2002a), has not been active for several years (Map 2). No gull colonies were observed on the lower Snake River in 2007, nor has there been any confirmed breeding by gulls on the lower Snake River since our research began in 1997 (Collis et al. 2002a).

An unknown number of ring-billed and California gulls were also confirmed to be nesting in Potholes Reservoir, Sprague Lake, and Banks Lake in 2007 (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 2007 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 22 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 913 adult American white pelicans were counted in the aerial photography taken on 22 May. This is a minimum count of adults present on the colony at the time of the photograph. The pelicans were divided between four nesting areas on the island: 401 pelicans were counted near the middle of the eastern shore of the island, 217 and 58 pelicans were counted in two distinct groups in the interior of the middle of the island, and 237 pelicans were counted in an area near the northern (upriver) end of the island. The total count of adult pelicans on Badger Island was down from the 1310 counted in 2006 in 3 distinct nesting areas. Until this year, counts from aerial photography had increased every year since 2001 (Figure 36), when only 263 pelicans were counted on Badger Island, suggesting a corresponding increase in the number of breeding pairs. Reasons for the decline in the aerial photo count and presumably in colony size in 2007 are not clear. Our boat-based counts resulted in a maximum count of 315 adults on 10 May, and a maximum count of 287 juveniles on 15 July. Maximum counts of juvenile pelicans during boat-based surveys were 238 in 2002, 141 in 2003, 329 in 2004, 296 in 2005, and 151 in 2006.

Other species: In addition to gulls and pelicans, other colonies of piscivorous waterbirds were recorded by our field crews in 2007, including colonies of great blue herons (*Ardea herodius*), black-crowned night-herons (*Nycticorax nycticorax*), and great egrets (*Casmerodius alba*) (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. 2002a). In general, gulls nesting on Rice Island (river km 34) ate mostly riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice Island/Miller Sands Spit and East Sand Island, respectively. At least some of these fish had been kleptoparasitized (i.e., stolen) from Caspian terns, which nested at the nearby colony on Rice Island (Collis et al. 2002a). In 2007, kleptoparasitism rates (proportion of fish delivered by terns to the colony that were subsequently stolen by gulls) for salmonid smolts delivered to the East Sand Island tern colony averaged 4.8%; steelhead smolts were kleptoparasitized at a higher rate (12.4%) than salmon smolts (2.6%). These data indicate that gulls nesting in close proximity to Caspian terns on East Sand Island have an impact on survival of juvenile salmonids by reducing the number of salmonid smolts successfully delivered the tern colony.

Finally, we attempted to recover PIT tags from plots that were set up within the glaucous-winged/western gull colonies at Rice Island and East Sand Island in 2007. PIT tags were not recovered in either plot. On Rice Island, all nesting attempts by gulls in the plot failed, causing them to abandon the plot prior to the chick-rearing. On East Sand Island there were only a few pairs of gulls nesting in the plot during the chick-rearing period; not enough birds to assess whether gulls were eating PIT-tagged smolts.

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

Brandt's and Pelagic Cormorants: As part of this study, we 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 extant) 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 suggested that at the level of the breeding colony, juvenile salmonids were a minor component of the diet.

California gulls that nest at the periphery of the Caspian tern colony on Crescent Island may have a negative effect on survival of juvenile salmonids because some individuals kleptoparasitize (i.e., steal) juvenile salmonids from terns as they return to the colony to feed their mates and young. Breeding adult terns may catch one to several fish on a successful foraging trip. Of these fish, the majority are consumed by the adult away from the colony in order to meet the adult's own energy requirements. A minority of the fish captured by breeding adult terns are brought back to the colony to feed their mate (pre-chick rearing) and young. These fish are subject to kleptoparasitism by gulls. Similar to other years, in 2007 kleptoparasitism rates on salmonid smolts delivered by terns to the Crescent Island colony averaged 13.1%, nearly 3 times higher than the rate observed at the East Sand Island tern colony (4.8%). As was observed at East Sand Island, the kleptoparasitism rates were higher on steelhead smolts (20.7%) than for salmon smolts (11.2%), suggesting that gulls prefer, or find it easier, to steal larger fish. These rates are useful in evaluating the relative vulnerability of different smolts to gull kleptoparasitism, but they are not representative of the proportion of all smolts caught by terns that were stolen by gulls. Therefore, empirical data on the cumulative impacts on smolt survival associated with gull kleptoparasitism are not available. Given that (1) California gulls nesting at Crescent Island significantly out-number Caspian terns nesting there, and (2) gulls kleptoparasitize only a small portion of the smolts delivered to the colony (most smolts captured by terns are immediately consumed by the tern and thus not available for gulls to steal), it is unlikely that smolts kleptoparasitized by gulls fulfill more than a small fraction of the food and energy requirements of the Crescent Island gull colony.

Finally, smolt PIT tags that were recovered from several gull colonies on the Columbia Plateau in 2006 (CBR 2007) corroborate our conclusion that the majority of gulls nesting at up-river locations pose little risk to salmonid survival (Collis et al. 2002a), with the possible exception of the California gulls nesting on Miller Rocks and Crescent Island (Table 5; see Section 3.3).

American White Pelicans: We do not collect data on diet composition of American white pelicans nesting on Badger Island because of the conservation concerns for this colony. Based on smolt PIT tag detections on the pelican colony, however, pelicans do not appear to be a significant source of smolt mortality (Table 5; 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

Gulls: PIT tags were recovered from two gull colonies in the Columbia River in 2007; Crescent Island (Rkm 510 in the McNary Pool) and Miller Rocks (Rkm 333 in The Dalles Pool; see Map 2). These gull colonies were scanned for PIT tags 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). Test PIT tags were sown at each colony to measure detection efficiency. PIT tags were sown (n = 100 per release per colony) prior to and immediately following the nesting season. PIT tags were recovered using hand-held electronic equipment and flat-plat detectors (Crescent Island only) during August 2007. Similar to the analytical approach used for Foundation Island cormorants, predation rate estimates from the gull colonies were adjusted for bias due to PIT tag detection efficiency, but not for deposition rate. As such, estimates of predation rates presented here are minimums.

Results and Discussion: A total of 1,192 and 2,295 PIT tags from 2007 migration year smolts were recovered from the Crescent Island and Miller Rocks gull colonies, respectively. These values increased to 1,877 and 2,653 after correcting for detection efficiency (Table 3). Results suggest that Crescent Island gulls consumed roughly 1/3rd (1,877/5,141) as many PIT-tagged smolts as Crescent Island terns and 1/4th (1,877/7,554) as many as Foundation Island cormorants in 2007. Results suggest that Miller Rocks gulls consumed roughly 1/2 (2,295/5,141) as many PIT-tagged smolts as Crescent Island terns and 1/3h (2,295/7,554) as many as Foundation Island cormorants in 2007. The estimated total number of smolt PIT tags deposited on each of these gull colonies is greater than that of Caspian terns nesting on Potholes Reservoir and American white pelicans nesting on Badger Island. Predation rates on salmonid smolts by Crescent Island gulls, however, were generally less than 0.5%; the two exceptions being steelhead from the upper Columbia River ESU (ca. 1.53%; Table 8) and sub-yearling Chinook from the mid-Columbia ESU (ca. 1.47%; Table 8). Based on smolt interrogations at John Day Dam (located just 12 Rkm upstream of Miller Rocks Island), predation rates by gulls nesting on Miller Rocks were also marginal, with rates less than 1.0% for most species and run-types interrogated passing the dam. The highest predation rate observed at Miller Rocks was for hatchery steelhead (ca. 1.41%, corrected for detection efficiency; see Table 3). These rates, however, maybe somewhat misleading due to the proximity of the gull colony to the John Day Dam, making it feasible for birds to forage in both the tailrace and forebay of the dam (interrogated smolts used to derive predation rate estimates are only indicative of predation in the dam’s tailrace).

Counts of the total number of gulls that nested on Crescent Island in 2007 are not available, but counts of nesting gulls were made within our PIT tag plots, where an estimated 60 pairs nested in 2007. Counts of the Miller Rocks gull colony were made from aerial photos in 2007, yielding an estimate of 3,500 nesting gulls. Estimates of per capita PIT tag consumption were twice as high for gulls nesting on Miller Rocks (ca. 0.38) compared to gulls nesting on Crescent Island (ca. 0.16; Table 5). Steelhead and yearling Chinook salmon were the most common species recovered, although other species and run-types were detected (Tables 5 and 7). Comparisons of per capita consumption rates for gulls from these two colonies suggest that gulls consume far fewer PIT-tagged fish per capita compared to nearby tern and cormorant colonies (Table 5).

The overall number of nesting gulls, however, far exceeds that of terns and cormorants in the McNary Pool and should be taken into account when evaluating impacts on the survival of juvenile salmonids.

Of the gull colonies studied in this region in previous years (see Collis et al. 2001), both Miller Rocks and Crescent Island gull colonies were identified as colonies that consumed salmonid smolts. Effects of Crescent Island gull predation are associated in part with nesting terns, from which the gulls kleptoparasitize fish, while the effects of Miller Rocks gull predation are solely from the gulls foraging on smolts themselves. In 2008, we are planning to increase efforts to count nesting gulls at both Miller Rocks and Crescent Island to gain a better understanding of the population status and impact on salmonid smolts of these gull colonies. To gain a better understanding of impacts, we are proposing to increase efforts to measure on-colony PIT tag detection efficiency and to spend more days searching for tags after the nesting season. The surprising number of smolt PIT tag found on Miller Rocks in 2007, in addition to the colony's close proximity to John Day Dam, bolsters the need for more accurate counts and increased PIT tag recovery efforts in 2008.

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 2007. The methods used to generate these estimates were similar to those described for Crescent Island terns (see Section 1.4.2) and Foundation Island cormorants (see Section 2.4.2). Test PIT tags (n = 100 per release) were sown on both the southern and northern nesting areas on 13 March (prior to the nesting season) and on 15 October (when pelicans had completely abandoned the island). Test tags could not be sown on Badger Island during the nesting season, as white pelicans are very sensitive to human disturbance on the colony. PIT tags were recovered in October 2007, after birds had completely left the island following the breeding season. Similar to the analytical approach used for Foundation Island cormorants, predation rate estimates from the Badger Island pelican colony were adjusted for bias due to PIT tag detection efficiency, but not for deposition rate. As such, estimates of predation rates presented here are minimums.

Results and Discussion: Of the 200 test tags sown on the Badger Island pelican colony in 2007, 64.5% were subsequently recovered on-colony (Table 3). There was little difference between detection rates of tags sown pre-season (ca. 58.0%) and post-season (ca. 71.0%). Detection efficiency in 2007 was identical to that in 2006 (64.5%) and similar to that measured in 2005 (58.0%).

An estimated 1,160 PIT tags (corrected for detection efficiency) from 2007 migration year smolts were deposited by Badger Island pelicans during the 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). Of the tags recovered, 36% (n = 423) were from sub-yearling Chinook salmon, 33% (n = 381) from steelhead, 15% (n = 172) from yearling Chinook salmon, 12% (n = 136) from coho salmon, and the remaining 4% (n = 48) from unknown run-type Chinook salmon. Overall, Badger Island pelicans consumed just 30 (0.10%) of the PIT-tagged smolts interrogated passing Lower Monumental Dam from 1 April to 31 July. Estimated predation rates from Badger Island pelicans were the lowest among the four avian colonies studied in McNary Pool during 2007 (Tables 6, 7, and 8). Data suggest that sub-yearling Chinook salmon from the middle Columbia River (not listed) were the most vulnerable (ca. 0.54% predation rate; Table 8) to white pelicans nesting on Badger Island, followed by hatchery steelhead from the Snake River (ca. 0.31%; Table 8). Taken as whole, however, the 1,160 PIT tags recovered from the Badger Island pelican colony provides evidence that the overall impact of white pelicans on survival of juvenile salmonids in the McNary Pool is negligible, especially when compared to that of Caspian terns and double-crested cormorants. The estimated per capita consumption rate of salmonid smolts by Badger Island pelicans also suggested that the effects of white pelicans on survival of juvenile salmonids are minimal compared to other piscivorous waterbirds investigated as part of this study (Table 5). Similar results and conclusions were drawn from the analysis of PIT tag recovery data from the white pelican colony during 2004 – 2006 (CBR 2006), although the largest number of PIT tags to date were found on the island in 2007.

SECTION 4: STEELHEAD VULNERABILITY STUDY

In 2007 we conducted a pilot study to investigate how smolt morphology, condition, and origin might be related to differences in smolt vulnerability to avian predation. We hypothesized that the probability of smolt mortality due to avian predation increases with the decreasing physical condition of the fish. We also hypothesized that river conditions and dam operational strategies may be linked in some way to smolt vulnerability to avian predators. Data collected as part this research will help regional fishery managers identify and potentially address those intrinsic and extrinsic factors that influence smolt vulnerability to avian predators. Steelhead were selected as the target species for this study because prior research has shown that they are the most vulnerable to predation by birds nesting on the Columbia River (Ryan et al. 2003; Antolos et al. 2005; Collis et al. 2001). The benefits of using steelhead for this study are three-fold: (1) we were likely to recovery a sufficient number of PIT tags from steelhead on bird colonies along the Columbia River to address a multitude of predation-related questions (more so than any other salmonid species or stock), (2) the incidence of morphological abnormalities (e.g., fungal infections, de-scaling, parasites, body injuries, etc.) is greater in steelhead than in other salmonid species (USACE, unpublished data), and (3) a better understanding of those factors responsible for the higher vulnerability of steelhead to avian predation will help resource managers implement measures to reduce avian predation on steelhead, if warranted and feasible. In addition, the tagging of steelhead as part of this study has the added benefit of refining estimates of smolt predation rates (see Section 1.4., 2.4, and 3.3) by incorporating run-of-the-river fish; fish of varying conditions, origins, and stocks that make up the Snake River ESU and are tagged throughout the run.

Data presented for this, the first of a three-year study, are preliminary and incomplete until further research and analysis is conducted. For example, we are still compiling and analyzing environmental data regarding river conditions and dam operational strategies.

Larger sample sizes and study replication are also needed. Results from this objective will be analyzed in greater detail in the project's final report and in peer-reviewed journal publications.

Methods: During April through June 2007, run-of-the-river steelhead smolts were collected and PIT-tagged at the Lower Monumental Dam and Ice Harbor Dam juvenile fish facilities. At the Lower Monumental Dam juvenile fish facility, steelhead were sampled four to seven days per week for 13 weeks starting in early April and ending in late June. Collections at Ice Harbor Dam were on Tuesdays and Fridays for 11 weeks starting in mid-April and ending in late June. Sampling at both locations was stopped when steelhead numbers were too low for productive sampling. Sampled steelhead were PIT-tagged, measured, weighed, photographed, and placed in a recovery tank where they were held up to 20 hours before being released into the dam's tailrace. Two general release times, morning and night, were used at each location to account for possible diurnal passage and predation effects. To reduce handling time, digital pictures were taken of each side of the steelhead, which allowed for detailed classification of external conditions by type and severity after the steelhead was released. We assessed the incidence and severity of different anomalies (e.g., external physical damage, disease, and parasite load) in each fish. In addition, each fish was assigned an overall condition ranking (1-4). These condition rankings were based on the presence, abundance, and severity of all the different anomalies observed in each fish and are defined as follows: rank 1 = no noticeable external damage, de-scaling < 10%; rank 2 = minor external damage, de-scaling 10% – 50%; rank 3 = open body injuries or fungal infection, parasite or external indications of a bacterial infection, de-scaling > 50%; and rank 4 = substantial fungal infections, parasites, bacterial lesions or body injuries, clinical abnormalities that suggested the fish was moribund.

As described in Section 1.4.1, piscivorous waterbird colonies were scanned for PIT tags following the breeding season. Recoveries of PIT tags on bird colonies were used to determine if susceptibility to avian predation varied by the differing physical conditions and morphology of the steelhead used in this study. In addition, PIT-tagged steelhead known to have survived past bird colonies – as indicated by detections at downstream dams (i.e., McNary, John Day, and Bonneville) and locations (towed PIT tag array in the Columbia River estuary) – were compared to those PIT-tagged steelhead consumed by birds in McNary Pool in order to test hypotheses regarding the relation between smolt survival and the physical condition and morphology of the smolt.

Results and Discussion: A total of 7,088 steelhead (6,335 hatchery and 753 wild) were tagged and released in 2007, 6,254 steelhead at Lower Monumental Dam and 834 steelhead at Ice Harbor Dam. The 6,254 steelhead PIT-tagged at Lower Monumental Dam represented 41% of the 15,097 steelhead collected at Lower Monumental Dam during the sampling period. The 834 steelhead PIT-tagged at the Ice Harbor Dam juvenile fish facility represented 90% of the 929 steelhead collected there. Of all the steelhead handled as part of this study (7,102), there were 3 direct mortalities and 11 steelhead ejected their tags prior to release, all of which were removed from subsequent analyses.

Nearly half (49%) of the steelhead PIT-tagged as part of this study were classified in condition rank 1 (excellent), while ranks 2, 3, and 4 comprised the other 51% of all the steelhead sampled. Of the steelhead given a condition rank of 2 (good), 89% were assigned this ranking based on the degree of de-scaling. In contrast, steelhead assigned a condition rank of 3 (fair) showed a variety of substandard external anomalies, including operculum damage (23%), body injuries (25%), and fungal injections (35%). In general, steelhead classified in condition rank 4 (poor) suffered from 3 different conditions; open body wounds (33%), severe fungal infections (67%), and large surface body injuries (23%).

The fork length of sampled steelhead averaged 218 mm (n = 7,088, SD = 28), while average mass was 91 g (n = 7,075, SD = 37). Both of these variables increased throughout the season, with late run steelhead being larger and heavier than early run steelhead. There was some evidence that early run steelhead were in better overall condition than late run steelhead, but sample sizes were small (< 200 fish a week) for the early part of the run. Early run samples were small at both Lower Monumental and Ice Harbor dams due to the lack of daily sampling and the paucity of steelhead migrating in the lower Snake River in early April. In the future, sample sizes could be enhanced by increasing the amount of time and number of days allowed for fish collection at the juvenile fish facilities in early and mid April at the dams.

A total of 954 PIT tags from steelhead included in this study were detected at various piscivorous waterbird colonies and roosts in McNary Pool, John Day Pool, The Dalles Pool, and the Columbia River estuary. When corrected for detection efficiency at each of the different bird colonies, we estimate that 1,266 PIT-tagged steelhead were consumed by piscivorous waterbirds, or 17.9% of all the steelhead tagged and released as part of this study (Table 13). This is a minimum estimate because this total is not corrected for deposition rate, the proportion of ingested PIT tags that are deposited on the colony. The magnitude of this source of bias is unknown for most avian colonies in the basin (see Section 1.4.1). Of all the PIT tags detected on bird colonies (corrected for detection efficiency), most (51.6%) were from bird colonies in McNary Pool, or 9.2% of all the steelhead tagged and released as part of this study (Table 13). Of the tags recovered on avian colonies in McNary Pool (corrected for detection efficiency), 323 (49.5%) were from the Crescent Island Caspian tern colony, 204 (31.2%) were from the Foundation Island double-crested cormorant colony, 80 (12.3%) were from the Crescent Island gull colony, 33 (5.0%) were from the Badger Island American white pelican colony, and 13 (2.0%) were from an area used by roosting terns and gulls (Table 13). Caspian terns nesting on East Sand Island consumed the largest percentage (6.0%) of the PIT-tagged steelhead used in this study, followed by Crescent Island terns (4.6%) and Foundation Island cormorants (2.9%; Table 13).

Preliminary results indicate that the condition and morphology of juvenile steelhead are factors associated with a smolt's vulnerability to avian predators. PIT tag detections on avian colonies in the McNary Pool suggest that avian predation is partially condition-dependent, with diseased steelhead or steelhead with severe external damage (condition ranks 3 and 4) more likely to be consumed than fish with little or no external damage or disease (condition ranks 1 and 2). For example, steelhead with severe external damage were 1.8 times more likely to be consumed by an avian predator than fish with no signs of external damage (Figure 37). Similarly, there was a positive relationship between the level of de-scaling and the rate of avian predation, with slight to severely de-scaled fish being 1.2 to 2.4 times more likely to end up on an avian colony than fish with little or no de-scaling (Figure 38). Sample sizes were small, however, for severely de-scaled steelhead (n = 44) and more data from this group are needed. Regardless, these preliminary results suggest that at least some smolt mortality is compensatory, and that not all mortality from avian predation is additive.

There was also evidence of an association between a fork length of a smolt and its relative vulnerability to avian predators in McNary Pool. For terns nesting on Crescent Island, steelhead between 190 and 250 mm were the most vulnerable, with predation as a function of steelhead length fitting a polynomial model ($p = 0.003$, based on a simple least squares regression; Figure 39). Conversely, small steelhead (< 169 mm) and large steelhead (> 270 mm) rarely ended up on the tern colony. Interestingly, this relationship between fork length and susceptibility to avian predation was not found for Foundation Island cormorants, where steelhead size was neither positively or negatively associated with predation rates ($p = 0.0977$, based on a simple least squares regression; Figure 40). It should be noted that sample sizes of steelhead less than 170 mm (n = 294) and greater than 270 mm (n = 152) were limited, and more data are needed to evaluate the association between vulnerability to avian predators and fish length or migration timing.

A total of 1,606 of the PIT-tagged steelhead released as part of this study (22.7%) were detected at or below McNary Dam (based on interrogations at dams and elsewhere). Preliminary results indicate that higher proportions of condition rank 1 and 2 fish successfully navigated McNary Pool relative to condition rank 3 and 4 fish. This trend extended downriver, with very small proportions of fair and poor condition steelhead interrogated while passing Bonneville Dam (ca. 4.6% relative to 14.1% at release). We are currently evaluating survival probabilities based on fish condition and other factors through the use of mark-recapture modeling techniques and logistic regression. Results of this analysis will be incorporated into future reports.

Based on the initial success of this pilot study in 2007, we are proposing to expand our PIT-tagging efforts to include steelhead from the upper Columbia ESU in 2008. Presently, very few empirical data exist to determine the impact of avian predators on this critically endangered ESU. Rock Island Dam has been selected as our fish capture and release site because it is the lowest dam on the mid-Columbia River where run-of-river fish from each of the four stocks from the endangered Upper Columbia River Steelhead ESU (Okanogan, Methow, Entiat and Wenatchee) can be sampled. Finally, in order to validate our scoring of fish condition based on physical anomalies in external appearance, we propose a pilot study whereby a sub-sample of the steelhead used in this study are screened to evaluate fish pathology and whole body chemistry as a measure of fish health. Such tests will help determine whether a fish's external condition – as determined at the time of examination at the dams – is correlated with disease pathogenicity or other indices of fish health. Such screening will also assist our investigation of how vulnerability to avian predation is related to internal indicators of fish health.

SECTION 5: 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 nine years, the numbers of double-crested cormorants nesting on East Sand Island have more than doubled during the same period to ca. 13,800 breeding pairs, the largest known breeding colony of double-crested cormorants in the world (Figure 41). 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 into the future. Productivity at the East Sand Island and Foundation Island cormorant colonies has also been consistently higher than productivity at the Caspian tern colonies in the estuary and up-river (Figure 42). In 2008, the U.S. Army Corps of Engineers will begin implementing the Caspian tern management actions outlined in the Final EIS (FEIS) and the Records of Decision (RODs) for Caspian tern management in the Columbia River estuary, a plan to redistribute a portion of the East Sand Island tern colony to alternative colony sites in interior Oregon and San Francisco Bay, California by 2015 (USFWS 2005, 2006). A substantial increase in the numbers of nesting Caspian terns along the mid-Columbia River as a result of tern management in the estuary is unlikely due to the paucity of suitable nesting habitat for terns in that region. Based on these results, it is possible that the cormorant breeding population will continue to expand for the foreseeable future, while numbers of Caspian terns nesting in the estuary and up-river will remain stable or decline as the RODs are implemented. The trajectories of other colonial waterbird populations along the Columbia River (e.g., gulls and pelicans) is less clear, and efforts will be made in 2008 to investigate the population trajectories of selected colonies where predation on salmonid smolts is believed to be significant (e.g., the gull colony on Miller Rocks).

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. 7-16 million smolts annually during 2003 – 2006 (Figure 43). Although consumption estimates for East Sand Island cormorants in 2007 are not yet available, combined smolt losses to terns and cormorants nesting on East Sand Island in 2007 are likely within this range. Estimated smolt losses to piscivorous birds that nest further up-river are more than an order of magnitude less than losses due to avian predation in the estuary. Additionally, when compared to the impact of avian predation on smolt survival further up-river, avian predation in the estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids from every 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 and the double-crested cormorant colony on Foundation Island may be exceptions to this rule; management of these small, up-river colonies may benefit certain salmonid stocks, particularly steelhead. Finally, although the current impact of double-crested cormorants nesting on the Columbia Plateau on smolt survival seems relatively small, the cormorant population on the Columbia Plateau appears to be expanding and there is ample unoccupied nesting habitat for cormorants in the region. Monitoring of double-crested cormorants on the Columbia Plateau to determine if they pose an increasing risk to salmonid survival may be warranted both during and after the birds nesting season.

