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

Final 2010 Final Report

This Final 2010 Annual Report 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This report is not for citation without permission of the authors.

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

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

Donald E. Lyons, Jessica Y. Adkins, Peter Loschl, Yasuko Suzuki, Dan Battaglia,
Tim Marcella, Timothy Lawes, Adam Peck-Richardson, Ladd Bayliss,
Lucy Faulquier, Dan Harvey, Emily Tompkins, James Tennyson,
Stephanie Collar, Allison Patterson, and Lindsay Adrean
USGS - Oregon Cooperative Fish and Wildlife Research Unit
Department of Fisheries and Wildlife
Oregon State University
Corvallis, Oregon 97331-3803

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

Richard D. Ledgerwood
Fish Ecology Division, Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard,
Seattle, Washington 98112-2097

Scott Sebring
Pacific States Marine Fisheries Commission
205 Southeast Spokane Street, Suite 100, Portland, Oregon 97202

Submitted: June 2011

Revised: October 2011

TABLE OF CONTENTS

EXECUTIVE SUMMARY

We conducted field studies in 2010 to assess the impact of predation by Caspian terns (*Hydroprogne caspia*), double-crested cormorants (*Phalacrocorax auritus*), and other piscivorous colonial waterbirds on juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River basin. Additionally, we monitored the Caspian tern colonies located outside the Basin that were recently established on alternative nesting habitat for Caspian terns displaced from East Sand Island, as part of the Caspian Tern Management Plan for the Columbia River Estuary.

The Caspian tern colony on East Sand Island, the largest of its kind in the world, consisted of about 8,283 breeding pairs in 2010, significantly less than in 2009 and the smallest the colony has been since it became fully established in 2001. Although the recent decline in size of the East Sand Island tern colony was coincident with a reduction in the amount of nesting habitat made available to terns on East Sand Island, nesting habitat did not appear to limit the size of the East Sand Island tern colony in 2010. Based on nesting densities observed at the East Sand Island tern colony over the past several years, plus poor nesting success during the 2010 El Niño, the reduction in available nesting habitat from five acres in previous years to 3.1 acres in 2010 was not the primary cause for the decline in colony size observed in 2010. Further reductions in the amount of Caspian tern nesting habitat provided on East Sand Island in future years will be necessary to realize the goal of relocating a majority of the East Sand Island tern colony to alternative sites, as prescribed in the Caspian Tern Management Plan.

Juvenile salmonids continued to be a large part of the diet of Caspian terns nesting on East Sand Island, comprising 33% of the overall diet in 2010, slightly higher than the 10-year average during 2000-2009 (30%). As in previous years, marine forage fishes dominated the diet of Caspian terns nesting on East Sand Island, comprising 62% of all identified bill loads in 2010. Caspian terns nesting at the East Sand Island colony consumed about 5.3 million juvenile salmonids (95% c.i. = 4.5 – 6.1 million) in 2010, not significantly different than the smolt consumption estimates from the previous two years. Since 2000, the average number of smolts consumed by Caspian terns nesting on East Sand Island was 5.3 million smolts per year, less than half the annual consumption of juvenile salmonids by Caspian terns in the Columbia River estuary prior to 2000, when the breeding colony was located on Rice Island. Further reductions in smolt consumption by terns nesting on East Sand Island will require a significant reduction in the size of the tern colony; future management plans are designed to reduce the size of the East Sand Island tern colony to about one-third its pre-management size.

Implementation of the federal management agencies' Caspian Tern Management Plan for the Columbia River Estuary continued outside the Columbia River basin, with the USACE-Portland District and its state and federal partners building four new Caspian tern nesting islands prior to the 2010 nesting season. Two of the four new islands are located in Lower Klamath National Wildlife Refuge, California (a 1-acre silt-core island in the Orems Unit and a 0.8-acre floating island on Sheepy Lake); one new island is located in Tule Lake National Wildlife Refuge, California (a 2-acre rock-core island in

Sump 1B); and one new island is located at Summer Lake Wildlife Area, Oregon (a 0.5-acre rock-core island in Gold Dike impoundment). The severe drought in the Upper Klamath Basin and adjacent areas of interior Oregon, however, precluded allocating water to three of the four impoundments where new islands were built. Nevertheless, Caspian terns quickly colonized the new 0.8-acre floating island at Sheepy Lake in Lower Klamath National Wildlife Refuge, where 258 pairs raised 168 young. Nineteen terns that had been banded in the Columbia River estuary were re-sighted at the Sheepy Lake tern island. We continued to monitor four other alternative colony sites constructed by the USACE-Portland District in interior Oregon during 2008 and 2009: Fern Ridge Reservoir tern island, Crump Lake tern island, and East Link and Dutchy Lake tern islands in Summer Lake Wildlife Area. No Caspian terns successfully nested at three of these four islands and the fourth experienced very low nesting success, apparently due to adverse weather conditions and low forage fish availability associated with climate conditions prior to and during the 2010 nesting season.

Diet composition and PIT tag recovery data from Caspian tern colonies in interior Oregon and northeastern California indicated these colonies were primarily consuming cyprinids (i.e., tui chub *Gila bicolor*), centrarchids (i.e., crappie *Pomoxis* spp.), and ictalurids (i.e., brown bullhead *Ameiurus nebulosus*) in 2010. Catostomids (suckers), several species of which are listed under the Endangered Species Act, were not identified in the diet of terns nesting at Crump Lake in 2010. One juvenile sucker (species unknown) was observed at the Summer Lake Caspian tern colony and four juvenile suckers (species unknown) were observed at the Sheepy Lake Caspian tern colony in 2010. Suckers represented a very small percentage (< 0.1%) of identifiable prey items at these two tern colonies. No sucker PIT tags were recovered from Caspian tern colonies in either interior Oregon or northeastern California in 2010.

East Sand Island is also home to the largest double-crested cormorant colony in western North America, consisting of about 13,596 breeding pairs in 2010; 2010 was the second consecutive year where the colony grew by more than 10%. Juvenile salmonids represented about 16.4% of the diet of double-crested cormorants nesting on East Sand Island in 2010, compared with 9.2% in 2009. Double-crested cormorants nesting at this colony consumed approximately 19.2 million juvenile salmonids (95% c.i. = 14.6 – 23.8 million) in 2010, the highest annual smolt consumption ever estimated for the East Sand Island cormorant colony. In the past two years, smolt consumption by double-crested cormorants nesting on East Sand Island was significantly greater than smolt consumption by Caspian terns nesting on East Sand Island.

Management options to reduce or limit smolt losses to the double-crested cormorant colony on East Sand Island are under consideration by federal, state, and tribal resource management agencies. In order to reduce predation on juvenile salmonids by double-crested cormorants in the Columbia River estuary, it will be necessary to reduce the size of the cormorant colony on East Sand Island. Non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the Pacific coast, seem more appropriate in the context of the cormorant colony on East Sand Island, whose initial growth appears to have occurred largely at the expense of other colonies in the region. As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses in the estuary will require analysis under the National Environmental Policy Act (NEPA), a process that is currently underway.

Further up-river in the Columbia Plateau region, Caspian terns and double-crested cormorants are also the two bird species responsible for most of the smolt losses to avian predators. Management options to reduce the impacts of these two avian predators on smolt survival along the mid-Columbia and lower Snake rivers are currently being considered by resource managers. In 2010, the largest breeding colonies of Caspian terns in the Columbia Plateau region were on Crescent Island (in McNary Pool) and on Goose Island (Potholes Reservoir, WA), where 375 pairs and 416 pairs nested, respectively. Caspian tern nesting success at the Crescent Island colony averaged 0.52 young raised per nesting pair, higher than in recent years, while the Goose Island tern colony experienced almost complete nesting failure in 2010, due primarily to disturbance by avian and mammalian predators. Three other smaller Caspian tern colonies in the Columbia Plateau region also failed or nearly failed to produce any young. In 2010, salmonid smolts represented 71% of tern prey items at the Crescent Island colony and 21% of tern prey items at the Goose Island colony; estimated smolt consumption by terns nesting at these two colonies was 420,000 smolts and 122,000 smolts, respectively. The largest colony of double-crested cormorants on the mid-Columbia River was on Foundation Island (in McNary Pool), where 308 pairs nested in 2010. Diet sampling during 2005-2010 indicated that ca. 50% (by mass) of the Foundation Island cormorant diet was juvenile salmonids during May (the peak of smolt out-migration), while less than 10% of the diet was salmonids during early April, June, and July.

A total of 36,764 PIT tags from 2010 migration year smolts were recovered on bird colonies in the Columbia Plateau region. PIT tag recoveries indicated that smolt losses in 2010 were similar for Foundation Island cormorants (8,481 tags) and Crescent Island terns (8,255 tags). Substantial numbers of 2010 smolt PIT tags were also detected on the Caspian tern colony on Goose Island in Potholes Reservoir (8,512 tags) and on a mixed California gull (*Larus californicus*) and ring-billed gull (*L. delawarensis*) colony on Miller Rocks in The Dalles Pool (5,045 tags). PIT tags recovered from the Caspian tern colony in Potholes Reservoir were almost exclusively from upper Columbia River salmonid ESUs, while PIT tags recovered on other bird colonies in the Plateau region consisted of smolts from upper Columbia, Snake, and middle Columbia ESUs. Preliminary results indicate that Caspian terns from the Goose Island colony in Potholes Reservoir consumed an estimated 9.6% of the juvenile steelhead (*Oncorhynchus mykiss*) PIT-tagged and released at Rock Island Dam on the upper Columbia River in 2010. Predation rates by Crescent Island terns on Snake River steelhead (ca. 2.8%) and by Foundation Island cormorants on Snake River steelhead (ca. 1.3%) and Snake River sockeye (ca. 1.7%) were also notable in 2010, although lower compared to previous years (2004-2009).

California and ring-billed gulls have nested in large numbers on islands on or near the mid- and upper Columbia River, but these gulls have generally consumed few fish and even fewer juvenile salmonids, with the exception of the gull colony on Miller Rocks in The Dalles Pool (see above). In 2010, the number of gulls counted on the Miller Rocks colony was 5,533, down from 6,016 gulls counted on colony during the 2009 breeding season. Despite this decline in the number of gulls counted on the Miller Rocks gull colony, the number of gulls utilizing Miller Rocks during the breeding season has increased by about 150% since 1998. Similarly, the American white pelican (*Pelecanus erythrorhynchos*) colony on Badger Island in McNary Pool has experienced significant growth since the late 1990's, increasing from 100 adults on colony in 1999 to 1,643 adults in 2010. Unlike the Miller Rocks gull colony, however, pelicans nesting at Badger Island are not consuming large numbers of juvenile salmonids, based on the relatively small numbers of smolt PIT tags detected on the colony. Continued monitoring of these and perhaps other incipient piscivorous waterbirds colonies in the Columbia River basin will be necessary to determine the magnitude and trend for total losses of juvenile salmonids to avian predators in the basin.

INTRODUCTION

A Columbia Basin-wide assessment of avian predation on juvenile salmonids (*Oncorhynchus* spp.) indicates that the most significant impacts to smolt survival occur in the Columbia River estuary (BRNW 2005a, 2006a, 2007, 2008, 2009a, 2010a). The combined consumption of juvenile salmonids by Caspian terns (*Hydroprogne caspia*) and double-crested cormorants (*Phalacrocorax auritus*) nesting on East Sand Island in the Columbia River estuary has recently been estimated at between 15 and 20 million smolts annually (BRNW 2010a). This represents approximately 15% of all the salmonid smolts that survive to the estuary in an average year. Estimated smolt losses to piscivorous colonial waterbirds that nest in the Columbia River estuary are more than an order of magnitude greater than those observed elsewhere in the Columbia River basin (BRNW 2010a). Additionally, when compared to the impact of avian predation in the Columbia Plateau region, avian predation in the Columbia River estuary affects juvenile salmonids belonging to every ESA-listed stock from throughout the Basin that have survived freshwater migration to the ocean, and presumably have a higher probability of returning as adults. For these reasons, management of the colonies of Caspian terns and double-crested cormorants on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, compared to potential benefits of management of other populations of piscivorous waterbirds. The Caspian tern colonies on Crescent Island (mid-Columbia River) and Goose Island (Potholes Reservoir) and the double-crested cormorant colony on Foundation Island (mid-Columbia River) may be exceptions to this rule; management of these relatively small colonies on or near the mid-Columbia River may benefit certain salmonid populations, in particular steelhead (*Oncorhynchus mykiss*; Antolos et al. 2005, BRNW 2010a).

Regional fish and wildlife managers in 1999 called for management action to reduce losses of juvenile salmonids to Caspian terns nesting in the Columbia River estuary. A management plan implemented in 2000 sought to relocate the Rice Island Caspian tern colony, the largest of its kind in the world, to a restored colony site on East Sand Island, 21 km closer to the ocean, where it was hoped terns would consume significantly fewer juvenile salmonids. Over 94% of the terns shifted to nesting on East Sand Island in 2000, where juvenile salmonids comprised 47% of the prey items, compared to 90% of prey items at Rice Island (Roby et al. 2002). During 2001–2009, all Caspian terns nesting in the Columbia River estuary used East Sand Island (BRNW 2010a). During 2001-2009, estimated consumption of juvenile salmonids by Caspian terns nesting on East Sand Island averaged 5.3 million smolts per year (SD = 1.10 million, n = 9 years), a ca. 62% reduction in annual consumption of smolts compared to when the Caspian tern colony was on Rice Island (BRNW 2010a).

Further management of Caspian terns to reduce losses of juvenile salmonids in the Columbia River estuary is currently in progress; the Records of Decision (RODs) for Caspian tern management in the estuary, signed in November 2006, stipulated the redistribution of approximately two-thirds of the East Sand Island tern colony to alternative colony sites in Oregon and California (USFWS 2005, 2006). This management is intended to further reduce smolt losses to terns in the estuary by at least

50%, while still maintaining the long-term viability of the Pacific Coast Caspian tern population. The U.S. Army Corps of Engineers – Portland District has constructed eight islands, five in interior Oregon and three in northeastern California, as alternative nesting habitat for Caspian terns currently nesting on East Sand Island. The Corps has plans to construct additional tern nesting islands in the next 2-3 years. Concurrently, the Corps will reduce the area of suitable nesting habitat for Caspian terns on East Sand Island from 5 acres to 1-1.5 acres, and hazing terns that attempt to establish new nesting colonies elsewhere in the Columbia River estuary.

Management options to reduce or limit smolt losses to the large double-crested cormorant colony on East Sand Island, which was estimated to have consumed 11.1 million juvenile salmonids (95% c.i. = 7.7 million to 14.5 million; BRNW 2010a) in 2009, are under consideration. In order to reduce predation on juvenile salmonids by double-crested cormorants in the Columbia River estuary, it will be necessary to reduce the size of the cormorant colony on East Sand Island. Non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the Pacific coast, seem more appropriate in the context of the cormorant colony on East Sand Island, whose growth appears to have been largely at the expense of other colonies in the region (Adkins et al. 2010). The East Sand Island cormorant colony now consists of about 40% of all breeding pairs in the Western North America population (Adkins et al. 2010). As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses in the estuary will require analysis under the National Environmental Policy Act (NEPA), including assessments of the (1) population status of Pacific Coast double-crested cormorants, (2) availability of suitable alternative nesting habitat outside the Columbia River basin, and (3) potential enhancement of salmonid recovery rates in the Columbia River basin should management of cormorants at East Sand Island be implemented.

The primary goals of this project in 2010 were to (1) evaluate the efficacy of management initiatives implemented to reduce predation on juvenile salmonids by Caspian terns nesting on East Sand Island, including the monitoring of alternative nesting islands created for Caspian terns outside the Columbia Basin; (2) collect, compile, and analyze data needed to complete the NEPA analysis required to evaluate management of (a) double-crested cormorants nesting on East Sand Island, (b) Caspian terns nesting on Crescent Island, the Blalock Islands, and Goose Island, and (c) double-crested cormorants nesting on Foundation Island; (3) investigate the number of other piscivorous colonial waterbirds (e.g., Brandt's cormorants [*Phalacrocorax penicillatus*], California brown pelicans [*Pelecanus occidentalis californicus*], American white pelicans [*Pelecanus erythrorhynchos*], and gulls [*Larus* spp.]) that use the Columbia River to nest or roost and assess their potential impacts on smolt survival; and (4) assist resource managers in the development of plans for long-term management of avian predation on juvenile salmonids from the Columbia River basin, as warranted.

STUDY AREA

The primary focus of our research and monitoring efforts in 2010 were at (1) the Caspian tern and double-crested cormorant colonies on East Sand Island in the Columbia River estuary (Map 1), (2) the Caspian tern and double-crested cormorant colonies in the Columbia Plateau region (Map 1), and (3) five recently constructed islands for Caspian tern nesting in interior Oregon (i.e., Fern Ridge Reservoir, Crump Lake, Dutchy Lake at Summer Lake Wildlife Area, and East Link impoundment at Summer Lake Wildlife Area) and northeastern California (i.e., Sheepy Lake at Lower Klamath National Wildlife Refuge; Map 2).

Additionally, this report provides information on nesting Caspian terns along the Washington Coast (i.e., Dungeness Spit and the Port of Bellingham); nesting Brandt's cormorants and roosting California brown pelicans on East Sand Island; nesting American white pelicans on Badger Island and the newly-formed colony on Miller Sands Spit in the Columbia River estuary; and various gull colonies in the Columbia River estuary, in the Columbia Plateau region, and at tern nesting islands in interior Oregon and northeastern California; Map 1 and Map 2).

SECTION 1: CASPIAN TERNS

1.1. Preparation and Modification of Nesting Habitat

Beginning in 2008, the U.S. Army Corps of Engineers (USACE) implemented management described in the January 2005 Final Environmental Impact Statement (FEIS) and November 2006 Records of Decision (RODs) for *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary* (USFWS 2005, 2006). This management plan, which was developed jointly by the U.S. Fish and Wildlife Service (USFWS; lead), the USACE, and NOAA Fisheries, seeks to redistribute the majority of Caspian terns nesting at the colony on East Sand Island in the Columbia River estuary (Map 1) to alternative colony sites (islands) in interior Oregon and the San Francisco Bay area by 2015 (Map 2). Three alternative colony sites in northeastern California were added to the plan in 2008: Tule Lake NWR (1 island) and Lower Klamath NWR (2 islands). The goal of the plan is to reduce Caspian tern predation on out-migrating juvenile salmonids (salmon and steelhead) in the Columbia River estuary, and thereby enhance recovery of salmonid stocks from throughout the Columbia River basin without negatively affecting the Pacific Coast population of Caspian terns. Thirteen of 20 evolutionarily significant units (ESUs) of Columbia Basin salmonids are currently listed as either threatened or endangered under the U.S. Endangered Species Act (ESA).

The Caspian Tern Management Plan called for the creation of approximately 7-8 acres of new or restored Caspian tern nesting habitat (islands) in interior Oregon (specifically Fern Ridge Lake, Crump Lake, and Summer Lake) and the San Francisco Bay area (specifically Don Edwards National Wildlife Refuge, Hayward Regional Shoreline, and Brooks Island; Map 2), and to actively attract Caspian terns to nest at these sites. As alternative tern nesting habitat is created or restored, the available tern nesting habitat on East Sand Island would be reduced from its historical size (approximately 5 acres) to 1.0 - 1.5 acres.

Creation of tern nesting habitat at alternative colony sites and the reduction of nesting habitat at East Sand Island was planned to occur in phases, at a ratio of two new acres of habitat provided for each acre of habitat reduction on East Sand Island. Once fully implemented, the management plan was expected to reduce the East Sand Island Caspian tern colony from its current size (approximately 9,500 breeding pairs) to about 3,125 – 4,375 breeding pairs, or a reduction in colony size of 60% - 70%. A reduction in the size of the East Sand Island Caspian tern colony to 3,125 – 4,375 pairs was estimated by NOAA Fisheries to increase the annual population growth rate (λ) of three ESA-listed ESUs of Columbia Basin steelhead by 1% or greater. Steelhead were the focus of NOAA Fisheries' analysis because previous studies had indicated that Caspian tern predation rates on juvenile steelhead exceeded those of other salmonid species in the Columbia River basin. The planned reduction in the size of the Caspian tern colony at East Sand Island was expected to reduce annual consumption of juvenile salmonids (smolts) from the Columbia River basin by about 3.0 million fish. Annual consumption of juvenile salmonids by Caspian terns during the period 2000-2009 averaged approximately 5.3 million smolts per year.

The potential for a reduction in Caspian tern nesting habitat at East Sand Island to 1 acre was addressed in the 2006 RODs. Before nesting habitat on East Sand Island could be reduced below 1.5 acres, however, additional alternative sites for tern nesting would need to be developed (the criteria for selection of alternative sites were described in Appendix G of the Final EIS). Three additional tern colony sites in northeastern California, one in Tule Lake National Wildlife Refuge and two in Lower Klamath National Wildlife Refuge, were recently identified as part of this on-going process, and environmental assessments were prepared for each site prior to island construction late in 2009 and early in 2010 (see below). A reduction in the area of the East Sand Island tern colony to 1 acre could potentially be accomplished with development of these and other alternative tern colony sites.

1.1.1. Columbia River Estuary

As part of Caspian Tern Management Plan, the USACE – Portland District prepared 3.1 acres of nesting habitat for Caspian terns on East Sand Island in early April 2010. Without annual restoration of the bare sand nesting habitat that Caspian terns prefer, the East Sand Island colony would likely be eliminated within a few years by rapidly encroaching pioneer vegetation. The amount of Caspian tern nesting habitat prepared on East Sand Island in 2010 was a slight reduction from the amount of nesting habitat prepared for terns in 2009 (3.5 acres) and a 38% reduction from what had been provided in previous year (5 acres). As stipulated in the Final Environmental Impact Statement (USFWS 2005: Chapter 2, Section 2.3.3), this 1.9-acre reduction in area of nesting habitat was allowed due to the creation and availability of 3.8 acres of new Caspian tern nesting habitat outside the Columbia River estuary (USFWS 2005; see below).