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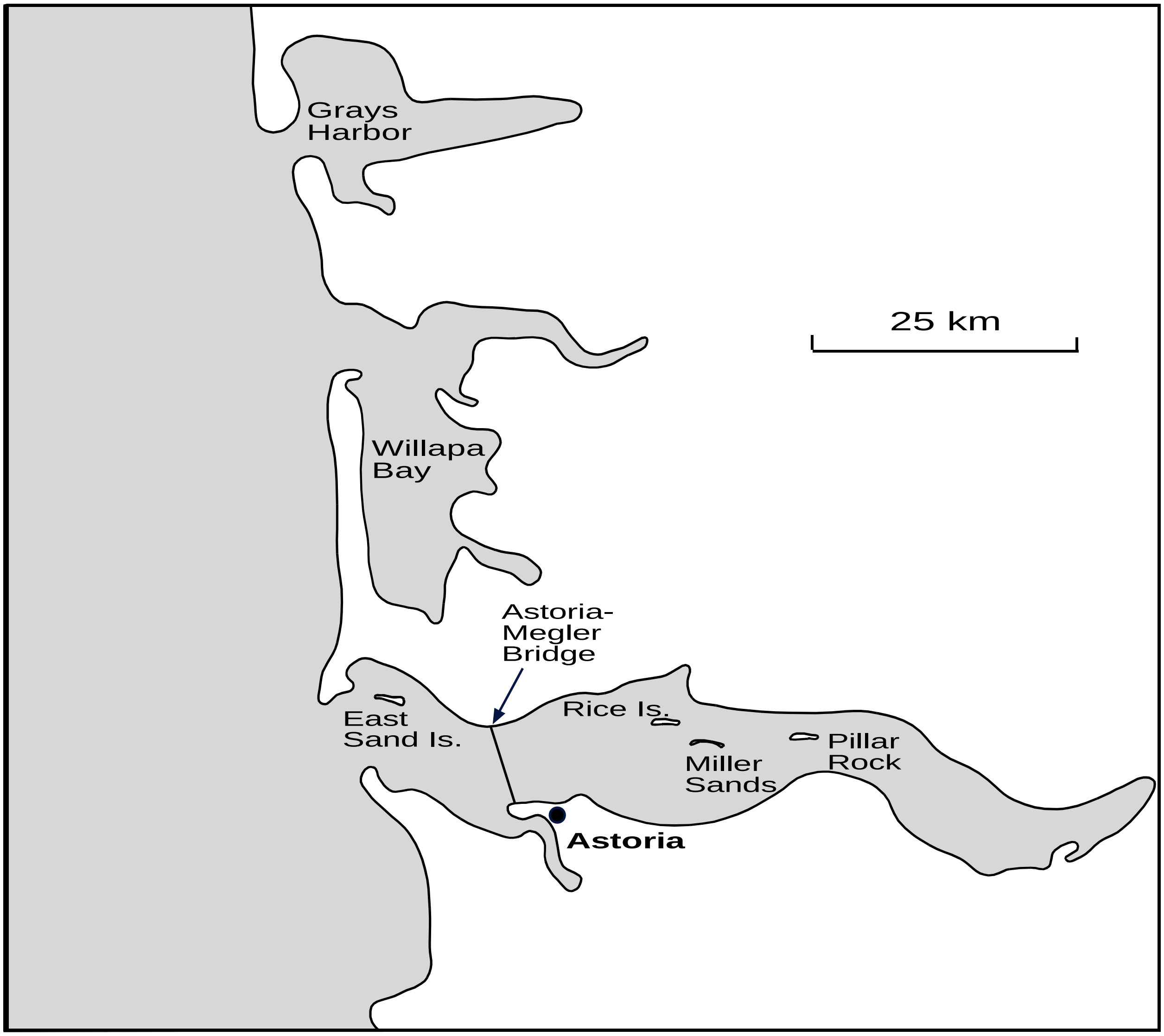
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Caspian terns			
1.1. Preparation and Modification of Nesting Habitat		x	
1.2. Colony Size and Productivity			
1.2.1. Columbia River Estuary	x	x	
1.2.2. Columbia Plateau	x		x
1.2.3. Coastal Washington	x[1]		
1.3. Diet Composition and Salmonid Consumption			
1.3.1. Columbia River Estuary	x		
1.3.2. Columbia Plateau	x		x
1.4. Salmonid Predation Rates			
1.4.1. Smolt PIT Tag Recoveries			x
1.4.2. Avian Predation Rates on Smolts	x		x
1.5. Dispersal and Survival	x		
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		

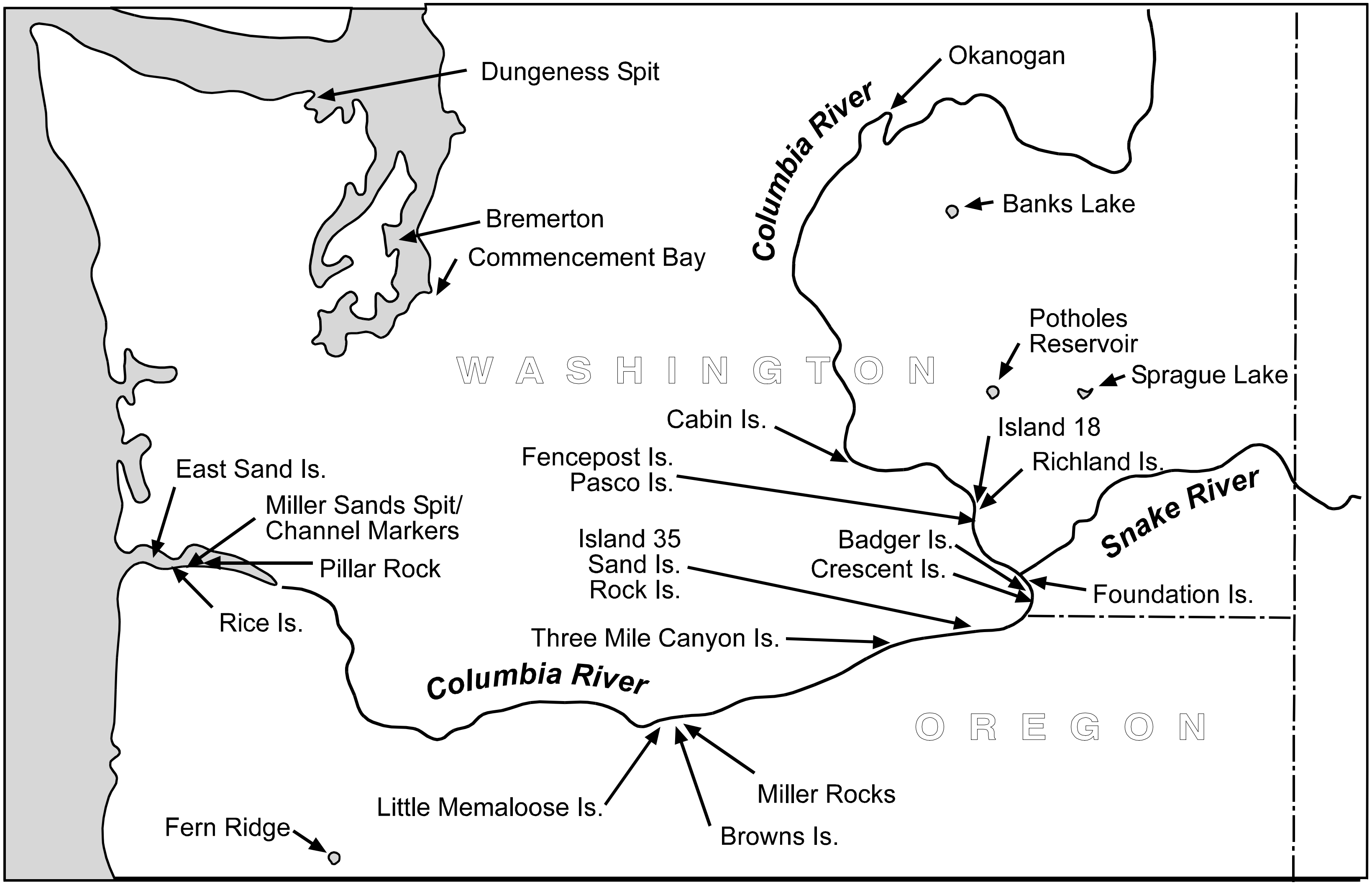
[1] Funding for monitoring of the Dungeness Spit and Naval Base Kitsap Caspian Tern colonies was provided by the U.S. Fish and Wildlife Service (see Roby et al. 2007 for full report).

	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	x		
2.2. Nesting Chronology and Productivity			
2.2.1. Columbia River Estuary	x		
2.2.2. Columbia Plateau			x
2.3. Diet Composition and Salmonid Consumption			
2.3.1. Columbia River Estuary	x		
2.3.2. Columbia Plateau			x
2.4. Salmonid Predation Rates			
2.4.1. Columbia River Estuary	x		
2.4.2. Columbia Plateau			x
2.5. Management Feasibility Studies			
2.5.1. Techniques to Encourage Nesting	x		
2.5.2. Techniques to Discourage Nesting	x		
2.6. Post-breeding Distribution and Diet on the Columbia Plateau			x

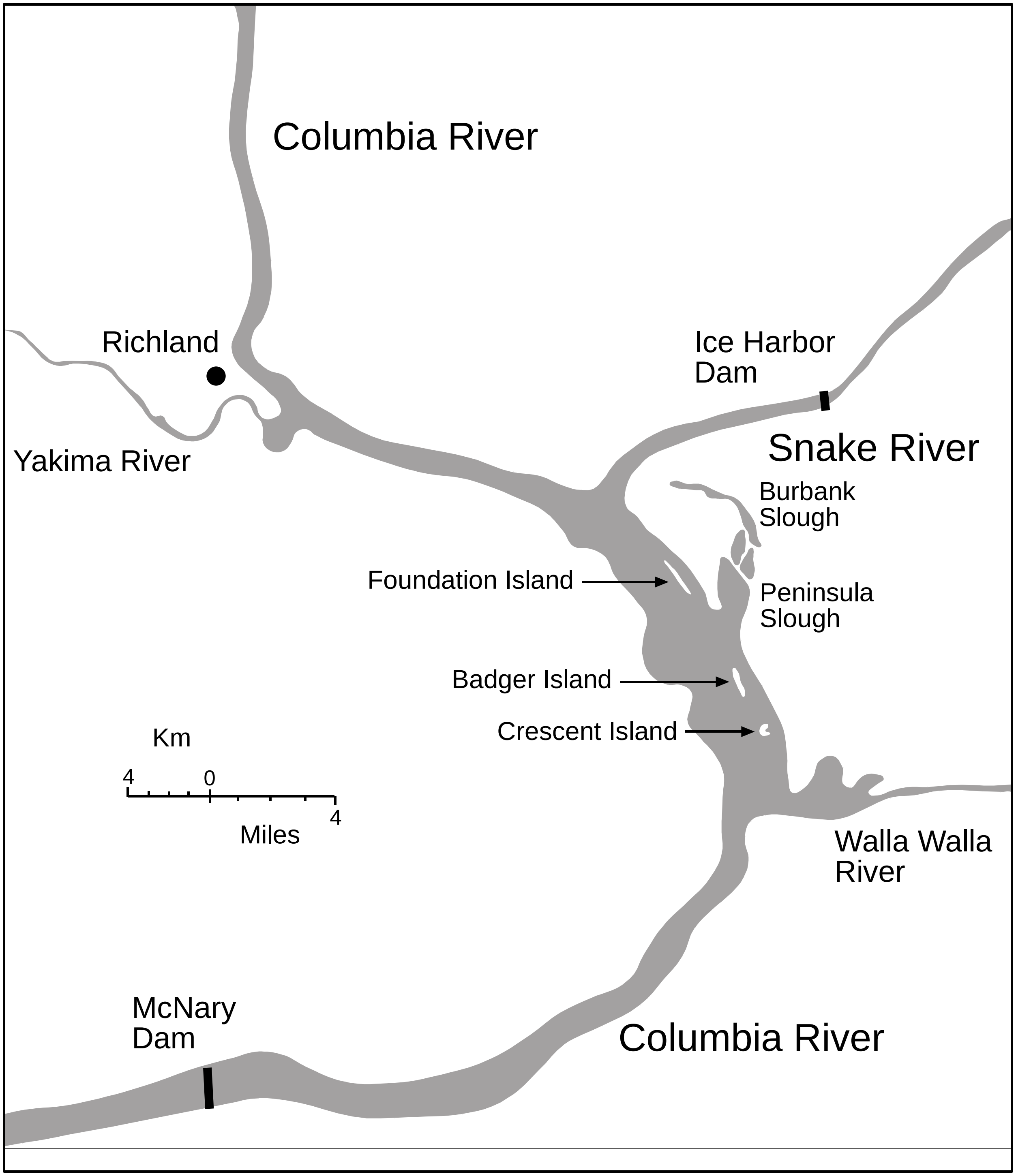
	Funding Responsibility by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Other Piscivorous Colonial Waterbirds			
3.1. Distribution			
3.1.1. Columbia River Estuary	x		
3.1.2. Columbia Plateau			x
3.2. Diet Composition			
3.2.1. Columbia River Estuary	x		
3.2.2. Columbia Plateau			x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



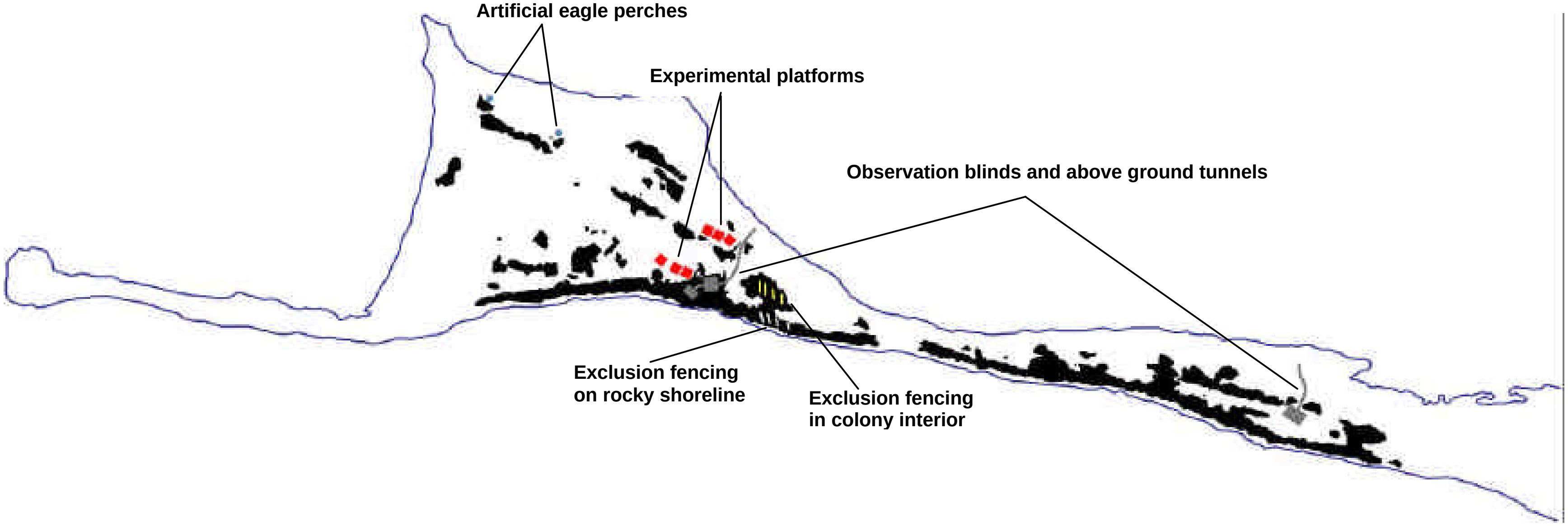
Map 1. Study area in the Columbia River estuary and along the southwest coast of Washington.



Map 2. 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 middle Columbia River.



Map 4. The distribution of nesting double-crested cormorants (shown in black) on East Sand Island in 2007 and the location of the experimental nesting plots (shown in red), exclusion fencing on rocky shoreline (white lines), exclusion fencing in colony interior (yellow lines), artificial eagle perches (blue dots), observations blinds (shown in gray), and access tunnels for observation blinds (see text for details). Nesting cormorants were restricted to the western end of the island (shown here), and did not nest anywhere else on East Sand Island in 2007.

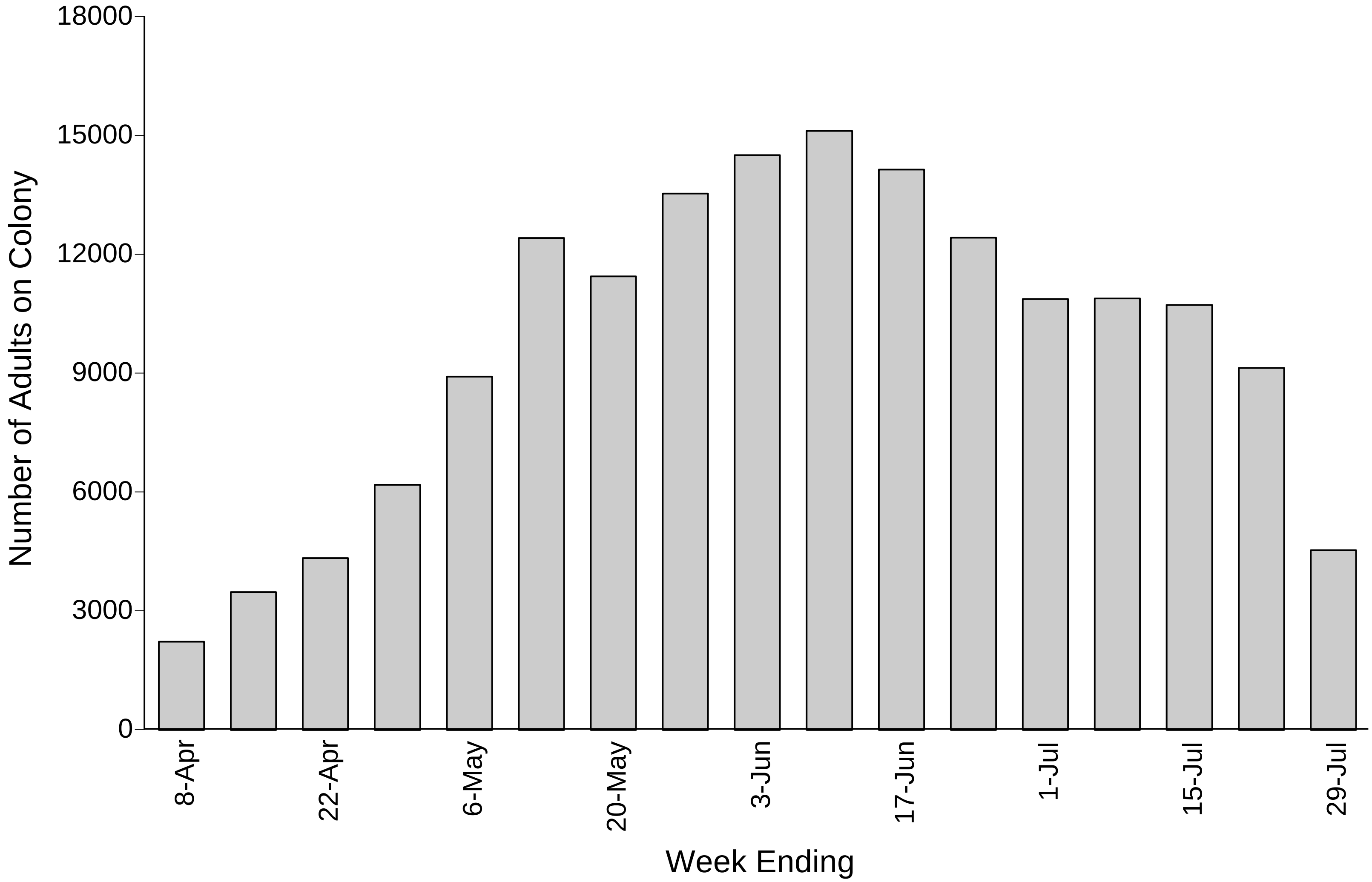


Figure 1. Weekly estimates from the ground of the number of adult Caspian terns on the East Sand Island colony in 2007.

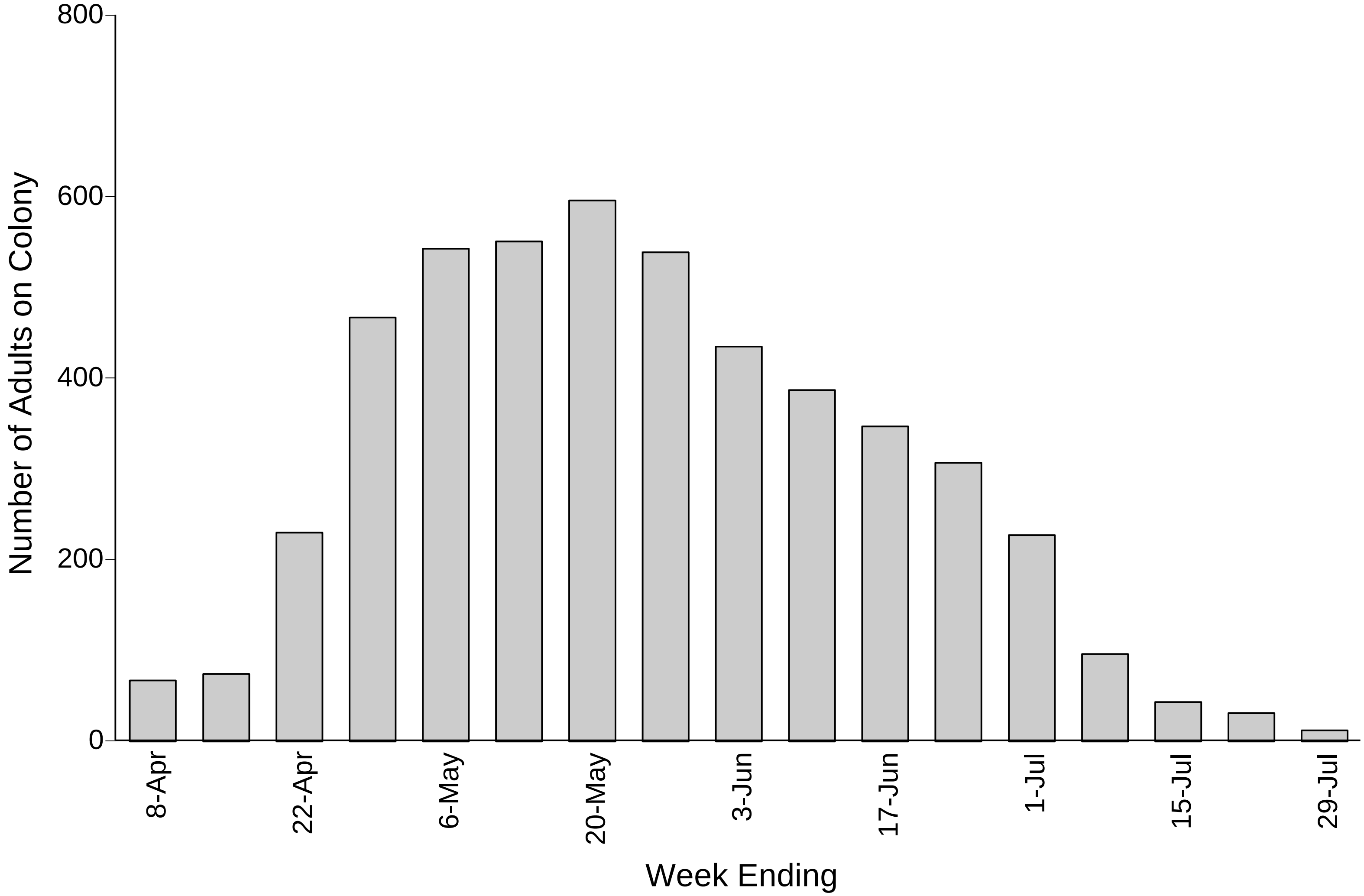


Figure 2. Weekly estimates from the ground of the number of adult Caspian terns on the Crescent Island colony in 2007.

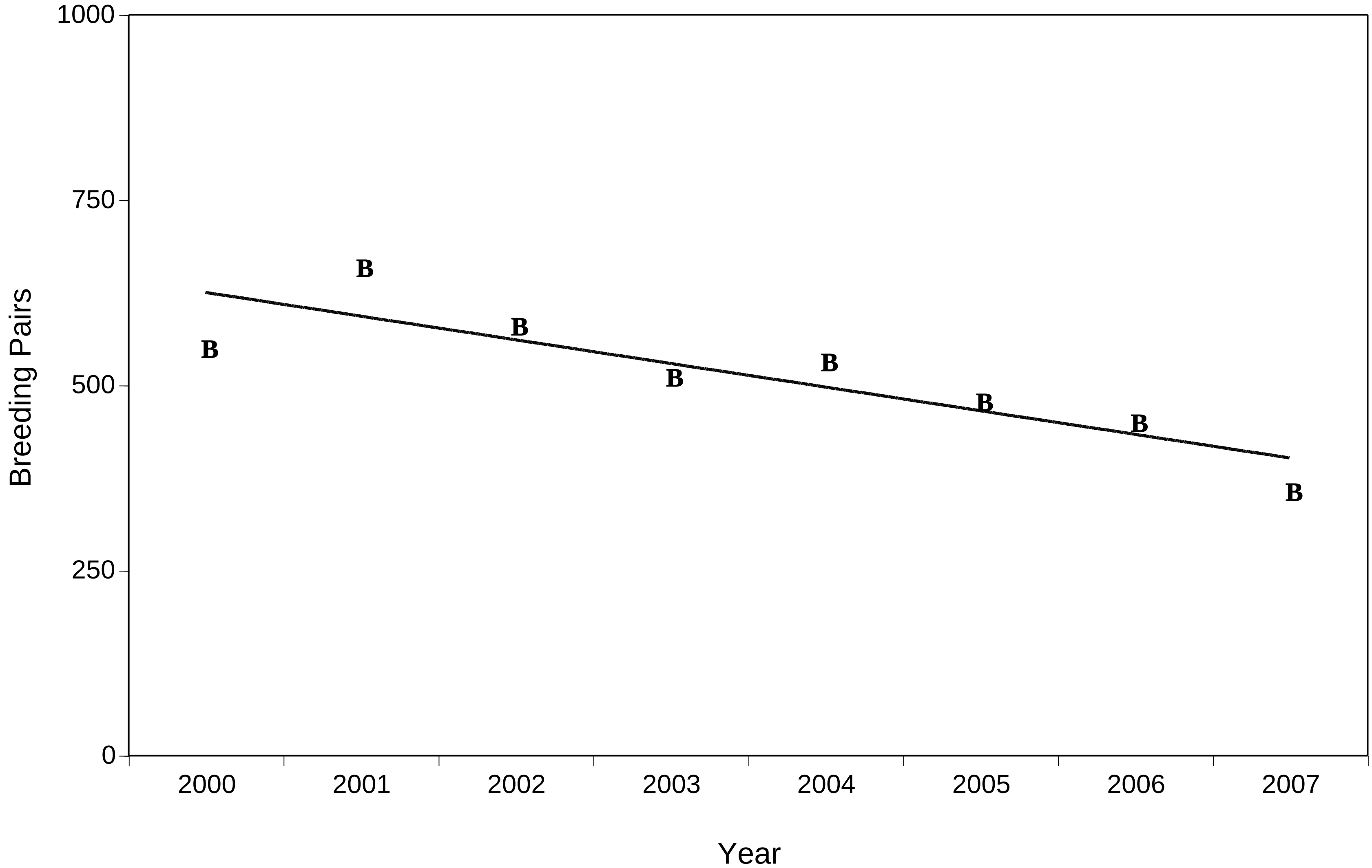


Figure 3. Population trends for Caspian terns nesting on Crescent Island during 2000-2007.

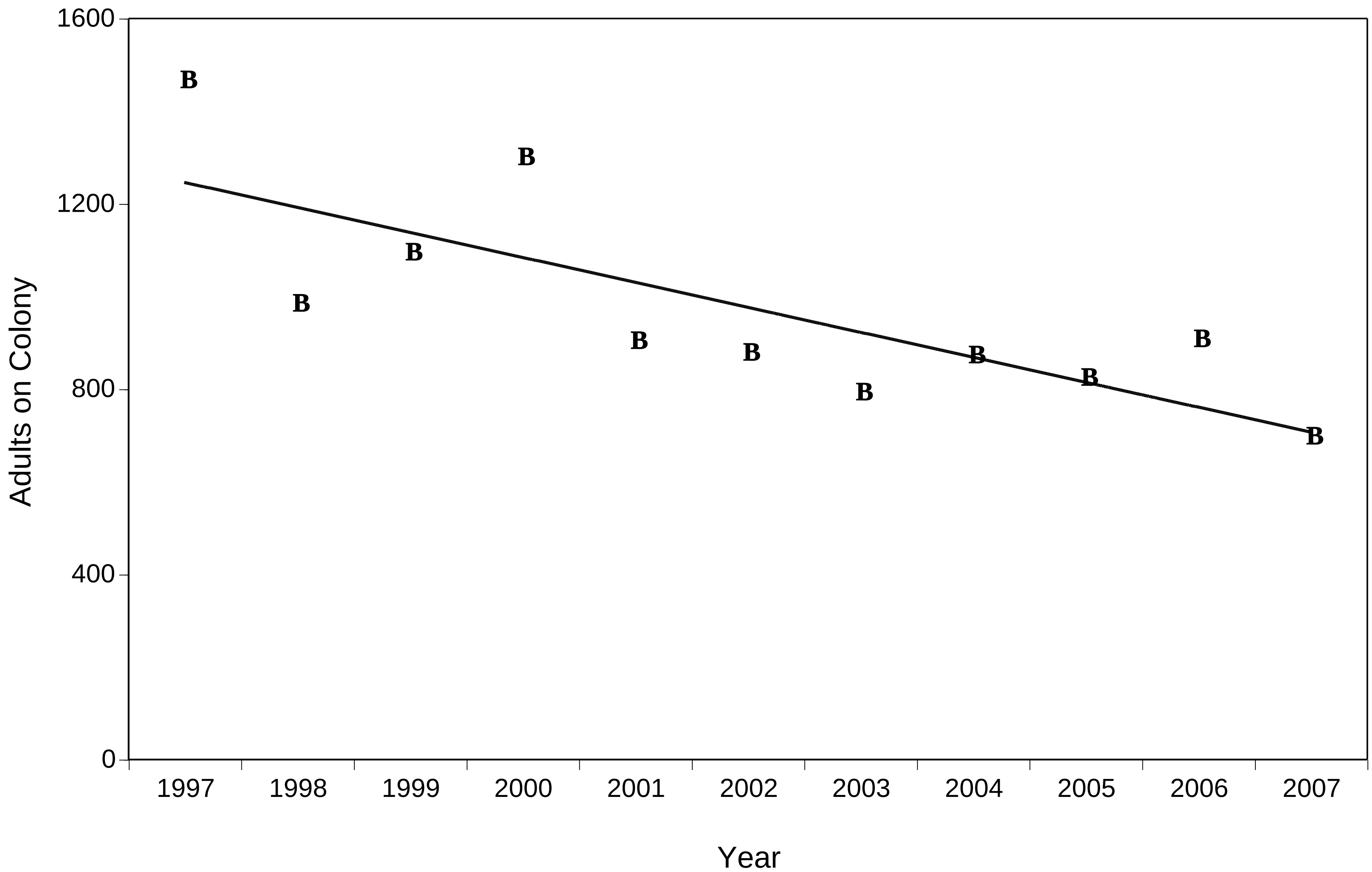


Figure 4. Population trends for Caspian terns nesting on the Columbia Plateau during 1997-2007.

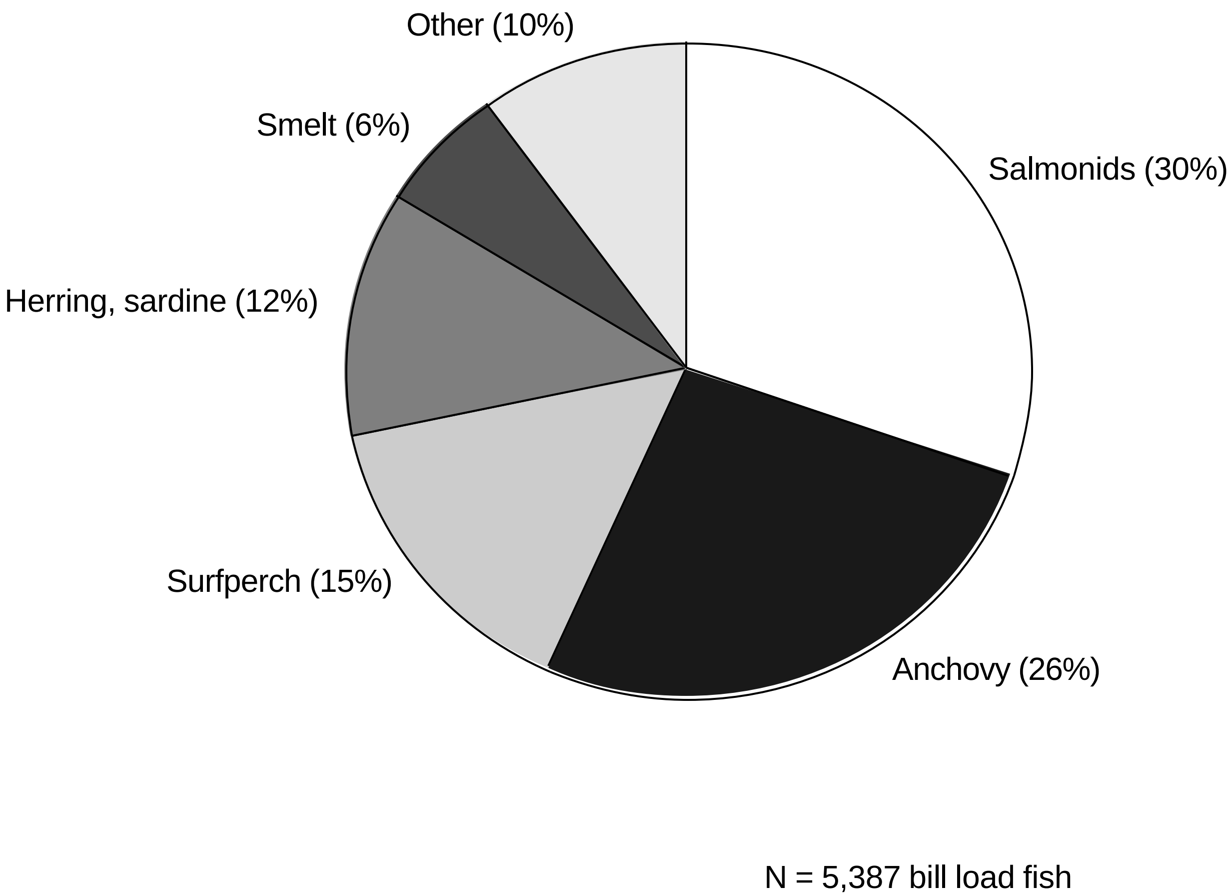


Figure 5. Diet composition of Caspian terns nesting on East Sand Island in 2007 (see text for methods of calculation).

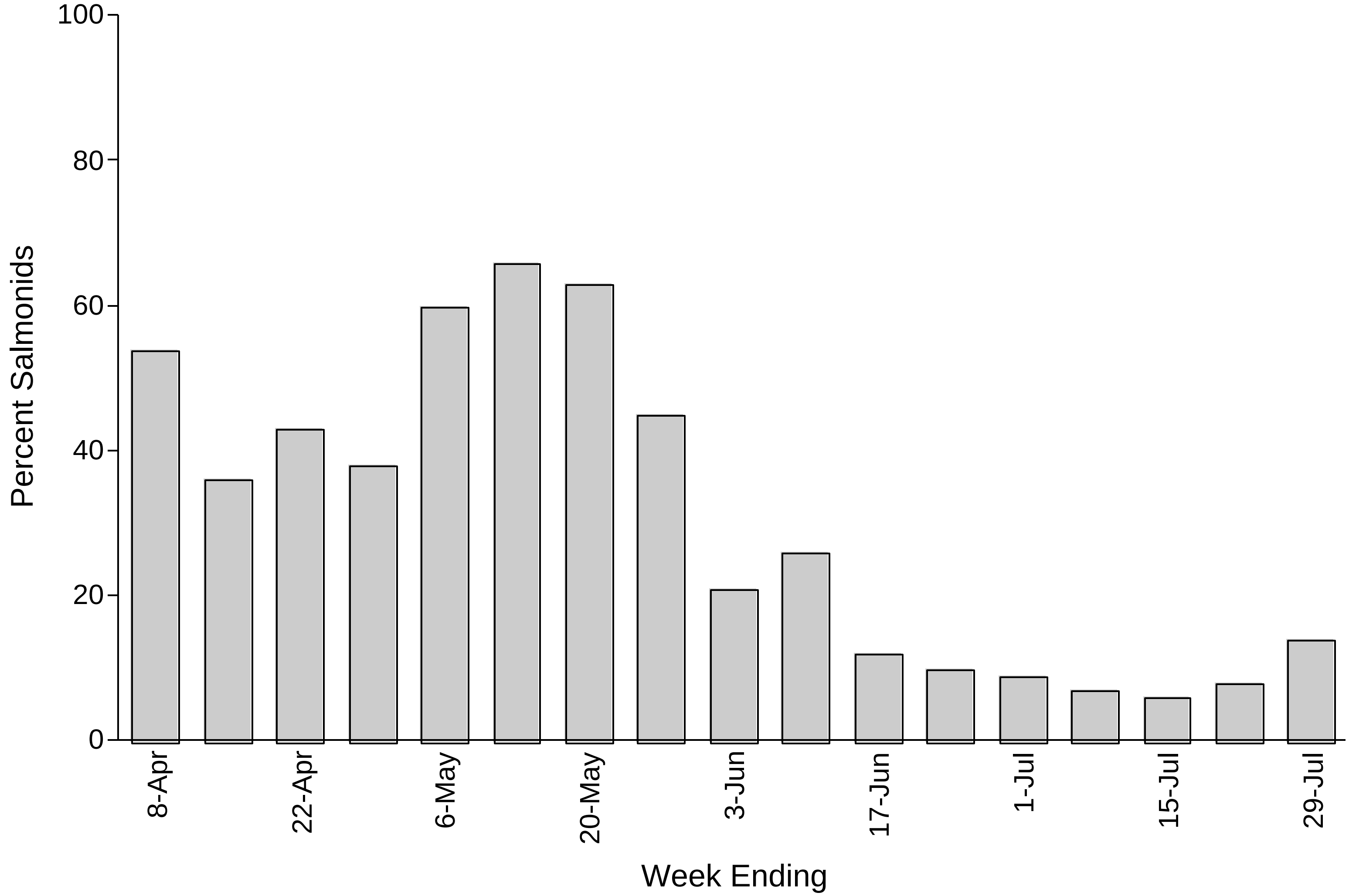


Figure 6. Weekly proportions of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island in 2007.

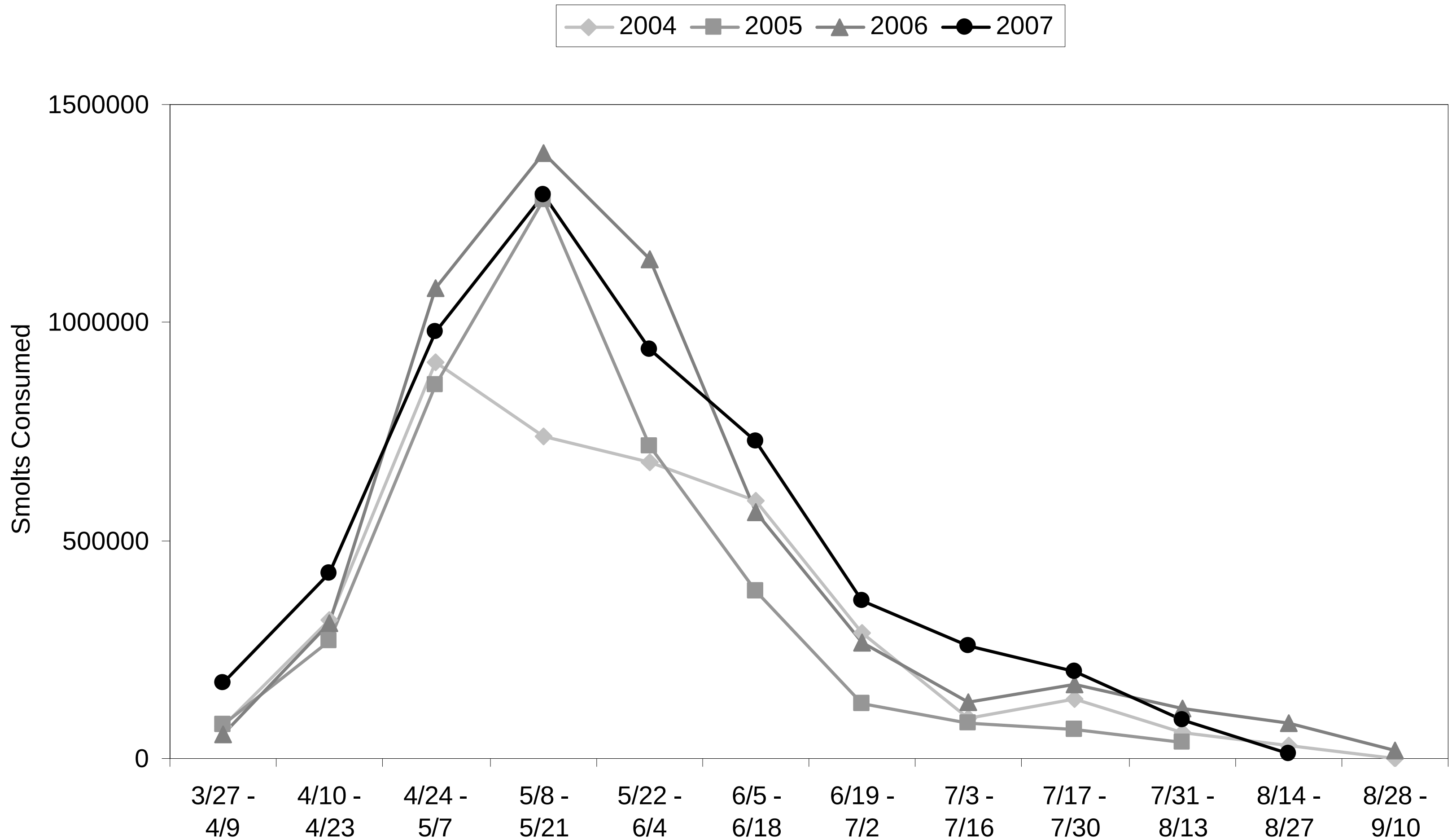


Figure 7. Estimated consumption of salmonid smolts by Caspian terns nesting on East Sand Island in the Columbia River estuary, broken into two-week periods across the breeding season during 2004-2007. Each data point includes steelhead, coho salmon, sockeye salmon, and yearling and sub-yearling Chinook salmon.

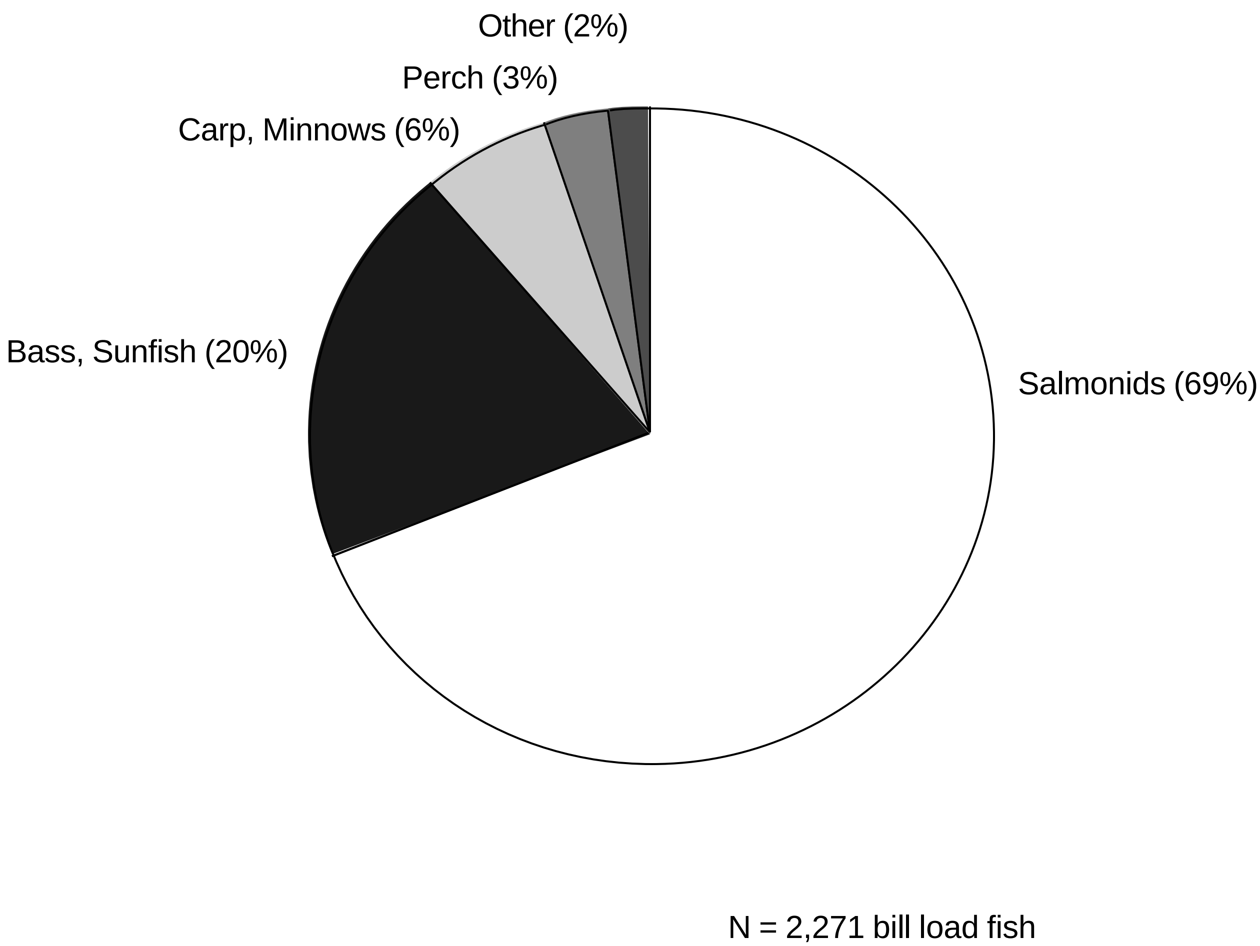


Figure 8. Diet composition of Caspian terns nesting on Crescent Island in 2007 (see text for methods of calculation).

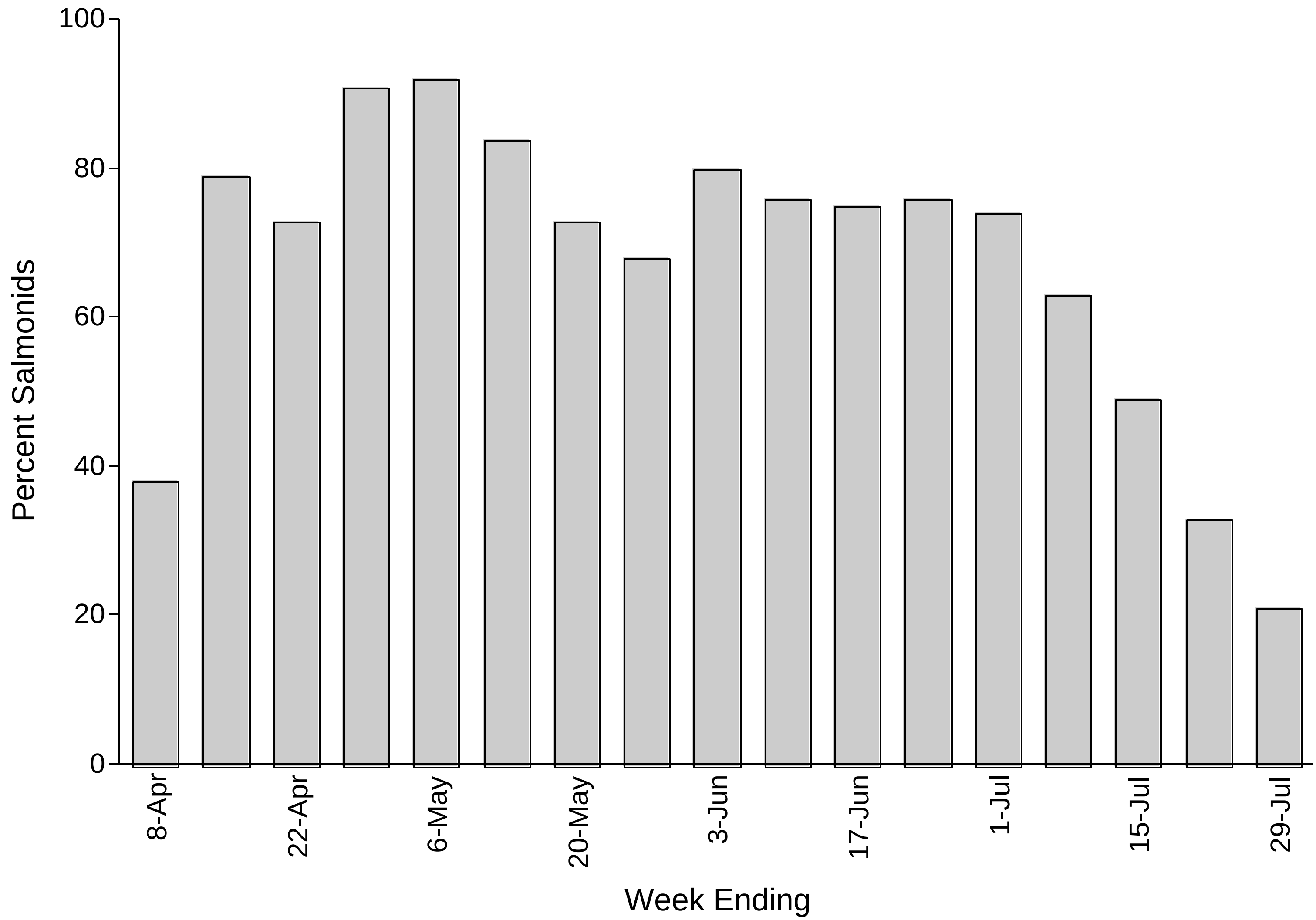


Figure 9. Weekly proportions of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island in 2007.

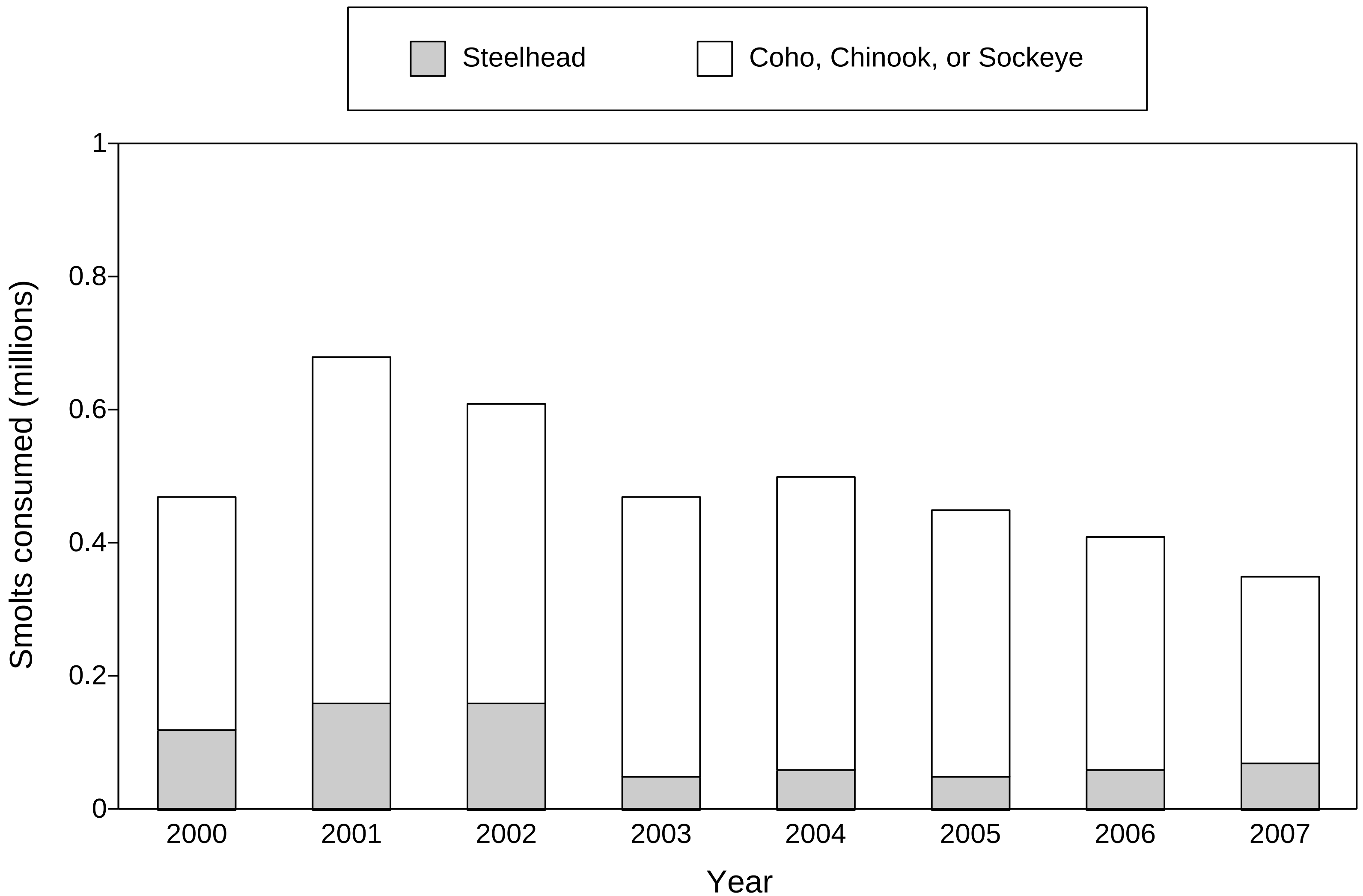


Figure 10. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting on Crescent Island during 2000-2007.

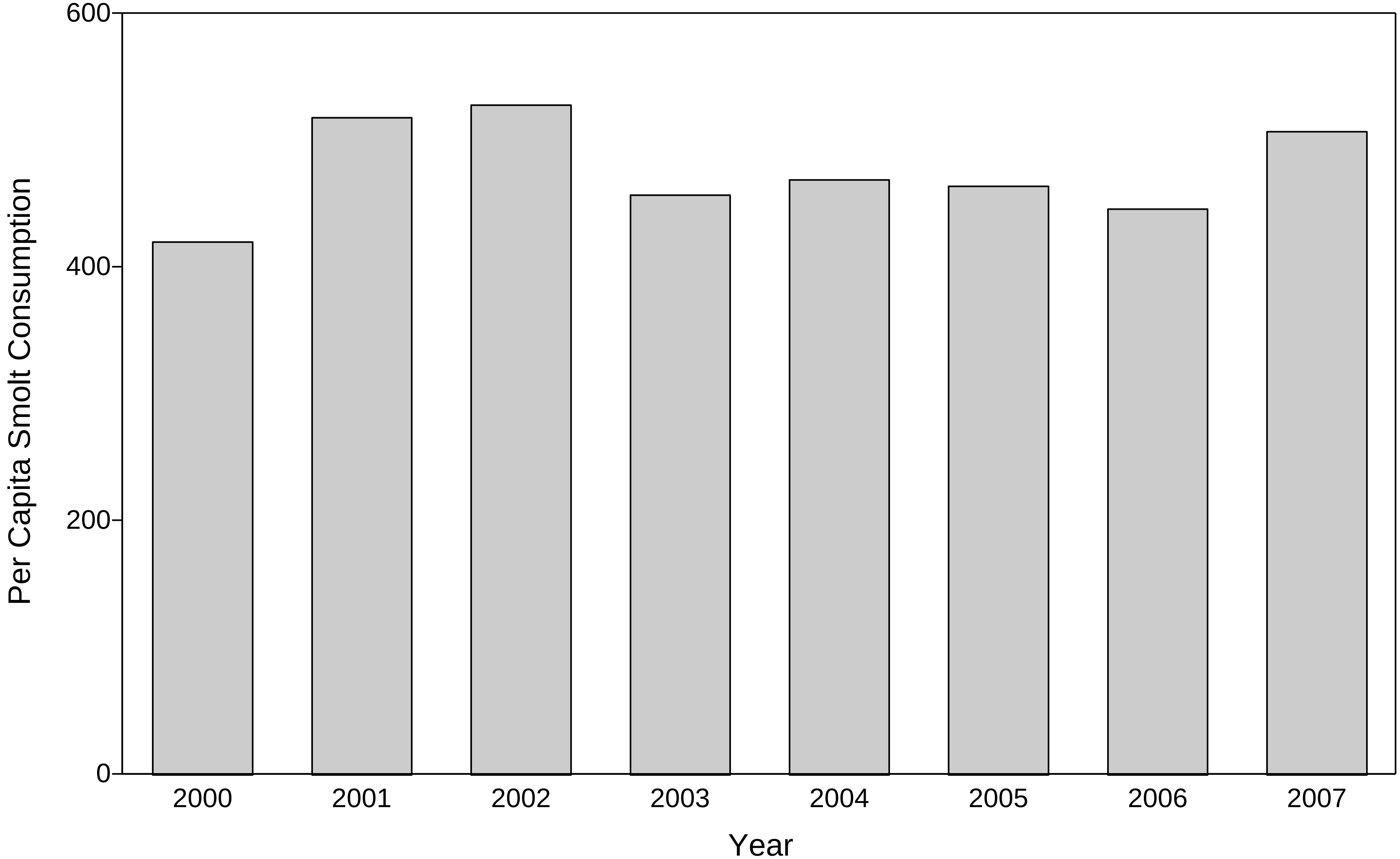


Figure 11. Estimated per capita annual consumption of juvenile salmonids by Caspian terns nesting on Crescent Island during 2000 - 2007.

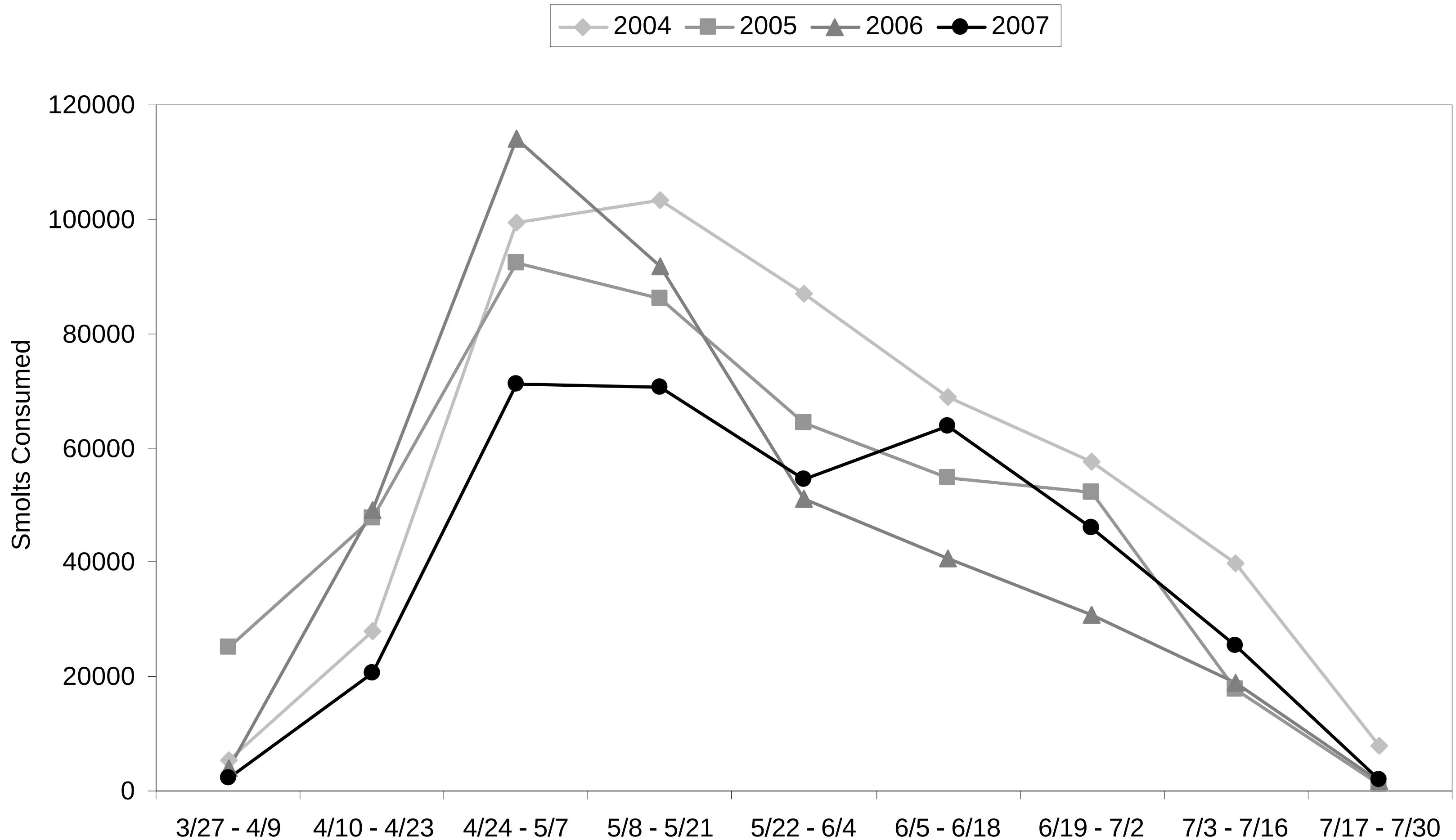


Figure 12. Estimated consumption of salmonid smolts by Caspian terns nesting on Crescent Island, broken into two-week periods across the breeding season during 2004-2007. Each data point includes steelhead, coho salmon, sockeye salmon, and yearling and sub-yearling Chinook salmon.