On 25 April, Caspian terns began digging nest scrapes near the high tide line on the southeast beach at East Sand Island. This area is outside the 3.1-acre area that was prepared for tern nesting on East Sand Island. On 28 April we were directed by resource managers to erect stakes and flagging at this satellite tern colony to dissuade Caspian terns from nesting. Terns continued to prospect for nest sites on the southeast beach of East Sand Island until mid-June; additional stakes and flagging were erected at the site in early and mid May until the satellite colony was abandoned on 19 June, presumably due to frequent disturbance by bald eagles and peregrine falcons, and possibly due to nest predation by a raccoon that resided on the island throughout the breeding season.

In previous years, work crews from NOAA Fisheries, Oregon Department of Fish and Wildlife, and USACE carried out various habitat modifications on the former tern colony site on Rice Island (e.g., fencing and flagging) prior to the breeding season to discourage terns from nesting there. This was not necessary in 2010 because the former colony site on Rice Island (ca. 7 acres) has become completely vegetated and was consequently unsuitable for tern nesting. On 2 May, 75 Caspian terns were observed in an upland area east of the old colony site on Rice Island. Stakes and flagging were erected in the areas where terns were attempting to nest on Rice Island on 6 May and again on 10 May, causing terns to abandon the site on 30 May. Active hazing or passive measures to discourage tern nesting (i.e., stakes and flagging) were not necessary at other dredged material disposal sites in the upper Columbia River estuary (i.e., Miller Sands Spit, Pillar Rock Sands, Puget Island) during the 2010 nesting season.

1.1.2. Interior Oregon and Northeastern California

The USACE and its state and federal partners have so far completed construction of eight islands (a total of 7.3 acres; Table 1) specifically designed for Caspian tern nesting as part of the Caspian Tern Management Plan (USFWS 2005). Two one-acre islands were built prior to the 2008 breeding season at Fern Ridge Reservoir and Crump Lake, two half-acre islands were built prior to the 2009 breeding season in Summer Lake Wildlife Area (East Link impoundment and Dutchy Lake), and four additional islands were built prior to the 2010 breeding season (a half-acre island at Gold Dike impoundment in Summer Lake Wildlife Area, a one-acre island at Orems Unit and a 0.8-acre island at Sheepy Lake in Lower Klamath NWR, and a two-acre island at Tule Lake Sump 1B in Tule Lake NWR). Of the 7.3 acres of tern nesting habitat that were created prior to the 2010 breeding season, only 3.8 acres were suitable for tern nesting in 2010; the islands at Gold Dike (Summer Lake Wildlife Area), Orems Unit (Lower Klamath NWR), and Tule Lake Sump 1B (Tule Lake NWR) were not surrounded by water in 2010, and therefore were unsuitable for tern nesting during that year. Social attraction techniques (i.e., decoys and audio playback systems; Kress 2000, Kress 2002, Roby et al. 2002) were used at each suitable site, with the exception of the Crump Lake tern island, to enhance prospects of tern nesting at each site.

1.2. Nesting Chronology, Colony Size, and Productivity

1.2.1. Columbia River Estuary

Methods: The number of Caspian terns breeding on East Sand Island in the Columbia River estuary during 2010 was estimated using low-altitude, high-resolution aerial photography of the colony taken near the end of the incubation period. The average of 3 direct counts of all adult terns on the colony in aerial photography, corrected using ground counts of the ratio of incubating to non-incubating terns on 12 different plots within the colony area, was used to estimate the number of breeding pairs on the colony at the time of the photography. Confidence intervals for the number of breeding pairs were calculated using a Monte Carlo simulation procedure to incorporate the variance in the multiple counts from the aerial photography and the variance in the ratios of incubating to non-incubating adult terns on the plots.

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

Periodic boat-based and aerial surveys of the dredged material disposal islands in the upper estuary (i.e., Rice Island, Miller Sands Spit, Pillar Rock Sands) were conducted during the 2010 nesting season in order to detect early signs of any nesting attempts by Caspian terns.

Results and Discussion: As was the case during 2001–2009, all nesting by Caspian terns in the Columbia River estuary occurred on East Sand Island in 2010. The colony attendance data suggest that the tern colony reached its maximum size in mid-May in 2010, earlier than was observed in previous years (Figure 1).

Based on the aerial photo census, we estimate that 8,283 breeding pairs of Caspian terns (95% c.i. = 7.412–9,154 breeding pairs) were nesting on East Sand Island at the peak of nesting activity (late May) in 2010. This estimate is significantly lower than our comparable best estimate of peak colony size at East Sand Island in 2009 (9,854 breeding pairs, 95% c.i. = 9,509–10,199 breeding pairs), and was the smallest colony size estimate measured at the colony since it became fully established in 2001. During 2000-2009, the size of the East Sand Island Caspian tern colony has been relatively stable, averaging about 9,315 breeding pairs at its annual peak (Figure 2). Despite the incremental reduction in the amount of tern nesting habitat made available to terns on East Sand

Island from 5 acres in previous years to 3.1 acres in 2010, nesting density at the East Sand Island tern colony has been roughly the same over the past four years (ca. 0.7 nests/m^2; Figure 3). These data suggest that nesting habitat was not a limiting factor on colony size at East Sand Island in 2010. To date, the East Sand Island tern colony continues to be the largest known breeding colony of Caspian terns in the world.

We estimate that 425 fledglings (95% c.i. = 269–580 fledglings) were produced at the East Sand Island tern colony in 2010. This corresponds to an average nesting success of 0.05 young raised per breeding pair (95% c.i. = 0.03–0.07 fledglings/breeding pair), the lowest productivity ever recorded at the East Sand Island tern colony (Figure 4). Nesting success at the East Sand Island Caspian tern colony peaked in 2001 and has trended downward since then (Figure 4). Two factors likely have contributed to declining productivity of the East Sand Island tern colony: ocean conditions and nest predation.

About 75 Caspian terns were observed loafing on upland areas of Rice Island on 2 May (Map 1). The behavior of these birds indicated an intention to nest at this dredged material disposal island, as evidenced by courtship displays, exchange of courtship meals, copulations, and digging of nest scrapes. Resource managers were informed of the situation and on 6 May and on 10 May stakes fixed with brightly colored flagging were erected in the areas used by terns to dissuade them from nesting at this incipient colony site. These efforts were effective in dissuading terns from roosting or nesting on Rice Island throughout the remainder of the 2010 nesting season. No other attempts by Caspian terns to nest in upland areas at other dredged material disposal sites in the upper estuary (i.e., Miller Sands Spit, Pillar Rock Sands, Puget Island; Map 1) were observed in 2010.

1.2.2. Columbia Plateau

Methods: Caspian tern colony size at Crescent Island on the mid-Columbia River and Goose Island in Potholes Reservoir (Map 1) in 2010, measured as the number of tern breeding pairs, was estimated by averaging three independent counts from aerial photography of all incubating terns on each colony during the peak of the incubation period. (Restricted access to Crescent Island during peak incubation due to nesting American white pelicans resulted in the necessity to use oblique aerial photography to determine colony size in 2010. Vegetation and topography precluded counting the number of total number of breeding pairs at the main tern colony on Goose Island from the observation blind.) Nesting success was estimated from ground counts of all fledglings on each colony just prior to fledging.

Periodic boat-based and aerial surveys of former Caspian tern breeding colony sites (i.e., Threemile Canyon Island, Blalock Islands, Miller Rocks, Cabin Island, Sprague Lake, and Banks Lake; Map 1) were conducted during the 2010 nesting season to determine whether these colony sites had been re-occupied. 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. If nesting Caspian terns were detected during aerial surveys at any of these traditional colony sites or at new colony sites, oblique photography was taken in order to estimate the number of nesting pairs.

Results and Discussion: Caspian tern attendance at the Crescent Island colony in 2010 was well below the average for 2000-2009 (Figure 5). This was associated with below average colony size (Figure 6) and nesting success (Figure 7) at the Crescent Island tern colony in 2010. About 375 breeding pairs of Caspian terns attempted to nest on Crescent Island in 2010, up slightly from the colony size in 2009. Caspian tern colony size on Crescent Island trended downward from 2001 to 2007, but has remained relatively stable since 2007 (Figure 6).

On 7 May, a satellite tern colony was initiated on Crescent Island on the upper beach in the cove south of the main colony and tern eggs were laid at this satellite colony site on 8 May. This is the first record of Caspian tern nesting on Crescent Island at a location outside the main colony site since our intensive colony monitoring began in 2000. Up to 11 breeding pairs of Caspian terns occupied this satellite colony until all nesting attempts failed in late May and the satellite colony was abandoned.

We estimated that 195 young terns fledged from the Crescent Island tern colony in 2010, or 0.52 young raised per breeding pair (Figure 7). Nesting success at the Crescent Island Caspian tern colony in 2010 was below the 10-year average for 2000-2009, but above what was observed during the previous two years (Figure 7).

At Potholes Reservoir, Caspian terns nested at two disjunct colony sites on Goose Island in 2010; the main colony was located on the western lobe of the island and a smaller satellite colony was located on the small eastern lobe of the island. The only weekly colony attendance data we have collected for Caspian terns nesting at Potholes Reservoir prior to 2010 was in 2001, when terns nested on Solstice Island to the north of Goose Island. Colony attendance at the Goose Island colony in 2010 was highest during the late incubation and early chick-rearing periods and then dropped off sharply during the late chick-rearing and fledging period as compared to terns nesting at Solstice Island in 2001 (Figure 8). The decline in colony attendance was associated with widespread nesting failure initially observed on the main subcolony during the first week of June. We estimate that a total of 416 breeding pairs attempted to nest on Goose Island in 2010, down from the colony size estimate in 2009 (487 breeding pairs; Figure 9). The Goose Island colony was the largest Caspian tern colony in the Columbia Plateau region in both 2009 and 2010.

Nearly all Caspian tern nesting attempts at Goose Island in 2010 failed. Only three young terns were raised to fledging age, or an average of only 0.01 young per breeding pair, the lowest nesting success recorded for Caspian terns at Potholes Reservoir (Figure 10). Poor nesting success at Goose Island in 2010 was apparently caused by a combination of unseasonably cool, wet weather and disturbance to nesting terns on the colony by great horned owls (*Bubo virginianus*) and at least three different American mink (*Neovison vison*).

Nocturnal visits to Goose Island by one or more great horned owls caused considerable disturbance to incubating and brooding Caspian terns on the colony. Nocturnal disturbance at Caspian tern colonies by great horned owls can cause all attending adult terns to abandon the colony until dawn. Coupled with cool, wet weather, young nestlings and late stage embryos can die of exposure. This appeared to be the primary factor limiting Caspian tern nesting success at Goose Island in 2010. There was a steady increase in the number of Caspian tern breeding pairs on the Goose Island tern colony until 30 May, when about 300 pairs were in attendance. Subsequently, attended nests declined by 25% by 2 June, when 21 dead chicks were counted on colony, all < 30 cm from their nest scrapes, wet, and apparently uninjured. This was a minimum count of the number of dead chicks on-colony, as many were still being brooded by their parents. Colony monitors, staying in the observation blind overnight, confirmed nighttime disturbance of the main tern colony by a great horned owl on 7 June, which perched on a tall metal pole that was situated near the main tern sub-colony. (The pole was a beacon designed to warn boaters on the reservoir of forecasted high winds, but had not been functional for several years.) By 11 June, when the high-wind advisory pole was removed, attended tern nests on the main sub-colony had dropped to about 50 nests.

Mink are very proficient predators on colonial waterbirds when they reach an island where a breeding colony is present, and can cause complete breeding failure at the colony. Three different mink were trapped and removed from Goose Island during the 2010 breeding season. While it is likely that the presence of several mink on Goose Island in 2010 contributed to the nearly complete breeding failure by Caspian terns, there is not direct evidence of such an impact. Mink predation on birds nesting on Goose Island was directed primarily toward ring-billed and California gulls, which nest by the thousands on Goose Island. A total of 96 gull carcasses were documented on Goose Island during the 2010 breeding season, and at least 37 showed signs of predation by mink; 18 gull carcasses were cached under rocks or in brush piles near the shores of the island. By comparison, only three carcasses of adult Caspian terns were documented on Goose Island in 2010. Two of these carcasses were observed on the breeding colony and appeared uninjured, while the third showed signs of predation or scavenging. No cached Caspian tern carcasses were found.

Nesting by Caspian terns on the Blalock Island group, located on the mid-Columbia River in John Day Pool, was first detected in 2005 when six pairs attempted to nest on Rock Island. The Rock Island colony peaked at 104 breeding pairs in 2008 and fell to 79 breeding pairs in 2009 before nesting terns abandoned the site and moved to Anvil Island (another island in the Blalock Island group) in 2010 (Figure 11). In 2010, the Caspian tern nesting colony on Anvil Island consisted of about 135 breeding pairs, the largest Caspian tern colony size ever recorded in the Blalock Island group (Figure 11). The Anvil Island Caspian tern colony completely failed in 2010, however, due to rising water levels in John Day Pool that flooded the colony site and possibly other unidentified factors. This is the fifth consecutive year that Caspian terns nesting at the Blalock Island group have failed or nearly failed to rear young: in 2006 due to mink predation, in 2007 due to avian predation, in 2008 due to unusually high water levels in John Day Pool during the incubation period, and in 2009 due to an unknown cause(s).

We found no evidence of Caspian terns attempting to nest at colony sites along the lower and mid-Columbia River or the lower Snake River, other than Crescent Island and Anvil Island, in 2010. Caspian tern nesting has not occurred at Threemile Canyon Island in John Day Pool (river km 414) since 2001, when American mink caused the colony to fail. Caspian terns have not been detected nesting on Miller Rocks in The Dalles Pool (river km 333) since 2001, when up to 20 breeding pairs attempted to nest on the edge of a large gull colony. Caspian terns have not attempted to nest on Cabin Island above Priest Rapids Dam (river km 641) since the late 1990s, when a large ring-billed gull (*Larus delawarensis*) colony existed before USDA-Wildlife Services dispersed the colony by oiling eggs and disturbing nesting birds (Pochop et al. 1998).

In addition to Caspian tern colony on Goose Island in Potholes Reservoir, we identified two other Caspian tern colonies in the Columbia Plateau region off the Columbia and Snake rivers in 2010. Thirty-four pairs nested on Twining Island in Banks Lake and 4 pairs nested on Harper Island in Sprague Lake. Caspian terns nesting at Twining Island failed to rear any young in 2010; at Harper Island tern nesting success in 2010 is unknown. Tern nesting on Banks and Sprague lakes has been sporadic since nesting at both sites was first confirmed in 1997, with colony sizes ranging between 0 and 61 breeding pairs at each site in each year.

There was of total of five active Caspian tern colonies in the Columbia Plateau region in 2010 (Figure 12), where a total of approximately 965 breeding pairs nested (Figure 13). This suggests that the number of Caspian terns nesting in the Columbia Plateau region has remained relatively stable since 2000, when the total number of breeding Caspian terns was estimated at just over 1,000 breeding pairs (Figure 13).

1.2.3. Coastal Washington

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

The number of Caspian terns breeding at sites in the Puget Sound area of Washington was assessed by conducting ground-based surveys periodically (every 1-2 weeks) throughout the breeding season. The number of Caspian terns attempting to nest at Dungeness Spit (in Dungeness National Wildlife Refuge near the city of Sequim, WA) and at the abandoned Georgia Pacific mill site at the Port of Bellingham (Map 1) was estimated by counting the number of terns sitting on nests during each visit. We also opportunistically assessed nesting chronology, productivity, and factors limiting colony size and nesting success at these colonies throughout the breeding season.

Results and Discussion: Although Caspian terns were commonly observed foraging and roosting in Willapa Bay and Grays Harbor throughout the 2010 breeding season, no nesting attempts by terns were detected in either area. This suggests that suitable Caspian tern nesting sites (i.e., islands that include unvegetated substrate, 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.

In 2010, the Caspian tern colony on Dungeness Spit in Dungeness NWR was not occupied until 12 May, when up to 170 Caspian terns were counted on the colony site used during 2003-2009. One Caspian tern egg was observed at the colony on 12 May but was depredated by a gull. Our best estimate of the peak size of the Caspian tern colony at Dungeness Spit in 2010 was ca. 200 breeding pairs on 24 May. The Dungeness Spit tern colony was completely abandoned on or before 29 May, apparently due to nest predation by coyotes (*Canis latrans*), bald eagles (*Haliaeetus leucocephalus*), and gulls. This Caspian tern colony grew steadily from 2003 to 2009, when the colony size reached ca. 1,500 breeding pairs, the second largest Caspian tern colony along the Pacific Coast of North America (after the colony on East Sand Island; BRNW 2010a). Based on re-sightings of banded Caspian terns in previous years, at least some of the growth in the Dungeness tern colony was due to immigration of birds from colonies in the Columbia River basin (i.e., East Sand and Crescent islands) and from Commencement Bay, Tacoma, WA (BRNW 2004, 2005b, 2006b, 2009b, 2010b). Despite repeated forays into the Dungeness Spit Caspian tern colony by mammalian predators in previous years, terns have been successful in raising some young at the colony in every year until 2009 and 2010, when coyotes and avian predators caused complete nesting failure at the colony.

During an aerial survey of the Puget Sound area conducted on 17 June 2010, Caspian terns were observed at the abandoned Georgia Pacific mill site at the Port of Bellingham. This colony was first established in 2009, when 200 adult terns, some with young, were counted at the site in early July. The tern colony was located on bare pavement and gravel at a location where an old warehouse was demolished in 2008. The area being used by nesting terns is fenced, providing some protection from mammalian predators. In 2010, we visited the tern colony at the Port of Bellingham six times, beginning in early July. During these visits, the count of adult Caspian terns at the site ranged from ca. 1,850 to ca. 2,950 birds. Our best estimate of the number of terns nesting at the site in 2010 was between 1,400 and 2,000 breeding pairs. Some of the terns colonizing this new site were likely from the failed colony at Dungeness Spit, WA; however, re-sightings of previously banded terns suggest that terns also immigrated from colony sites in the Columbia River estuary, San Francisco Bay, interior Oregon, and the Columbia Plateau region (see below). Caspian tern productivity at the Port of Bellingham colony was good; we estimated that 900 - 1,400 young terns fledged from the colony, or 0.5 - 1.0 young raised per breeding pair. Nest predation, a major limiting factor to colony size and nesting success at other tern colonies in the region, did not appear to be a large factor at this site. Port of Bellingham officials plan to begin an environmental cleanup of the site, which includes the area used by nesting terns, in 2011. The Port plans to dissuade Caspian terns from nesting at the site in 2011. Continued monitoring of the Puget Sound area in 2011 and beyond will be necessary to determine where Caspian terns displaced from the Port of Bellingham colony site might attempt to nest and whether Caspian tern management initiatives implemented on East Sand Island cause more terns to prospect for nest sites in the Salish Sea region.

1.2.4. Interior Oregon and Northeastern California

Methods: We constructed observation blinds at the periphery of each of the islands specifically designed and built for Caspian tern nesting in interior Oregon (i.e., Fern Ridge Reservoir, Crump Lake, Dutchy Lake at Summer Lake Wildlife Area, and East Link impoundment at Summer Lake Wildlife Area) and in northeastern California (i.e., Sheepy Lake at Lower Klamath National Wildlife Refuge; Map 2). We used a combination of habitat enhancement, social attraction using tern decoys and audio playback of vocalizations, limited gull control, and continuous monitoring of these newly created islands to help establish and maintain Caspian tern colonies at each site (see Kress 1983 for further details on these methods). Social attraction methods were not implemented at the Crump Lake tern island because managers decided that the Caspian tern colony at this site in 2009 had reached the target number of breeding pairs. Data on colony attendance, colony size, productivity, and limiting factors for colony size and productivity were collected 3-7 days per week at each island, with the exception of Fern Ridge Reservoir. Because there has been no prior history of Caspian terns nesting at Fern Ridge Reservoir or elsewhere in the Willamette Valley, video cameras installed in the blind were used as the primary means to monitor the island, instead of direct observation by a field crew.

The numbers of Caspian tern pairs breeding at colonies in interior Oregon and northeastern California were estimated from ground counts of incubating adult terns near the end of the incubation period. Nesting success (number of young raised per breeding pair) at each colony was estimated from ground counts of young at the colony at the beginning of the fledging period.

Periodic aerial, road-based, and boat-based surveys of other sites in central, south-central, and south-eastern Oregon and northeastern California (Map 3) were conducted during the 2010 nesting season in order to detect nesting attempts by Caspian terns and other colonial piscivorous waterbirds.

Results and Discussion: Caspian terns were observed during the 2010 nesting season at each of the five suitable tern nesting islands built by the Corps in interior Oregon and northeastern California (Figure 14); Caspian terns attempted to nest at three of these islands (Crump Lake island, East Link island, Sheepy Lake island), but the Caspian terns observed on the islands at Fern Ridge Reservoir and Dutchy Lake never attempted to nest at those sites.