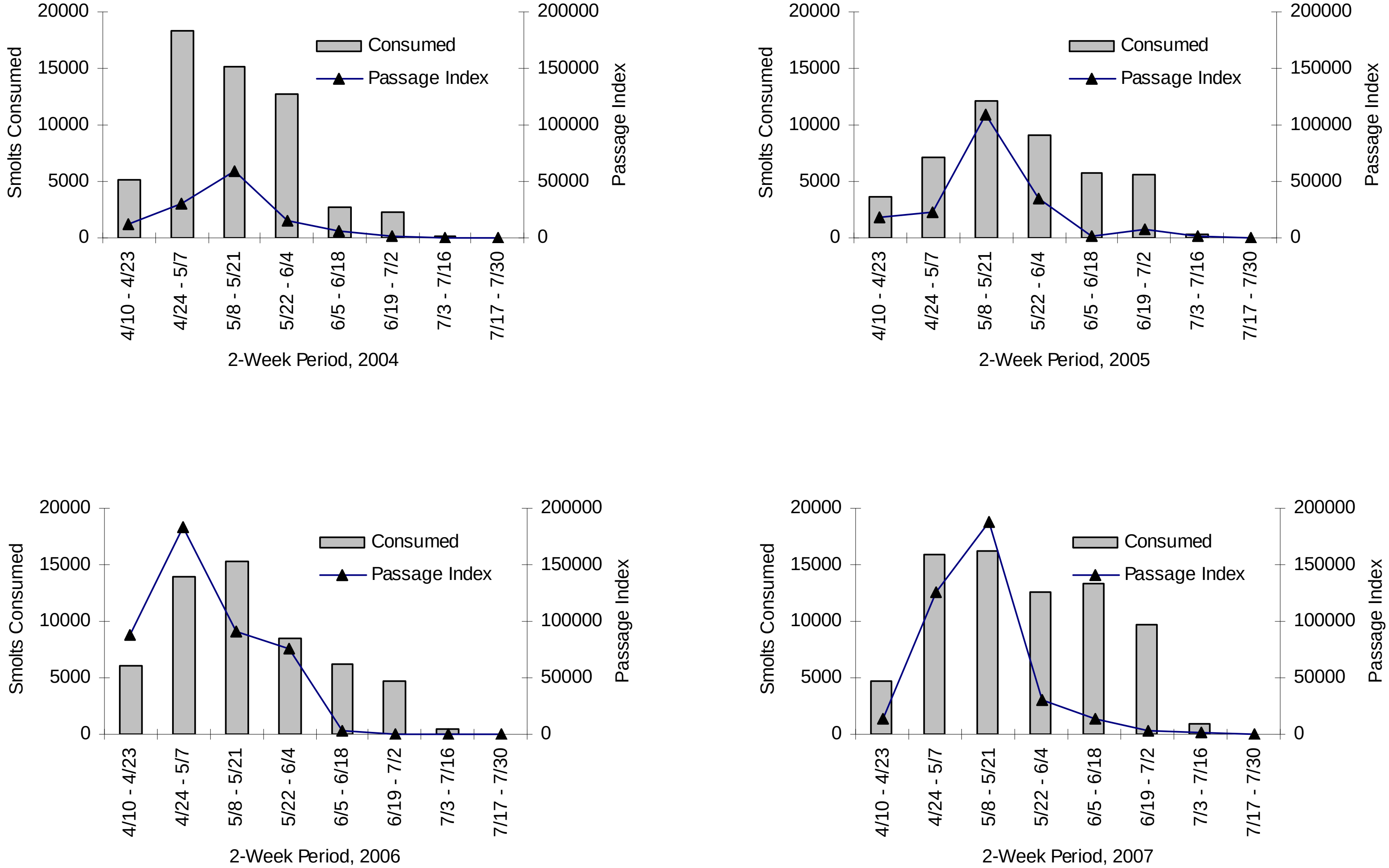


Figure 13. Estimated consumption of steelhead by Crescent Island terns during 2004-2007, broken into two-week periods. Passage index is for steelhead smolts passing McNary Dam on the mid-Columbia River (FPC 2007).

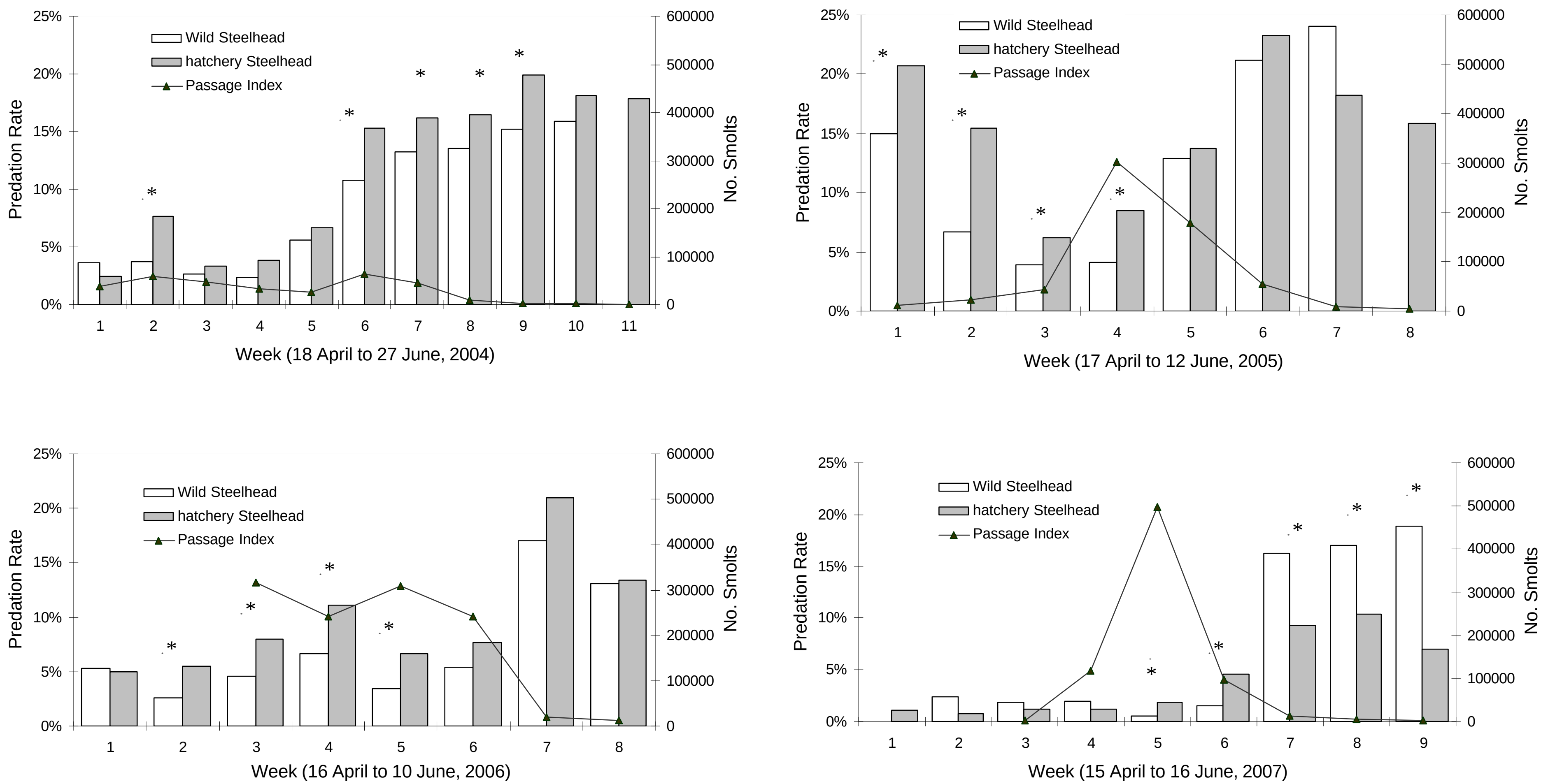


Figure 14. Weekly estimated predation rates on hatchery- and wild-origin steelhead from the Snake River by Caspian terns nesting on Crescent Island during 2004-2007. Predation rates are based on the proportion of PIT-tagged steelhead interrogated while passing Lower Monumental Dam that were subsequently recovered on the tern colony. Passage index is for steelhead smolts passing Lower Monumental Dam on the Snake River. Rates are corrected for on-colony detection efficiency but not for deposition rate. Asterisks denote a significant difference ($P < 0.01$) in the proportion of hatchery- and wild-origin smolts consumed by terns.

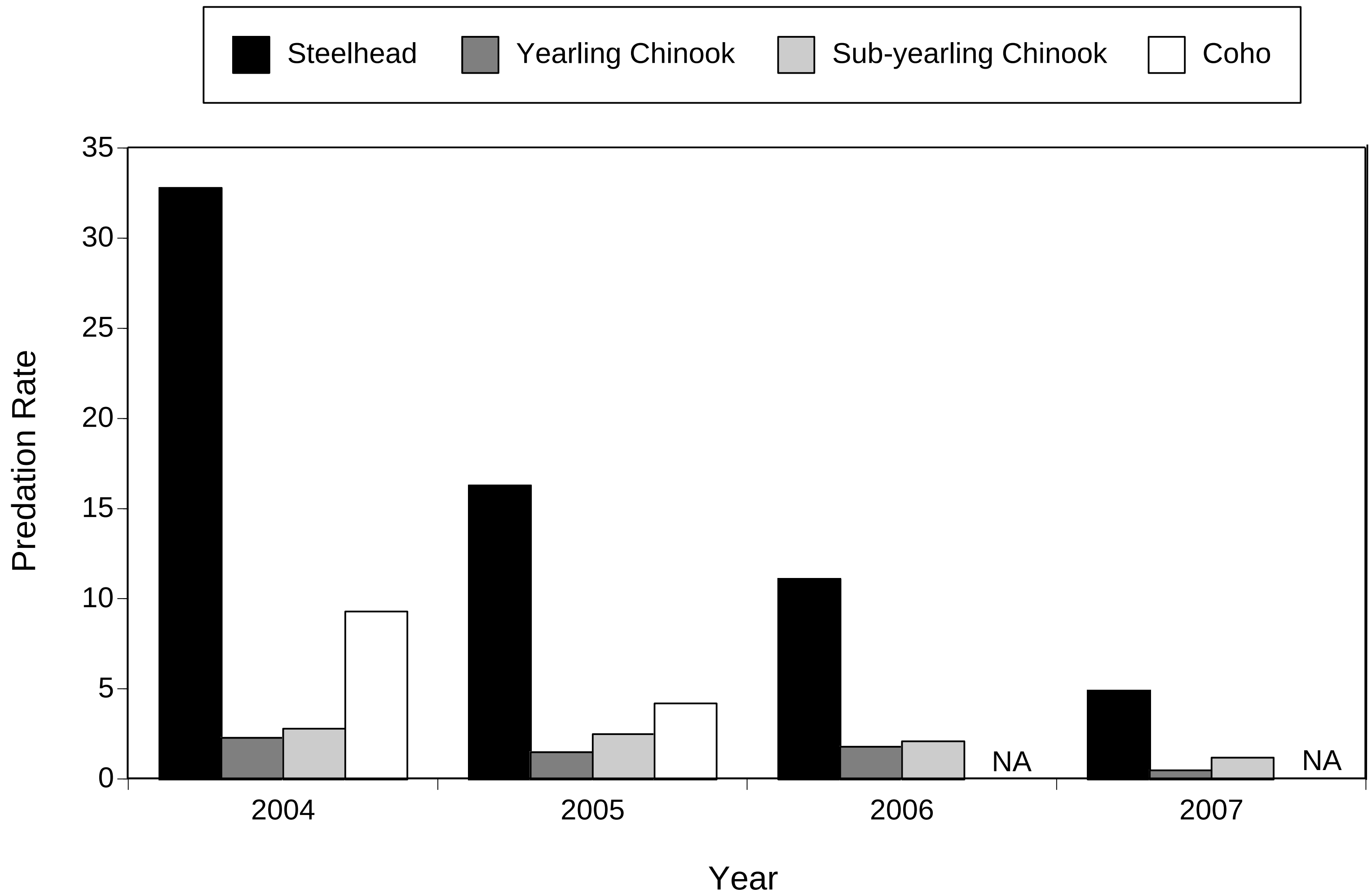


Figure 15. Predation rates on in-river PIT-tagged salmonid smolts from the Snake River by Caspian terns nesting on Crescent Island during 2004-2007. Adjusted predation rates (i.e., corrected for detection efficiency and deposition rate) are based on the proportion of smolts interrogated while passing Lower Monumental Dam that were subsequently detected on the tern colony.

Figure 16. Predation rates (based on PIT tag recoveries) on Snake River steelhead by Caspian terns nesting on Crescent Island during 2004 - 2007. For each year, predation rates are shown for in-river migrants plus for the entire Snake River steelhead ESU (including smolts that were transported past the dams and not subject to predation from Crescent Island terns). The proportion of the steelhead run that was transported was 96.4%, 94.0%, 75.3%, and 41.1% in 2004, 2005, 2006, and 2007, respectively.

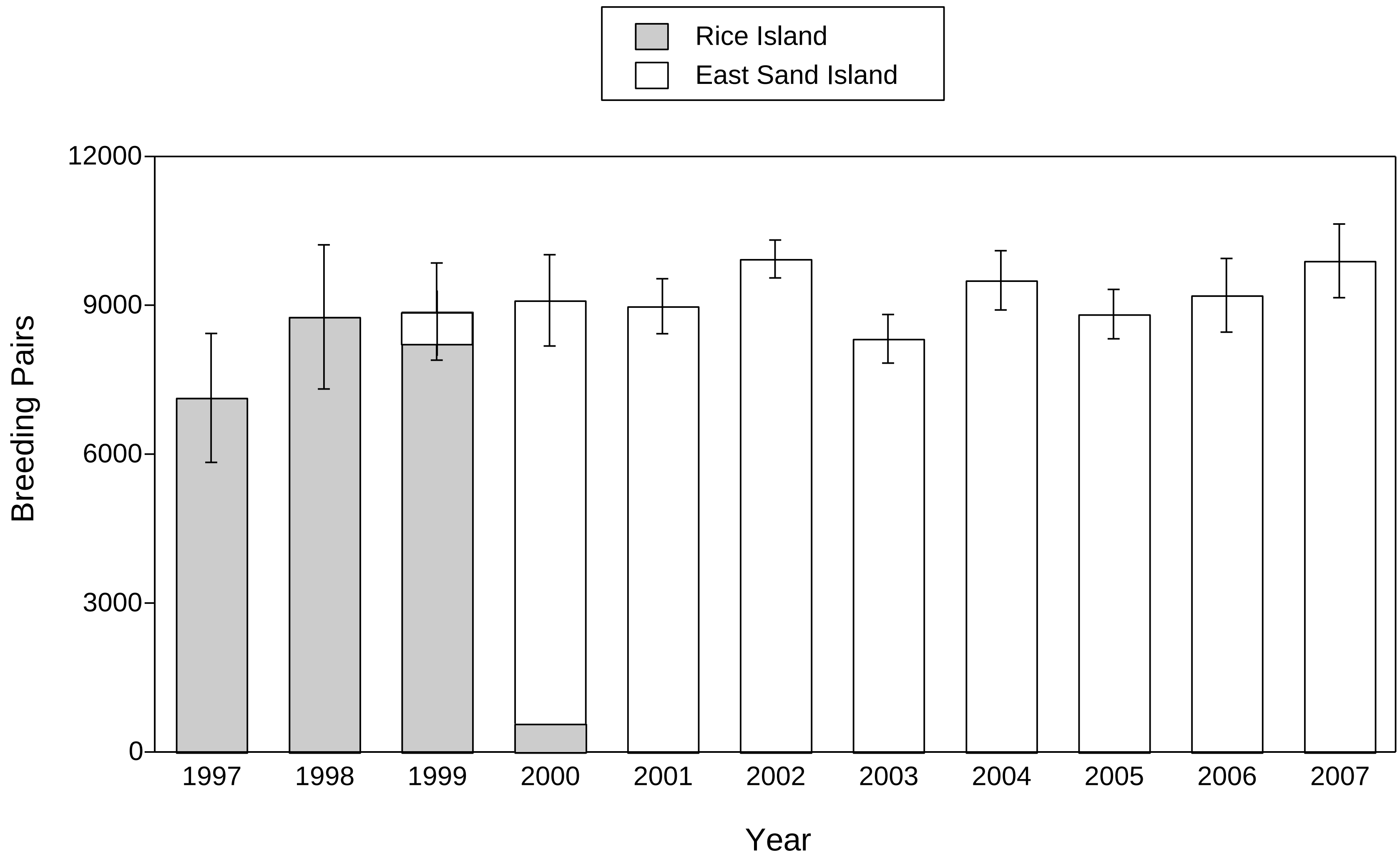


Figure 17. Caspian tern colony size in the Columbia River estuary during 1997 - 2007.

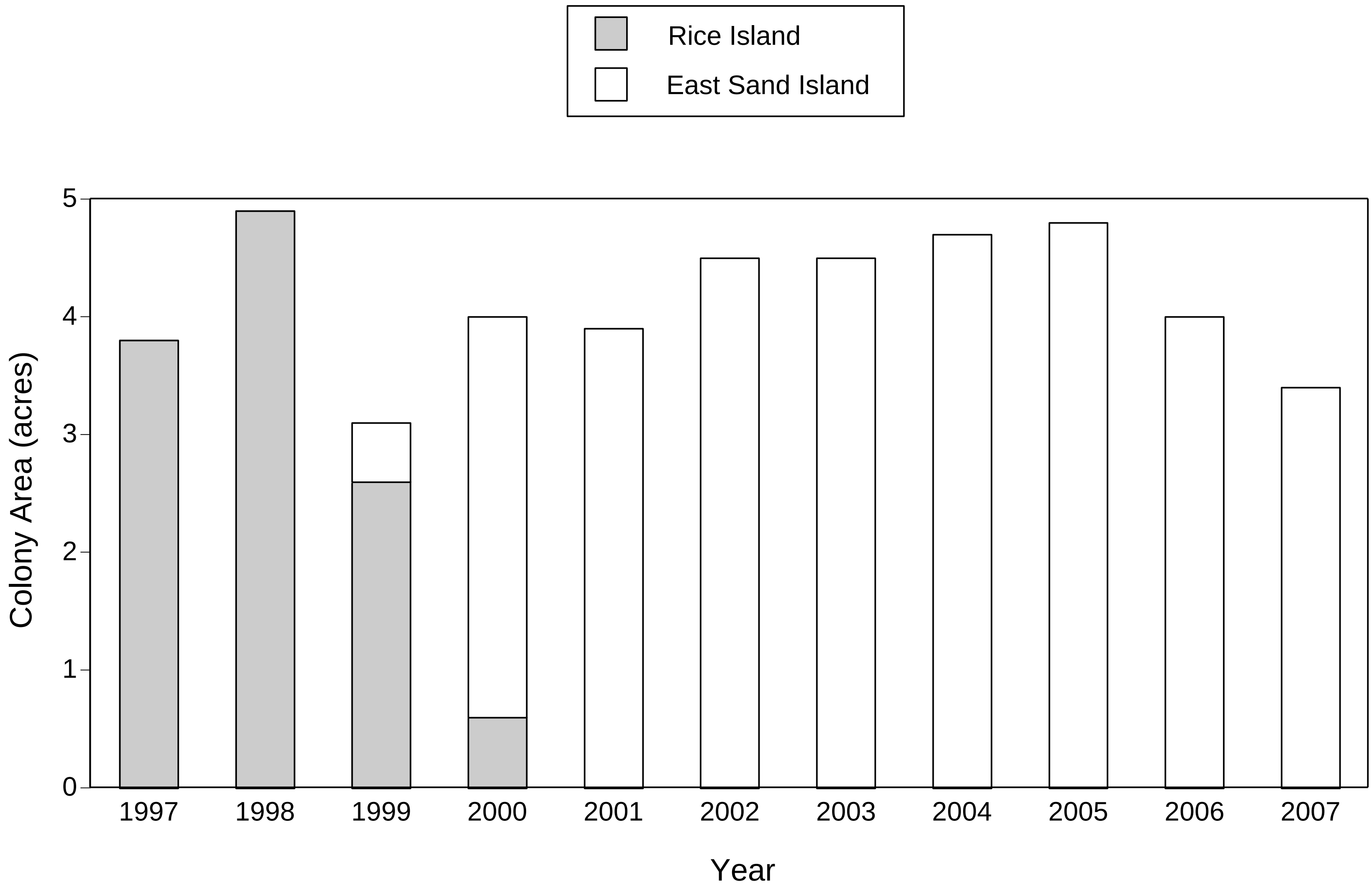


Figure 18. Area occupied by nesting Caspian terns at colonies in the Columbia River estuary during 1997 - 2007.

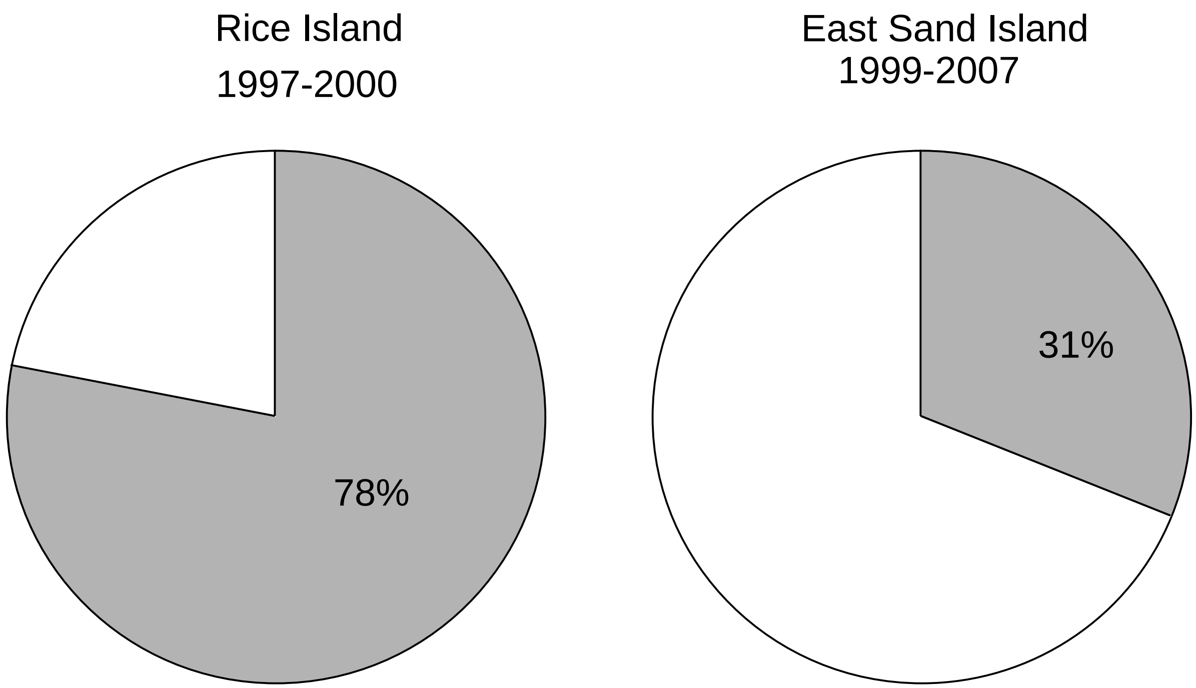


Figure 19. Mean annual proportion of juvenile salmonids in the diet of Caspian terns nesting on Rice Island (n = 4 years) and on East Sand Island (n = 9 years) in the Columbia River estuary during 1997-2007.

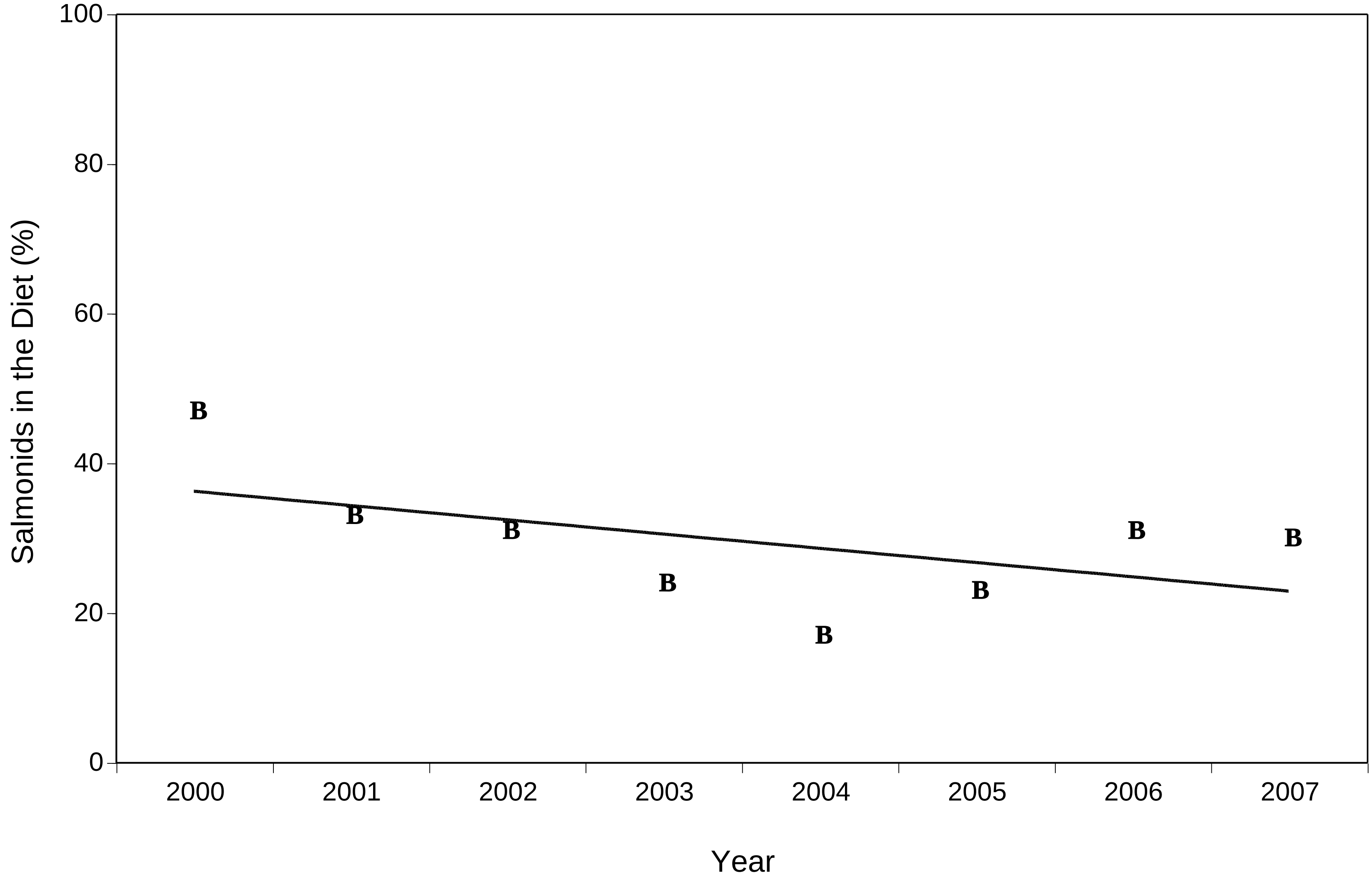


Figure 20. Proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island during 2000-2007.