Colony attendance at the Crump Lake tern island (Warner Valley, Oregon) in 2010 was well below the average for 2008-2009 (Figure 15). About 70 breeding pairs of Caspian terns attempted to nest at the Crump Lake tern colony in 2010, down considerably from the colony size estimates in 2008 (ca. 430 breeding pairs) and in 2009 (ca. 700 breeding pairs; Figure 16). As was the case in 2008 and 2009, high nest predation rates on Caspian tern eggs by California gulls (*Larus californicus*) at the Crump Lake tern island necessitated removal of a few problem gulls using firearms (under permit); a total of seven gulls that were preying on tern eggs were removed in 2010. Despite these efforts, only two tern chicks hatched at the colony and both were depredated by gulls, resulting in complete nest failure at the Crump Lake tern island in 2010 (Figure 17). Although gull predation on tern eggs and chicks was the most significant proximal factor limiting the size and productivity of Caspian terns nesting on Crump Lake tern island in 2010, drought, a cold, late spring, and low forage fish availability (especially tui chub) were likely the ultimate cause of colony failure in 2010.

At Summer Lake Wildlife Area, Caspian terns nested at only one (East Link impoundment) of the two islands available for tern nesting in 2010 (see Section 1.1.2). Although Caspian terns were observed on the floating tern island at Dutchy Lake throughout the 2010 breeding season (mid-April through mid-August), in contrast to 2009 no Caspian terns initiated nesting there. Compared to 2009, Caspian tern colony attendance at the two Summer Lake tern islands in 2010 was generally higher during the early part of breeding season (April through early July) and lower during the later part of the breeding season (mid-July through August; Figure 18). We estimate that 29 breeding pairs attempted to nest at the East Link tern island in 2010, up from a total of 15 breeding pairs at both Summer Lake tern islands in 2009 (Figure 19). A total of six California gulls that were observed repeatedly preying on Caspian tern eggs were shot under permit at the East Link tern island in 2010. Despite these efforts, only three young terns fledged from the East Link colony in 2010, or 0.10 young raised per breeding pair, considerably lower than the combined nesting success at the East Link and Dutchy Lake tern islands in 2009 (0.8 young raised per breeding pair; Figure 20). As with the Crump Lake tern colony, the proximal cause of the poor productivity for Caspian terns nesting at Summer Lake Wildlife Area in 2010 was nest predation by gulls, but the ultimate cause was apparently the drought, unseasonably cool weather, and low forage fish availability.

Caspian terns quickly colonized the new 0.8-acre floating island at Sheepy Lake in Lower Klamath National Wildlife Refuge (Figure 21), where 258 breeding pairs raised 168 young in 2010. As was the case at the Crump Lake and East Link tern colonies, limited gull control was deemed necessary at the Sheepy Lake tern colony. Three California gulls that were repeatedly observed depredating tern eggs at the Sheepy Lake colony were shot under permit. Nesting success at the Sheepy Lake colony (0.65 young raised per breeding pair) was the highest observed at any of the tern colonies we monitored in 2010, with the possible exception of the tern colony at the Port of Bellingham (0.5-1.0 young raised per breeding pair), also a relatively new colony site.

Based on observations at other Caspian tern colonies, productivity tends to be relatively high in the first few years after a colony becomes fully established and generally declines thereafter. For example, during the first three year when Caspian terns nested on East Sand Island in the Columbia River estuary (1999 - 2001), productivity was high and has declined more or less steadily over the subsequent nine years (Figure 4). Whether this same trend applies to the new Caspian tern colonies at Crump Lake (Figure 17), Summer Lake (Figure 20), and the Upper Klamath Basin remains to be seen. Gradual declines in productivity of Caspian tern colonies over time is at least partially attributable to gradual increases in nest predation by gulls and other predators at each colony site. Continuous colony monitoring and limited gull control for several years will likely be necessary at newly established Caspian tern colonies in interior Oregon and northeastern California in order to establish and maintain tern colonies at each of these sites in future years.

In 2010, the total number of Caspian terns nesting at islands created as alternative habitat for Caspian terns displaced from East Sand Island as part of the Caspian Tern Management Plan (USFWS 2005) was 358 breeding pairs, roughly half the number of terns that nested at these sites in the previous year (712 breeding pairs; Figure 22). This decline occurred despite there being a 60% increase in the amount of suitable nesting habitat made available to Caspian terns in interior Oregon and northeastern California in 2010 compared to 2009 (Table 1). Drought conditions over-winter and adverse spring weather, both associated with the 2009-2010 El Niño, delayed onset of tern nesting and resulted in low forage fish availability (especially tui chub) during the 2010 nesting season. Climate conditions were likely to blame for this unexpected decline in the total number of Caspian tern breeding pairs that used these inland colony sites in 2010 compared to the previous two years (Figure 22).

Based on an aerial survey conducted in mid-June, no other Caspian tern colonies in central, south-central, or southeastern Oregon or northeastern California were active in 2010 (Map 3). In 2009, Caspian tern nesting activity was detected on an island in the eastern arm of Clear Lake Reservoir, Clear Lake NWR, where approximately 35 pairs nested. Caspian terns did not nest at this site in 2010.

1.3. Diet Composition and Salmonid Consumption

1.3.1. Columbia River Estuary

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

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

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

Results and Discussion: Of the bill load fish identified at the East Sand Island Caspian tern colony during the 2010 nesting season, on average 33% were juvenile salmonids (n = 4,815 bill loads). This proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island, averaged over the entire nesting season, was slightly higher than the 10-year average (30%; Figure 23). As in previous years, marine forage fishes (i.e., anchovies [Engraulidae], surf perch [Embiotocidae], smelt [Osmeridae], and herring [Clupeidae]) were prevalent, together averaging 62% of all identified bill loads in the diet of terns nesting on East Sand Island in 2010 (Figure 24). The peak in the proportion of salmonids in the diet of Caspian terns nesting on East Sand Island occurred in mid-May, similar to the trend observed during the previous 10 years (Figure 25). The proportion of salmonids in the tern diet was generally higher in June and July of 2010 as compared to the 10-year average for those two months (Figure 25), when primarily sub-yearling Chinook were being consumed.

Our best estimate of total smolt consumption by Caspian terns nesting on East Sand Island in 2010 was 5.3 million smolts (95% c.i. = 4.5 – 6.1 million), not significantly different than the previous two years (average = 6.5 million smolts; 95% c.i. = 5.6 – 7.3 million; Figure 26). Since 2000, the average number of smolts consumed by Caspian terns nesting on East Sand Island was 5.3 million smolts per year (Figure 26). This is less than half the annual consumption of juvenile salmonids by Caspian terns in the Columbia River estuary prior to 2000, when the breeding colony was located on Rice Island in the upper Columbia River estuary.

Of the juvenile salmonids consumed in 2010, we estimate that 41% were coho salmon (best estimate = 1.8 million; 95% c.i. = 1.5 – 2.2 million), 24% were yearling Chinook salmon (best estimate = 1.3 million; 95% c.i. = 1.0 – 1.5 million), 20% were steelhead (best estimate = 1.0 million; 95% c.i. = 0.9 – 1.2 million), 15% were sub-yearling Chinook salmon (best estimate = 0.8 million; 95% c.i. = 0.6 – 0.9 million), and < 1% were sockeye salmon (best estimate = 0.04 million; 95% c.i. = 0.03 – 0.05 million; Figure 27).

1.3.2. Columbia Plateau

Methods: The taxonomic composition of the diet of Caspian terns nesting on Crescent Island in the mid-Columbia River and Goose Island in Potholes Reservoir 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 and Goose Island was 50 and 100 bill load identifications per week, respectively (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 (see Antolos et al. 2005). 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 and Goose Island tern colonies due to the potential impact of lethal sampling on such small colonies. Diet composition data were not collected at the Crescent Island tern colony during a 2-week period in mid-May because the island could not be accessed without disturbing a new satellite colony of Caspian terns, which failed late in May.

Estimates of annual smolt consumption by Caspian terns nesting at the Crescent Island and Goose Island colonies 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. For the Goose Island Caspian tern colony, both steelhead smolts from the Columbia River and resident rainbow trout stocked in Potholes Reservoir (and other nearby water bodies) were available to Goose Island terns. Based on the morphology (degree of smoltification) of each identified fish, it was possible to confidently classify 1/4 of the *O. mykiss* brought to the colony as steelhead smolts, leaving 3/4 of them as unidentified, either steelhead or resident rainbow trout. Uncertainty in the unidentified fish caused us to calculate consumption based on two different scenarios. First, we assumed all *O. mykiss* identified in tern bill loads were anadromous steelhead smolts from the upper Columbia River (upper bound of the anadromous salmonid consumption estimate), and second, we assumed that only 1/4 were steelhead and the remainder were resident rainbow trout (lower bound of the anadromous salmonid consumption estimate).

Results and Discussion: Of the bill load fish identified at the Crescent Island Caspian tern colony, on average 71% were juvenile salmonids (n = 981 bill loads). The annual proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island has been strikingly consistent (about 66%) over the last 11 years (Figure 28). Each year, millions of juvenile salmonids are released from Columbia Basin hatcheries, which provide Crescent Island terns with a reliable and relatively consistent food supply, as compared to the food supply available to terns nesting near the coast (e.g., East Sand Island). Juvenile salmonids were by far the most prevalent prey type in the diet of Caspian terns nesting on Crescent Island in 2010, followed by centrarchids (bass and sunfish, 15%) and cyprinids (carp and minnows, 9%; Figure 29). The proportion of juvenile salmonids in the diet of Crescent Island Caspian terns was highest in late April during 2010, a week earlier than the observed peak during the previous 10 years, and generally declined gradually thereafter (Figure 30). Seasonal changes in the proportion of salmonids in the diet probably reflect changes in availability of hatchery-reared smolts near the Crescent Island tern colony. The proportion of salmonids in the diet of Crescent Island Caspian terns was consistently higher throughout the breeding season compared to that of Caspian terns nesting on East Sand Island (Figure 25).

We estimated that Caspian terns nesting on Crescent Island consumed 420,000 juvenile salmonids in 2010 (95% c.i. = 300,000 – 540,000), not significantly greater than consumption of juvenile salmonids in 2009 (best estimate = 360,000, 95% c.i. = 270,000 – 450,000). Total smolt consumption by Caspian terns nesting on Crescent Island has trended downward from 2001 to 2008, but has been stable over the past two years (Figure 31). In 2010, steelhead comprised an estimated 13% of the identifiable salmonid smolts consumed, or roughly 55,000 fish. The number of steelhead smolts consumed by Crescent Island terns has been nearly constant over the past eight years (Figure 32).

Of the bill load fish identified at the Goose Island Caspian tern colony, on average 21% were juvenile salmonids (n = 1,656 bill loads). Based on morphological characteristics of the salmonids identified at the colony, we estimate that a minimum of 73% of the identified salmonids were anadromous (steelhead or salmon) fish from the Columbia River, with the remainder being resident trout from Potholes Reservoir and perhaps other nearby lakes and reservoirs. The fact that terns are commuting over 100 km round trip from the nesting colony to the Columbia River to forage, corroborated by Maranto et al. (2010) and the PIT tag results presented here (see Section 1.4), suggests that forage fish availability near the nesting colony may be limiting. In 2010, centrarchids (bass and sunfish) were the most prevalent prey type in the diet of Caspian terns nesting on Goose Island (63%), followed by salmonids (salmon and trout; 21%; Figure 33). The proportion of juvenile salmonids in the diet of Goose Island Caspian terns was highest in early May (58% of identifiable bill loads), with a second peak observed in early June (44% of identifiable bill loads; Figure 34). The proportion of salmonids in the diet of Goose Island Caspian terns was consistently lower throughout the breeding season compared to that of Caspian terns nesting on Crescent Island (Figure 30).

We estimated that Caspian terns nesting on Goose Island consumed between 110,000 (assuming 1/4 of identified O. mykiss were steelhead) and 134,000 (assuming all identified O. mykiss were steelhead) anadromous juvenile salmonids from the Columbia River in 2010, roughly a quarter to one-third the number of juvenile salmonids consumed by Caspian terns nesting on Crescent Island during that same year. We estimate that salmon (i.e., Chinook, coho, or sockeye) comprised between 74% - 91% and steelhead comprised between 9% - 26% (depending on the ratio of steelhead to resident trout) of the total number of anadromous salmonid smolts consumed by Goose Island terns in 2010, similar to the relative proportions of salmon and steelhead consumed by Crescent Island terns in 2010.

1.3.3. Coastal Washington

Methods: The taxonomic composition of the diet of Caspian terns nesting at the Port of Bellingham colony was determined by direct observation of adults as they returned to the colony with fish (i.e., bill load observations; described above). The target sample size was 25 bill load identifications per site visit, with six site visits occurring from 1 July to 6 August (see above for further details on the analysis of diet composition data).

Results and Discussion: Of the bill load fish identified at the Port of Bellingham tern colony (n = 124), there were 39 (31%) clupeids, 26 (21%) snake pricklebacks (*Lumpenus sagitta*), 15 (12%) salmonids, 12 (10%) surfperch, 10 (8%) sculpins (cottids), 10 (8%) smelt, 9 (7%) anchovy, and 3 (2%) Pacific sand lance (*Ammodytes hexapterus*). Although diet composition data were not collected throughout the entire 2010 breeding season at the Port of Bellingham tern colony, the prey types consumed were similar to those consumed at the Dungeness Spit tern colony during 2004-2006 (BRNW 2004, BRNW 2005b, BRNW 2006b). The diet composition data collected at these two coastal Washington colonies indicate that salmonids represent roughly 10-30% of the overall diet (BRNW 2004, BRNW 2005b, BRNW 2006b), generally lower than what has been observed at the East Sand Island tern colony. Dungeness Spit was one of the alternative Caspian tern colony sites outside the Columbia River basin where managers sought to actively relocate terns from the East Sand Island colony as part the Draft EIS for Caspian tern management in the Columbia River estuary. The site was dropped from the Final EIS and RODs, however, because of concerns over the potential for increased tern predation on ESA-listed Puget Sound Chinook salmon and Hood Canal chum salmon (USFWS 2005, 2006).

1.3.4. Interior Oregon and Northeastern California

Methods: The taxonomic composition of the diet of Caspian terns nesting on the tern islands at Crump Lake, East Link, and Sheepy Lake were determined by direct observation of adults as they returned to the colony with fish (i.e., bill load observations; described above). Bill load fish we identified each week throughout the breeding season at each site (see above for further details on the analysis of diet composition data). Fishes were identified to the lowest taxonomic grouping possible using visual observation. Visual identifications were verified using voucher specimens whenever possible. In addition, fish tags (coded wire tags, PIT tags, and floy tags) were recovered on selected tern colonies to estimate tern predation rates on fish species of special concern to resource managers (e.g., juvenile salmonids in San Francisco Bay [see Appendix 1], Warner suckers at Crump Lake, and Lost River suckers and shortnose suckers at Sheepy Lake).

Results and Discussion: A moderate number of Caspian tern bill loads (N = 455) were identified at the Crump Lake colony in 2010. The diet composition of Caspian terns nesting on the Crump Lake tern island in 2010 consisted primarily of centrarchids (crappie and bass; 73.1% of the identifiable prey items), followed by tui chub (*Gala bicolor*; 13.2%) and ictalurids (bullhead catfish *Ameiurus nebulosus*; 12.4%; Figure 35).

This was markedly different than the diet composition of Caspian terns nesting at the Crump Lake colony during 2008-2009 when 65.5% of the identifiable prey items were tui chub (Figure 35). Also different in 2010 was the absence of suckers in the diet (based on over 160 hours of fish watch observations at the colony and our PIT tag recovery efforts at the colony following the breeding season [see Section 1.4.3]). In 2009, one sucker (0.02% of identifiable prey items) that was observed on the colony during fish watch observations could not be positively identified as an ESA-listed Warner sucker (BRNW 2010b). In 2008, five suckers were observed in the bill loads of Caspian terns nesting on Crump Lake tern island, one of which was positively identified as a Warner sucker (BRNW 2009b).

A moderate number of Caspian tern bill loads (N = 360) were identified at the East Link colony in Summer Lake Wildlife Area during 2010. As was the case in 2009, the diet composition of Caspian terns nesting at Summer Lake Wildlife Area consisted primarily of tui chub (79.8% of the identifiable prey items), followed by rainbow trout (15.4%), and centrarchids (crappie and bass; 4.1%; Figure 36). One sucker (0.3% of identifiable prey items) was observed during fish watch observations at the East Link tern colony in 2010. It is unknown whether this sucker was an ESA-listed Warner sucker or an unlisted species. Warner suckers are not endemic to Summer Lake, although a small number of fish were intentionally moved to the area by the Oregon Department of Fish and Wildlife and the U.S. Fish and Wildlife Service several years ago as part of salvage operation due to draught conditions in the Warner Valley (P. Scheerer, ODFW, pers. comm.).

A large number of Caspian tern bill loads (N = 1,340) were identified at the Sheepy Lake colony in 2010. The diet composition of Caspian terns nesting on the Sheepy Lake tern island consisted primarily of blue chub (*Gila coerulea*) and tui chub (77.8% of the identifiable prey items), followed by centrarchids (crappie and bass; 19.6%), and ictalurids (bullhead catfish; 1.5%; Figure 37). Two juvenile suckers (0.1% of identifiable prey items) were observed during fish watch observations at the Sheepy Lake tern colony in 2010. Two additional suckers were incidentally observed by researchers at the colony during the 2010 breeding season. We could not positively identify any of the suckers seen at the Sheepy Lake tern colony as either the ESA-listed Lost River sucker or the ESA-listed shortnose sucker. A un-listed species of sucker, the Klamath largescale sucker (*Catostomus snyderi*) is also found in the study area.

1.4. Predation Rates Based on PIT Tag Recoveries

Since 1987, passive integrated transponder (PIT) tags have been placed in salmonids and other fishes to study their behavior and survival. PIT tags were first discovered on piscivorous waterbird colonies in 1996 (Collis et al. 2001). Beginning in 1998, specially designed electronics (antennas and transceivers) were developed and used to recover PIT tags *in situ* on bird colonies (Ryan et al. 2003). PIT tags provide specific information on each fish, including species, stock, rear-type (hatchery or wild), run-timing, and temporal availability to avian predators (based on detections of live fish passing PIT tag antenna arrays). Recoveries of PIT tags on bird colonies can be used to estimate predation rates and to compare the relative susceptibility of different fish populations to avian predation

(Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005; Maranto et al. 2010; Evans et al. 2011).

The main objectives of this study were to use information collected from PIT tags to (1) determine colony-specific avian predation rates, (2) evaluate whether avian predation rates differ by fish species or stock, and (3) assess differences in predation rates based on the location of a bird colony relative to the population of fish being consumed.

Research aimed at recovering PIT tags from bird colonies in the Columbia River basin was conducted in collaboration with NOAA Fisheries (POC, Richard Ledgerwood) and focused on bird predation of ESA-listed juvenile salmonids. Research in interior Oregon and northeastern California was conducted in collaboration with the Oregon Department of Fish and Wildlife (POC: Paul Scheerer), the USGS-Klamath Falls Field Station (POC: Dave Hewitt), USFWS-Upper Klamath Basin Refuges (POC: Dave Mauser and John Beckstrand), and the USFWS-Klamath Falls Field Station (POC: Ron Larson), and focused on bird predation on ESA-listed suckers.

<u>1.4.1. Columbia River Estuary</u>

Methods: The methods of Evans et al. (2011) were used to recovery and analyze PIT tags recovered from bird colonies in the Columbia River basin in 2010. Briefly, PIT tag antennas were used to recover PIT tags *in situ* after birds dispersed from their breeding colonies (August to September). PIT tags were detected by systematically scanning the entire area occupied by birds during the nesting season (referred to as a "pass"). Numerous passes were then conducted until the number of previously undetected PIT tags found during a pass was ≤ 5% of the total number of PIT tags found during all previous passes.

Not all PIT tags egested by birds on their nesting colony are subsequently found by researchers after the nesting season (Ryan et al. 2003; Evans et al. 2011). To address this source of bias, we calculated PIT tag detection efficiency at each colony by sowing PIT tags on the colony (hereafter referred to as "control tags") and then searched for these tags after the nesting season to calculate a recovery rate (hereafter referred to as "detection efficiency"). The sowing of control tags was conducted during several discrete stages of the birds' nesting season: (1) prior to the initiation of egg-laying (March to April), (2) during the egg incubation period (April to May), (3) during the chick-rearing period (May to June), and (4) immediately following the fledging of young (July to August). During each sowing of control tags, equal numbers of control tags were randomly sown throughout the area occupied by nesting birds during the breeding season. The number of discrete events when control tags were sown varied, but was no less than one (at the beginning of the nesting season) and no more than four. The total number of control tags sown also varied by colony, with sample sizes ranging from a minimum of 100 to a maximum of 400 per colony, per breeding season.

We queried the regional salmonid PIT Tag Information System (PTAGIS 2010), maintained by the Pacific States Marine Fisheries Commission, to acquire data on PIT-tagged smolts released in the Columbia River basin during 2010. PIT-tagged smolts were grouped by stock, with each stock representing a unique combination of species (Chinook, coho, sockeye, steelhead), run-type (spring, summer, fall, winter), and river-of-origin. River-of-origin was based on each smolt's capture, tagging, and release location and included (1) the Willamette River, (2) the middle Columbia River (from the confluence with the Snake River downstream to Bonneville Dam), (3) the upper Columbia River (above the confluence with the Snake River), and (4) the Snake River.

Availability of PIT-tagged smolts to avian predators nesting at different colonies was determined by detections of PIT-tagged smolts at the nearest upstream hydroelectric dam with juvenile fish interrogation capabilities (Map 1). Predation rates were calculated using a multi-step approach. First, for each salmonid stock, the proportion of PIT-tagged smolts consumed by avian predators on day *j* ($\hat{q}_j$) was estimated by dividing the number of PIT-tagged smolts detected at a dam on day *j* that were subsequently recovered on a bird colony (recovered$_j$) by the total number of smolts detected at that dam on day *j* (available$_j$) (eq. 1).

$$(1) \quad \hat{q}_j = \frac{recovered_j}{available_j}$$

Second, we used logistic regression to estimate colony-specific daily detection efficiencies, whereby a binary response of detections (detected/not detected) was modeled as a function of time since control tags were placed on the bird colony:

$$(2) \quad \hat{p}_j = \frac{e^{(\beta_0 + \beta_1 t_j)}}{1 + e^{(\beta_0 + \beta_1 t_j)}} ,$$

where $\hat{p}_j$ is the probability of detecting a control tag deposited on day *j*, β_0 is the regression intercept, β_1 is the regression slope, and t_j is the independent variable for deposition date. Next, to calculate daily predation rates ($\hat{r}_j$), the proportion of available PIT-tagged smolts recovered on a bird colony on day *j* ($\hat{q}_j$) was corrected for colony-specific detection efficiency on day *j* ($\hat{p}_j$) (eq. 3).

$$(3) \quad \hat{r}_j = \frac{\hat{q}_j}{\hat{p}_j} ,$$

where $\hat{r}_j$ is the adjusted predation rate of PIT-tagged smolts by birds from a particular colony on day *j*. To calculate weekly and seasonal predation rates, daily estimates of the total number of smolts consumed were summed and divided by the total number of smolts available within that same time period. Confidence intervals for predation rates were estimated using a bootstrapping simulation technique (Efron & Tibshirani 1986; Manly 1998). Annual or seasonal predation rate estimates and 95% confidence intervals were calculated for each unique stock of PIT-tagged smolts consumed by birds from each colony.

To control for imprecise results that might arise from small sample sizes, estimates of predation rates were only calculated for stocks where ≥ 500 PIT-tagged smolts were interrogated while passing an upstream dam during the nesting season. Only PIT-tagged smolts detected at a dam during the bird nesting season (1 March to 31 August for colonies in the estuary) were included in these analyses, as these smolts were known to be available to birds nesting at the colony. Analyses were conducted using R statistical software, with statistical significance set at $\alpha = 0.05$.

Finally, it is important to note that even after adjustments for detection efficiency are made to the number of PIT tags recovered on-colony by researchers, an unknown number of smolt PIT tags consumed by birds are not accounted for due to off-colony deposition (Evans et al. 2011). For example, an unknown number of PIT tags from consumed fish are deposited (regurgitated or defecated) off-colony at loafing or stages areas. Thus, predation rates based on PIT tag recoveries on bird colonies are minimum estimates of predation.

Results and Discussion: Following the nesting season, 35,862 PIT-tagged smolts (Chinook, coho, sockeye, and steelhead combined) from the 2010 migration year were recovered on the East Sand Island Caspian tern colony (Table 2). This number expands to an estimated 42,693 smolts, once adjustments are made to account for on-colony PIT tag detection efficiency. Of the control tags sown on the East Sand Island tern colony to measure PIT tag detection efficiency (n = 400), 336 or 84.0% were detected after the nesting season (Table 2).

Based on minimum predation rates of PIT-tagged smolts last detected passing Bonneville Dam (lowermost dam on the Columbia River) or Sullivan Dam (lowermost dam on the Willamette River; Map 1), steelhead were the most susceptible salmonid species to predation by East Sand Island terns in 2010, with predation rates ranging from 5.8% to 9.9% (depending on stock; Table 3). Coho salmon smolts were the next most susceptible to predation by East Sand Island terns (3.8% to 7.4%, depending on stock), followed by Chinook salmon (0.5% to 3.5%) and sockeye salmon (0.3% to 1.1%) stocks (Table 3). Predation rates on steelhead, coho, Chinook, and sockeye stocks in 2010 were lower than those during 2004-2009 (Evans et al. 2011). Adequate sample sizes (≥ 500 per stock, per year) of PIT-tagged coho from the Snake River, however, were not available during 2004-2009 for comparison. It should also be noted that data regarding the impacts of East Sand Island Caspian terns on PIT-tagged smolts originating from the lower Columbia River are not presented here due to the paucity of in-stream PIT tag detectors below Bonneville and Sullivan dams. As such, the impacts of predation by East Sand Island Caspian terns on lower river salmonid stocks (i.e., stocks entering the mainstem Columbia River below the aforementioned dams), some of which are ESA-listed (i.e., coho, steelhead), are largely unknown. Sebring et al. (2010) reported predation rates on coho and fall Chinook salmon released from hatcheries near East Sand Island by terns between 2.4% and 4.4%, respectively, in 2009.

A more detailed analysis of PIT tag recoveries on the East Sand Island Caspian tern colony, including an analysis of smolt susceptibility based on rear-type (hatchery, wild) and run-timing, is provided in Evans et al. (2011) for data collected during 2004-2009.

1.4.2. Columbia Plateau

Methods: The methods for calculating predation rates on juvenile salmonids based on PIT tag recoveries at Caspian tern colonies in the Columbia Plateau region are the same as those described in Section 1.4.1.

Results and Discussion: Following the 2010 nesting season, a total of 6,253 PIT-tagged smolts from the 2010 migration year (Chinook, coho, sockeye and steelhead combined from all release sites) were recovered on the Crescent Island Caspian tern colony (Table 2). This number expands to an estimated 8,337 smolts once adjustments are made to account for on-colony PIT tag detection efficiency. Of the control tags sown on the Crescent Island tern colony to measure PIT tag detection efficiency (n = 400), 300 or 75.0% were detected after the nesting season (Table 2).

Of the available PIT-tagged fish last detected passing Lower Monumental (Snake River) or Rock Island Dam (upper Columbia River; Map 1), predation rates by Crescent Island terns were highest for upper Columbia (1.2%, 95% c.i. = 1.0 - 1.6%) and Snake River (2.8%, 95% c.i.= 2.4 - 3.2%) steelhead stocks (Table 4). Predation rates were substantially lower (< 1.0%) for other species (Chinook, coho, and sockeye) and stocks (Table 4). Predation on smolts originating from rivers downstream of Lower Monumental and Rock Island dams but upstream of McNary Dam (i.e., within the foraging radius of Crescent Island terns) on the middle Columbia River are not included here and could differ to an unknown degree. Predation rates on smolts by Crescent Island terns in 2010 were significantly lower relative to the previous six years. For example, predation rate on Snake River steelhead by Crescent Island terns during 2004-2009 was estimated at 7.4% (95% c.i. = 7.2 - 7.7%) of available fish (Evans et al. 2011).

A total of 4,405 PIT-tagged smolts from the 2010 migration year were recovered on the Goose Island Caspian tern colony in Potholes Reservoir, WA (Table 2). This number expands to an estimated 7,595 smolts, once adjustments are made to account for on-colony PIT tag detection efficiency. Of the control tags sown on the Goose Island tern colony to measure PIT tag detection efficiency (n = 400), 232 or 58.0% were detected after the nesting season (Table 2).

Of the PIT-tagged fish last detected passing Rock Island Dam, impacts by Goose Island terns were greatest on steelhead, with an estimated minimum predation rate of 9.6% (95% c.i. = 8.3 - 11.3%) in 2010 (Table 4). Predation rates on other salmonids species and stocks were much less (< 1.0%; Table 4). Predation rates on salmonid species and stocks by terns nesting on Goose Island were lower than those observed in 2009, but similar to those observed during 2007-2008 (Evans et al. 2011). A more detailed analysis of the impact of Goose Island Caspian terns on steelhead from the upper Columba River ESU in 2010 is provided in Section 4 of this report.

Following the nesting season, a total of 1,099 PIT-tagged smolts from the 2010 migration year were recovered on the Blalock Islands Caspian tern colony (Table 2). No measure of PIT tag detection efficiency was available for this colony in 2010 because Caspian terns unexpectedly moved from Rock Island to Anvil Island and pre-season control tags used to measure detection efficiency were sown on Rock Island in 2010. Both islands (Rock and Anvil) are within the Blalock Islands chain and are < 2 km apart from one other Detection efficiency data collected at Caspian tern colonies on Rock Island in previous years (2007-2009) averaged 88.3% (Evans et al. 2011), suggesting that most of the PIT tags deposited on-colony by terns were subsequently found by researchers.

Predation rates in 2010 indicate that steelhead stocks were the most susceptible to Blalock Island Caspian terns compared to the other salmonid species available below McNary Dam (mid-Columbia River), with predation rates ranging from 0.5 to 0.6%, depending on stock (Table 5). Predation rates on other salmonids species and run-types were negligible (≤ 0.1%). Overall, results from 2010 indicated that the Blalock Islands tern colony posed little risk to salmonid smolt survival. These low predation rates are primarily associated with the small size of the colony (ca. 136 breeding pairs) and complete nest failure (i.e., no young produced) at the Blalock Island tern colony in 2010 (see Section 1.2.2).

Only 110 PIT-tagged smolts from the 2010 migration year were recovered on the Twining Island Caspian tern colony on Banks Lake (Table 2). This number expands to an estimated 183 smolts once adjustments are made to account for on-colony PIT tag detection efficiency. Of the control tags sown on the tern colony to measure PIT tag detection efficiency (n = 100), 60 or 60.0% were detected after the nesting season (Table 2).

Due to the extremely low numbers of smolt PIT tags recovered from the Caspian tern colony on Twining Island (n=113; all species and release sites combined), predation rate estimates were not generated for 2010. The vast majority of fish (97% or 114) were from upper Columbia River releases, suggesting terns rarely traveled to the Snake River to forage. The small numbers of PIT tags deposited by terns on Twining Island is attributable to the small size of the colony (34 breeding pairs), the distance of the colony from anadromous salmonids in the upper Columbia River (> 70 km), and the presumed availability of forage fish at Banks Lake and in the surrounding area.

1.4.3. Coastal Washington

There was no attempt to recover smolt PIT tags from Caspian tern colonies in coastal Washington during 2010.

1.4.4. Interior Oregon and Northeastern California

Methods: Similar to salmonids in the Columbia River basin, Warner suckers, Lost River suckers, shortnose suckers, and Klamath largescale suckers (*Catostomus snyderi*) are

PIT-tagged to evaluate their behavior and survival following release, all of which, with the exception of Klamath largescale suckers, are ESA-listed species. We evaluated the impacts of Caspian terns nesting at the Crump Lake and Sheepy Lake (Map 2) tern islands on suckers by recovering PIT tags on various bird colonies in interior Oregon and northeastern California. Due to differences in the life history, behavior, and monitoring of sucker populations compared to salmonid populations, however, different analytical methods were needed to evaluate sucker losses to Caspian tern predation.

PIT tag antennas were used to recover PIT tags *in situ* after birds dispersed from their nesting colonies (September to October). PIT tags were detected by systematically scanning the entire area occupied by birds during the nesting season, with a minimum of two passes made at each bird colony, following each nesting season. Detection efficiency data were collected from Caspian tern colonies and, to a lesser extent, from double-crested cormorant, American white pelican, and other piscivorous waterbird colonies (see Sections 2.4 and 3.3) by intentionally sowing control tags on-colony (see Section 1.4 for details). Due to uncertainties regarding when (date) PIT-tagged suckers were consumed by birds following their release and a lack of detection efficiency data at some colonies, however, it was not possible to model detection efficiency as a function of time (as was done for juvenile salmonids; see Section 1.4). Similarly, determining the total number of PIT-tagged suckers available to birds during the nesting season could not be precisely estimated due to a lack of in-season detection histories of PIT-tagged suckers. Each year, the total number of suckers available to birds was based on the number of suckers that were PIT-tagged and released within the basin (Klamath or Warner) where the bird colony was located. The total number released does not account for other sources of mortality that occurred prior to the bird breeding season, however, and therefore overestimates the availability of PIT-tagged suckers to avian predators to an unknown degree.

Data on the impact of bird colonies on sucker survival were evaluated to determine how many fish were consumed by species (i.e., Lost River, shortnose, Warner, Klamath largescale, or unknown sucker species) and location (i.e., Clear Lake, Upper Klamath Lake, Lower Klamath Lake, Crump Lake, Gerber Reservoir, Lake Ewauna, and their tributaries). Due to uncertainties regarding when sucker PIT tags were consumed and a lack of detection efficiency data at particular colonies, we did not attempt to correct the number of tags recovered by researchers for on-colony detection efficiency. Similar to results from PIT-tagged juvenile salmonids (see Section 1.4), sucker PIT tag recoveries were also not adjusted for the number of tags deposited by birds off-colony (i.e., at loafing areas). As such, the number of sucker PIT tags deposited on a bird colony that were subsequently recovered by researchers is a minimum estimate of the number consumed by birds. We investigated the association between the size (fork-length) and age-class (juvenile, adult) of suckers consumed by birds and deposited on their colonies, when possible.

Estimates of impacts on survival of ESA-listed sucker from predation by piscivorous waterbirds nesting at colonies in interior Oregon and northeastern California will be refined as we increase the number of years in which PIT tags are recovered and as data on inter-annual differences in detection efficiency become available. Given the current data restrictions, however, results presented here should be considered preliminary.

Results and Discussion: We searched the Crump Lake tern island (Map 2) for sucker PIT tags following the 2008, 2009, and 2010 nesting seasons. One sucker PIT tag was recovered following the 2008 nesting season (Table 6). The PIT tag was from a 22-cm Warner sucker that was captured and released by ODFW into Crump Lake in June 2008. Based on PIT tags sown by researcher's prior to the nesting season (n = 50), detection efficiency on the Crump Lake tern island was estimated at 94.0% in 2008. No sucker PIT tags were recovered following the 2009 and 2010 nesting seasons.

A total of 580 Warner suckers were PIT-tagged and released into Warner Valley lakes (n = 131) and streams (n = 449) during 2008-2010. The small number (n = 1) and percentage (0.2%) of Warner sucker PIT tags recovered on the Crump Lake Caspian tern colony suggests that mortality of Warner suckers caused by Caspian terns has been low since the island was build during the winter of 2007-08.

We searched the Sheepy Lake Caspian tern island (Map 2) in Lower Klamath NWR for sucker PIT tags following the 2010 nesting season. No sucker PIT tags were found on the island (Table 6). Detection efficiency of PIT tags sown on the island prior to and after the nesting season (n = 100) was 96.0% in 2010.

Similar to results from the Crump Lake Caspian tern colony, data from the Sheepy Lake Caspian tern colony suggest that sucker losses to terns were minimal in 2010. The USGS released a total of approximately 4,800 Lost River suckers and 4,500 shortnose suckers from the fall of 2009 to the spring of 2010. Although no PIT-tagged suckers were found on the Sheepy Lake tern island, four juvenile suckers were observed as tern bill loads at the colony in 2010 (see Section 1.3.4), indicating that Sheepy Lake terns did consume suckers, albeit rarely. Because these fish were not tagged, however, it is not known whether they were ESA-listed suckers or non-listed suckers (i.e., Klamath largescale sucker).

See Section 3.3.4 for additional information on sucker PIT tag recoveries on bird colonies in the Upper Klamath and Warner basins.

1.5. Color banding and band resightings

In 2010, we continued our efforts to band breeding adult Caspian terns and chicks near fledging at multiple colony sites as part of a demographic study. The banding efforts are part of our continuing objective to measure movement rates among breeding colonies, age at first reproduction, and survival rates for Caspian terns in the Pacific Coast population (age at first reproduction and survival rate data will be presented in a subsequent report). Results presented here track the movements of banded Caspian terns among colonies, either within or between years, to better assess the consequences of various management initiatives implemented as part of the Caspian Tern Management Plan.

1.5.1. Columbia River Estuary

Methods: In 2010, adult and fledgling Caspian 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. This compliment of bands allows us to individually identify each banded bird from a distance, such that the banding location (colony), banding year, and age of the bird at banding are known. Tern chicks that were too small to receive color bands were banded with a federal numbered metal band only. Adults were captured using noose mats placed around active nests. Tern chicks were captured by herding flightless young into holding pens located at the periphery of the colony. Once captured, Caspian terns were immediately transferred to small crates designed to hold birds until they were banded and released. Banding operations were conducted during periods of moderate temperatures to reduce the risk of heat stress for captive terns.

Caspian terns that were color banded in previous years (2001 – 2009) were re-sighted on the East Sand Island tern colony by researchers using binoculars and spotting scopes 5-7 days a week throughout the 2010 breeding season.

Results and Discussion: A total of 125 breeding adults and 223 fledglings were captured and color banded at the East Sand Island tern colony in 2010. In addition, 13 smaller tern chicks were banded with metal bands only.

In 2010, a total of 632 previously color-banded Caspian terns were re-sighted at the East Sand Island tern colony. Of the 632 re-sighted terns, 577 (91%) were banded at East Sand Island (196 as adults and 381 as chicks), 33 (5%) were banded at Crescent Island (4 as adults, 29 as chicks), 13 (2%) were banded as chicks at Dungeness Spit, 6 (1%) were banded as chicks at Brooks Island or Knight Island in San Francisco Bay, 2 (< 1%) were banded as chicks at Goose Island or Solstice Island in the Potholes Reservoir, and 1 (< 1%) was banded as an adult at Crump Lake tern island. Band re-sightings at the East Sand Island tern colony indicate that terns are moving from both inland and coastal colonies to East Sand Island.

1.5.2. Columbia Plateau

Methods: The methods for capture and banding at tern colonies in the Columbia Plateau region were the same as those described in Section 1.5.1. Terns that were color banded in previous years were re-sighted at the Crescent Island and Goose Island tern colonies 2-3 days per week throughout the breeding season in 2010.

Results and Discussion: Adult Caspian terns were color banded at the Goose Island tern colony for the first time in 2010, when 49 adults were banded. At Crescent Island, 186 tern chicks near fledging were color banded and 29 smaller tern chicks were metal banded in 2010.

In 2010, a total of 122 and 81 previously color-banded Caspian terns were re-sighted at the Crescent Island colony and the Goose Island colony, respectively. Of the 122 banded terns re-sighted at the Crescent Island colony, 117 (96%) were banded at Crescent Island (70 as adults and 47 as chicks), and 5 (4%) were banded as chicks at East Sand Island. Of the 81 banded individuals re-sighted at Goose Island, 50 (62%) were banded at Crescent Island (9 as adults and 41 as chicks), 11 (14%) were banded as chicks at East Sand Island, 10 (12%) were banded as chicks at Goose Island, 9 (11%) were banded as chicks at Solstice Island in Potholes Reservoir, and 1 (1%) was banded as an adult at Crump Lake, Warner Valley, Oregon.

Movements of adult Caspian terns between colonies in the Columbia River estuary and the Columbia Plateau region appear to be mostly unidirectional; no movement of banded adults from the Columbia River estuary to the Columbia Plateau colonies was confirmed, whereas some individuals banded as adults at Crescent Island were re-sighted at East Sand Island. Band re-sightings at the Goose Island tern colony indicate that there was substantial inter-colony movement of terns from Crescent Island to Goose Island, but not from Goose Island to Crescent Island. However, because no adult Caspian terns were color banded at the Goose Island colony prior to 2010, re-sighting of adult terns on Crescent Island that had formerly nested on Goose Island was unlikely. Continued banding and monitoring at all Caspian tern colony sites in the region will be necessary to confirm whether observed trends in inter-colony movements are consistent across years and to better understand movements of terns among colonies in the Columbia River basin.

1.5.3. Coastal Washington

Methods: The methods for capture and banding at the Port of Bellingham tern colony were the same as those described in Section 1.5.1. In 2010, band re-sightings were conducted on five separate visits to the Dungeness Spit tern colony from mid-April to late May and on six separate visits to the Port of Bellingham tern colony from early July to early August.

Results and Discussion: A total of 218 tern chicks near fledging were color banded and 34 smaller chicks were metal banded at the Port of Bellingham colony in 2010.

In 2010, a total of 91 and 7 previously color-banded Caspian terns were re-sighted at the Port of Bellingham colony and the Dungeness Spit colony, respectively. Of the 91 banded terns that were re-sighted at the Port of Bellingham colony, 70 (77%) were banded at East Sand Island (12 as adults and 58 as chicks), 11 (12%) were banded at Crescent Island (1 as an adult and 10 as chicks), 6 (7%) were banded as chicks at Dungeness Spit, 2 (2%) were banded as chicks at Goose Island, 1 (1%) was banded as an adult at Crump Lake, and 1 (1%) was banded as a chick at Brooks Island. Of the seven previously color-banded individuals that were re-sighted at Dungeness Spit tern colony, all were banded as chicks at East Sand Island.

The vast majority of the banded terns re-sighted at the Port of Bellingham and Dungeness Spit tern colonies were originally banded at the East Sand Island colony. Band re-sightings at the Port of Bellingham tern colony in 2010 confirmed that some of the terns seen at that colony were previously re-sighted at the Dungeness Spit colony before that colony was abandoned in late May, 2010 (n = 3), suggesting that a large number of the terns at the Port of Bellingham colony may have come from that failed colony at Dungeness Spit.

1.5.4. Interior Oregon and Northeastern California

Methods: The methods for capture and banding at tern colonies in interior Oregon and northeastern California were the same as those described in Section 1.5.1. The adult terns banded at the East Link tern island in Summer Lake Wildlife Area and at the Sheepy Lake tern island in Lower Klamath NWR were also fitted with GPS data loggers in order to test the feasibility of using remotely downloadable GPS data loggers to assess foraging habitat use by nesting Caspian terns (results from this feasibility study will be presented in a subsequent report). Terns that were color banded in previous years were re-sighted at the Sheepy Lake, Summer Lake, and Crump Lake tern colonies 3-6 days per week throughout the breeding season in 2010.