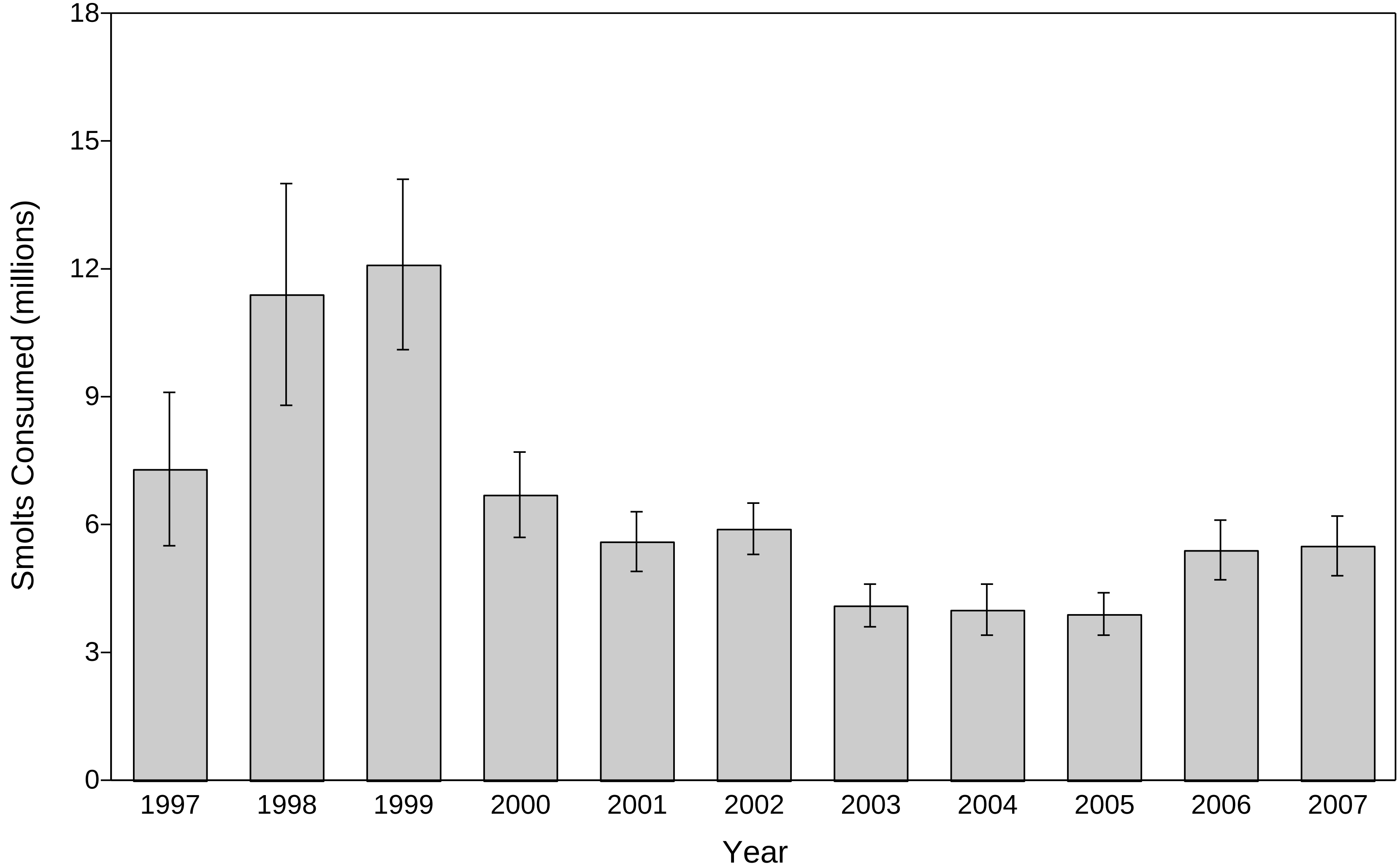


Figure 21. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting in the Columbia River estuary during 1997 - 2007.

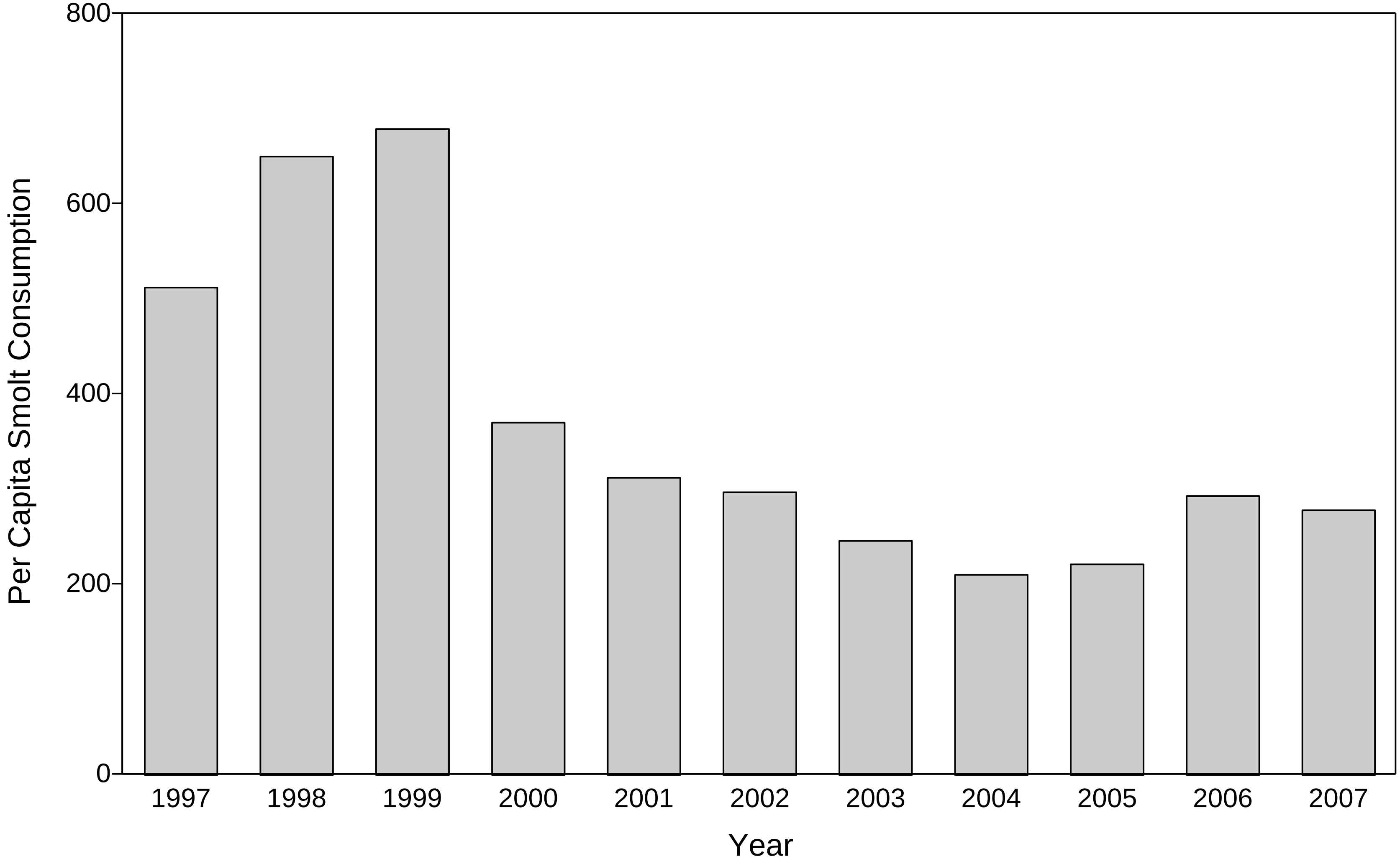


Figure 22. Estimated per capita annual consumption of juvenile salmonids by Caspian terns nesting in the Columbia River estuary during 1997 - 2007.

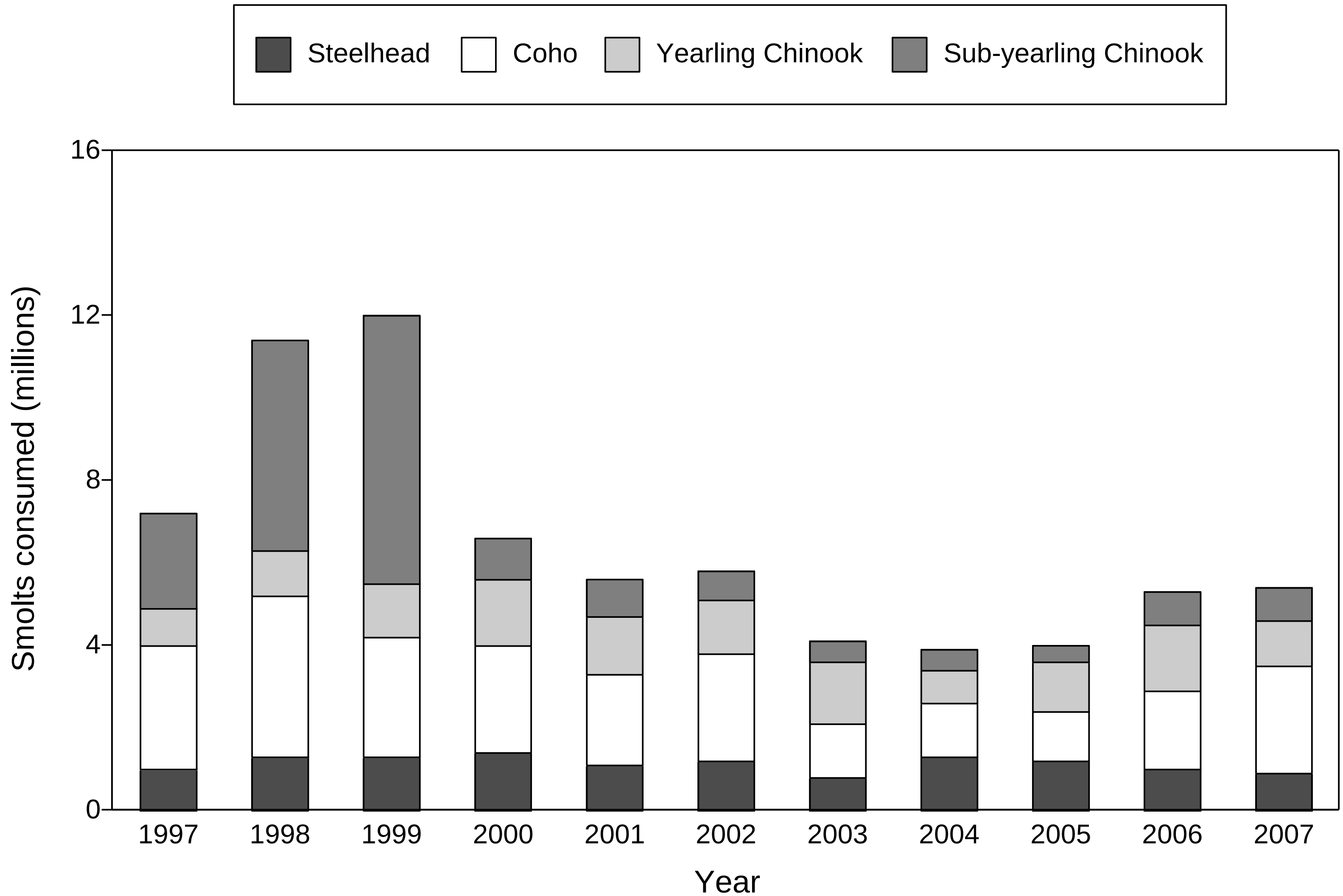


Figure 23. Estimated total annual consumption of four species of juvenile salmonids by Caspian terns nesting in the Columbia River estuary during 1997-2007.

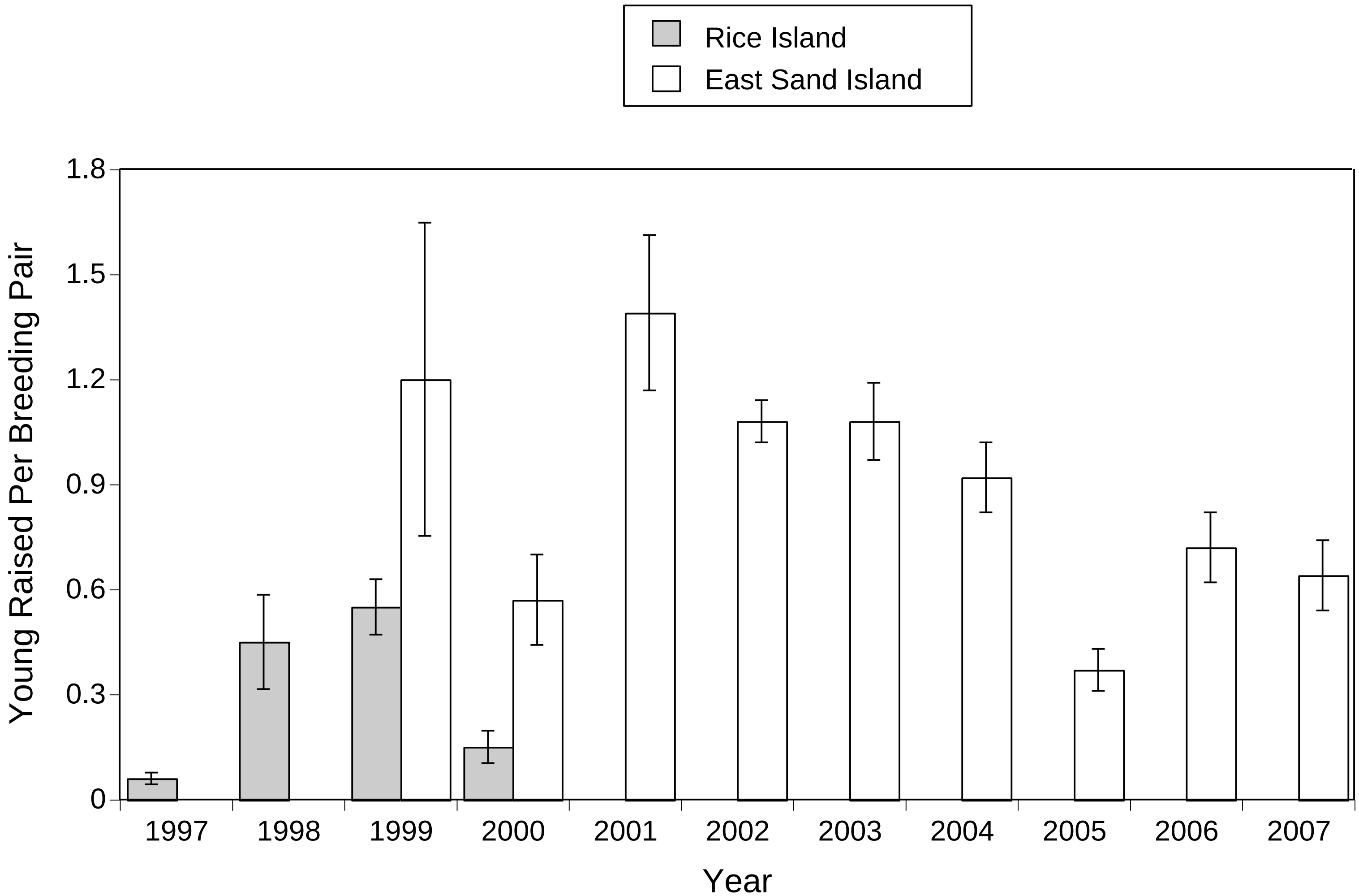


Figure 24. Average productivity (young fledged per breeding pair) of Caspian terns nesting at two colonies in the Columbia River estuary during 1997 - 2007.

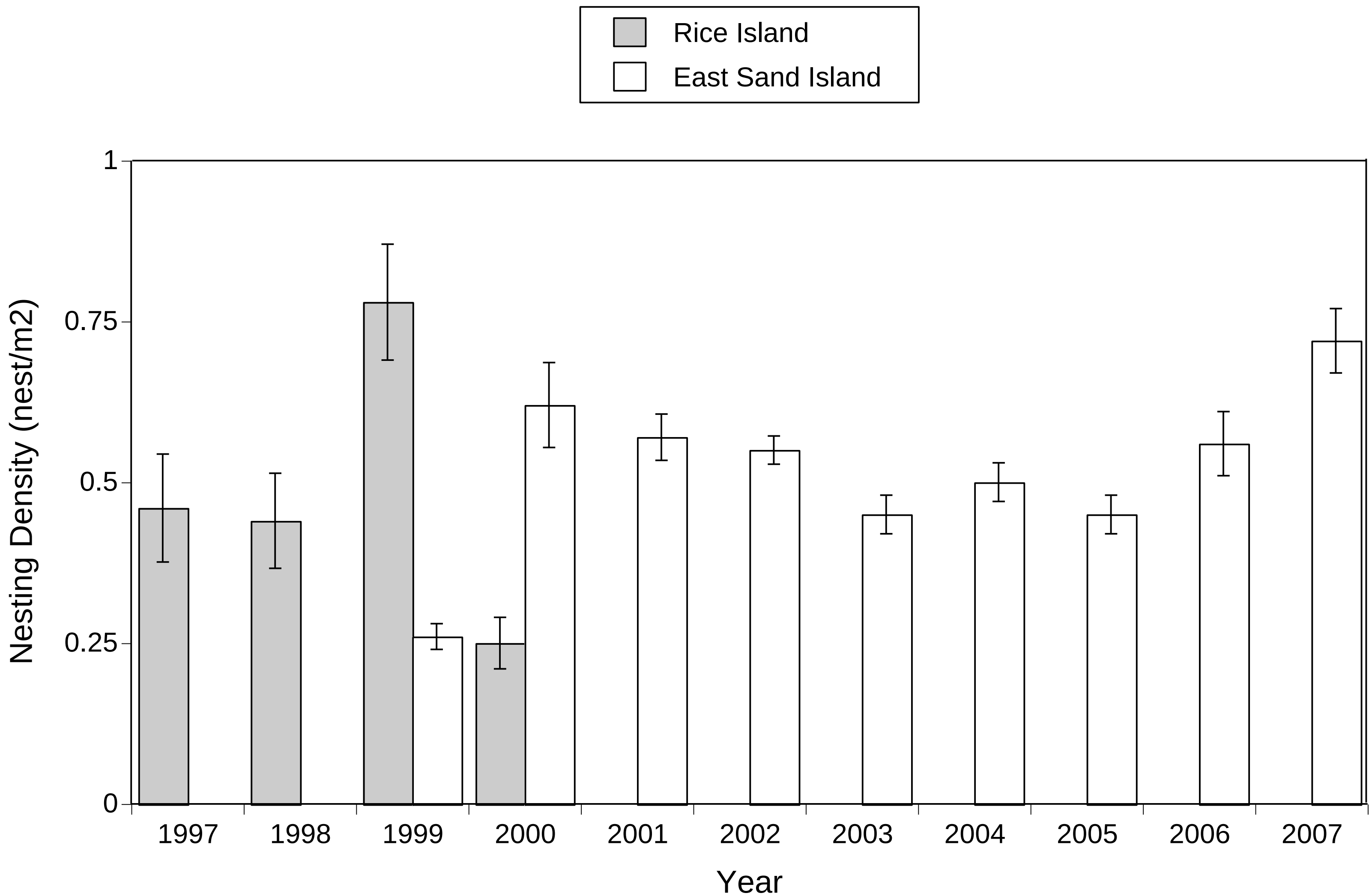


Figure 25. Average nest density for Caspian terns nesting at two colonies in the Columbia River estuary during 1997 - 2007.

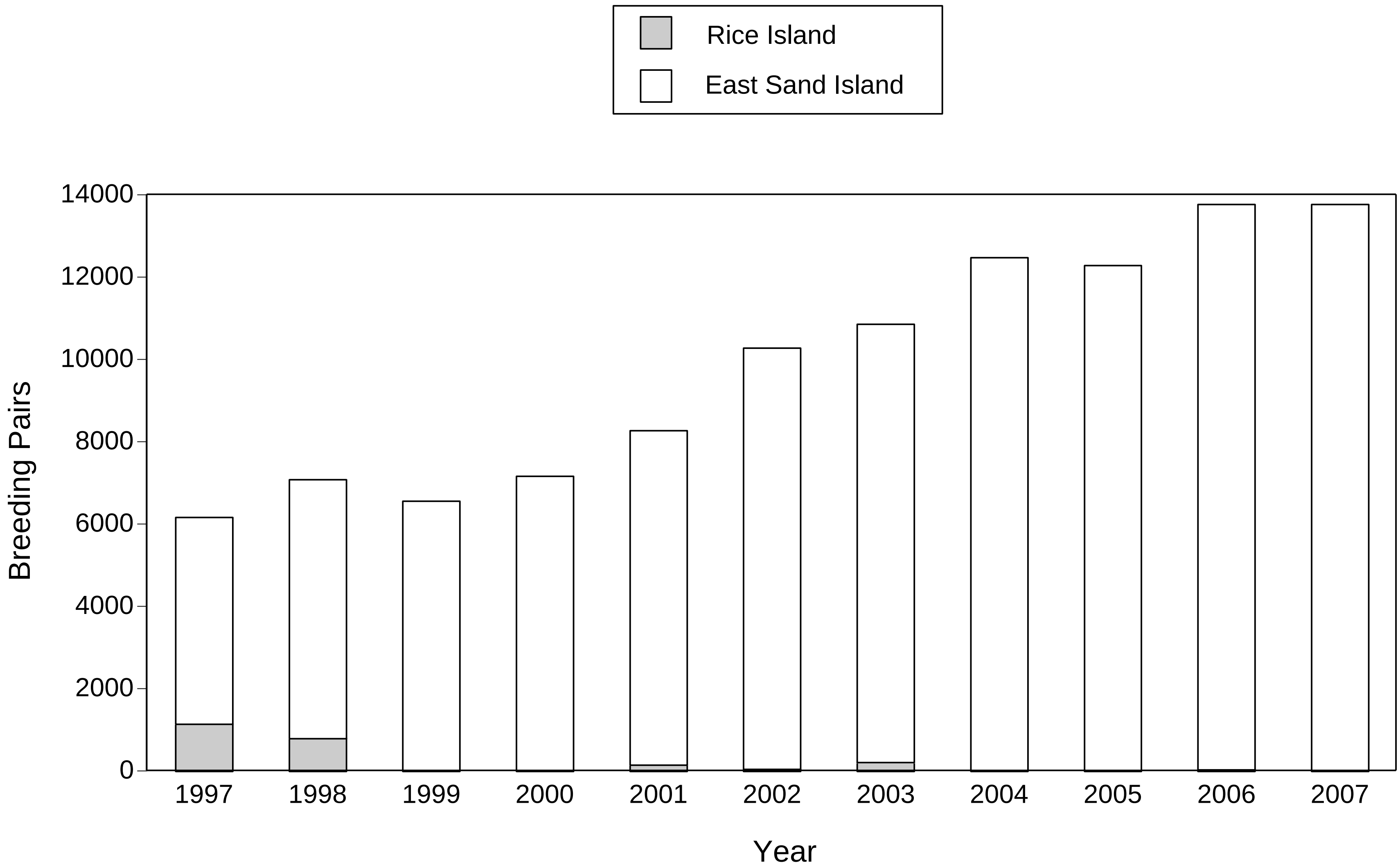


Figure 26. Numbers of breeding pairs of double-crested cormorants nesting at two colonies in the Columbia River estuary during 1997 - 2007.

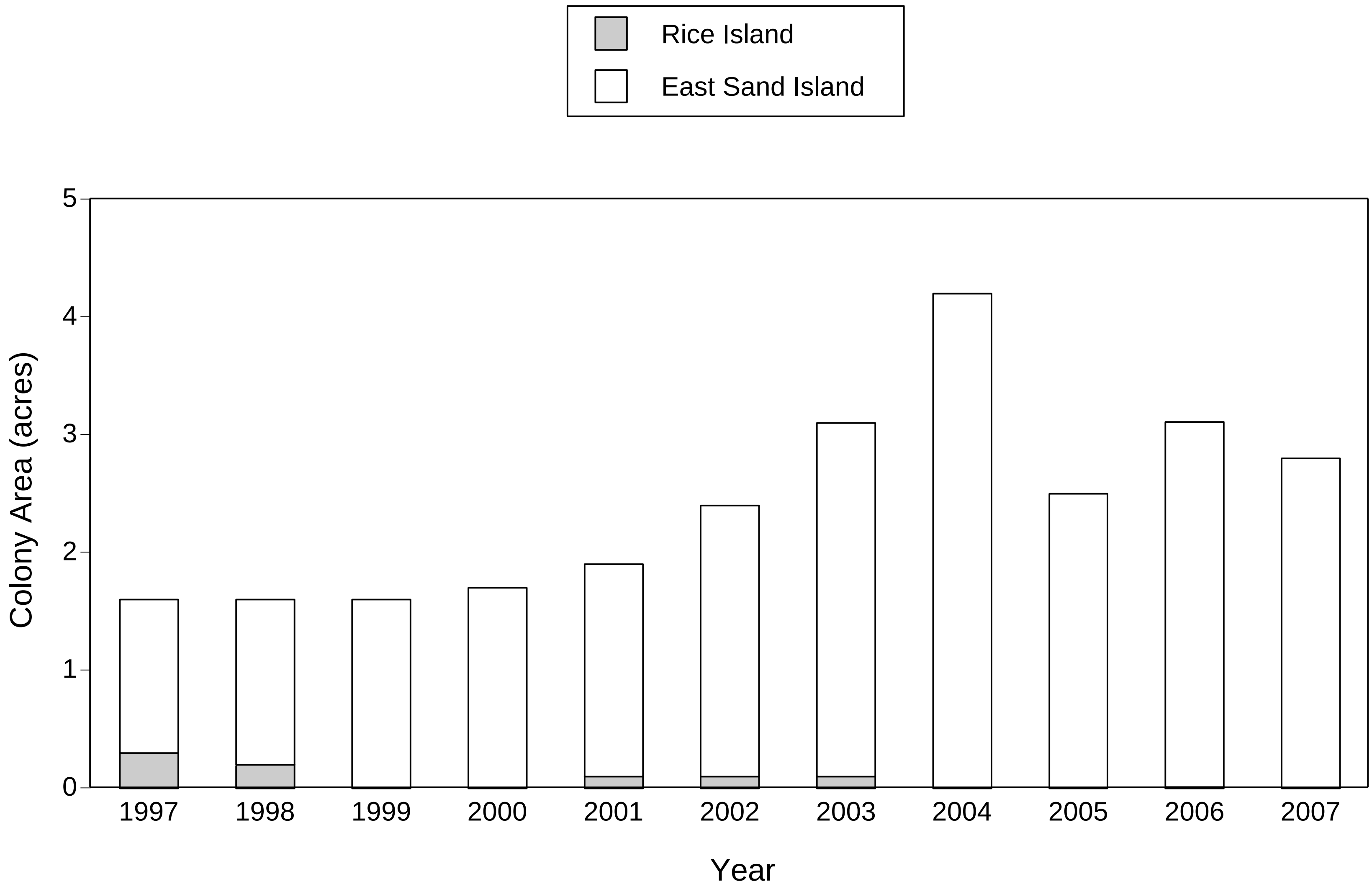


Figure 27. Area occupied by nesting double-crested cormorants at two colonies in the Columbia River estuary during 1997 - 2007.