Results and Discussion: In 2010, six adult Caspian terns were color-banded at colonies in interior Oregon and northeastern California; 3 each at the East Link and Sheepy Lake tern colonies. At the Sheepy Lake tern colony, 64 tern chicks near fledging were color-banded and 66 smaller tern chicks were metal banded in 2010.

In 2010, a total of 52 and 7 previously color-banded Caspian terns were re-sighted at the Crump Lake colony and the Summer Lake colony, respectively. Of the 52 color-banded terns that were re-sighted at the Crump Lake colony, 23 (44%) were banded at Crump Lake (21 as adults and 2 as chicks), 13 (25%) were banded at East Sand Island (2 as adults and 11 as chicks), 12 (23%) were banded as chicks at Crescent Island, 2 (4%) were banded as chicks at Solstice Island, 1 (2%) was banded as a chick at Goose Island, and 1 (2%) was banded as a chick at Brooks Island in San Francisco Bay. Of the 7 color-banded terns that were re-sighted at Summer Lake, 4 (57%) were banded as chicks at Crescent Island, 2 (29%) were banded as chicks at East Sand Island, and 1 (14%) was banded as an adult at Crump Lake. A total of 46 previously color-banded Caspian terns were re-sighted at the colony on Sheepy Lake in Lower Klamath NWR; 19 (41%) were banded at East Sand Island (3 as adults and 16 as chicks), 13 (28%) were banded at Crump Lake (11 as adults and 2 as chicks), 10 (22%) were banded as chicks at Crescent Island, 2 (4%) were banded as chicks at Goose Island, and 2 (4%) were banded as chicks at Solstice Island.

Re-sightings of banded Caspian terns at the newly established colony at Sheepy Lake in Lower Klamath NWR revealed that terns banded at several different colonies, both coastal and interior, were quick to find the new nesting habitat provided there. Terns originally banded at East Sand Island, more than 500 km from Sheepy Lake, comprised the highest number of band re-sightings at the Sheepy Lake colony. Movements of banded terns among the alternative tern nesting islands created in interior Oregon and northeastern California sites was also documented.

SECTION 2: DOUBLE-CRESTED CORMORANTS

2.1. Nesting Distribution and Colony Size

2.1.1. Columbia River Estuary

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

A major source of uncertainty in past bioenergetics estimates of smolt consumption by East Sand Island cormorants has been colony size across the breeding season (at times other than late incubation, when the colony is censused from aerial photography). In previous years we used estimates of colony size made from blinds or from boats just off shore. Such estimates are limited due to poor visibility of birds behind vegetation, debris, and other birds. During 2008-2010 we implemented a new approach to estimating colony size across the breeding season by expanding the use of aerial photography. In addition to the photography taken during late incubation (early June), high resolution aerial photography of the colony was taken approximately every 2 weeks throughout the season, beginning in early May and concluding in early September. In total, aerial photography of the entire cormorant colony was taken nine times (including the late incubation photography). To count active nests in this additional aerial photography of the East Sand Island cormorant colony (as well as count aerial photography of other colonies of terns, gulls, etc.), we developed a GIS-equipped computer workstation where digitized photos could be viewed and birds counted.

Boat-based and aerial surveys of 12 navigational markers near Miller Sands Spit and Fitzpatrick Island (river km 38 and 53, respectively) were conducted 4 - 6 times per month from early April through late July in 2010. Because nesting chronology varied among the different channel markers, the number of breeding pairs at each marker was estimated using the greatest number of attended nests observed on each of the markers throughout the season. Any well maintained nest structure attended by an adult and/or chick was considered active. To minimize impacts to nesting cormorants (i.e., chicks jumping from nests into the water when disturbed), we did not climb the navigational markers and check nests to estimate productivity.

A boat-based survey of the Astoria-Megler Bridge in the Columbia River estuary was conducted in late May 2010. Our vantage point on the water enabled us to get an exact count of the number of attended nests on the underside of the bridge; however, visual confirmation of eggs and very small chicks was not possible. Any well maintained nest structure that was attended by an adult was considered active, along with any nests containing visible nestlings.

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

Results and Discussion: Fewer than 100 pairs of double-crested cormorants nested on East Sand Island in 1989. Growth in the breeding population since 1989 has resulted in the East Sand Island colony becoming the largest known colony of double-crested cormorants in western North America (Anderson et al. 2004; L. Wires, University of Minnesota, pers. comm.; T. King, USDA-Wildlife Services, pers. comm.). We estimated that 13,596 breeding pairs (95% c.i. = 13,130 – 14,062 breeding pairs) attempted to nest at East Sand Island in 2010, compared to 12,087 breeding pairs (95% c.i. = 11,929 – 12,245 breeding pairs) in 2009. The East Sand Island double-crested cormorant colony experienced unprecedented growth from 1997 to 2007, nearly tripling in size during that period (Figure 38). Then in 2008, the colony experienced an unexpected decline (20%) before rebounding to nearly its peak size by 2010 (Figure 38). The growth of the East Sand Island colony appears to be exceptional among colonies of double-crested cormorants along the coast of the Pacific Northwest, most of which are stable or declining. The available data suggest that much of the early growth of the East Sand Island colony was caused by immigration from colonies outside the Columbia River estuary. More data are needed to assess the extent to which factors limiting the size and reproductive success of colonies throughout the Pacific Northwest are influencing population trends at the East Sand Island colony.

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

In 2010, a maximum count of 254 pairs of double-crested cormorants nested on 12 channel markers located in the upper estuary near Miller Sands Spit (n = 8 channel markers) and Fitzpatrick Island (n = 4), similar to the count from the previous year (235 breeding pairs). Peak nest counts at these two groups of markers were recorded during our last survey in late June. Nesting chronology among the different channel marker colonies appeared to be more synchronous than in 2009.

In 2010, we again observed double-crested cormorants nesting near the pelagic cormorant colony on the Astoria-Megler Bridge. During a boat-based census on 11 June, 63 nests were attended by double-crested cormorants, more than twice the number counted on the bridge in May of 2009.

2.1.2. Columbia Plateau

Methods: Periodic boat-based and land-based counts of attended nest structures were used to estimate the size of the double-crested cormorant colony on Foundation Island in 2010 (Map 1). 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 2010.

Periodic boat- and land-based surveys were conducted at sites where cormorant nesting had been reported previously (i.e., colonies at the mouth of the Okanogan River, at North Potholes Reservoir, and on Harper Island in Sprague Lake; Map 1). In addition, an incipient double-crested cormorant colony on Crescent Island was also monitored. At each site we counted attended nests to obtain a rough estimate of the number of breeding pairs at each colony. We also flew aerial surveys along the lower and middle Columbia River from The Dalles Dam to Rock Island Dam, and along the lower Snake River from the confluence with the Clearwater River to its mouth, searching for new double-crested cormorant colonies.

Results and Discussion: In 2010, the double-crested cormorant colony on Foundation Island consisted of a minimum of 308 pairs (Figure 39), roughly the same colony size as the previous year and still the largest cormorant colony on the mid-Columbia River. All nesting at this cormorant colony occurs in trees. During 2003-2006 the Foundation Island cormorant colony gradually grew from about 250 breeding pairs to about 360 breeding pairs, before leveling off and then declining to about 310 breeding pairs in 2009-2010 (Figure 39). Data on colony attendance indicated that, in 2010, the Foundation Island cormorant colony reached its maximum size in late April, a week earlier than average based on data from previous years (Figure 40).

On 3 May, five double-crested cormorant nests were discovered in the trees on Crescent Island. This is the first record of double-crested cormorants attempting to nest on Crescent Island since intensive colony monitoring began in 2000. All of these nesting attempts subsequently failed on or before 14 June. The cause of nest failure at this incipient colony is unknown.

The largest double-crested cormorant colony in the entire Columbia Plateau region in 2010 was on Potholes Reservoir in North Potholes Reserve, where ca. 830 breeding pairs nested (Figure 41). This colony has gradually declined in size from ca. 1,150 breeding pairs in 2006 to just over 800 breeding pairs in 2009-2010 (Figure 41). As with the Foundation Island colony, cormorants at the North Potholes colony nest in trees, and at North Potholes the trees are flooded for much of the nesting season. Although this colony is the largest of its kind in the region, there is little evidence that these birds commute to the Columbia River to forage on juvenile salmonids, based on the scarcity of salmonid PIT tags beneath the colony.

Based on our counts of cormorant nests at the Okanogan colony, we estimate that there was a minimum of 26 breeding pairs at the colony in 2010, smaller than in 2009 (36 breeding pairs).

We estimated that 86 breeding pairs of cormorants nested at the colony on Harper Island in Sprague Lake in 2010, more than double the size in 2009 (42 breeding pairs). This colony apparently first formed in 2008 when an estimated 38 breeding pairs nested on the island. Harper Island is also home to a large California and ring-billed gull colony and a small Caspian tern colony.

Aerial surveys of the lower, mid-, and upper Columbia River and lower Snake River revealed no other double-crested cormorant colonies in 2010.

There was of total of four active double-crested cormorant colonies in the Columbia Plateau region in 2010, where a total of approximately 1,250 breeding pairs nested (Figure 42). This suggests that the number of double-crested cormorants nesting in the Columbia Plateau region has remained relatively stable since 2005, when the number of breeding double-crested cormorants was estimated at ca. 1,150 breeding pairs (Figure 43).

2.1.3. Coastal Washington

Methods: In 2010, we counted cormorant nests on channel markers in Grays Harbor, WA during two aerial survey flights in early and late May. No boat-based surveys of nesting cormorants were conducted in Grays Harbor during 2010.

Results and Discussion: We counted a maximum of 44 cormorant nests on five different channel markers during the late May aerial survey of Grays Harbor.

2.1.4. Interior Oregon and Northeastern California

Methods: In 2010, we conducted two aerial surveys (22 April and 14-15 June) in interior Oregon and northeastern California (Map 3) looking for breeding colonies of double-crested cormorants. Additionally, periodic land- and boat-based surveys were conducted throughout the breeding season to verify nesting by cormorants at sites identified in aerial surveys.

Results and Discussion: Based on aerial, land, and boat-based surveys in 2010, double-crested cormorants were confirmed to be nesting at six different locations; Upper Klamath NWR (ca. 350 individuals at three different sites), Sheepy Lake (ca. 125 individuals on several tule mat islands), Unit 6 at Lower Klamath NWR (ca. 30 individuals at two different sites), Hyatt Lake (< 20 breeding pairs), Pelican Lake (< 10 breeding pairs), and River's End Reservoir (<10 breeding pairs). The historical nesting islands for double-crested cormorants at Clear Lake were not occupied in 2010.

2.2. Nesting Chronology and Productivity

2.2.1. Columbia River Estuary

Methods: Two elevated blinds located in the East Sand Island cormorant colony were used to observe nesting cormorants in 2010 (Map 4). The blinds were accessed via above-ground tunnels to prevent disturbance to nesting cormorants and gulls, as well as roosting California brown pelicans, which were listed as an endangered species until late 2009. In 2010, 150 individual nesting attempts by double-crested cormorants in six 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 per month) from a boat.

Results and Discussion: We estimated that 30,047 fledglings (95% c.i. = 27,481 – 32,613 fledglings) were produced at the East Sand Island cormorant colony in 2010. This corresponds to an average productivity of 2.21 young raised per breeding pair (95% c.i. = 2.03 – 2.39 fledglings/breeding pair), significantly lower than productivity the previous year, which was the highest ever recorded at the East Sand Island colony (2.80 young raised per breeding pair, 95% c.i. = 2.60 – 3.00 fledglings/breeding pair; Figure 44). Recent improvements in ocean conditions may have contributed to above average nesting success at the East Sand Island cormorant colony in recent years (Figure 44). Nevertheless, these results indicate that the size of the East Sand Island cormorant colony is not currently limited by food supply.

Confirmation of eggs in cormorant nests on channel markers and on the Astoria-Megler Bridge was not possible from our vantage on the water, but small chicks (7-14 days post-hatch) were observed on 21 June on the channel markers and on 11 June on the Astoria-Megler Bridge during the 2010 nesting season. These data suggest that nesting chronology was similar at these two sites, and within the range observed at the East Sand Island cormorant colony in 2010. Due to our poor vantage and infrequent visits, we were unable to estimate nesting success for cormorant nests on the upper estuary channel markers or the Astoria Bridge.

2.2.2. Columbia Plateau

Methods: We monitored 73 cormorant nesting attempts at the Foundation Island colony from the observation blind in 2010, employing weekly visits from mid-April through late July. Productivity was estimated from the number of chicks in monitored nests at 28 days post-hatching. Because of the distance of the blind from the colony and our vantage below the elevation of the nests, we assumed that chicks were approximately 10 days old when first observed.

Results and Discussion: Productivity at the Foundation Island cormorant colony averaged 2.64 fledglings/nest in 2010, which is high in comparison to the range observed at that colony in previous years (Figure 45).

2.2.3. Coastal Washington

It is unknown whether double-crested cormorants nesting on channel markers in Grays Harbor were successful in rearing young in 2010.

2.2.4. Interior Oregon and Northeastern California

Methods: Most of the breeding colonies of double-crested cormorants in interior Oregon and northeastern California were visited late in the breeding season to determine if they were successful in rearing young.

Results and Discussion: The cormorant breeding colonies at Upper Klamath NWR, Sheepy Lake, and Pelican Lake all failed to produce young in 2010. Nesting success at the other known cormorant colonies (i.e., Unit 6 at Lower Klamath NWR, Hyatt Lake, and River's End Reservoir) in 2010 is unknown.

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 foregut (stomach and esophagus) samples per week. Immediately after collection, the cormorant's abdominal cavity was opened, the foregut removed, and the contents of the foregut emptied into a whirl-pak. Each foregut 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 foregut samples were identified to genus and species, whenever possible. Intact salmonids in foregut samples were identified as Chinook salmon, sockeye salmon, coho salmon, steelhead, or unknown based on otolith[1] and/or genetics[2] analyses. Unidentifiable fish soft tissue samples were artificially digested (work that is ongoing) according to the methods of

[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.

Petersen et al. (1990, 1991). Once digested, diagnostic bones (i.e., otoliths, cleithra, dentaries, and pharyngeal arches) were removed from the sample and identified to species using a dissecting microscope (Hansel et al. 1988). Unidentified fish soft tissue samples that did not contain diagnostic bones and samples comprised of bones only (i.e., no soft tissue) were excluded in diet composition analysis. Taxonomic composition of double-crested cormorant diets was expressed as % of identifiable prey biomass. The prey composition of cormorant diets was calculated for each 2-week period throughout the nesting season. The diet composition of cormorants over the entire breeding season was based on the average of these 2-week percentages.

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

Results and Discussion: Based on identifiable fish tissue in foregut samples, juvenile salmonids comprised 16.5% of double-crested cormorant diets (by mass) at East Sand Island in 2010 (n = 134 adult foregut samples or a total of 23,356 g of identifiable fish tissue). The annual proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island in 2010 was the second highest ever recorded at that colony and was nearly twice as high as the estimate in 2009 (9.2%; Figure 46).

The diet of double-crested cormorants, which forage by pursuit-diving throughout the water column, at the East Sand Island colony is more diverse (Figure 47) than that of Caspian terns nesting on the same island (Figure 24). On average, anchovy is the single most prevalent prey type for cormorants, followed by various marine and freshwater taxa (Figure 47). In 2010, the prey category “other” consisted of nine different taxa, all less than 5% of the diet, with the exception of stickleback, which was 10% of the diet. The peak in the proportion of salmonids in the diet of double-crested cormorants nesting on East Sand Island during 2010 was in early May, as was the case in previous years, and remained relatively high in June and late July (Figure 48), when primarily sub-yearling Chinook were being consumed.

Our best estimate of total smolt consumption by double-crested cormorants nesting on East Sand Island in 2010 was 19.2 million smolts (95% c.i. = 14.6 – 23.8 million), nearly twice the number of smolts consumed the previous year and the highest estimated annual smolt consumption by cormorants nesting on East Sand Island ever recorded (Figure 49). Annual smolt consumption by double-crested cormorants nesting on East Sand Island has

---

[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).

been trending upward since 2003, with the exception of 2005 when smolt consumption was at the lowest level ever recorded at that colony (Figure 49). For the second consecutive year estimates of smolt consumption by East Sand Island cormorants were significantly higher than that of Caspian terns nesting on East Sand Island (Figure 26). Of the juvenile salmonids consumed in 2010, we estimated that 69.8% were sub-yearling Chinook salmon (best estimate = 13.4 million; 95% c.i. = 9.1 – 17.6 million), 15.6% were coho salmon (best estimate = 3.0 million; 95% c.i. = 2.3 – 3.7 million), 7.8% were steelhead (best estimate = 1.5 million; 95% c.i. = 1.2 – 1.8 million), 6.8% were yearling Chinook salmon (best estimate = 1.3 million; 95% c.i. = 1.0 – 1.6 million), and 0.2% were sockeye salmon (best estimate = 0.03 million; 95% c.i. = 0.01 – 0.06 million; Figure 50).

2.3.2. Columbia Plateau

Methods: During the breeding season for double-crested cormorants nesting on Foundation Island, we lethally sampled small numbers of adult cormorants commuting back to the colony after foraging trips during 2005-2010. Because of small sample sizes of collected foregut samples and uneven distribution of collected samples across the breeding season within any particular sample year, samples were pooled across years. During 2005-2010, a total of 140 adult cormorants were sampled in seven different time periods (n = 9 in early April, n = 22 in late April, n = 38 in early May, n = 26 in late May, n = 20 in early June, n = 16 in late June, and n = 9 in early July). Contents of these collected foreguts were removed and other tissues were sampled as well. All diet samples were analyzed in our laboratory at Oregon State University to estimate diet composition of cormorants nesting on Foundation Island during 2005-2010 (see section 2.3.1 for description of diet analysis). Taxonomic composition of double-crested cormorant diets was expressed as percent of identifiable prey biomass. The prey composition of cormorant diets was calculated for five 2-week periods during the nesting season. The diet composition of cormorants over the entire 10-week period was based on the average of these 2-week percentages collected during 2005-2010. Bioenergetics estimates of smolt consumption by double-crested cormorants nesting on Foundation Island during 2005-2010 are presented in a subsequent report (see Lyons et al. 2011).

Results and Discussion: Based on identifiable fish tissue in foregut samples, juvenile salmonids comprised 21.9% of double-crested cormorant diets (by mass) at the Foundation Island colony in 2005-2010 (n = 140 adult foregut samples, or a total of 32,188 g of identifiable fish tissue). The peak in the proportion of salmonids in the diet of double-crested cormorants nesting on Foundation Island during 2005-2010 apparently occurred in early May and declined thereafter (Figure 51). On average, centrarchids (bass and sunfish) are the single most prevalent prey type for Foundation Island cormorants (Figure 52). These diet composition results should be interpreted cautiously, however, because they are based on relatively small sample sizes and are pooled across several years.

Smolt consumption estimates for double-crested cormorants nesting on Foundation Island in 2010 are not available. Previous studies have shown that despite a somewhat smaller colony and less specialization on salmonids, Foundation Island cormorants consumed more salmonid biomass than Caspian terns nesting on Crescent Island, due primarily to the larger body size of cormorants and consequently greater individual energy requirements. Best estimates of salmonid consumption by Foundation Island cormorants ranged from 470,000 to 880,000 smolts annually (based on pooled data collected during 2005-2009; Lyons et al. 2011).

2.3.3. Coastal Washington

No diet composition data were collected for double-crested cormorants nesting along the Washington coast in 2010.

2.3.4. Interior Oregon and Northeastern California

Although no diet composition data were collected for double-crested cormorants nesting outside the Columbia River basin, PIT tags from ESA-listed suckers were recovered on mixed piscivorous waterbird colonies (which included double-crested cormorants) in interior Oregon and northeastern California, see Section 3.3.4 for those results.

2.4. Predation Rates Based on PIT Tag Recoveries

2.4.1. Columbia River Estuary

Methods: The methods for calculating predation rates on juvenile salmonids based on PIT tag recoveries at the East Sand Island double-crested cormorant colony are the same as those described for Caspian terns in Section 1.4.1.

Results and Discussion: Following the nesting season, 24,554 PIT-tagged smolts from the 2010 migration year were recovered on the East Sand Island double-crested cormorant colony (Table 2). This number expands to an estimated 32,308 smolts once adjustments are made to account for on-colony PIT tag detection efficiency (Table 2). Of the control tags sown on the East Sand Island cormorant colony to measure PIT tag detection efficiency (n = 400), 304 or 76.0% were detected after the nesting season (Table 2). The estimated number of smolt tags deposited on this cormorant colony was the second highest of all bird colonies scanned in the Columbia River basin in 2010. Only Caspian terns nesting on East Sand Island deposited more PIT tags (ca. 42,693 tags; Table 2).

Based on minimum predation rates of PIT-tagged smolts last detected passing Bonneville or Sullivan dams (Map 1), fall Chinook (primarily sub-yearlings) from the middle Columbia River were the most susceptible salmonid species to predation by East Sand Island cormorants, with a predation rate of 11.1% (c.i. = 9.7 -12.4%; Table 3). This was the highest stock-specific predation rate documented during this study by a particular colony in 2010 (Tables 3-5). Steelhead smolts were the next most susceptible to cormorant predation (2.4% - 3.9%, depending on stock), followed closely by coho (2.0 - 3.4%, depending on stock) and sockeye (1.2% - 1.7%, depending on stock; Table 3).

With the exception of fall Chinook, predation rates on different salmonids species and stocks by cormorants were similar, suggesting cormorants were consuming fish in rough proportion to their relative availability. It should be noted, however, that data regarding the impacts of East Sand Island cormorants on PIT-tagged smolts originating from the lower Columbia River are not presented here due to the paucity of in-stream PIT tag detectors below Bonneville and Sullivan dams. Data from Sebring et al. (2010) indicated that cormorant predation rates on lower river fall Chinook salmon (ca. 17%) and coho salmon (ca. 15%) released from hatcheries near the East Sand Island colony were substantially higher than those of PIT-tagged fish last detected passing Bonneville Dam in 2009.