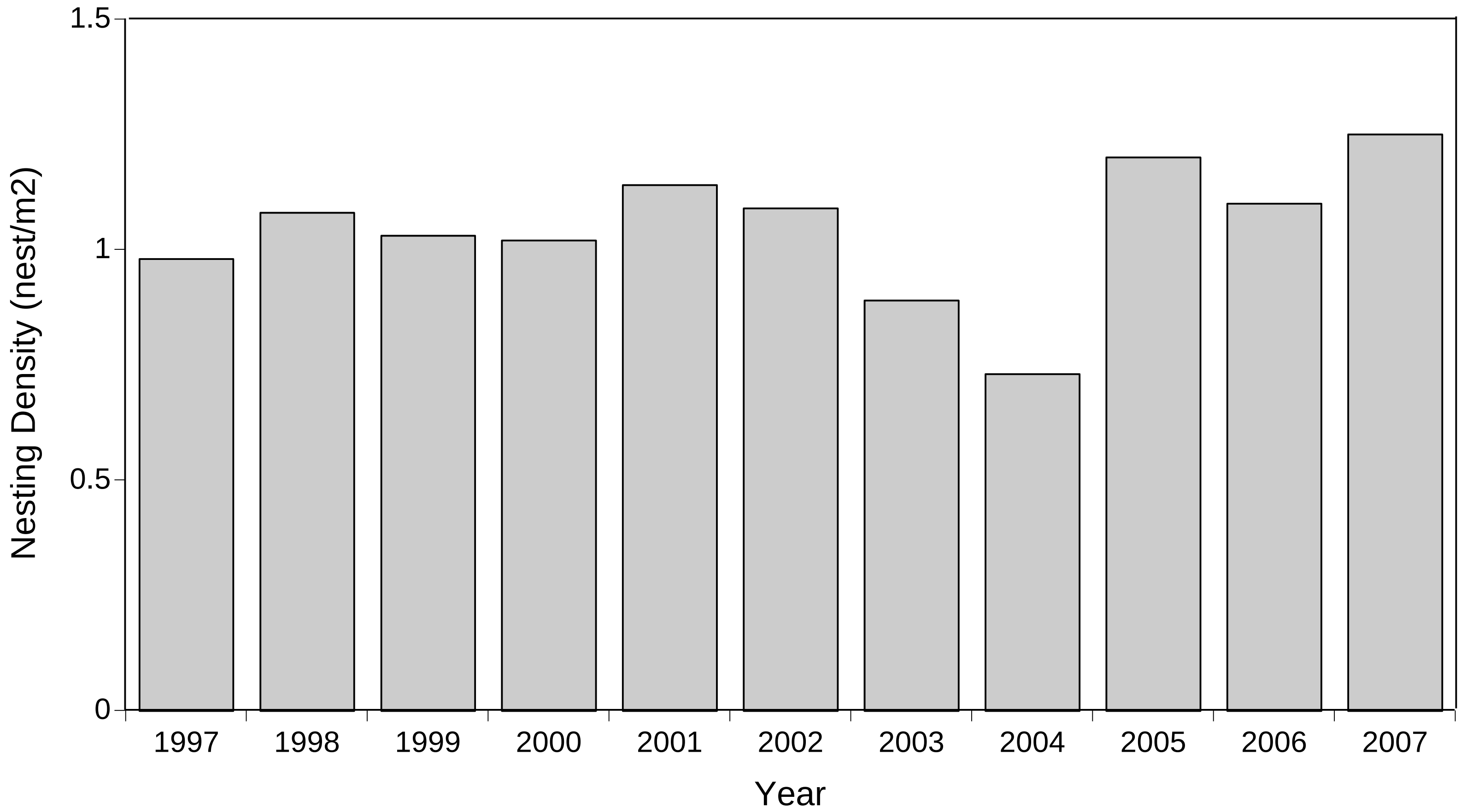


Figure 28. Average nest density for double-crested cormorants nesting on East Sand Island in the Columbia River estuary during 1997 - 2007.

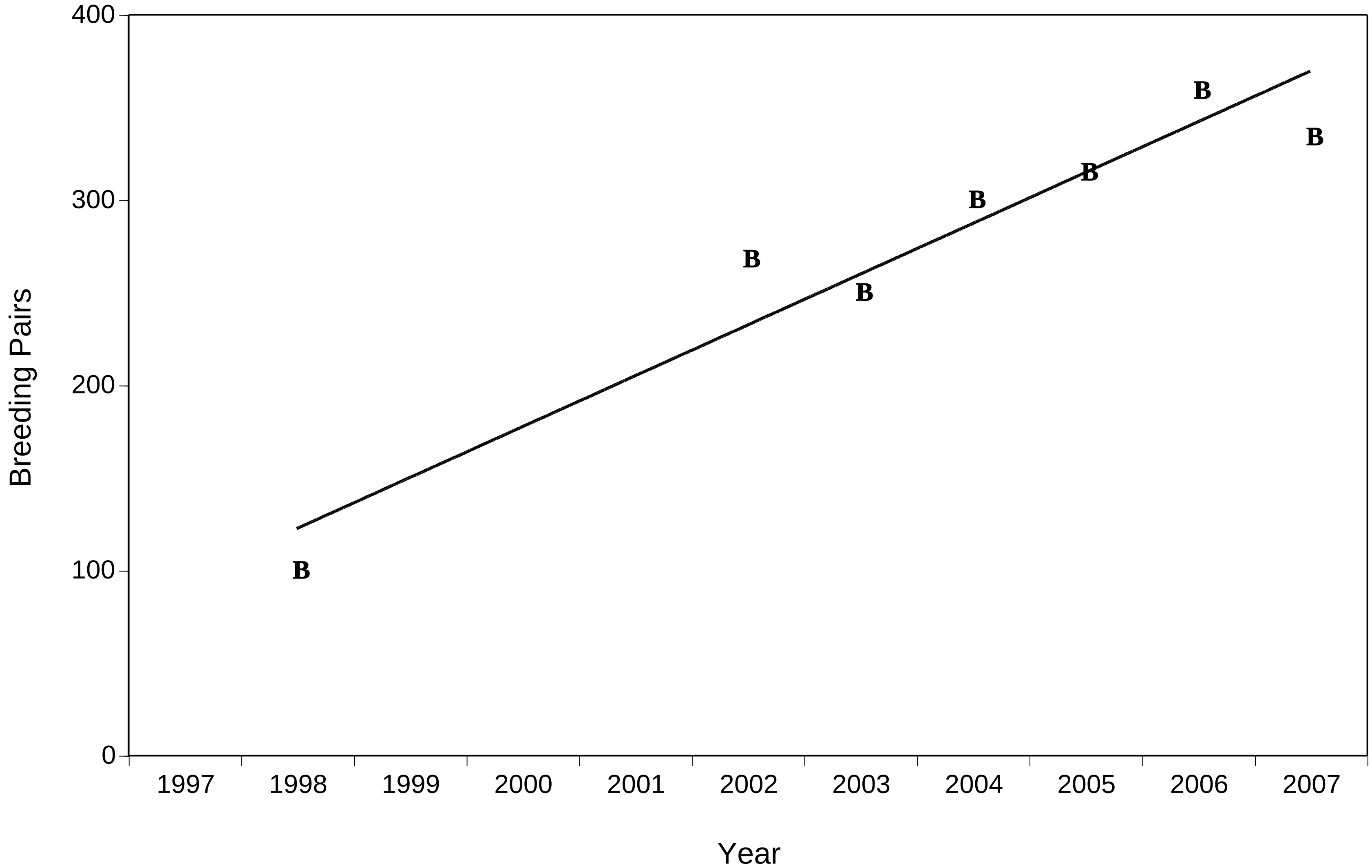


Figure 29. Population trends for double-crested cormorants nesting on Foundation Island during 1998-2007. Missing data points indicate that no colony count was conducted during that year.

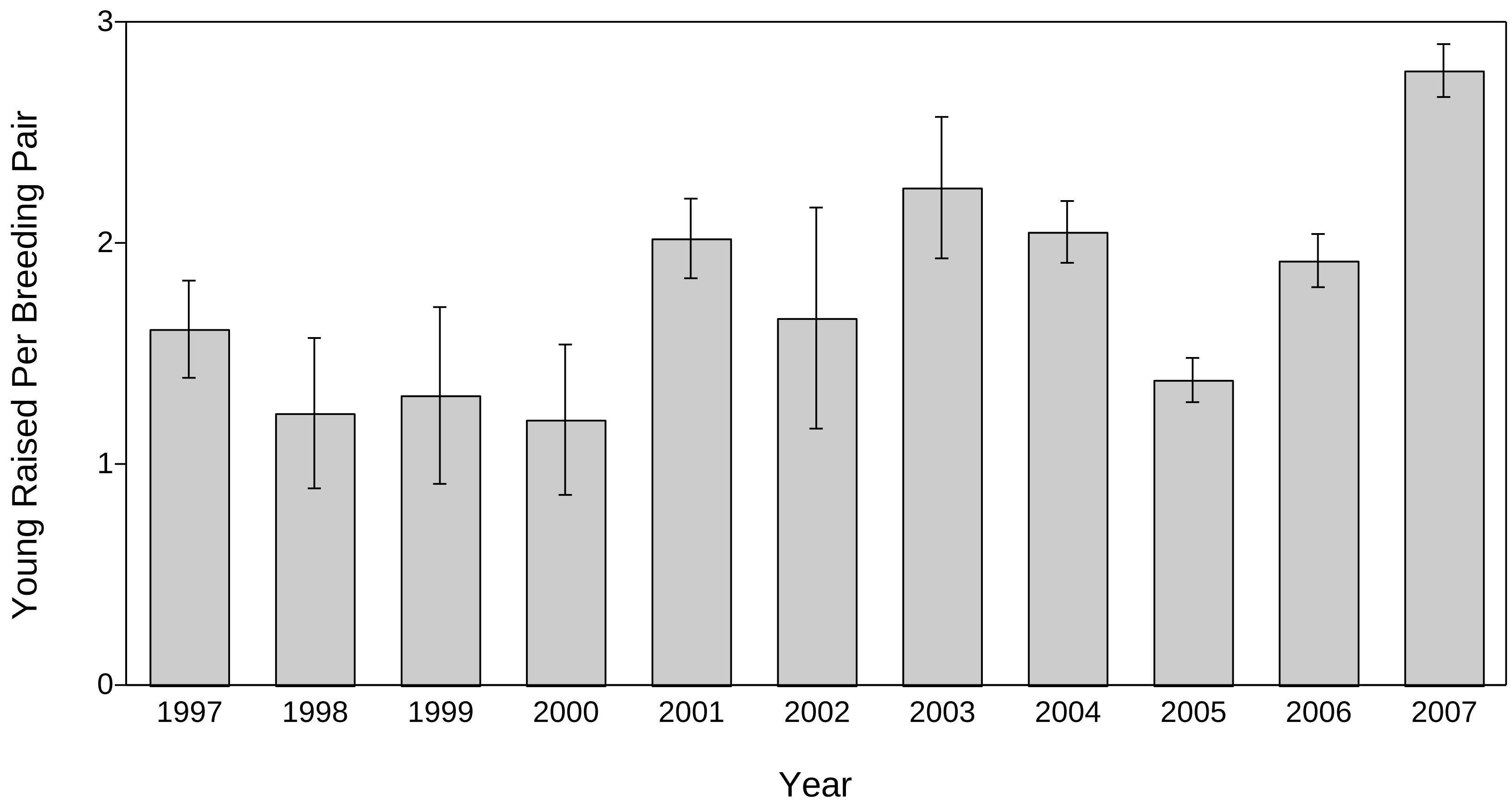
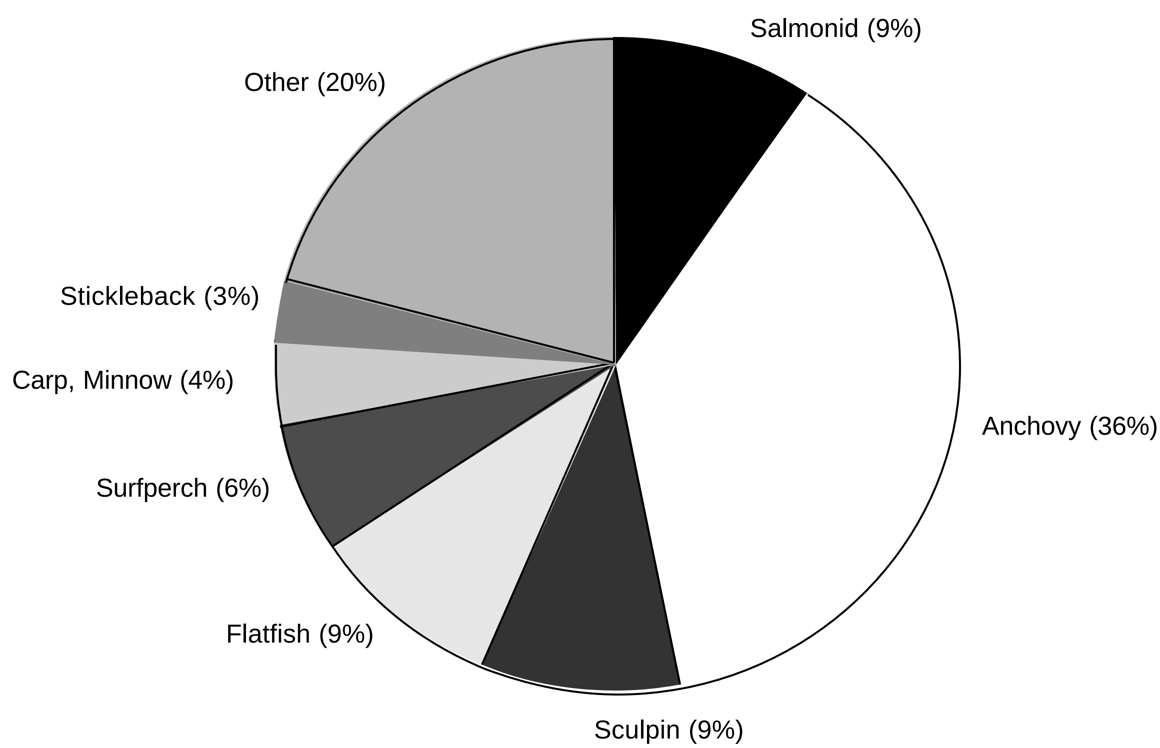


Figure 30. Average productivity (young fledged per breeding pair) of double-crested cormorants nesting on East Sand Island during 1997 - 2007.



N = 137 adult foregut samples

Figure 31. Diet composition of double-crested cormorants nesting on East Sand Island in 2007 (see text for methods of calculation).

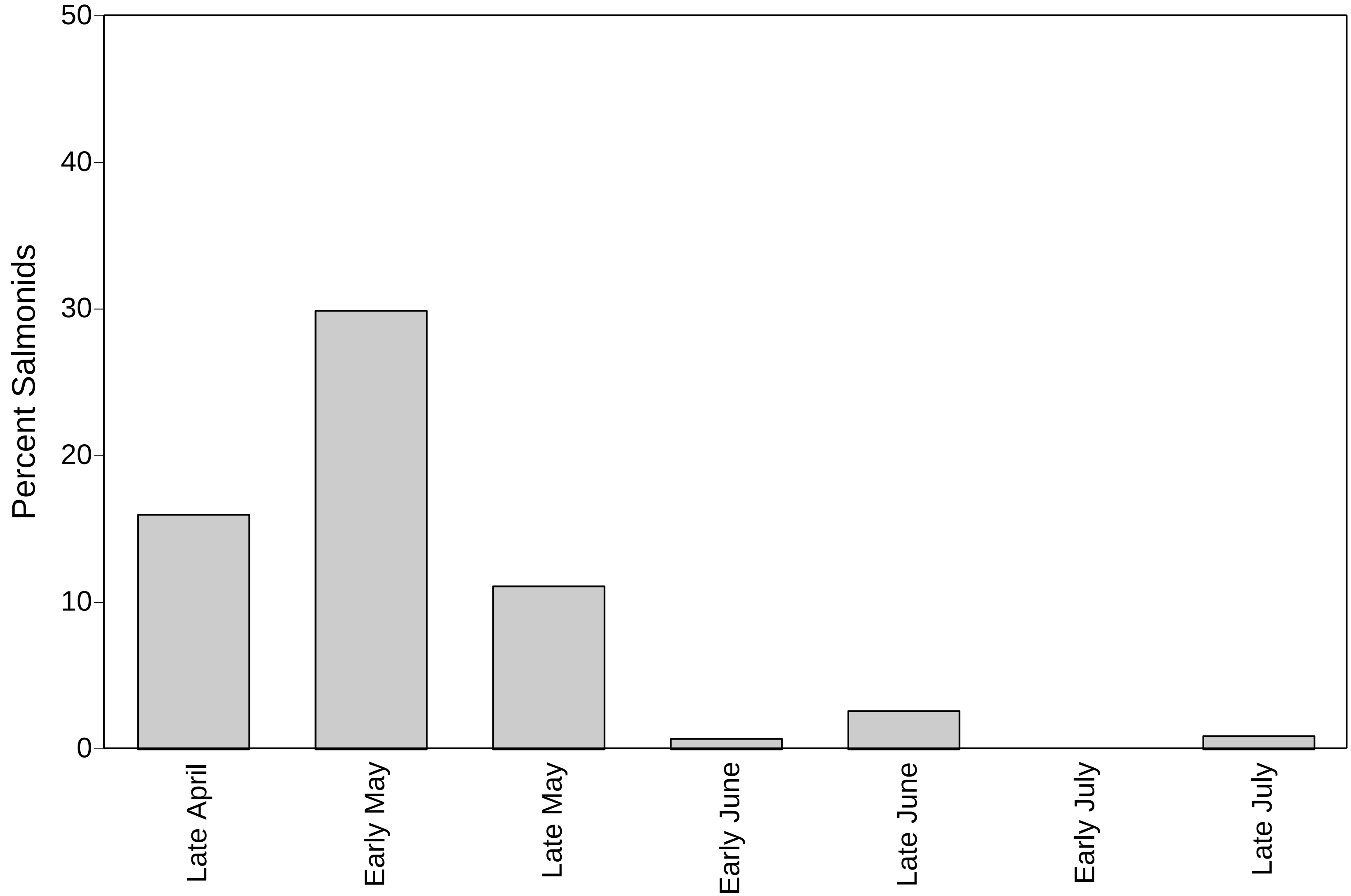


Figure 32. Bi-monthly proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island in the Columbia River estuary in 2007.

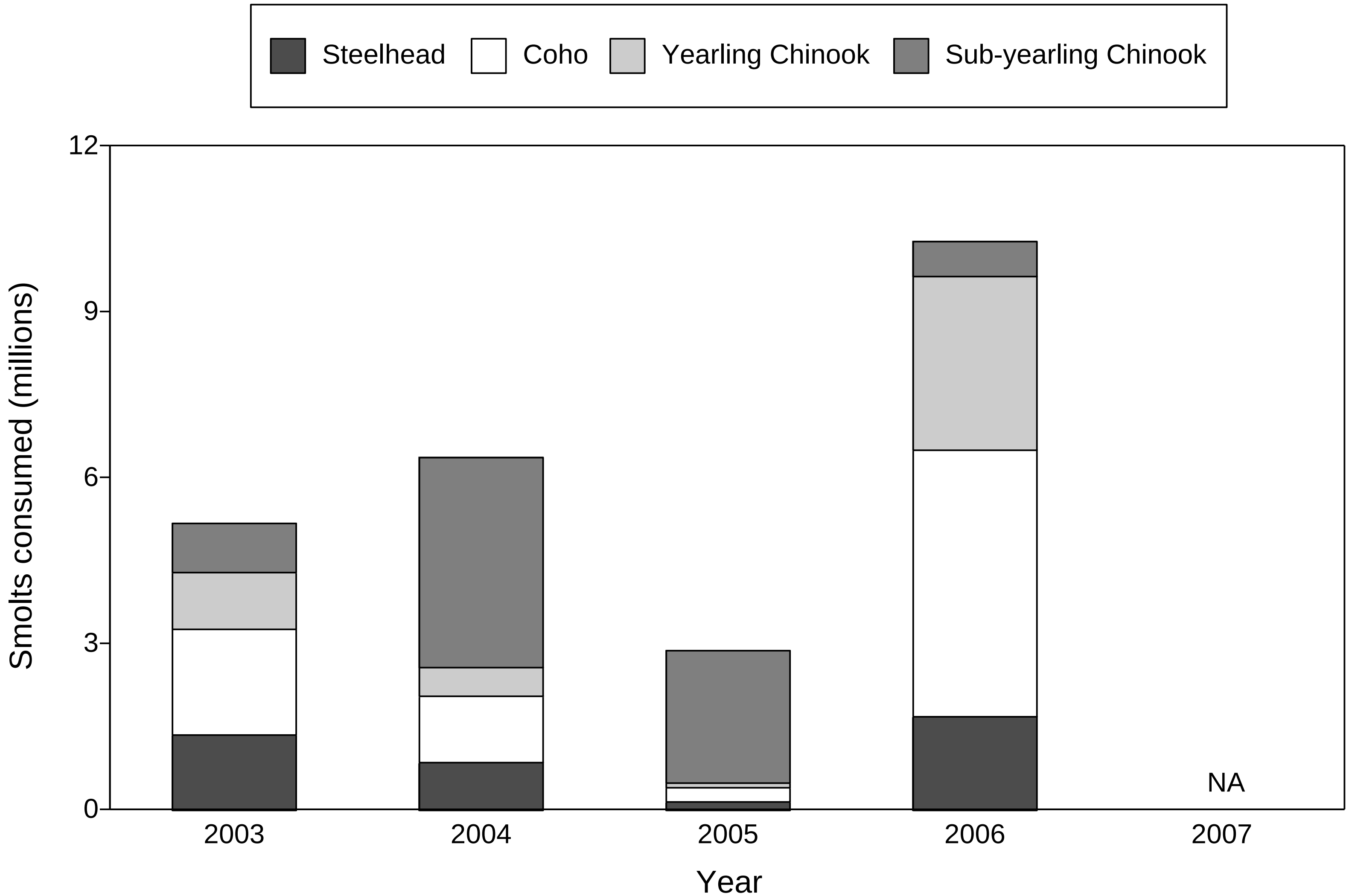


Figure 33. Estimated total annual consumption of four species of juvenile salmonids by double-crested cormorants nesting on East Sand Island in the Columbia River Estuary during 2003-2007.

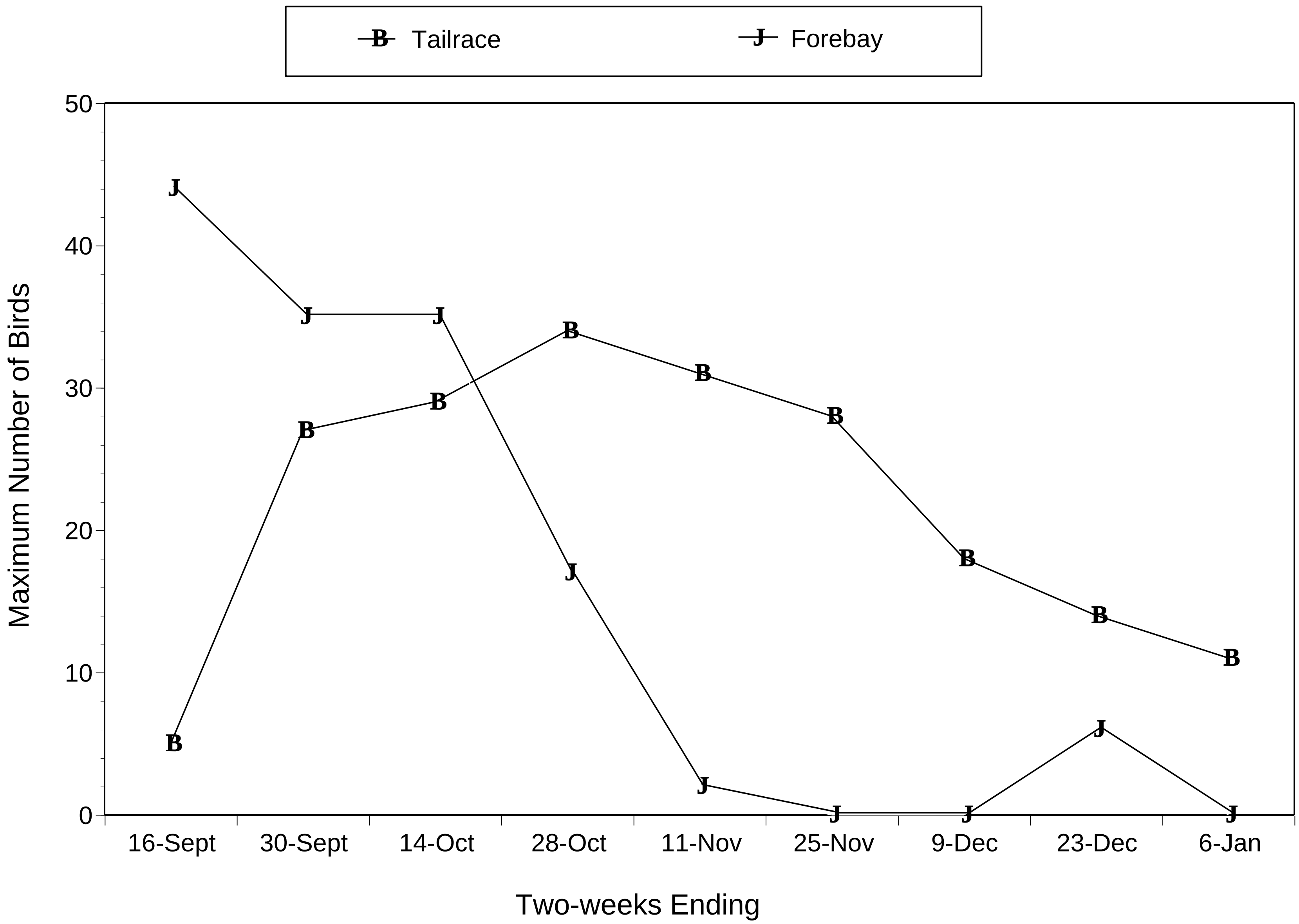


Figure 34. Maximum number of double-crested cormorants counted near Lower Granite Dam during two-week periods from September to December 2007.

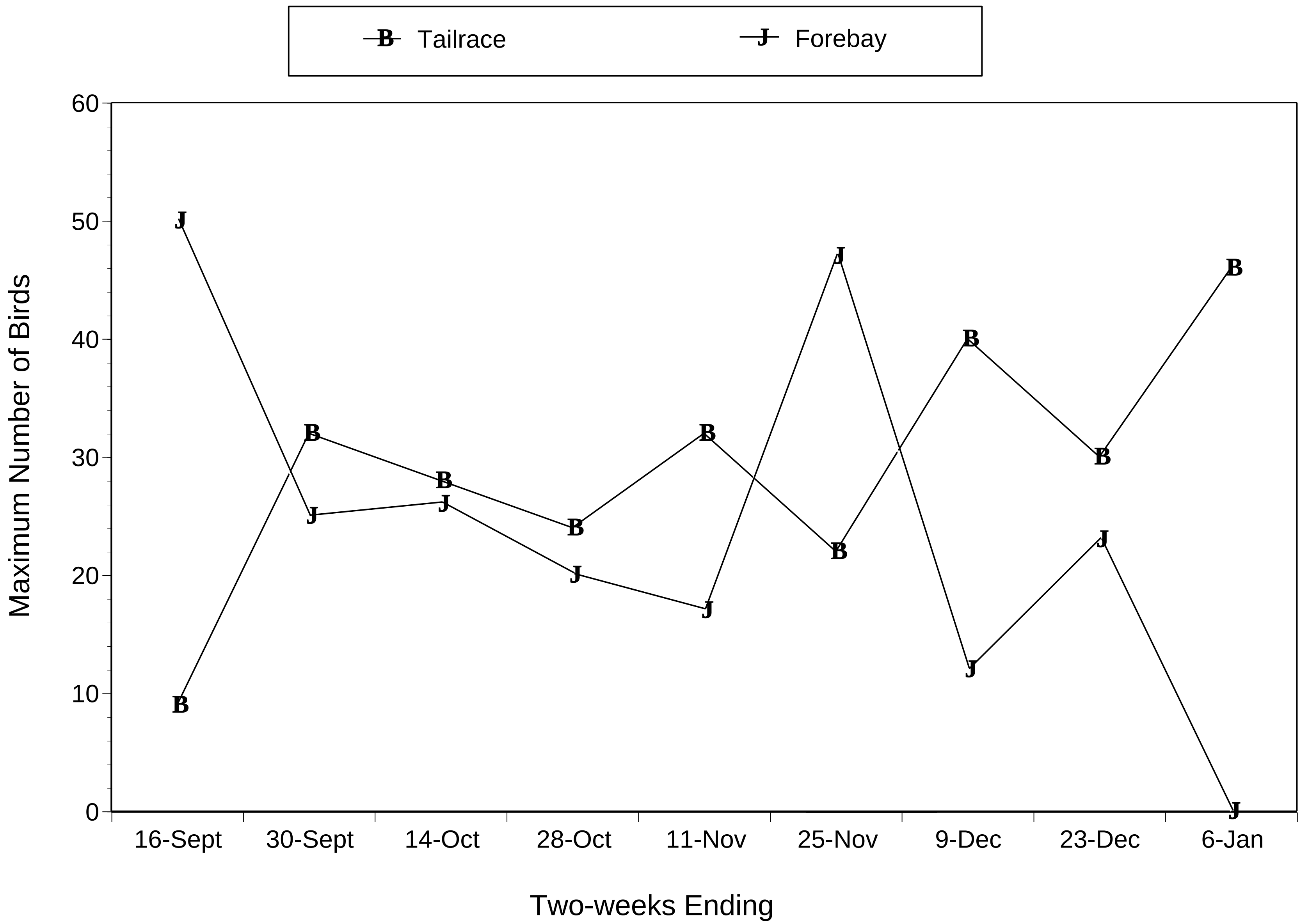


Figure 35. Maximum number of double-crested cormorants counted near Little Goose Dam during two-week periods from September to December 2007.