A more detailed analysis of PIT tag recoveries on the East Sand Island double-crested cormorant colony, including an analysis of smolt susceptibility based on rearing-type (hatchery, wild) and run-timing, is provided in Evans et al. (2011) for data collected during 2004-2009.

2.4.2. Columbia Plateau

Methods: The methods for calculating predation rates on juvenile salmonids based on PIT tag recoveries at the Foundation Island double-crested cormorant colony are the same as those described for Caspian terns in Section 1.4.1. The Foundation Island cormorant colony was the only piscivorous waterbird colony scanned for tags in 2010 that was located in trees as opposed to on the ground. PIT tag recovery at the Foundation Island cormorant colony was carried out with PIT tag antennas (as described above) used to scan the ground underneath the nesting colony. Because some egested PIT tags are likely retained within cormorant nests in the trees on Foundation Island, predation rate estimates based on PIT tag recoveries at Foundation Island may underestimate the actual predation impacts of that colony to a greater extent than at ground-nesting piscivorous waterbird colonies scanned in 2010.

Results and Discussion: Following the nesting season, 5,343 PIT-tagged smolts from the 2010 migration year were recovered on the Foundation Island double-crested cormorant colony (Table 2). This number expands to an estimated 8,481 smolts once adjustments are made to account for on-colony PIT tag detection efficiency (Table 2). Of the control tags sown on the Foundation Island cormorant colony to measure PIT tag detection efficiency (n = 400), 252 or 63.0% were detected after the nesting season (Table 2). The number of smolt PIT tags deposited by Foundation Island cormorants was very similar to the number deposited by Crescent Island Caspian terns (ca. 8,337) and was the third largest of all avian colonies scanned for PIT tags in the Columbia River basin in 2010 (Table 2).

Of the available PIT-tagged fish last detected passing Lower Monumental or Rock Island Dam (Map 1), predation rates by Foundation Island cormorants were highest for Snake River sockeye (1.7%, c.i. = 0.5% - 3.1%) and Snake River steelhead (1.3%, c.i. = 1.0% - 1.6%; Table 4). Predation rates were somewhat lower for most Chinook stocks (~ 1.0%; Table 4). Predation rates on smolts originating from rivers downstream of Lower

Monumental and Rock Island Dams but upstream of McNary (i.e., within the foraging radius of Foundation Island cormorants) on the middle Columbia River are not known and could differ from predation rates on upper Columbia and Snake river stocks.

For the third consecutive year, PIT tags from bull trout (*Salvelinus confluentus*) were found on the Foundation Island cormorant colony following the 2010 nesting season. A total of seven new bull trout PIT tags were recovered in 2010. Since 2008, a total of 24 PIT tags from bull trout have been recovered on the Foundation Island cormorant colony. Bull trout found on the cormorant colony ranged from 13 to 30 cm (fork length) at the time of tagging and release, with the majority of fish originating from the Walla Walla River basin. It is unknown, however, how large the fish were when they were actually consumed or where within the river they were consumed (e.g., in the mainstem Walla Walla River, in a tributary of the Walla Walla River, or in the Columbia River). Over 9,000 bull trout from the Walla Walla River basin have been PIT-tagged since 2006. In addition to bull trout, PIT tags from juvenile white sturgeon (*Acipenser transmontanus*) and adult northern pikeminnow (*Ptychocheilus oregonensis*) have also been recovered on the Foundation Island cormorant colony.

A more detailed analysis of PIT tag recoveries on the Foundation Island double-crested cormorant colony, including an analysis of smolt susceptibility based on rearing-type (hatchery, wild) and run-timing, is provided in Evans et al. (2011) for data collected during 2004 to 2009.

2.4.3. Coastal Washington

There was no attempt to recover smolt PIT tags from the nests of double-crested cormorants in Grays Harbor in 2010.

2.4.4. Interior Oregon and Northeastern California

Several different double-crested cormorant colonies in interior Oregon and northeastern California were scanned for sucker PIT tags following the 2009 and 2010 nesting seasons. Because double-crested cormorants nested in and amongst other nesting piscivorous waterbirds, primarily American white pelicans, we could not positively associate a specific sucker PIT tag with a particular species of avian predator. As such, sucker PIT tags recovered from mixed species bird colonies were pooled for all predators present on the island and are presented in Section 3.3.4.

2.5. Color banding

Methods: In 2010, adult and juvenile double-crested cormorants were banded at East Sand Island in the Columbia River estuary with a federal numbered metal leg band on one leg and a field-readable plastic leg band engraved with a unique alphanumeric code on the other. This was the third year of a prospective long-term effort to collect information on the survival and movements of double-crested cormorants from the East

Sand Island colony and to study dispersal patterns and recruitment of cormorants to other colonies using re-sightings of banded individuals.

Prior to 2008, double-crested cormorants at East Sand Island had never been banded with field-readable plastic leg bands. Banding of nestling cormorants with federal metal leg bands had not been conducted on East Sand Island since 2000, when the U.S. Fish and Wildlife Service discontinued nocturnal pre-fledgling cormorant banding efforts due to concerns over potential impacts to roosting California brown pelicans, an formerly ESA-listed species (de-listed in November 2009). Our banding efforts in 2008-2010 were conducted in such a way as to minimize disturbance to California brown pelicans that continue to use East Sand Island as a major night-time roost site.

From on-colony access tunnels that concealed our presence (Map 4), adult and juvenile cormorants that were within arm's reach of the tunnel were captured by hand on their nests. Once captured, cormorants were transported to an adjacent processing area, banded, and released. Capture occurred at night, as this minimized disturbance to the cormorant colony and other nesting and roosting birds.

Results and Discussion: A total of 125 adult and 13 juvenile cormorants were captured, banded, and released at the East Sand Island colony in 2010. In the previous two years, 90 juvenile cormorants were banded at the East Sand Island colony. Currently, we lack a sufficient number of banded cormorants on the East Sand island colony to assess the inter-colony movements and demography of double-crested cormorants. Continued efforts to band large numbers of cormorants at East Sand Island and increased efforts to re-sight previously banded individuals will provide important information on colony site fidelity, survival, and other factors important in determining the status of the Western North America Population of double-crested cormorants. Furthermore, these banding and re-sighting efforts will allow us to determine inter-colony movements of double-crested cormorants to both predict and assess the outcome of various management strategies, should they be deemed necessary.

2.6. Management Feasibility Studies

2.6.1. Techniques to Encourage Nesting

Methods: In 2010, we continued studies to test the feasibility of potential management techniques for reducing losses of juvenile salmonids to cormorant predation in the Columbia River estuary. This study seeks to determine whether habitat enhancement and social attraction techniques can be used to induce double-crested cormorants to nest at alternative colony sites outside the Columbia River estuary where they have not previously nested and, if so, whether these techniques can be used to redistribute some of the double-crested cormorants nesting in the Columbia River estuary to alternative colony sites outside the estuary, if deemed necessary by resource management agencies.

In 2010, habitat enhancement (i.e., placement of old tires filled with nesting material on a floating platform) and social attraction techniques (i.e., decoys and audio playback systems; Kress 2000, Kress 2002, Roby et al. 2002) were used at Dutchy Lake in the Summer Lake Wildlife Area in attempt to attract double-crested cormorants to nest at the site. We chose Dutchy Lake for this feasibility study because three previous attempts (during 2007-2009) to attract double-crested cormorants to nest at Fern Ridge Reservoir using these techniques had failed. As was the case in Fern Ridge Reservoir, double-crested cormorants are summer residents but do not currently nest at Summer Lake Wildlife Area. The floating platform was launched and anchored in Dutchy Lake about 100 meters southwest of the observation blind on the Dutchy Lake tern island. The floating platform, about 30 feet long by 15 feet wide, was assembled in 2010 from sections of floating dock material. Plywood sideboards about 30-cm high were attached to the sides of the floating platform to retain material on the platform. Fifty-four old tires were placed on the platform, and sticks and other fine woody debris were placed in each tire for nesting material. In mid-April, 31 hand-painted double-crested cormorant decoys (Mad River Decoys, Vermont) were secured on the platform and two audio playback systems, each with two speakers, were placed on the platform, along with the solar panels and deep cycle batteries necessary to power the audio systems. On 25 May, the tires on the nesting platform were painted white in an attempt to simulate cormorant excrement and make the platform more attractive to prospecting cormorants. The platform was checked from the observation blind on the Dutchy Lake tern island 2-4 times a week throughout the field season for any signs of cormorant nesting.

Results and Discussion: Although double-crested cormorants were often observed roosting on the Dutchy Lake tern island, cormorants did not attempt to nest or roost on the floating platform during the 2010 nesting season. Bald eagles and peregrine falcons (*Falco peregrinus*) were observed at Summer Lake Wildlife Area during the 2010 nesting season, but they were not observed near the nesting platform and likely were not a factor in the failure of cormorants to use the platform. Caspian terns did not nest on the Dutchy Lake tern island in 2010, perhaps due to adverse weather and drought conditions that led to low forage fish availability during the 2010 nesting season. These same factors might explain why cormorants failed to nest on the platform or anywhere else in Summer Lake Wildlife Area in 2010.

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

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

2.6.2. Techniques to Discourage Nesting

Methods: In 2010, we continued our investigations of a technique to dissuade nesting by double-crested cormorants on East Sand Island, specifically by covering a discrete area previously used by nesting cormorants with pond liner material. In 2010, the pond liner dissuasion technique was tested again on a much larger portion of the same colony area (Map 4). Using the original dissuasion area from 2009, the 2010 pond liner was expanded to the west to encompass a total of 300 square meters along the rip-rap nesting habitat. The pond liner was installed using nearly the same methods as in 2009, and installation was completed on 1 April 2010, before cormorants arrived on the island to nest.

Results and Discussion: The area of rip-rap covered by pond liner remained free of nesting cormorants for the entire 2010 breeding season. The pond liner was compromised once, however, when a wind storm on 19 May lifted large sections of the pond liner, leaving several areas of rip-rap exposed. This did not compromise the efficacy of the pond liner in dissuading cormorants from nesting. Using data on double-crested cormorant nesting density in 2010, approximately 348 nests were excluded from the 2010 pond liner dissuasion area, as compared to 80 in 2009.

Conclusions: Although the use of a pond liner to dissuade nesting cormorants on East Sand Island was effective in both 2009 and 2010, there are several issues that should be considered before large scale deployment of this method is considered for reducing the numbers of double-crested cormorants nesting at this colony. A combination of high cost and difficulty of deployment are a problem with this method. Logistically, the most important consideration is the weight of the pond liner. With one roll weighing over 100 kilograms, the logistics of transport and installation are difficult. Due to the harsh environment on East Sand Island, the pond liner must be removed at the conclusion of the breeding season, thus adding to transport difficulties. Before any increase in the use of pond liner for dissuasion of nesting cormorants on East Sand Island is implemented, transportation capabilities must be enhanced and improved.

SECTION 3: OTHER PISCIVOROUS COLONIAL WATERBIRDS

3.1. Distribution

3.1.1. Columbia River Estuary

Methods: In 2010, land-based, boat-based, and aerial surveys were conducted throughout the breeding season to locate piscivorous waterbird colonies in the Columbia River estuary. Colony size estimates for gulls in 2010 are not available; instead, results from 2009 colony counts are presented here. Peak numbers of California brown pelicans using East Sand Island as a night-time roost in 2010 were determined by periodic boat-based surveys conducted in the evening from mid-May through mid-September.

Results and Discussion: A total of eight nesting colonies of piscivorous waterbird species other than Caspian terns and double-crested cormorants (i.e., glaucous-winged/western gulls, ring-billed gulls, Brandt's cormorants, American white pelicans, and pelagic cormorants) were identified at four different locations in the Columbia River estuary: East Sand Island, Rice Island, Miller Sands Spit, and the Astoria-Megler Bridge. In addition, East Sand Island was once again the location of a large roosting aggregation of California brown pelicans.

Gulls − Based on surveys conducted in 2010, glaucous-winged/western gulls nested on East Sand Island, Rice Island, and Miller Sands Spit, and ring-billed gulls nested on East Sand Island (Map 1). Precise estimates of colony size in 2010 are not available.

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

California Brown Pelicans − East Sand Island is the largest known post-breeding night-time roost site for California brown pelicans, and the only known night roost for this species in the Columbia River estuary (Wright 2005). In 2010, the first California brown pelicans were observed roosting on East Sand Island on 16 April. The number of brown pelicans roosting on East Sand Island peaked at about 11,468 on 10 August, more than 5,000 fewer pelicans than was observed on East Sand Island during peak counts in 2009. The peak number of brown pelicans roosting on East Sand Island occurred later than in

2009, and more in line with seasonal trends in earlier years (2003-2006). when high counts were recorded in late July and early August. As was the case in 2009, we observed breeding behavior by brown pelicans roosting on East Sand Island (i.e., courtship displays, nest-building, attempted copulations) in 2010, but there was no evidence of egg-laying by brown pelicans in either year. Bald eagle activity was the most common source of non-researcher related disturbance to brown pelicans roosting on East Sand Island in 2010.

American white pelicans − On 9 June 2010, American white pelicans were observed roosting on a mudflat on the northeast tip of East Sand Island, the first record of white pelicans in the Columbia River estuary since this study began in 1997. On 1 July, roughly 100 adult American white pelicans were observed nesting in the upper Columbia River estuary on Miller Sand Spit. These birds were successful in rearing young at the site; in early August 64 large chicks were counted at the colony. This is the first nesting record of American white pelicans in the Columbia River estuary.

Brandt's and Pelagic Cormorants − A small colony of Brandt's cormorants consisting of 44 breeding pairs became established on East Sand Island amidst the double-crested cormorant colony in 2006. This colony grew to 288, 508, and 684 breeding pairs in 2007, 2008, and 2009, respectively. In 2010, the East Sand Island Brandt's cormorant colony continued to grow and was estimated at 985 breeding pairs (Figure 53). Formerly, a small breeding colony of Brandt's cormorants existed on a pile dike at the western end of East Sand Island, but this site was abandoned in 2006 because of storm damage to the pile dike during the severe winter of 2005-2006. Brandt's cormorants were first documented to nest on that pile dike in 1997, when a few pairs were found nesting there (Couch and Lance 2004).

At least 106 breeding pairs of pelagic cormorants nested on the Astoria–Megler Bridge in 2010. This is the only site in the Columbia River estuary where pelagic cormorants are known to nest. Pelagic cormorants have been observed nesting on the underside of the southern portion of the Astoria-Megler Bridge since we began surveying the structure in 1999.

3.1.2. Columbia Plateau

Methods: In 2010, we conducted two aerial surveys (20-21 May and 17 June) in the Columbia Plateau region looking for colonies of piscivorous waterbird species other than Caspian terns and double-crested cormorants (i.e., California gulls, ring-billed gulls, and American white pelicans). Additionally, periodic land- and boat-based surveys were conducted throughout the breeding season to verify nesting by piscivorous waterbirds at colony sites identified during aerial surveys. For colonies of special interest, high-resolution, vertical aerial photography was taken during the late incubation period and three independent counts of individual birds were conducted using an in-house GIS workstation to estimate colony size.

Results and Discussion: A total of nine gull colonies and one American white pelican colony were identified in the Columbia Plateau region during 2010.

Gulls – In 2010, California and/or ring-billed gulls were confirmed nesting on five different islands on the Columbia River between The Dalles Dam and Rock Island Dam: Miller Rocks (river km 333), Threemile Canyon Island (river km 413), Anvil Island (one of the Blalock Islands at river km 445), Crescent Island (river km 510), and Island 20 (river km 545; Map 1). The large gull colony on Island 18 (river km 553) was abandoned in 2008, due apparently to a combination of coyote predation and human disturbance, and was not re-colonized in 2009 or 2010. Precise estimates of gull colony size on the mid- and upper Columbia River in 2010 was only available for Miller Rocks, where 5,300 California gulls and 232 ring-billed gulls were counted on aerial photography of the colony.

In 2009, a complete census of gull colonies on the mid- and upper Columbia River was conducted and a total of ca. 41,700 adult gulls were counted on colonies from The Dalles Dam to Rock Island Dam (Figure 54), 22% fewer than the number counted at colonies in the same stretch of river during 1998 (ca. 53,200; Collis et al. 2002a). The decline in regional gull numbers on-colony was largely due to reductions in numbers nesting on islands in the Tri-Cities area (Islands 18, 19, and 20; ca. 35,000 gulls and ca. 19,000 gulls were counted at colonies on these islands in 1998 and 2009, respectively) and Threemile Canyon Island (ca. 11,100 gulls and ca. 6,200 gulls were counted at this colony in 1998 and 2009, respectively; Figure 54, Collis et al. 2002a). Despite this overall decline in the number of gulls counted on colonies in the mid-Columbia River from 1998 to 2009, three colonies increased in size during this period (Miller Rocks: ca. 2,200 gulls and ca. 6,000 gulls counted on-colony in 1998 and 2009, respectively; Blalock Islands: 0 gulls and ca. 1,600 gulls counted on-colony in 1998 and 2009, respectively; Crescent Island: ca. 4,600 gulls and ca. 8,600 gulls counted on-colony in 1998 and 2009, respectively; Figure 54, Collis et al. 2002a). The near doubling in the size of the California gull colony on Crescent Island over the last decade is particularly interesting because there has been a concurrent decline in the size of the Crescent Island Caspian tern colony by about 50%. No gull colonies were detected on the lower Snake River in 2009-2010, nor has there been any confirmed breeding by gulls on the lower Snake River since our research began in 1997 (Collis et al. 2002a). The total number of gulls nesting on the mid-Columbia River in 2009 was nearly equally divided between California gulls and ring-billed gulls (Figure 54).

Ring-billed and California gulls were also confirmed to be nesting on Goose Island in Potholes Reservoir, on Harper Island in Sprague Lake, and on Twining and Goose islands in Banks Lake during 2010 (Map 1), but precise estimates of colony size were not available in 2010. A total of ca. 21,500 gulls were counted at these off-river colonies in 2009, roughly half the number of gulls counted on colonies located on islands in the mid-Columbia River.

American White Pelicans − We conducted boat-based counts of American white pelicans at the colony on Badger Island in the mid-Columbia River each week during the 2010 nesting season (Map 1). 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. High-resolution, vertical aerial photography was taken of the colony on 23 May, during the incubation period, in order to estimate colony size. Complete counts of active pelican nests on Badger Island are not possible from the water because most nests are located in the interior of the island and are concealed by thick, brushy vegetation. However, most pelicans present on the island were visible in the aerial photography. We did not correct counts of adult pelicans from aerial photography to estimate the number of breeding pairs (as with Caspian terns), but used numbers of adult pelicans from the aerial photos as an index to the number of breeding pairs utilizing Badger Island. As it was only possible to obtain index counts of adults and juveniles at the Badger Island pelican colony; it was not possible to estimate nesting success (number of young raised per breeding pair).

A mean of 2,048 adult American white pelicans were counted in the aerial photography taken on 23 May, up from 1,754 white pelicans counted on Badger Island in 2009. American white pelicans first nested on Badger Island in 1997 (ca. 20 breeding pairs), prior to that they nested on Crescent Island for several years (Figure 55). The Badger Island American white pelican colony experienced unprecedented growth from 1997 to 2010, increasing by more than two orders of magnitude during that period (Figure 55). Available nesting habitat on Badger Island does not appear to be a factor limiting pelican colony size, but continued monitoring will be necessary to determine whether growth of the Badger Island colony continues.

On 23 March, more than 50 American white pelicans were observed on Crescent Island and fresh raccoon tracks were observed on the beach at Badger Island. The presence of one or more raccoons may have caused some pelicans from Badger Island to prospect for alternative nests sites on Crescent Island. On 27 March, 20 American white pelican nests with 1-2 eggs were discovered in a wooded area beside the cove on Crescent Island, the first pelican nesting attempts on Crescent Island since 1998. In the aftermath of discovering the incipient white pelican colony on Crescent Island, visits to Crescent Island were suspended in order to avoid further disturbances to nesting pelicans, a species listed as endangered in the State of Washington. Nevertheless, by 11 April all American white pelicans had abandoned the incipient colony on Crescent Island, presumably to re-nest at the larger pelican colony on Badger Island. Our discovery of the incipient Crescent Island pelican colony on 27 March, and the associated disturbance to the nesting pelicans, likely contributed to the abandonment of the Crescent Island colony.

Our boat-based counts resulted in a maximum count of 56 juvenile white pelicans on 19 July. Annual maximum counts of juvenile pelicans during boat-based surveys have ranged from 141 – 329 during the period 2002 – 2009.

3.1.3. Coastal Washington

Comprehensive surveys of nesting gulls, Brandt's cormorants, and pelagic cormorants were not conducted along the coast of the State of Washington in 2010.

3.1.4. Interior Oregon and Northeastern California

Methods: In 2010, we conducted two aerial surveys (22 April and 14-15 June) in interior Oregon and northeastern California (Map 3) looking for colonies of piscivorous waterbird species other than Caspian terns and double-crested cormorants (i.e., ring-billed gulls, California gulls, and American white pelicans). Additionally, periodic land- and boat-based surveys were conducted throughout the breeding season to verify nesting by these other piscivorous waterbird species at sites identified in aerial surveys.

Results and Discussion: Based on aerial, land-, and boat-based surveys in 2010, gulls were confirmed to be nesting at 8 different locations and American white pelicans were confirmed to be nesting at 4 different locations in interior Oregon and northeastern California.