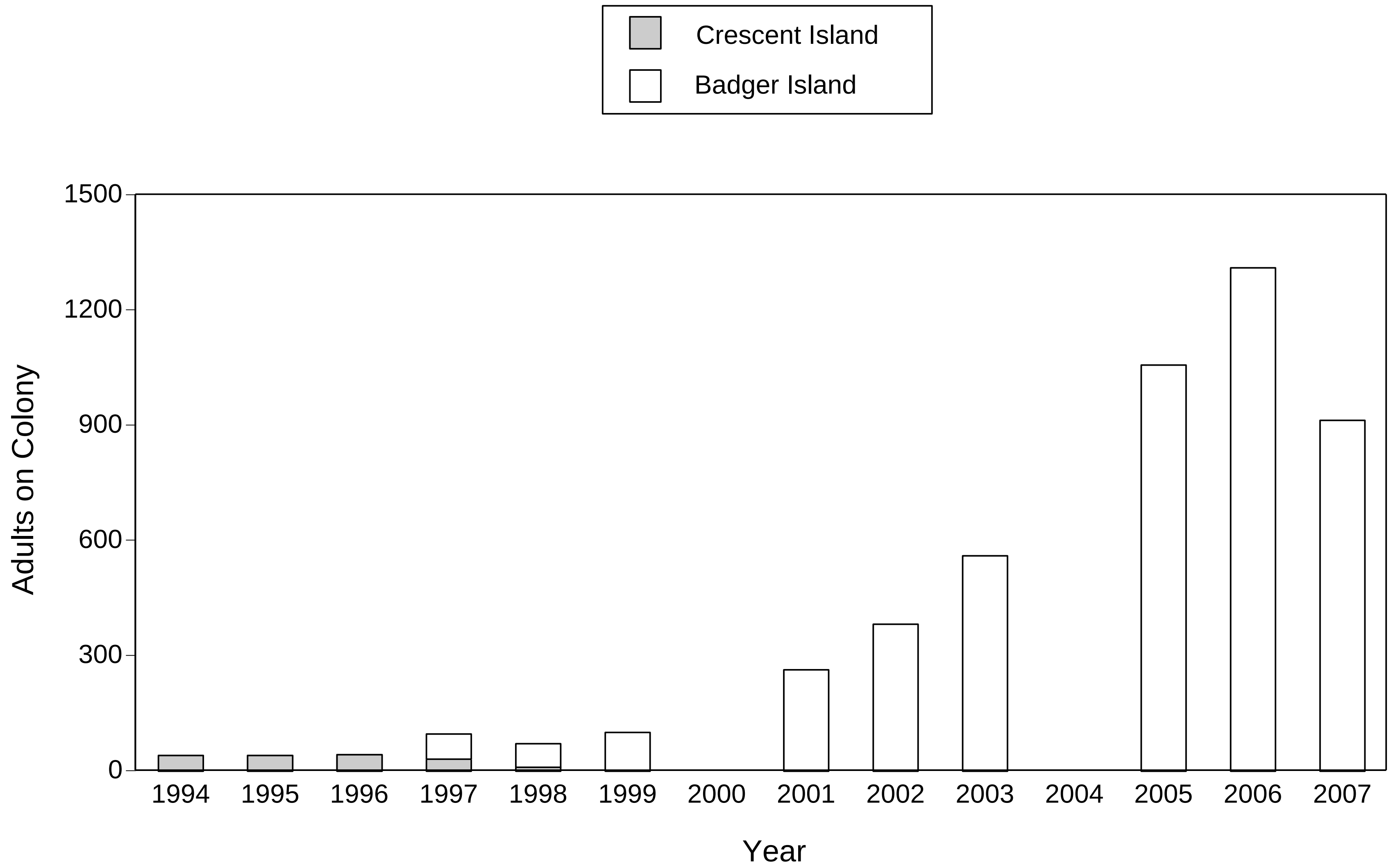


Figure 36. Population trends for American white pelicans nesting at two colonies on the mid-Columbia River during 1994-2007. Missing bars indicate that no colony counts were conducted during that year.

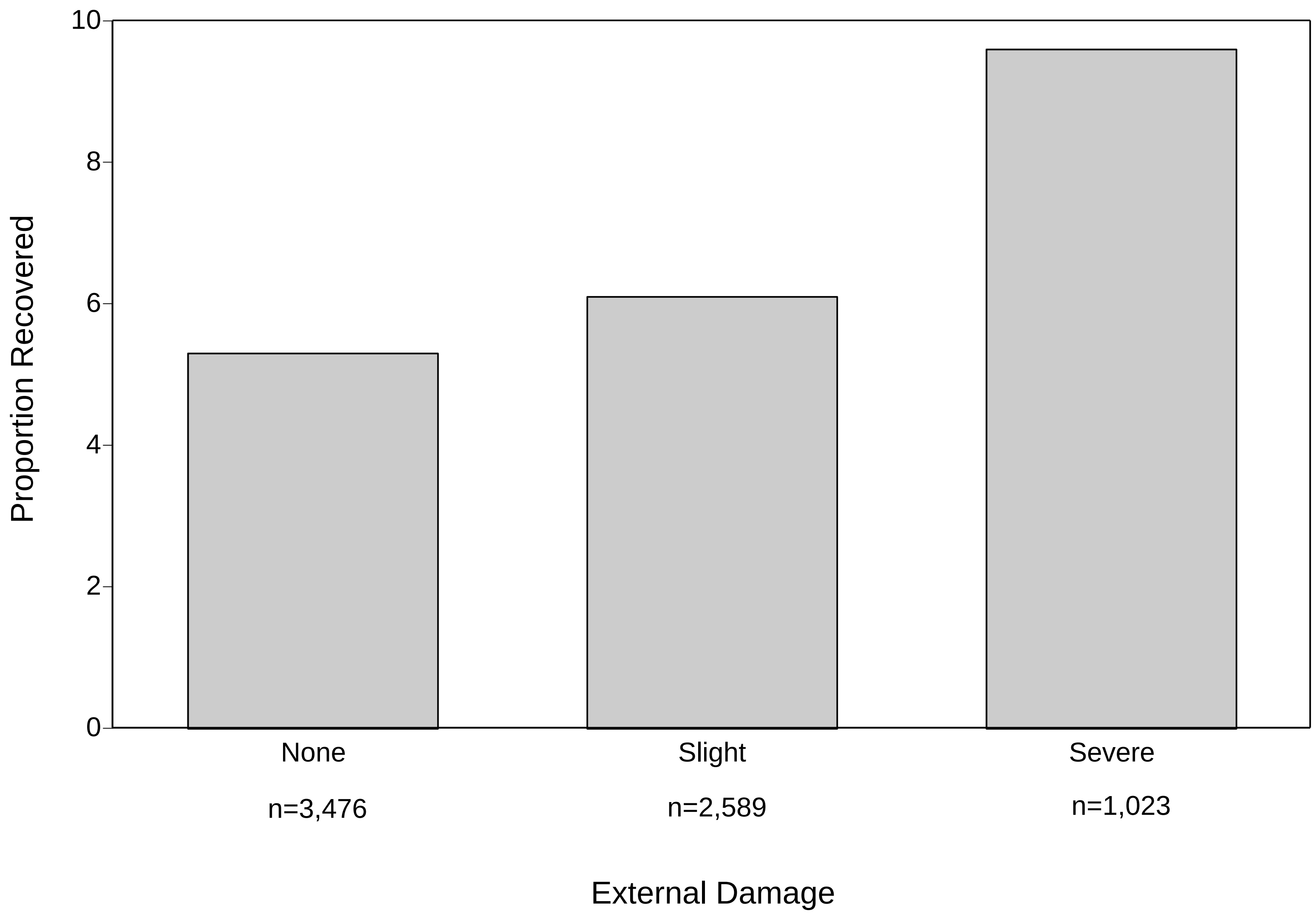


Figure 37. Proportion of PIT-tagged Snake River steelhead in different condition categories (based on the degree of external damage observed on the fish when tagged at Lower Monumental or Ice Harbor dams) that were subsequently recovered on piscivorous waterbird colonies in the McNary Pool in 2007.

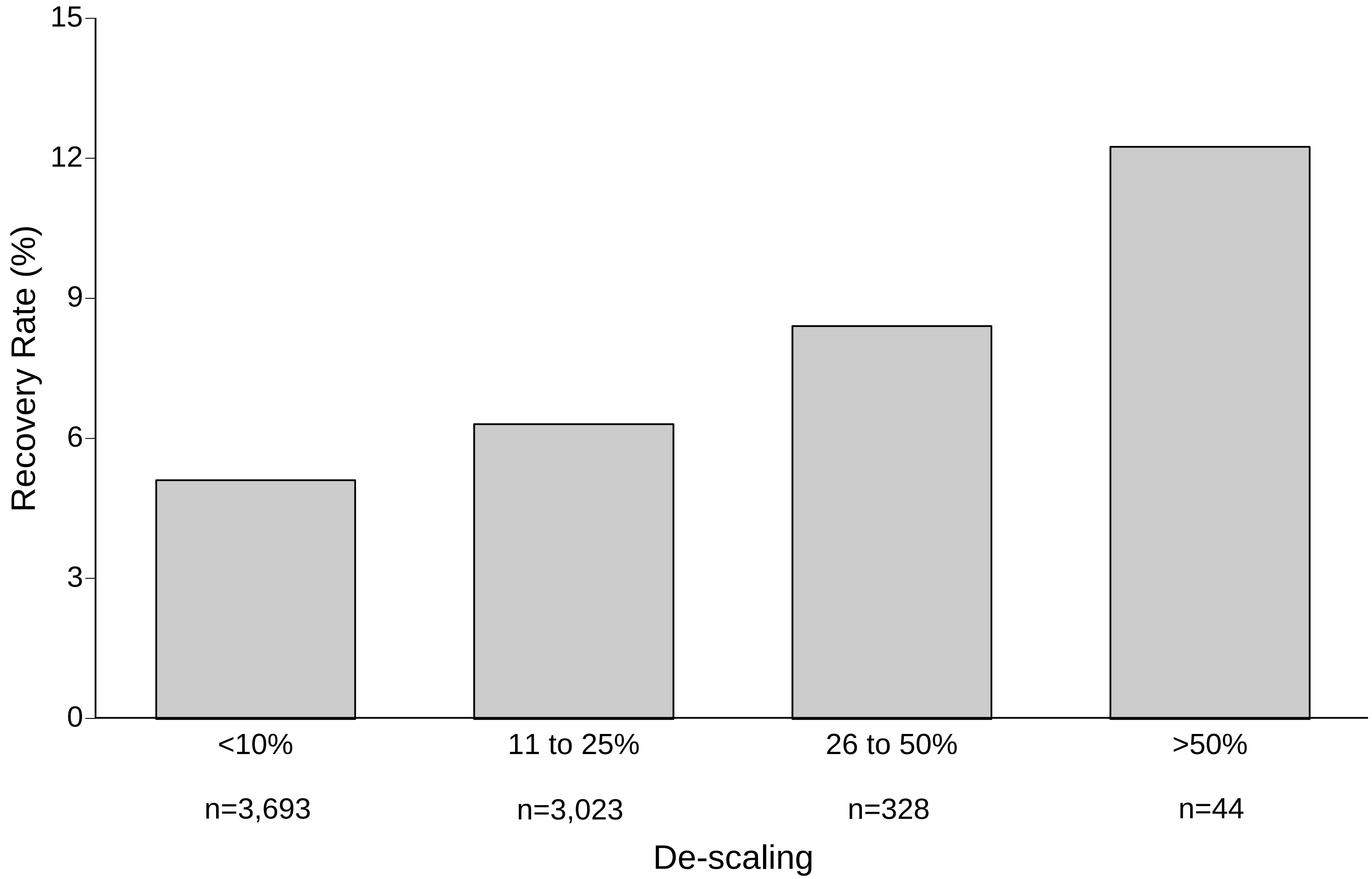


Figure 38. Predation on Snake River steelhead by avian predators nesting in the McNary Pool as a function of the extent of fish de-scaling. Recovery rates represent the proportion of PIT-tagged steelhead with that level of de-scaling at tagging that were subsequently recovered on piscivorous waterbird colonies in the McNary Pool in 2007.

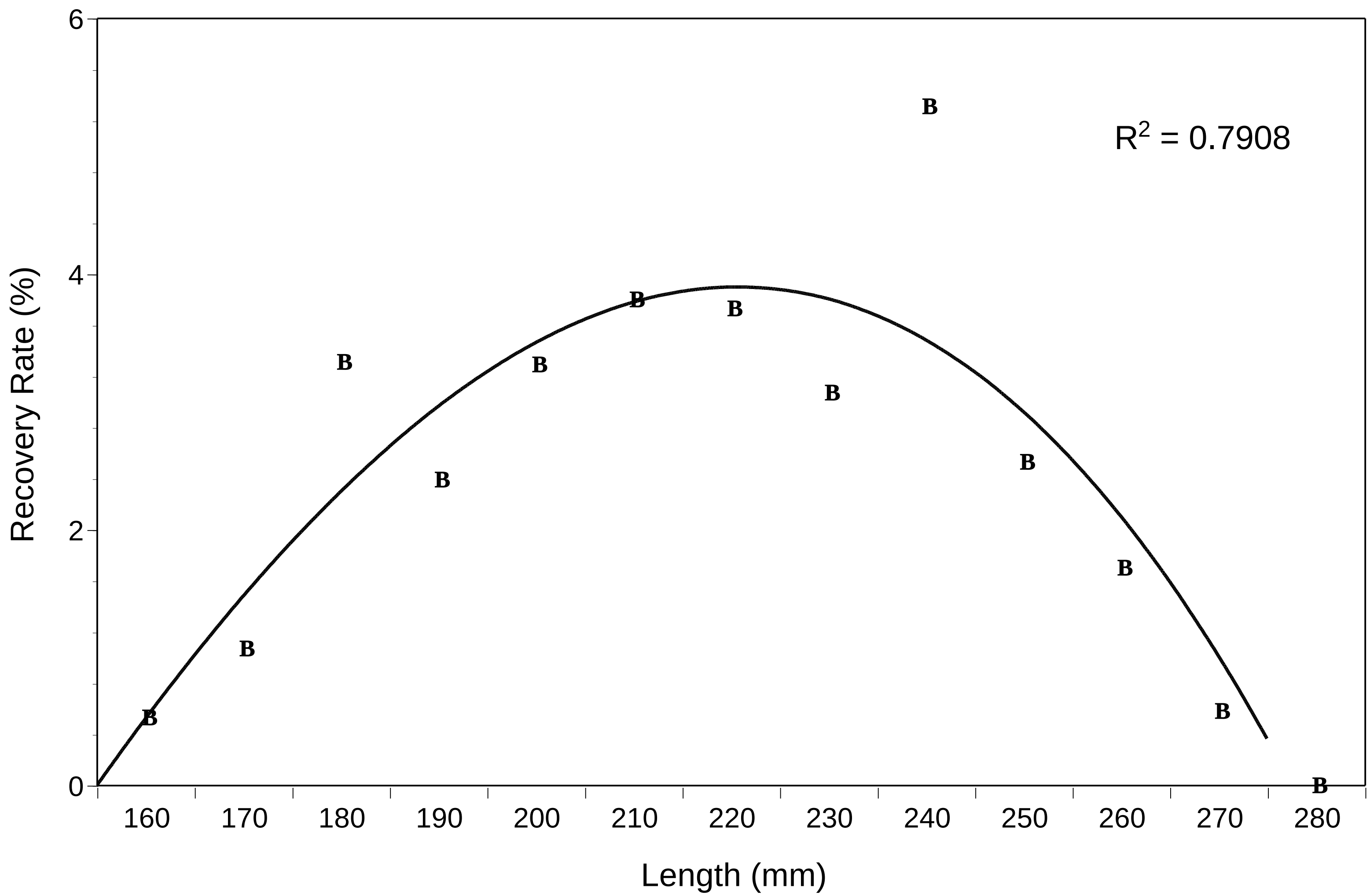


Figure 39. Predation rates on Snake River steelhead by Caspian terns nesting on Crescent Island as a function of fish length. Recovery rates represent the proportion of released PIT-tagged steelhead in that size range that was subsequently recovered on the Crescent Island tern colony in 2007.

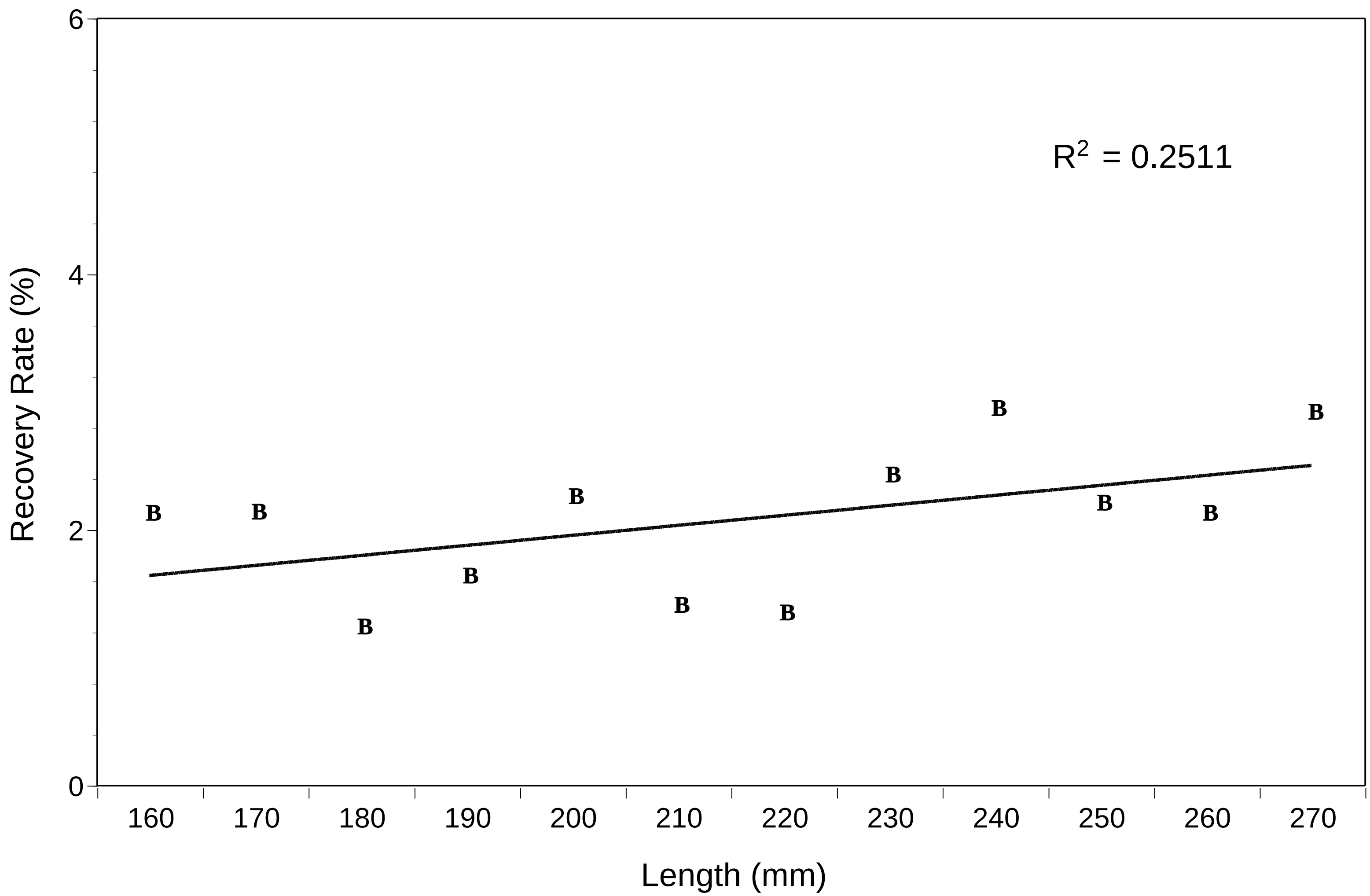


Figure 40. Predation rates on Snake River steelhead by double-crested cormorants nesting on Foundation Island as a function of fish length. Recovery rates represent the proportion of released PIT-tagged steelhead in that size range that was subsequently recovered on the Foundation Island cormorant colony in 2007.

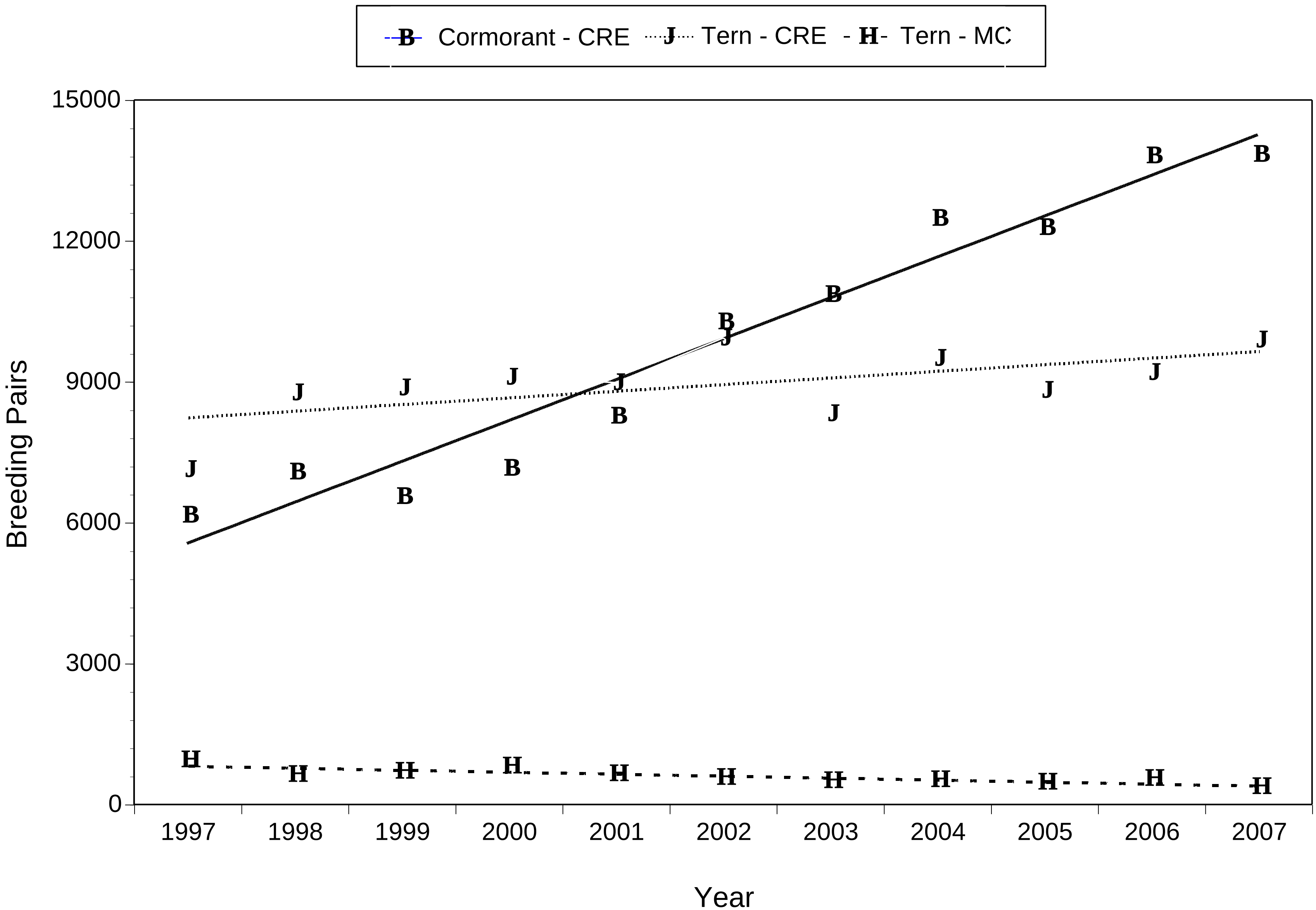


Figure 41. Trends in size of the double-crested cormorant and the Caspian tern colonies in the Columbia River estuary (CRE) compared with the Caspian tern colonies on the mid-Columbia River (MC) during 1997 - 2007.

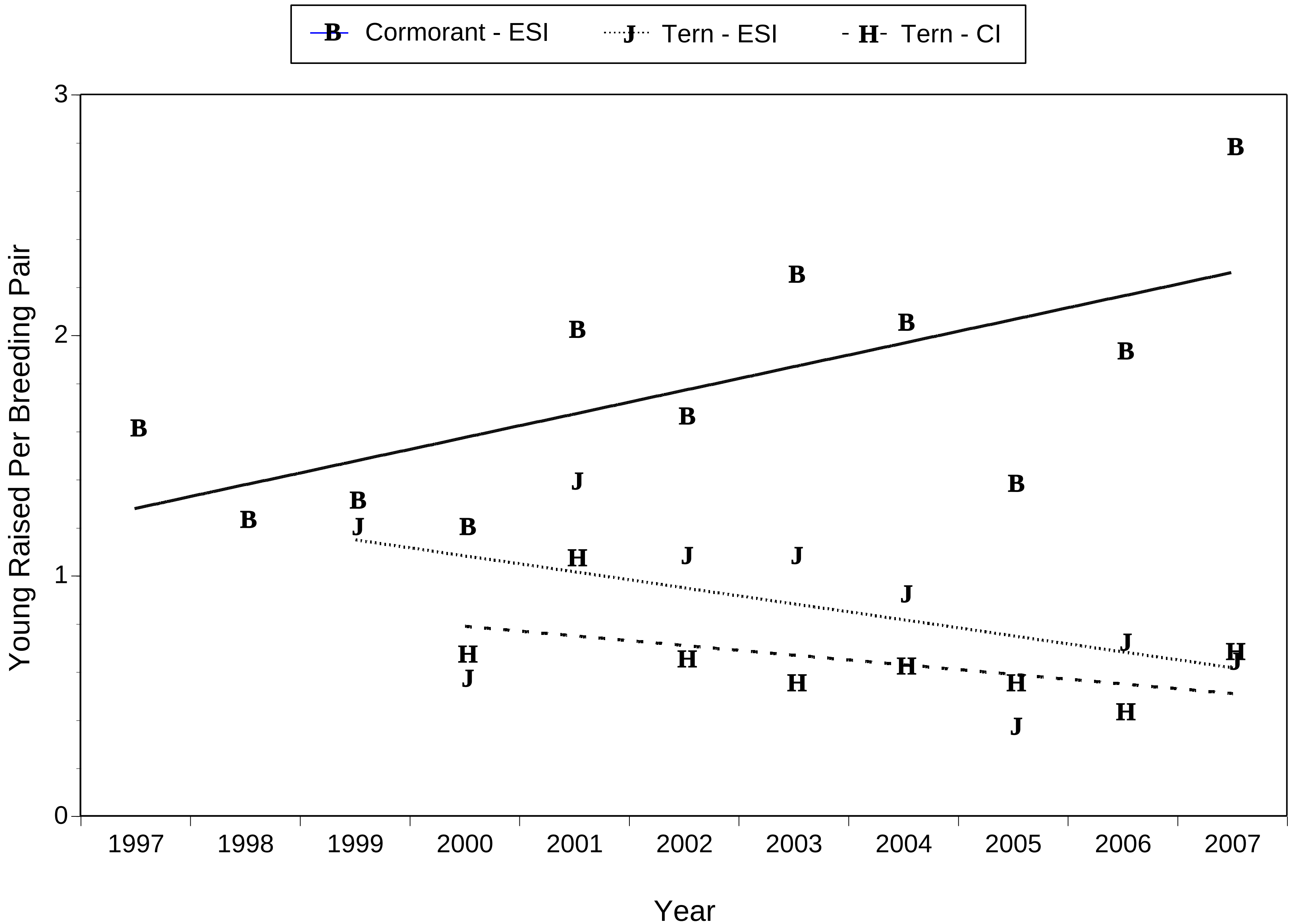


Figure 42. Trends in nesting success of double-crested cormorants and Caspian terns nesting on East Sand Island (ESI) compared with Caspian terns nesting on Crescent Island (CI) during 1997 - 2007.