Gulls – In 2010, gulls (i.e., ring-billed and California) nested at the Crump Lake tern island (over 1,000 breeding pairs), the Sheepy Lake tern island (over 1,000 breeding pairs), the East Link tern island (nearly 500 breeding pairs), Clear Lake (ca. 600 individuals at three different sites), Gerber Reservoir (ca. 350 individuals at two different sites), Tule Lake (ca. 150 individuals), Pelican Lake (ca. 60 breeding pairs), and Upper Klamath Lake (ca. 50 individuals). Gulls were successful in rearing young at 4 locations (i.e., Sheepy Lake, East Link, Crump Lake, and Pelican Lake); nesting success at all other gull colonies in interior Oregon and northeastern California was not determined.

American White Pelicans – In 2010, American white pelicans nested at Clear Lake (ca. 750 individuals at three different sites), Sheepy Lake (ca. 500 individuals on a tule mat island), Upper Klamath Lake (ca. 75 individuals at three different tule mate islands), and Pelican Lake (1 breeding pair). All nesting attempts by American white pelicans in interior Oregon and northeastern California are believed to have failed in 2010.

3.2. Diet Composition

3.2.1. Columbia River Estuary

Gulls − We have not collected diet composition data for gulls nesting in the Columbia River estuary for several years. Our previous research indicated that, in contrast to the gulls nesting at colonies in the Columbia Plateau region (see below), glaucous-winged/western gulls nesting in the Columbia River estuary consumed primarily fish (Collis et al. 2002a). In general, gulls nesting on Rice Island (river km 34) ate mostly riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice Island/Miller Sands Spit and East Sand Island, respectively. At least some of these fish had been kleptoparasitized (i.e., stolen) from Caspian terns, which nested at the nearby colony on Rice Island throughout the 1990s (Collis et al. 2002a). In 2010, 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 9.9%; steelhead smolts were kleptoparasitized at a higher rate (17.8%) than salmon smolts (7.4%). These data indicate that gulls nesting in close proximity to Caspian terns on East Sand Island have an impact on survival of juvenile salmonids by reducing the number of salmonid smolts successfully delivered to the tern colony.

California Brown Pelicans − Brown pelicans feed primarily on schooling marine forage fishes and, near their breeding grounds in southern California, the diet of brown pelicans consists almost entirely of anchovies (Engraulidae) and sardines (Clupeidae; Tyler et al. 1993). There is an abundance of these and other schooling marine forage fishes near East Sand Island (Emmett et al. 2006), and presumably these fish species comprise the majority of the diet of brown pelicans that roost on East Sand Island. In 2011, we will attempt to recover smolt PIT tags from roost sites used by California brown pelicans on East Sand Island to better assess the impacts of brown pelicans on smolt survival. These data will be provided in a subsequent report.

Brandt's and Pelagic Cormorants − As part of this study, we did not collect diet data on Brandt's or pelagic cormorants nesting in the Columbia River estuary. Based on a study conducted in 2000, the frequency of occurrence of juvenile salmonids in the diet of Brandt's cormorants nesting in the Columbia River estuary was estimated at 7.4% (Couch and Lance 2004). Very little is known about the diet of pelagic cormorants along the Oregon Coast (Hodder 2003), but they are believed to forage primarily on marine and estuarine fishes. Due to small colony sizes and the previously-documented diet preferences of Brandt's and pelagic cormorants, the impacts of these birds on survival of juvenile salmonids from the Columbia River basin are expected to be negligible. Smolt PIT tag recoveries on the East Sand Island Brandt's cormorant colony in 2010 support this conclusion (see Section 3.3.1).

3.2.2. Columbia Plateau

Gulls − We have not collected diet composition data from gulls nesting on islands in the lower and middle Columbia River for several years. Our previous research indicated that there were small amounts of fish in general, and salmonids in particular, in the diets of California and ring-billed gulls nesting at colonies on the mid-Columbia River in the late 1990's. The only mid-Columbia River gull colonies where juvenile salmonids were found in diet samples were the California gull colonies on Little Memaloose Island (15% of total biomass from stomach contents; this colony is no longer extant) and Miller Rocks (3% of total biomass from stomach contents). Gulls from these two colonies were known to prey on juvenile salmonids in the tailrace of The Dalles Dam (J. Snelling, OSU, pers. comm.; Zorich et al. 2010). Gulls from other up-river colonies may occasionally prey on juvenile salmonids when available in shallow pools or near dams (Ruggerone 1986; Jones et al. 1996), but our results from the late 1990's suggested that at the level of the breeding colony, juvenile salmonids were a minor component of the diet.

California gulls that nest at the periphery of the Caspian tern colony on Crescent Island may have a negative effect on survival of juvenile salmonids because some individuals kleptoparasitize (i.e., steal) juvenile salmonids from terns as they return to the colony to feed their mates and young. On an average foraging trip, however, breeding adult terns catch several fish, and of these fish, the majority are consumed by the adult away from the colony in order to meet the adult's own energy requirements. A minority of the fish captured by a breeding adult tern are brought back to the colony to feed its mate (pre-chick rearing) or young. Only these fish are subject to kleptoparasitism by gulls. In 2010 kleptoparasitism rates on salmonid smolts delivered by Caspian terns to the Crescent Island colony averaged 16.0%. As was observed at East Sand Island, kleptoparasitism rates were higher on steelhead smolts (20.7%) than on salmon smolts (14.8%), suggesting that gulls prefer, or find it easier, to steal larger fish. These rates are useful in comparing gull kleptoparasitism rates among tern colonies and evaluating the relative vulnerability of different species of smolts to gull kleptoparasitism, but they are not representative of the proportion of all salmonid smolts caught by terns that were subsequently stolen by gulls (i.e., the vast majority of fish captured by terns are not subject to gull kleptoparasitism). Therefore, empirical data on the cumulative impacts on smolt survival associated with gull kleptoparasitism are not available. Given that (1) California gulls nesting at Crescent Island significantly out-number Caspian terns nesting there, and (2) gulls kleptoparasitize only a small portion of the smolts captured by adult terns nesting at the colony (most smolts captured by terns are immediately consumed by the tern and thus not available for gulls to steal), it is unlikely that smolts kleptoparasitized by gulls fulfill more than a very 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 in the Columbia Plateau region during 2007-2010 corroborate our conclusion that the majority of gulls nesting at colonies on the mid-Columbia River pose little risk to salmonid survival, with the possible exception of the California gulls nesting on Miller Rocks and Crescent Island (Evans et al. 2011; also see Section 3.3.2).

American White Pelicans − We do not collect data on diet composition of American white pelicans nesting on Badger Island because of the conservation status of this species in Washington. Based on smolt PIT tag detections on the Badger Island white pelican colony, however, pelicans do not appear to be a significant source of smolt mortality (Table 4; see Section 3.3.2). Despite this, the Badger Island white pelican colony appears to be growing and there is an increasing number of non-breeding white pelicans along the Columbia and Snake rivers, where they are often observed foraging below mainstem hydroelectric dams (Tiller et al. 2003, authors' unpublished data) and at sites in the Yakima River basin (A. Stephenson, Yakima Klickitat Fisheries Project, pers. comm.), presumably foraging on out-migrating juvenile salmonids. The impact of breeding and non-breeding white pelicans on survival of juvenile salmonids from some runs is not well understood.

3.2.3. Coastal Washington

Diet data were not collected at other piscivorous waterbirds colonies along the Washington Coast (see Section 3.2.1 for a general description of the diet of other piscivorous waterbirds nesting at estuary/coastal colonies).

3.2.4. Interior Oregon and Northeastern California

Although no diet data was collected from other piscivorous waterbirds in interior Oregon and northeastern California, PIT tags were recovered and used to evaluate impacts of avian predation on suckers (see Section 3.3.4).

3.3. Predation Rates Based on PIT tag Recoveries

3.3.1. Columbia River Estuary

Methods: The methods for calculating predation rates on juvenile salmonids based on PIT tag recoveries at the East Sand Island Brandt's cormorant colony are the same as those described in Section 1.4.1.

Results and Discussion: Following the nesting season, 199 PIT tags from smolts (Chinook, coho, sockeye, and steelhead) from the 2010 migration year were recovered on the Brandt's cormorant colony at East Sand Island (Table 2). Of the control PIT tags sown on the Brandt's cormorant colony on East Sand Island to measure PIT tag detection efficiency (n = 100), 83 or 83.0% were detected after the nesting season (Table 2). Once corrected for PIT tag detection efficiency, the estimated number of smolt PIT tags deposited on the Brandt's cormorant colony was 240 (Table 2).

Of the PIT-tagged fish last detected passing Bonneville and Sullivan dams (Map 1), < 0.1% (all species and stocks) were deposited on the Brandt's cormorant colony in 2010 (Table 3). Of all the piscivorous waterbird colonies examined in 2010, estimates of predation rates on smolts by Brandt's cormorants were the lowest. Results from the Brandt's cormorant colony in 2010 were also very similar to those in 2009; when 176 PIT-tagged smolts were recovered on-colony. Brandt's cormorants consumed and deposited just 0.26 and 0.24 PIT-tagged smolts per nesting pair in 2009 and 2010, respectively. By comparison, on-colony deposition rates for double-crested cormorants on East Sand Island were 2.97 and 2.38 PIT-tagged smolts per nesting pair in 2009 and 2010, respectively.

Data presented here provide over-whelming evidence that Brandt's cormorants consumed far fewer salmonid smolts per capita than Caspian terns and double-crested cormorants nesting on East Sand Island in 2010. Several factors may account for this. First, the nesting chronology of Brandt's cormorants differs from that of Caspian terns and double-crested cormorants in the estuary, with colony attendance peaking in late June, compared to mid May for Caspian terns and early June for double-crested cormorants. This difference in nesting chronology may be important because by late June the peak of the smolt run has passed, especially for large groups of PIT-tagged steelhead and yearling Chinook (FPC 2011). Second, differences in salmonid smolt consumption between Brandt's cormorants and other piscivorous waterbirds nesting on East Sand Island are likely attributable to differences in foraging behavior and diet composition. Brandt's cormorants are considered a pelagic seabird that usually forages for prey in the marine environment, where non-salmonid prey types (e.g., anchovy, herring, smelt, and others) are common. Consequently, it is likely that salmonid prey types make up a much smaller proportion of the diet of Brandt's cormorants compared to that of Caspian terns and double-crested cormorants. Third, relative to double-crested cormorants, Brandt's cormorants are smaller (by mass), with a lower daily energy requirement.

3.3.2. Columbia Plateau

Methods: The methods for calculating predation rates on juvenile salmonids based on PIT tag recoveries at the gull colonies on Miller Rocks and Crescent Island and the American white pelican colony on Badger Island are the same as those described for Caspian tern colonies in Section 1.4.1.

Results and Discussion: Following the nesting season, a total of 3,784 PIT-tagged smolts from the 2010 migration year were recovered on the Miller Rock Island gull colony (Table 2). This number expands to 5,045 smolt PIT tags once adjustments are made to account for on-colony PIT tag detection efficiency. Of the control tags sown on the colony prior to and after the nesting season to measure PIT tag detection efficiency (n = 200), 150 or 75.0% were detected (Table 2).

Of the PIT-tagged fish last detected passing McNary Dam (Columbia River; Map 1), predation rates by Miller Rocks gulls were highest on steelhead stocks from the Snake (1.4%) and upper Columbia (1.1%) rivers (Table 5). Predation rates on salmon species (Chinook, coho, sockeye) and stocks (Snake River, Upper Columbia River, Middle Columbia River) were generally ~ 0.5% of the available PIT-tagged fish (Table 5). Smolt predation rate estimates from 2010 by Miller Rocks gulls were similar to those recorded in 2009 (Evans et al. 2011).

A total of 3,148 PIT-tagged smolts from the 2010 migration year were recovered on the Crescent Island gull colony (Table 2). This number expands to 4,010 smolt PIT tags once adjustments are made to account for on-colony PIT tag detection efficiency. Of the control tags sown on the colony to measure PIT tag detection efficiency (n = 200), 157 or 78.5% were detected after the nesting season (Table 2).

Of the PIT-tagged fish last detected passing Lower Monumental or Rock Island dams (Map 1), deposition rates (predation rates plus kleptoparasitism rates) by Crescent Island gulls were highest on steelhead stocks from the upper Columbia River (1.1%) and Snake River (0.6%; Table 4). Predation/kleptoparasitism rates on juvenile salmon were significantly lower than on juvenile steelhead, at 0.1 - 0.2% of the available fish (Table 4). Predation/kleptoparasitism rates on steelhead from the upper Columbia River ESU by gulls on Crescent Island were higher than those observed in previous years (ca. 0.7% during 2007 to 2009; Evans et al. 2011), but differences in predation/kleptoparasitism rates between years were not statistically significant. Predation/kleptoparasitism rates on other, non-steelhead salmonid species and stocks in 2010 were similar to those observed in previous years (Evans et al. 2011). Differences in predation/kleptoparastism rates on steelhead stocks compared to salmon stocks by gulls on Crescent Island could be directly related to gulls disproportionately kleptoparasitizing (stealing) steelhead smolts compared to salmon smolts from terns nesting on Crescent Island. Adkins et al. (2011) observed that kleptoparasitism rates by Crescent Island gulls on steelhead smolts were 2 to 3 times higher than those on salmon smolts, apparently because of the larger average size of steelhead smolts compared to salmon smolts. A large but unknown fraction of all smolt PIT tags annually deposited on the Crescent Island gull colony may be from fish originally captured by Caspian terns nesting on Crescent Island. Unlike Crescent Island gulls, gulls nesting on Miller Rocks must capture their own fish prey, as there is no Caspian tern colony on Miller Rocks.

Following the nesting season, 2,319 PIT-tagged smolts from the 2010 migration year were recovered on the Badger Island American white pelican colony (Table 2). Of the control PIT tags sown on the colony to measure PIT tag detection efficiency (n = 200), 149 or 74.5% were detected after the nesting season (Table 2). Consequently, the estimated number of smolt PIT tags deposited on the Badger Island pelican colony was 3,113 PIT tags, once adjustments were made to account for on-colony PIT tag detection efficiency.

Of the PIT-tagged fish last detected passing Lower Monumental or Rock Island dams (Map 1), predation rates by Badger Island pelicans on Snake River steelhead (ca. 0.3%) were the highest (Table 4). Predation rates on other species (Chinook, coho, sockeye) and stocks were 0.1% or less (Table 4). Predation rates from 2010 were similar to those recorded during 2005-2009 (Evans et al. 2011), and suggest smolt losses to Badger Island American white pelicans were minor, especially in comparison to nearby tern and cormorant colonies on Crescent Island and Foundation Islands, respectively. Predation rates on smolts originating from the middle Columbia River (downstream of Lower Monumental and Rock Island dams but upstream of McNary Dam), however, are unknown and may differ from predation rates on upper Columbia River and Snake River stocks.

In 2010, 21 tags from adult salmonids were deposited by pelicans on the Badger Island colony. The majority of fish (N = 16) were from post-spawn (kelt) adult steelhead (tagged at Lower Granite or Roza dams during April, May, and June). Pre-spawn adult sockeye, steelhead, and jack Chinook salmon – tagged at the Bonneville Dam fishway during upstream migration – were also recovered on the pelican colony in 2010. Also of note were three PIT tags from bull trout tagged in the Walla Wall River basin that were detected on the Badger Island pelican colony in 2010, making a total of six bull trout PIT tags recovered on the colony since scanning began in 2005.

A more detailed analysis of PIT tag recoveries on the Miller Rocks and Crescent Island gull colonies and the Badger Island pelican colony, including an analysis of smolt susceptibility based on rearing-type (hatchery, wild) and run-timing is provided in Evans et al. (2011) for data collected during 2007-2009.

3.3.3. Coastal Washington

There was no attempt to recover smolt PIT tags from other piscivorous waterbirds colonies located along the Washington Coast in 2010.

3.3.4. Interior Oregon and Northeastern California

Methods: The same methods used to recover sucker PIT tags from Caspian tern colonies in interior Oregon and northeastern California (see Section 1.4.4) were used to recover sucker PIT tags at other piscivorous waterbird colonies. Because these other piscivorous waterbird species (i.e., double-crested cormorants, American white pelicans, California gulls, ring-billed gulls, great blue herons [*Ardea Herodias*], great egrets [*Ardea alba*], black-crowned night-herons [*Nycticorax nycticorax*], and possibly others) nested in close proximity to each other, we were unable to determine which bird species consumed the recovered sucker PIT tags. As such, PIT tags were analyzed for all bird species combined (hereafter referred to as "mixed bird species" colonies).

Mixed bird species colonies in interior Oregon and northeastern California were scanned for PIT tags after the 2009 and 2010 nesting seasons. Scanning for sucker PIT tags at these colonies was done in collaboration with ODFW (at Pelican Lake in Warner Valley during 2010; Map 3) and with the USGS-Klamath Field Station and the USFWS-Klamath Basin National Wildlife Refuges (at upper Klamath Lake, lower Klamath Lake, and Clear Lake in 2009 and 2010; Map 3).

Results and Discussion: Based on aerial and road-based surveys, American white pelicans, double-crested cormorants, great egrets, great blue herons, California gulls, and ring-billed gulls used the island on Pelican Lake for nesting in 2010. Relatively small numbers of birds (< 100 breeding pairs, all species combined) were observed on the island during the 2010 nesting season. A total of 15 Warner sucker PIT tags were recovered from the island in 2010 (Table 6). The oldest tag was from a Warner sucker released in 2006. When this fish was consumed is unknown because the year the tag was found on the island by researchers is not necessarily the year the tag was deposited on the island by a bird. At the time of tagging and release, suckers ranged from 15 to 31 cm, spanning the size range of both juvenile and adult Warner suckers. No data on PIT tag detection efficiency were available for the bird island on Pelican Lake.

In 2010, 60 Warner suckers were PIT-tagged and released by the ODFW into Warner Basin lakes (n = 30) and streams (n = 30). A minimum seasonal or yearly consumption estimate of 6.7% (4/60) of the available PIT-tagged suckers was documented in 2010 by birds on the Pelican Lake island (Table 7). By comparison, no PIT-tagged Warner suckers were recovered on the nearby Caspian tern colony at Crump Lake island in 2010

(Table 7; see also Section 1.4.4). Because no measure of on-colony PIT tag detection efficiency was available for the island on Pelican Lake and because the year of consumption is not known for the majority of sucker tags recovered on the island (n = 11 or 73% of tags), accurate annual predation rates and data regarding inter-annual variation for this colony are not available.

Based on two aerial surveys, American white pelicans and double-crested cormorants nested on two islands in Clear Lake (Map 3). In 2009, roughly 5,000 pelicans and 200 cormorants were counted on the two islands. In 2010, the number was substantially lower, at roughly 500 pelicans, with no cormorants observed during the aerial surveys in April and June. The June photography suggests that most of the pelicans failed to produce young, with fewer than 50 adults counted and no young visible. In addition to pelicans and cormorants, several thousand California and ring-billed gulls and a small number (< 50 individuals per species) of great egrets, great blue herons, and possibly other species (e.g., black-crowned night-herons) nested in 2009. Of these other species, only gulls were observed nesting in 2010. A total of 324 sucker PIT tags were found on the two Clear Lake bird islands following the 2009 and 2010 nesting season (Table 6). PIT tag detection efficiency was estimated at 76.0% (n = 100 control tags) in 2009 and 83.0% (n = 100 control tags) in 2010. The detection efficiency for PIT tag deposited by birds prior to the 2009 nesting season on Clear Lake, however, is unknown but is presumable less than 76% as detection probabilities have been shown to decrease the longer a PIT tag remains on an bird island (Evans et al. 2010). The majority of sucker tags were from shortnose suckers (63% or 203), followed by Lost River suckers (19% or 63), Klamath largescale suckers (14% or 45), and unidentified suckers (4% or 13). The oldest PIT tags recovered were from three suckers released into Clear Lake in 1995. Because suckers were first PIT-tagged in the region 15 years ago, the number of PIT tags recovered by researchers on Clear Lake bird colonies in 2009 and 2010 represent cumulative impacts to PIT-tagged suckers.

The length (fork length) of suckers consumed by birds varied considerably, from fish as small as 7 cm to as large as 69 cm recovered on bird colonies in the Upper Klamath Basin. The heaviest (mass) fish recovered on a bird colony was a 3.5 kg Lost River sucker. At the time of tagging and release, the majority (> 90%) of suckers were adult-sized, ranging between 30 cm and 69 cm (mean = 39 cm).

Results demonstrate that piscivorous waterbirds nesting on islands in Clear Lake traveled to other lakes and streams to consume PIT-tagged suckers, as 90 or 28% of the sucker tags recovered on Clear Lake bird islands were from suckers released into Upper Klamath Lake, tributaries of Upper Klamath Lake (e.g., Sprague and Williamson rivers), Gerber Reservoir, Lake Ewauna, or Lower Klamath Lake. Relative to their availability at release, however, results indicate that predation on suckers originating from Clear Lake was higher than that of suckers originating from adjacent water bodies (Table 7).