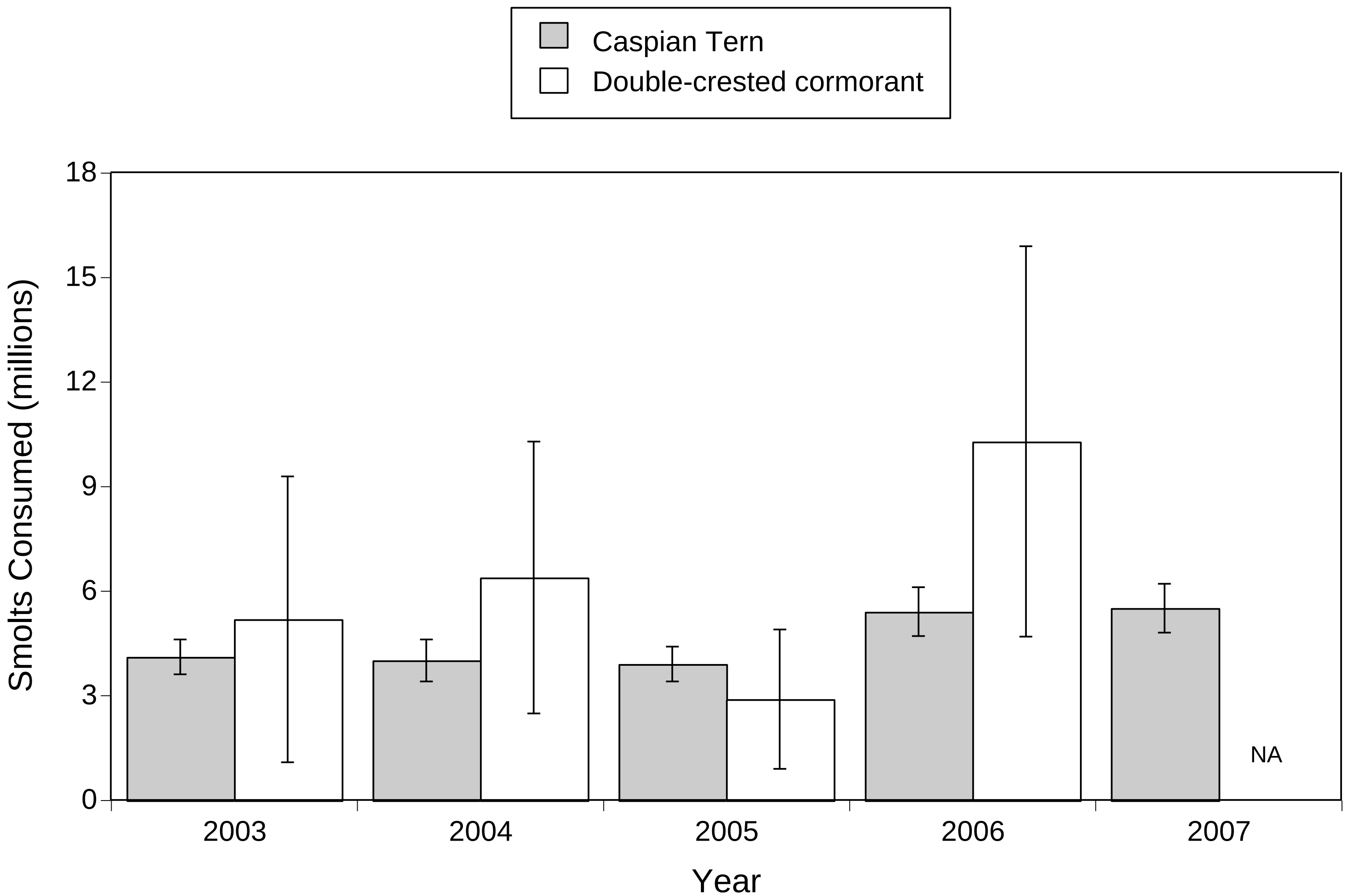


Figure 43. Estimated total annual consumption of juvenile salmonids by Caspian terns and double-crested cormorants nesting on East Sand Island in the Columbia River estuary during 2003 - 2007.

Table 1. Counts of piscivorous waterbirds at colonies throughout the Columbia River basin in 2007. Species include American white pelican (AWPE), brown pelican (BRPE), Caspian tern (CATE), Forster's tern (FOTE), double-crested cormorant (DCCO), Brandt's cormorant (BRCO), pelagic cormorant (PECO), California gull (CAGU), ring-billed gull (RBGU), glaucous-winged/western gull (GWGU/WEGU), great blue heron (GBHE), black-crowned night-heron (BCNH), and great egret (GREG). Counts of terns and cormorants are the number of breeding pairs; the count of brown pelicans is the peak number of roosting individuals; all other counts are of the number of individuals on colony. Asterisks indicate counts from 2006 (colonies not counted in 2007).

Water Body	Location	River km	Species	Colony Size
Columbia River estuary				
	East Sand Island	8	CATE	9,895
			DCCO	13,771
			BRCO	288
			GWGU/WEGU	8,587*
			RBGU	1,389*
			BRPE	7,660
	Astoria Bridge	16	PECO	133
			DCCO	11
	Rice Island	34	GWGU/WEGU	1,727*
	Miller Sands Spit	37	GWGU/WEGU	704*
			DCCO	90
Middle Columbia River				
	Browns Island	318	GBHE	10-100
	Little Miller Island	327	GBHE	10-100
	Miller Rocks	333	RBGU/CAGU	3,509
	Three Mile Island	413	RBGU/CAGU	1,000-10,000
	Sand Island	445	GBHE/GREG	10-100
	Rock Island	445	RBGU	100-1,000
			CATE	43
	Crescent Island	510	CATE	355
			RBGU/CAGU	1,000-10,000
			GBHE/BCNH	10-100
	Badger Island	511	AWPE	913
	Foundation Island	518	DCCO	> 334
			GBHE	10-100
			BCNH	unknown
Upper Columbia River				
	Fencepost Island	545	CAGU	1,000-10,000
	Island 18	553	RBGU/CAGU	1,000-10,000
	Hanford Reach	594	DCCO	8
			GREG	10-100
	Goose Island	641	GBHE	10-100
	Okanogan Island	858	DCCO	10
Snake River				
	Lyons Ferry R.R. Trestle	59	GBHE	15
	Chief Timothy S.P.	211	GBHE	=10
Clearwater River				
	Island near Lapwai	15	GBHE	10-100
Yakima River				
	North of Selah	193	DCCO	unknown
Potholes Reservoir				
	Goose Island	-	CATE	282
			RBGU/CAGU	100-1000
	North Potholes	-	DCCO	1,015
			GBHE	unknown
			GREG	unknown
Sprague Lake				
	Harper Island	-	RBGU/CAGU	1,000-10,000
Banks Lake				
	Twining Island	-	CATE	31
			RBGU/CAGU	1,000-10,000
	Goose Island	-	RBGU/CAGU	unknown

Table 2. Diet composition (% of identifiable prey items) of Caspian terns nesting on Rice Island and East Sand Island in the Columbia River estuary during 1999-2007.

	1999		2000		2001	2002	2003	2004	2005	2006	2007
Prey Type	Rice	East Sand	Rice	East Sand	East Sand	East Sand	East Sand	East Sand	East Sand	East Sand	East Sand
Herring, sardine, shad	1.8	8.2	1.7	10.1	20.3	18.4	18.5	29.3	12.3	4.9	11.7
Anchovy	6.5	15.9	0.5	11.6	22.4	14.1	23.7	25.2	33.4	31.4	26.3
Peamouth, pike minnow	1.0	0.5	0.9	0.8	0.6	0.5	0.1	0.7	0.1	0.0	0.3
Smelt	0.9	3.8	0.7	5.6	5.1	7.3	17.6	9.3	8.8	8.5	5.5
Salmonid	**76.5**	**45.6**	**89.6**	**46.5**	**32.5**	**31.1**	**24.1**	**16.8**	**22.6**	**31.1**	**29.8**
Cod	0.0	0.0	0.0	0.0	2.2	0.1	0.3	2.4	0.0	0.0	0.0
Sculpin	1.3	3.3	1.9	5.1	3.6	2.4	3.0	3.1	2.8	3.0	2.6
Surfperch	2.8	10.7	1.2	10.0	5.9	11.6	6.7	11.5	16.4	16.5	14.8
Pacific sand lance	0.1	5.9	0.1	5.6	3.1	2.5	4.5	0.2	1.7	0.6	2.6
Flounder	0.3	0.2	1.8	0.6	0.2	0.1	0.0	0.2	0.2	0.1	0.2
Other	8.7	5.8	1.6	3.9	3.9	11.9	1.5	1.4	1.7	3.9	6.2
Total no. identified prey	5,305	5,486	5,023	5,387	6,007	5,661	5,476	5,854	5,536	5,549	5,387

Table 3. Average detection efficiency (DE) of PIT tags sown on avian colonies in the Columbia River basin in 2007. PIT tags were distributed haphazardly throughout the entire colony or within experimental plots (denoted by an asterisk). Colonies include American white pelicans (AWPE), Caspian terns (CATE), double-crested cormorants (DCCO), and California gulls (CAGU). N indicates the number of test tags released, SE is the standard error of the average detection efficiency, and NR is the number of discrete release events when tags were sown on-colony.

Location	Colony	N	DE	SE	NR
North Potholes	DCCO*	50	62.0	-	1
	CATE*	200	53.0	26.0	2
Foundation Island	DCCO	400	67.8	5.7	4
Badger Island	AWPE	200	64.5	5.0	2
Crescent Island	CATE	800	69.8	14.4	4
	CAGU*	200	63.5	21.7	2
Rock Island	CATE	200	88.0	0.0	2
Miller Rocks	CAGU	200	86.5	4.4	2
Miller Sand Spit	DCCO	200	58.0	26.5	2
East Sand Island	CATE	600	90.3	4.1	4
	DCCO*	600	80.2	8.3	2

Table 4. Estimated predation rates on PIT-tagged salmonid smolts by Caspian terns (CATE) and double-crested cormorants (DCCO) nesting on East Sand Island in 2007. Predation rates are based on the number of PIT-tagged fish interrogated (I) passing Bonneville Dam (In-river) or released (Rel) from transportation barges directly below Bonneville Dam (Transport). Rear-types are for hatchery (H), wild (W), and unknown (U) smolts and run-types are for summer, spring/summer (Spr/Sum), fall, and unknown. Sample sizes of interrogated/released fish less than 100 were not included in the analysis. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (Table 3), but not deposition rates, and are therefore minimum estimates.

	In-river			Transport		
Species / Run Type	**No. I**	**CATE**	**DCCO**	**No. Rel**	**CATE**	**DCCO**
W Summer Steelhead	2,804	16.00%	4.63%	20,324	7.72%	3.19%
H Summer Steelhead	8,962	13.52%	2.90%	50,714	8.72%	2.38%
W Spr/Sum Chinook	2,555	1.08%	2.47%	2,533	0.39%	1.46%
H Spr/Sum Chinook	32,666	2.06%	1.53%	31,712	1.74%	2.11%
W Fall Chinook	478	0.93%	2.33%	NA	NA	NA
H Fall Chinook	2,943	2.33%	1.89%	559	1.58%	0.66%
U Fall Chinook	1,486	3.20%	6.99%	178	1.87%	4.17%
W U Run Chinook	1,979	0.62%	2.44%	17,631	0.89%	1.85%
H U Run Chinook	8,995	2.18%	1.82%	24,604	1.14%	1.49%
W Coho	NA	NA	NA	NA	NA	NA
H Coho	3,070	5.84%	1.93%	NA	NA	NA
W Sockeye	NA	NA	NA	NA	NA	NA
H Sockeye	905	1.84%	5.74%	NA	NA	NA

Table 5. Estimated per capita consumption of 2007 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, Chinook salmon, coho salmon, and sockeye salmon. Values for per capita consumption are corrected for PIT tag detection efficiency, but not deposition, and are therefore minimums. PIT tags were recovered from nesting locations using two different approaches: recoveries from the entire colony (C) or from plots within the colony (P). Estimates of per capita PIT tag consumption were derived by dividing the total number of tags recovered (R; corrected for detection efficiency) by the number of breeding adults on the colony or in the plots.

River Segment / Avian Colony (est. number of breeding adults)	**Approach**	**R**	**Steelhead**	**Chinook**	**Coho**	**Sockeye**	**Total**
Inland Reservoirs and Lakes							
Potholes Reservoir CATE (564)	C	2,219	3.08	0.44	0.36	0.05	3.93
Potholes Reservoir DCCO (334)	P	6	0.01	0.01	0.00	0.00	0.02
Banks Lake CATE (62)	C	31	0.44	0.04	0.00	0.00	0.50
McNary Pool							
Badger Island AWPE (1,826)	C	1,160	0.21	0.35	0.07	0.00	0.64
Foundation Island DCCO (668)	C	7,554	4.61	6.46	0.16	0.07	11.31
Crescent Island CATE (710)	C	5,141	4.58	2.37	0.26	0.03	7.24
Crescent Island CAGU (120)	P	19	0.09	0.05	0.01	0.00	0.16
John Day Pool							
Rock Island CATE (86)	C	677	4.53	3.05	0.29	0.00	7.87
The Dallas Pool							
Miller Rocks CAGU (7,000)	C	2,653	0.20	0.14	0.03	0.00	0.38
Columbia River Estuary							
Miller Sands Spit DCCO (106)	C	533	1.66	3.14	0.13	0.10	5.03
East Sand Island CATE (19,290)	C	25,362	0.80	0.48	0.04	0.01	1.31
East Sand Island DCCO (464)	P	272	0.20	0.37	0.01	0.01	0.59

Table 6. Estimated predation rates on wild in-river PIT-tagged salmonid smolts by avian predators nesting in McNary Pool during 2007. Colonies include American white pelicans (AWPE) on Badger Island, Caspian terns (CATE) on Crescent Island, double-crested cormorants (DCCO) on Foundation Island, and California gulls (CAGU) on Crescent Island. 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 wild-origin that were released into the fish's natal river. Predation rates are corrected for bias due to PIT tag detection efficiency (Table 3), but not for deposition rates, and are therefore minimum estimates. Predation rates do not account for other mortality that took place between the fish's release location and McNary Pool. Ninety five percent confidence intervals (±) were based on variation derived from multiple release groups of PIT-tagged smolts within the corresponding ESU (Table 7).

			Predation Rate		
ESU	**Released**	**CATE**	**DCCO**	**CAGU**	**AWPE**
SR steelhead	44,733	1.61% (0.73)	0.58% (0.20)	0.36% (0.15)	< 0.10%
UCR steelhead	5,044	0.49% (0.24)	< 0.10%	< 0.10%	< 0.10%
MCR steelhead	2,484	1.70% (1.30)	4.23% (3.61)	0.10% (0.03)	0.13% (0.10)
SR Fall Chinook	1,979	< 0.10%	< 0.10%	< 0.10%	< 0.10%
UCR Spr/Sum Chinook	15,799	< 0.10%	< 0.10%	< 0.10%	< 0.10%
SR Spr/Sum Chinook	77,992	0.28% (0.12)	0.31% (0.10)	0.11% (0.01)	< 0.10%
SR sockeye	917	0.51%	0.64%	< 0.10%	< 0.10%

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

Table 7. Stock-specific predation rates on in-river PIT-tagged salmonid smolts by Crescent Island Caspian terns (CATE), Foundation Island double-crested cormorants (DCCO), Badger Island American white pelicans (AWPE), and Crescent Island California gulls (CAGU) in 2007. 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 locations are included. Sample sizes and predation rates are listed separately for hatchery-origin (H) and wild-origin (W) fish. Predation rates are corrected for bias due to PIT tag detection efficiency on-colony, but not deposition rates, and therefore are minimum estimates. Smolt mortality from the individual stock's release site to the vicinity of McNary Pool is not accounted for.

Species	**ESU**	**Stock**	**Number Released**		**Hatchery Predation Rate**				**Wild Predation Rate**			
			H	W	CATE	DCCP	AWPE	CAGU	CATE	DCCP	AWPE	CAGU
Steelhead	SR	Imnaha River	2,029	5,200	1.93%	1.81%	0.31%	0.39%	4.80%	1.47%	<0.10%	0.97%
		Grande Ronde River	1,497	3,852	2.20%	1.38%	0.31%	0.84%	0.98%	0.31%	<0.10%	0.20%
		Clearwater River	3,826	22,011	1.27%	1.61%	0.16%	0.49%	0.28%	0.27%	<0.10%	0.10%
		Salmon River	8,662	11,909	1.92%	1.63%	0.48%	0.64%	0.41%	0.28%	<0.10%	<0.10%
		Lower Snake	12,922	1,761	0.73%	0.72%	0.18%	0.41%	1.60%	0.58%	<0.10%	0.45%
	UCR											
		Okanogan River	19,920	-	0.87%	<0.10%	<0.10%	0.34%	NA	NA	NA	NA
		Methow River	2,287	782	0.69%	0.32%	<0.10%	1.03%	0.80%	<0.10%	<0.10%	0.20%
		Entiat River	-	1,084	NA	NA	NA	NA	0.58%	0.14%	<0.10%	<0.10%
		Wenatchee River	28,539	3,178	0.62%	<0.10%	<0.10%	0.83%	0.10%	<0.10%	<0.10%	<0.10%
	MCR											
		Walla Walla & Touchet	18,810	753	1.73%	5.95%	0.19%	0.15%	3.13%	8.20%	<0.10%	0.21%
		Yakima River		11,39					<0.10%	0.13%	<0.10%	0.14%
		Umatilla River	2,142	592	0.22%	0.41%	0.36%	0.37%	0.27%	0.25%	0.26	<0.10%
Chinook	SR Fall	Mainstem Snake River	22,173	1,979	0.36%	0.36%	<0.10%	0.12%	<0.10%	<0.10%	<0.10%	<0.10%
	SR S/S	Salmon River	164,652	49,108	<0.10%	0.41%	<0.10%	<0.10%	<0.10%	0.10%	<0.10%	<0.10%
		Grande Ronde/Imnaha	39,268	16,461	0.10%	0.28%	<0.10%	<0.10%	0.20%	0.25%	<0.10%	<0.10%
		Clearwater River	164,237	11,919	0.24%	0.45%	<0.10%	<0.10%	0.28%	0.31%	<0.10%	<0.10%
		Lower Snake River	2,303	504	0.14%	0.70%	<0.10%	0.14%	0.62%	0.58%	<0.10%	0.31%
	UCR S											
		Methow River	6,177	693	<0.10%	<0.10%	<0.10%	<0.10%	<0.10%	<0.10%	<0.10%	<0.10%
		Entiat River	999	4,357	0.16%	<0.10%	<0.10%	0.16%	<0.10%	0.10%	<0.10%	<0.10%
		Wenatchee River	24,957	10,749	<0.10%	<0.10%	<0.10%	<0.10%	<0.10%	0.14%	<0.10%	<0.10%
Sockeye	SR	Redfish Lake	7,332	917	0.11%	0.52%	<0.10%	0.13%	0.51%	0.64%	<0.10%	<0.10%

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

Table 8. Estimated predation rates on PIT-tagged salmonid smolts traveling through McNary Pool by avian predators nesting at colonies in McNary Pool during 2007. Colonies include American white pelicans (AWPE) on Badger Island, Caspian terns (CATE) on Crescent Island, double-crested cormorants (DCCO) on Foundation Island, and California gulls (CAGU) on Crescent Island. Predation rates are based on the proportions of fish interrogated/tagged at Lower Monumental Dam (LMO), Rock Island Dam (RIS), or in the McNary Pool (McP; fish tagged and released below Priest Rapids and Ice Harbor dams but upstream of McNary Dam) that were subsequently detected on-colony. Predation rates on hatchery (H), wild (W), and unknown (U) rear-type smolts are listed separately. Chinook are designated by run-type as spring/summer (Spr/Sum), fall, and unknown. Sample sizes (N) of interrogated/tagged fish less than 100 were excluded. Predation rates are corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not deposition, and are therefore minimum estimates.

				Predation Rate				
Location	**Species/Run-type**	**Origin**	**N**	**CATE**	**DCCO**	**CAGU**	**AWPE**	**All**
LMO	Steelhead	Hatchery	13,481	3.13%	2.35%	0.85%	0.31%	6.64%
		Wild	3,369	3.04%	2.31%	0.51%	< 0.1%	5.87%
	Spr/Sum Chinook	Hatchery	20,550	0.28%	0.74%	0.08%	< 0.1%	1.11%
		Wild	1,920	0.17%	0.77%	0.25%	< 0.1%	1.26%
	Fall Chinook	Hatchery	1,814	0.70%	0.81%	< 0.1%	< 0.1%	1.60%
		Unknown	249	< 0.1%	1.77%	< 0.1%	< 0.1%	1.77%
	Unknown Chinook	Unknown	12,003	0.24%	0.91%	0.22%	< 0.1%	1.39%
	Sockeye	Hatchery	206	< 0.1%	0.71%	< 0.1%	< 0.1%	0.71%
RIS	Steelhead	Hatchery	2,465	1.87%	0.06%	1.53%	0.13%	3.59%
		Wild	1,086	2.12%	< 0.1%	0.15%	< 0.1%	2.27%
	Spr/Sum Chinook	Unknown	4,455	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%
	Sockeye	Wild	2,068	0.31%	0.14%	0.23%	0.00%	0.68%
McP	Steelhead	Hatchery	28,875	1.19%	4.00%	0.15%	0.26%	5.60%
		Wild	2,484	1.01%	2.60%	0.13%	< 0.1%	3.80%
	Spr/Sum Chinook	Hatchery	57,732	0.19%	1.14%	< 0.1%	0.15%	1.50%
		Wild	3,131	0.25%	1.08%	< 0.1%	0.15%	1.48%
	Fall Chinook	Hatchery	35,803	0.19%	0.44%	< 0.1%	0.56%	1.24%
		Wild	748	< 0.1%	< 0.1%	1.47%	< 0.1%	1.47%
		Unknown	5,874	< 0.1%	< 0.1%	< 0.1%	0.50%	0.58%
	Coho	Hatchery	4,5762	0.26%	0.20%	< 0.1%	0.26%	0.78%

Table 9. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants nesting on East Sand Island in the Columbia River estuary during 1999-2007. Data from 1999-2004 and 2006-2007 are based on the analysis of soft tissue and diagnostic bones recovered from samples of stomach contents from adults. Data from 2005 are preliminary and include only the analysis of soft tissue.

Prey Type	1999	2000	2001	2002	2003	2004	2005	2006	2007
Herring, sardine, shad	4.6	9.8	13.4	27.8	6.5	13.7	10.3	2.8	1.7
Peamouth, pike minnow	8.4	5.2	2.6	4.5	3.9	5.1	5.3	5.5	4.2
Sucker	4.3	1.0	0.0	0.0	2.4	1.9	3.5	1.1	0.7
Smelt	0.8	0.5	0.7	6.1	1.7	1.2	0.3	2.0	0.0
Salmonid	**24.6**	**15.8**	**8.9**	**5.1**	**8.3**	**4.9**	**1.9**	**10.8**	**8.8**
Stickleback	1.6	4.3	0.1	0.8	0.3	3.4	7.7	12.3	2.9
Sculpin	4.2	14.1	11.0	6.9	4.6	4.7	16.9	6.4	9.4
Surfperch	7.6	6.8	5.5	5.1	6.5	5.5	16.5	7.8	5.6
Pacific sand lance	0.0	4.5	1.5	1.3	4.6	0.1	0.0	0.0	0.0
Flounder	8.5	17.4	12.7	9.0	9.3	11.9	8.6	4.7	9.0
Anchovy	27.8	15.1	17.9	17.4	20.6	45.5	28.0	33.0	37.7
Cod	0.1	2.8	10.9	1.1	5.6	1.3	0.0	0.0	0.0
Lamprey	1.4	1.2	0.6	0.1	0.4	0.2	0.0	0.2	0.2
Gunnel	0.0	0.2	0.1	0.1	1.1	0.1	0.0	0.6	0.2
Other	6.2	1.3	14.2	14.6	24.3	0.5	1.0	12.8	19.6
Total mass (g)	11,414	17,858	15,162	20,099	24,472	32,883	27,128	20,684	21,834

Table 10. Diet composition (% identifiable biomass in regurgitations) of double-crested cormorants nesting on Foundation Island in the mid-Columbia River during 2-week sampling periods in 2007. All samples are regurgitations collected from beneath nesting trees.

Sample period	N	Salmonid	Cyprinid	Sucker	Centrarchid	Perch	Catfish
5/1-5/16	22	50.0%	13.6%	0.0%	18.2%	13.6%	4.6%
5/17-5/31	22	4.6%	36.4%	9.1%	36.4%	4.6%	9.1%
6/1-6/16	17	0.0%	17.7%	0.0%	47.1%	17.7%	17.7%
TOTAL[a]	61	18.2%	22.6%	3.0%	33.9%	11.9%	10.4%

\a The total percentages are the average percent biomass for all regurgitations (n = 61) collected on Foundation Island during 2007.

Table 11. Diet composition (% identifiable biomass in stomach contents samples) of adult double-crested cormorants nesting on Foundation Island in the mid-Columbia River on five different sampling dates in 2007.

Sample date	N	Salmonid	Cyprinid	Sucker	Sculpin	Centrarchid	Perch	Catfish	Unid. non-salmonid
4/19/07	8	0.0	15.8	21.0	0.0	22.7	0.0	12.9	27.6
5/02/07	9	30.1	9.5	0.0	0.0	54.5	0.2	4.3	1.4
5/16/07	10	42.7	3.5	6.1	0.0	21.4	0.0	23.1	3.3
5/30/07	8	0.0	25.6	6.1	2.9	44.3	0.0	16.9	4.3
6/15/07	10	7.4	13.6	30.8	0.0	19.0	0.0	25.3	3.9
TOTAL[a]	45	16.0	13.6	12.8	0.6	32.4	0.1	16.5	8.1

[a] The total percentages are the average of the sample date percentages.

Table 12. Diet composition (% identifiable biomass in stomach contents samples) of double-crested cormorants over-wintering on the Snake River. Cormorants were collected near Little Goose and Lower Granite dams on four different occasions during October–December 2007.

Location/sample date	N	Salmonid	Shad	Cyprinid	Sculpin	Centrarchid	Unid. non-salmonid
Little Goose Dam							
10/04/07	3	0.0	0.0	33.3	0.0	66.7	0.0
11/06/07	5	0.0	40.0	0.0	20.0	20.0	20.0
12/07/07	5	15.8	84.2	0.0	0.0	0.0	0.0
12/28/07	10	23.7	75.9	0.0	0.0	0.0	0.4
TOTAL [a]	23	9.9	50.0	8.3	5.0	21.7	5.1
Lower Granite Dam							
10/04/07	5	33.3	0.0	0.0	0.0	65.2	1.5
11/06/07	5	0.0	0.0	25.0	0.0	25.0	50.0
12/07/07	5	0.0	99.5	0.0	0.0	0.0	0.5
12/28/07	0	–	–	–	–	–	–
TOTAL [a]	15	11.1	33.2	8.3	0.0	30.1	17.3
Combined							
10/04/07	8	16.7	0.0	16.7	0.0	65.9	0.7
11/06/07	10	0.0	22.2	11.1	11.1	22.2	33.4
12/07/07	10	7.0	92.7	0.0	0.0	0.0	0.3
12/28/07	10	23.7	75.9	0.0	0.0	0.0	0.4
TOTAL [a]	38	11.8	47.7	7.0	2.8	22.0	8.7

[a] The total percentages are the average of the sample date percentages.

Table 13. Numbers and percentages of steelhead tagged and released at Lower Monumental Dam (n = 6,254) and Ice Harbor Dam (n = 834) in 2007 that were subsequently recovered on avian colonies throughout the Columbia River basin. Recovery percentages (percentage of tagged fish recovered) are corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not for deposition rates, and therefore are minimum estimates.

River Segment	**Island**	**Avian Colony**	**No. Recovered**	**% Recovered**
McNary Pool	Crescent	Caspian tern	323	4.6%
		California gull	80	1.1%
	Foundation	Double-crested cormorant	204	2.9%
	Badger	American white pelican	33	0.5%
	Other (loafing areas)	Mixed species	13	0.2%
John Day Pool	Rock	Caspian tern	40	0.6%
The Dalles Pool	Miller Rock	California Gull	97	1.4%
Estuary	East Sand	Caspian tern	422	6.0%
		Double-crested cormorant	54	0.8%
ALL			1,266	17.9%