During the fall of 2008 to the spring of 2010 the USGS released approximately 18,000 PIT-tagged shortnose and Lost River suckers into Upper Klamath Basin lakes and streams. Of these, only 28 were subsequently found by researchers on Clear Lake bird colonies, with minimum annual sucker consumption estimates ranging from 0% to 1.6% of the available PIT-tagged suckers, per year (Table 7). As such, the number of PIT-tagged suckers annually consumed, with the tag deposited by birds on-colony and subsequently found by researchers, was relatively low compared to the total number recovered in 2009 and 2010 (324 fish; Table 6). Minimum annual consumption rates in 2009 were similar amongst Clear Lake Lost River suckers (1.6%) and Clear Lake shortnose suckers (1.4%). Rates in 2009 were substantially lower for Upper Klamath Lake Lost River suckers (ca. 0.1%) and Upper Klamath Lake shortnose suckers (ca. 0.3%). In 2010, consumption of all PIT-tagged suckers by birds on Clear Lake islands was dramatically lower than those in 2009; just five Clear Lake shortnose suckers (0.3%) were recovered in 2010 (Table 7). Releases of PIT-tagged suckers during 2009 (~ 8,000 fish) and 2010 (~ 9,000 fish) were similar and suggest that differences between the two years were related to the number and nesting success of birds nesting on Clear Lake islands and not the number of PIT-tagged suckers available in each year.

Double-crested cormorants and American white pelicans nested on several tule (matted down bulrush *Schoenoplectus californicus*) islands in Upper Klamath NWR (Map 3) in 2009 and 2010. In 2009, counts of adults on tule islands totaled roughly 2,000 double-crested cormorants and 400 American white pelicans. The colonies were substantially smaller in 2010, with roughly 250 cormorants and 100 pelicans counted in April of 2010. By June 2010, the colonies had completely failed, with no nesting birds observed during the aerial survey. A total of 108 sucker PIT tags were recovered on Upper Klamath NWR bird colonies from scanning efforts in 2009 and 2010 (Table 6). Data on PIT tag detection efficiency are not available for Upper Klamath bird colonies. The majority of sucker tags were from shortnose suckers (38% or 41), followed by Lost River suckers (35% or 38), Klamath largescale suckers (15% or 16), and unidentified suckers (12% or 13). Similar to results from Clear Lake, the majority of tags (87 or 81%) were from fish released prior to 2009 and were presumably consumed by birds nesting in Upper Klamath NWR in previous years. Unlike piscivorous colonial waterbirds nesting at Clear Lake, however, there was little evidence that pelicans and cormorants nesting in Upper Klamath NWR traveled outside of the immediate area to consume PIT-tagged suckers. Of the 108 PIT-tagged suckers recovered on Upper Klamath bird islands, all (100%) were from suckers tagged and released in Upper Klamath Lake or a tributaries of Upper Klamath Lake (i.e., Sprague or Williamson rivers).

Of the approximately 17,000 PIT-tagged suckers released by the USGS from the fall of 2008 to the spring of 2010, only 18 were subsequently found by researchers on an Upper Klamath NWR pelican and cormorant colony (Table 7). Minimum annual sucker consumption estimates ranged from 0% to 3.6% of the available suckers, per year (Table 7). The highest predation rate was associated with juvenile suckers (species unknown) released during the spring of 2009. Minimum consumption rates between Lost River (0.1%) and shortnose (0.3%) suckers by birds nesting in Upper Klamath NWR were similar in 2009. Interestingly, birds nesting in Clear Lake in 2009 consumed as many suckers released in Upper Klamath Lake as birds nesting in Upper Klamath NWR in 2009 (Table 7). No PIT-tagged suckers were recovered following the failed 2010 nesting season in Upper Klamath NWR.

American white pelicans and double-crested cormorants also nested on a tule island in Sheepy Lake (Map 3) in 2009 and 2010. In 2009, counts indicated that roughly 350 pelicans and 150 double-crested cormorants used the island. Similar to pelican and cormorant colonies in Upper Klamath and Clear lakes, the Sheepy Lake tule island colony also failed to produce young in 2010. In 2010, roughly 500 pelicans and 100 cormorants were counted on the Sheepy Lake island in April, but by June the colony was abandoned. The lack of birds nesting on the island during the summer of 2010 resulted in rapid growth of the bulrushes, which prevented the colony site from being scanned by researchers for PIT tags that year. Scanning of the colony following the 2009 nesting season resulted in recovery of just 3 sucker PIT tags, two shortnose suckers and one Lost River sucker (Table 6). Estimates of minimum annual consumption rates ranged from 0% to 0.1% (Table 7). A direct comparison between pelicans and cormorants nesting on the Sheepy Lake tule island and Caspian terns nesting on the Sheepy Lake tern island was not possible due to a lack of scanning at both sites during the same year. Nonetheless, the small number of sucker PIT tags found on all bird islands in Lower Klamath NWR (tern, cormorant, and pelican) suggests impact to suckers were minor, especially when compared to colonies on Clear Lake and Upper Klamath Lake, colonies that are in close proximity to PIT-tagged sucker populations.

The vast majority of PIT-tagged suckers are tagged as adults, not juveniles, so the impact of avian predation based on PIT tag recoveries presented here may not be representative of all sucker life history stages. Shortnose and Lost River suckers are long-lived fishes and can be exposed to predators, especially pelicans that are capable of consuming large fish (> 70 cm; Scoppettone et al. 2006), for many years (upwards of 40 years; Janney et al. 2008). Of the small numbers of juvenile suckers from the Upper Klamath Basin that were tagged in 2009 (n = 169) and 2010 (n = 54), 6 or 2.7% were found on bird colonies in Upper Klamath NWR. More research is needed to determine if the larger proportion of consumed juvenile suckers was related to difference in vulnerability based on the age of the fish, the behavior of the fish, the release location of the fish, or other factors, or is simply due to small sample sizes of released juveniles. Furthermore, suckers may not be tagged in proportion their relative availability in each water body, which could influence the interpretation of the results. Research is also needed to determine whether specific environmental conditions (e.g., poor water quality, loss of deep water refugia due to habitat modification; Banish et al. 2009) or individual fish characteristics (e.g., disease, stress, and/or injury) are associated with sucker susceptibility to bird predation. Hostetter et al. (2011) demonstrated that diseased and injured juvenile salmonids were more susceptible to double-crested cormorant predation than healthy fish.

Finally, because many of the piscivorous waterbirds that nest in interior Oregon and northeastern California nest in close proximity to one another, it was difficult to determine which avian predator (double-crested cormorant, American white pelican, or others) was responsible for a PIT-tagged sucker's demise. There was evidence that predation on PIT-tagged suckers by Caspian tern colonies was minor, especially in comparison to that of pelican and cormorant colonies, with just one sucker PIT tag found on a Caspian tern colony since scanning effort began in 2008. In addition, bird colonies (pelican, cormorant, and tern) in Lower Klamath NWR consumed fewer PIT-tagged suckers than those in Clear and Upper Klamath lakes. This finding suggests that non-sucker food resources may be locally abundant in Lower Klamath NWR. More data from bird colonies in Lower Klamath NWR, however, are needed to test this hypothesis.

SECTION 4: STEELHEAD SUSCEPTIBILITY STUDY

In 2010 we continued a study initiated in 2007 to investigate how smolt morphology, condition, and origin influence smolt susceptibility to avian predation. We hypothesized that the probability of smolt mortality due to avian predation increases with decreasing physical condition of the fish. We also hypothesized that river conditions and dam operations may influence smolt susceptibility 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 susceptibility to avian predators. Steelhead were selected as the model species for this study because prior research has shown that they are the most susceptible to predation by birds nesting on the Columbia River (Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005). The benefits of using steelhead for this study are three-fold: (1) we were likely to recover a sufficient number of PIT tags from steelhead on bird colonies along the Columbia River to address a multitude of predation-related questions (more so than any other salmonid species or run-type), (2) the incidence of morphological abnormalities (e.g., external symptoms of disease, de-scaling, parasites, body injuries, etc.) tends to be greater in steelhead smolts relative to smolts of other salmonid species (USACE, unpublished data), and (3) a better understanding of those factors responsible for the higher susceptibility of steelhead to avian predation will help resource managers implement measures to reduce avian predation on ESA-listed steelhead ESUs, if warranted and feasible. In addition, the tagging of steelhead as part of this study has the benefit of refining estimates of smolt predation rates (see Sections 1.4, 2.4, and 3.3) on Upper Columbia River Steelhead.

Data presented for 2010 are preliminary and incomplete until further research and analysis is conducted. Results from the Upper Columbia River Steelhead Vulnerability Study will be fully analyzed in a comprehensive report (tentative completion date of January 2012) and in planned peer-reviewed journal publications. Data collected as part of the Snake River Steelhead Susceptibility Study during 2007 - 2009 have been finalized (see Hostetter et al. 2011).

Methods: From 13 April through 19 June 2010, run-of-the-river steelhead smolts were collected and PIT-tagged at the Rock Island Dam juvenile fish collection facility (Map 1). Steelhead were PIT-tagged, measured (mm, fork length), weighed (g), photographed, and placed in a recovery tank, where they were held for up to 12 hours before being released into the dam's tailrace. Two general release times, morning and night, were used to account for possible diurnal passage and predation effects. To reduce handling time, digital photographs were taken of each side of the steelhead, which allowed for a detailed classification of external conditions by type and severity. We assessed the incidence and severity of different anomalies (e.g., externally-visible physical damage, disease, and parasite load) for each tagged fish. In addition, each fish was assigned to one of three overall condition ranks: good, fair, or poor. These condition rankings were based on the presence, abundance, and severity of all the various anomalies observed in each fish and are defined as follows: good = no noticeable external damage, de-scaling < 10%; fair = minor external damage, de-scaling 10% – 50%; poor = open body injuries, external symptoms of disease (fungal, bacterial, or viral infections), parasite infestations, or de-scaling > 50% (see Hostetter et al. 2011).

As described in Section 1.4, piscivorous waterbird colonies were scanned for PIT tags following the breeding season. Recoveries of PIT tags on the Goose Island Caspian tern colony were used to determine if susceptibility to avian predation varied by external condition of steelhead used in this study. We focused analyses associating external fish condition to avian predation susceptibility on the Goose Island tern colony – instead of the other colonies located further downstream – as our methods were less likely to characterize smolt condition several days following a fish's release. Logistic regression was used to evaluate whether the probability of recovering a steelhead on a bird colony was associated with individual fish characteristics, including external condition. Predation rates (Section 1.4) were generated for several bird colonies throughout the Columbia River basin. Unlike the predation rates presented in Section 1.4, 2.4, and 3.3, however, predation rates on steelhead smolts released from Rock Island Dam were not adjusted for in-river survival to the foraging vicinity of downstream bird colonies by limiting detections to fish interrogated at dams. As such, predation rates represent the proportion of PIT-tagged fish available in the tailrace of Rock Island Dam that were subsequently consumed by birds nesting at a particular colony, regardless of that colony's distance from Rock Island Dam. Weekly predation rates were also generated using the release date of PIT-tagged steelhead at Rock Island Dam. As previously noted (Section 1.4), predation rates are adjusted for bias due to PIT tag detection efficiency, but not for deposition rate, and are therefore minimum estimates of predation rates.

Results and Discussion: A total of 7,364 steelhead were tagged and released from Rock Island Dam (n = 5,386 hatchery-raised smolts, n = 1,978 wild smolts) in 2010. Sampling efforts were conducted in concert with the run-at-large, with the largest numbers of smolts PIT-tagged (n = 5,727 or 77.8% of all tagged fish) during the peak out-migration period of 1 May to 7 June (a period encompassing ca. 80% of the run enumerated while passing Rock Island Dam in 2010). Overall, 68.5% of the steelhead PIT-tagged as part of the study were classified as in good condition, 20.4% were in fair condition, and 11.1% were in poor condition. A variety of external anomalies were evident in steelhead ranked as poor, including superficial and open body injuries (41.0%), moderate to severe de-scaling (14.2%), and external symptoms of disease (17.2%). Steelhead ranked in fair condition primarily suffered from superficial body abrasions (81.9%) and moderate de-scaling (29.2%). Conversely, external damage among fish in good condition was limited to minor patches of de-scaling (4.6%).

Of the 7,364 steelhead tagged and released from Rock Island Dam, 976 (13.3%) were subsequently recovered on a bird colony in the Columbia River basin. This number expanded to an estimated 1,473 (20.0%) when corrected for on-colony detection efficiency (Table 8). Avian predators consumed a minimum of 22.7% of the hatchery steelhead and 12.6% of the wild steelhead that were PIT-tagged and released from Rock Island Dam in 2010 (Table 8). Impacts from predation were evident from the large numbers of smolt PIT tags recovered on the East Sand Island tern and cormorant colonies in the Columbia River estuary, the Crescent Island tern colony in McNary Pool, and the Goose Island tern colony in Potholes Reservoir (Table 8). Recoveries of steelhead on the Goose Island Caspian tern colony at Potholes Reservoir (an off-river colony) were especially notable, with estimated predation rates of 10.9% and 5.9% for hatchery and wild steelhead smolts, respectively (Table 8). Predation rates by Goose Island terns in 2010 (9.6% of PIT-tagged steelhead) were significantly lower than 2009 estimates (15.5% of PIT-tagged steelhead; Figure 56). This reduction in predation rate by Goose Island terns in 2010 corresponded with a decrease in Caspian tern colony size (Figure 9) and poor productivity (Figure 10) at Goose Island in 2010 relative to 2009. Predation rates by Caspian terns were once again highest for steelhead migrating in June (Figure 56). However, increases in predation rates during June were not as substantial as those recorded in 2008 and 2009, possibly due to the dramatic decline in the size of the Goose Island Caspian tern colony during June 2010.

Preliminary results from this study indicate that susceptibility of smolts to avian predation was associated with external condition and morphology of steelhead smolts. PIT tag detections on the Goose Island tern colony indicated that avian predation was partially condition dependent, with diseased or injured steelhead more likely to be consumed than steelhead with little or no external evidence of injuries or disease (Figure 57). For example, only 5.0% of steelhead in good condition were recovered on the Goose Island tern colony during 2008-2010. The proportion of steelhead in fair condition (6.8%) and poor condition (6.5%) recovered on the Goose Island tern colony during the same years was, however, significantly higher than steelhead in good condition (Figure 57). These results support previous findings indicating that smolts in degraded condition are more likely to be consumed by avian predators compared to relatively healthy smolts (Hostetter et al. 2011b).

Adult detections at fishways at Bonneville Dam indicated that 674 or 1.7% of the 39,660 PIT-tagged steelhead smolts released at part of this study during 2007-2009 have returned as adults. Inter-annual differences in adult returns were detected, with the highest percentage of adults returning in 2008 (3.2%), relative to 2007 (0.6%) and 2009 (0.7%). Adult return data are not complete, however, as steelhead smolts released in 2008 (3-salt adults), 2009 (2 and 3-salt adults), and 2010 (all adults) are still pending. Overall (all migration years), we anticipate that upwards of 1,000 adults will return to Bonneville Dam from smolts PIT-tagged as part of this study. Returns of steelhead tagged during this study will further our understanding of how individual smolt characteristics and avian predation during out-migration are associated with smolt to adult return rates (SARs) in ESA-listed steelhead populations. These data will be presented in future reports and publications.

SECTION 5: SYSTEM-WIDE OVERVIEW

5.1. Population Trajectories for Colonial Piscivorous Waterbirds

The numbers of Caspian terns nesting in the Columbia River basin have remained fairly stable over the past decade. In contrast, the numbers of double-crested cormorants nesting on East Sand Island have nearly doubled during the same period to ca. 13,600 breeding pairs by 2010, the largest known breeding colony of double-crested cormorants in western North America (Figure 38). Despite apparently ample unused nesting habitat for double-crested cormorants on East Sand Island, the size of the colony has apparently stabilized in recent years, and has not exceeding the maximum colony size observed in 2007. Productivity at the East Sand Island cormorant colony has been above the 13-year average for the past five years (Figure 44), suggesting that some other factor(s) has recently limited the increase in size of this cormorant colony. Similarly, the size of the double-crested cormorant breeding population in the Columbia Plateau region has stabilized or even declined in the last few years, despite unused suitable nesting habitat and good nesting success at both the Foundation Island and North Potholes colonies. Productivity at both the East Sand Island and Foundation Island cormorant colonies has been consistently higher than productivity at Caspian tern colonies, whether in the Columbia River estuary or in the Columbia Plateau region.

In 2008, the U.S. Army Corps of Engineers began implementing the management actions outlined in the Final EIS (FEIS) and the Records of Decision (RODs) for Caspian tern management in the Columbia River estuary, a plan to redistribute a portion of the East Sand Island Caspian tern colony to alternative colony sites in interior Oregon and San Francisco Bay, California by 2015 (USFWS 2005, 2006). A major influx of nesting Caspian terns in the Columbia Plateau region as a result of management to reduce the numbers of Caspian terns nesting in the estuary appears unlikely due to the apparent paucity of suitable nesting habitat for Caspian terns in the Columbia Plateau region. However, given the large size of the Caspian tern colony on East Sand Island (ca. 9,500 pairs) relative to the total breeding population in the Columbia Plateau region (ca. 965 pairs), management to reduce the size of the East Sand Island tern colony could significantly increase the size of the Columbia Plateau breeding population. Depending on where immigrants to the Columbia Plateau region recruit back into the breeding population, this potential increase in the size of the regional breeding population could affect survival of some upper Columbia River and Snake River stocks of salmonids.

Based on recent nesting success and the apparent availability of suitable habitat at a number of colony sites in the Columbia River basin, it is possible that the double-crested cormorant breeding population will resume the expansion that was observed during the early 2000s, while numbers of Caspian terns nesting in the Columbia River basin will decline as management is implemented on East Sand Island. The American white pelican colony on Badger Island and the California brown pelican night-time roost on East Sand Island appear to be steadily increasing, although neither species appears to be a significant mortality factor for juvenile salmonids from the Columbia River basin. The trajectories of the various gull colonies along the Columbia River are variable, with some increasing dramatically over the last decade (e.g., Miller Rocks and Crescent Island) and others declining just as dramatically (e.g., Richland Islands, Threemile Canyon Island). Overall, the breeding populations of ring-billed gulls and California gulls in the Columbia Plateau region appear to have declined somewhat in the last decade. In contrast, the population of glaucous-winged/western gulls in the Columbia River estuary has increased slightly in the last decade.

5.2. Relative Impact of Avian Predators on Salmonid Smolt Survival

Caspian terns that nest on Crescent Island in the mid-Columbia River had the highest proportion of juvenile salmonids in their diet, much higher than Caspian terns or double-crested cormorants that nest at the much larger colonies on East Sand Island in the Columbia River estuary. Nevertheless, a system-wide assessment indicates that the most significant impacts of avian predation on survival of juvenile salmonids from the Columbia River basin occur in the estuary. Caspian terns and double-crested cormorants nesting on East Sand Island together consumed 6 million - 25 million smolts annually during 2003 – 2010 (based on the sum of the best estimates of total smolt consumption by birds nesting at these two colonies in each year). The magnitude of avian predation in the Columbia River estuary represents about 5-20% of all juvenile salmonids that reach the estuary during out-migration. Estimated smolt losses to piscivorous colonial waterbirds that nest further up-river (ca. 1 million smolts annually) are more than an order of magnitude less than losses due to avian predation in the estuary. Additionally, when compared to the impact of avian predation on smolt survival further up-river, avian predation in the estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids from every ESA-listed stock in the Columbia River basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary.

For these reasons, management of Caspian terns and double-cormorants nesting on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other colonies of piscivorous waterbirds. Nonetheless, the Caspian tern colonies on Crescent Island and on Goose Island (Potholes Reservoir) and the double-crested cormorant colony on Foundation Island are also significant sources of salmonid smolt mortality; management of these small colonies in the Columbia Plateau region may benefit certain salmonid stocks, particularly the Snake River and Upper Columbia ESUs of steelhead. Management of other inland piscivorous waterbird colonies in the Columbia Plateau region would provide relatively small and perhaps undetectable increases in stock-specific smolt survival. Further work is necessary, however, to translate smolt consumption and predation rate estimates into assessments of the potential benefits for threatened and endangered salmonid populations of reducing avian predation in the region. The analysis of potential benefits from management of piscivorous waterbirds for restoring ESA-listed stocks of salmonids is key to informed decision-making, as resource managers consider management of specific waterbird colonies and identify management objectives.

ACKNOWLEDGMENTS

This study was funded by the Bonneville Power Administration (COTRs: Dorothy Welch, John Skidmore), the U.S. Army Corps of Engineers, Walla Walla District (COTR: Chris Pinney), and the U.S. Army Corps of Engineers, Portland District (COTR: Paul Schmidt). We thank the McNary National Wildlife Refuge (Lamont Glass, Dave Linehan, and Brian Alan), Potholes Game Reserve (Richard Finger), the U.S. Army Corps of Engineers (Jim Beal, Kat Beal, Walter Damian, Chris Pinney, Kenneth Fone, Mike Halter, Mark Halupczok, George Melanson, Bill Spurgeon, Mark Plummer, Paul Schmidt, and Eric Volkman), Dungeness National Wildlife Refuge (Kevin Ryan, Sue Thomas, and Annette de Knijf), Chelan County PUD (Steven Hemstrom and Barry Keesee), Klamath Basin National Wildlife Refuges (Dave Mauser, John Beckstrand, and Tracy Albro), USFWS-Klamath Falls Fish and Wildlife Office (Ron Larson), the USGS-Klamath Falls Field Station (David Hewitt, Summer Burdick), the Summer Lake Wildlife Area (Marty St. Louis), and the Oregon Department of Fish and Wildlife (Paul Scheerer) for permitting access to the study sites.

We very much appreciate the hard work and dedication of the many field technicians, interns, and volunteers whose contributions to this research were invaluable. The 2010 field crew and staff were Ross Adams, Lindsay Adrean, Elaine Bianchi, Mike Brown, Ben Cate, Stefanie Collar, Megan Friesen, Kelsey Green, Ken Gustafson, Angela Johnson, Marla Koberstein, Will Mashburn, Allison Mohoric, Caleb Osborn, Allison Patterson, Lauren Reinalda, Christine Schukraft, John Sheggeby, Christina Stuart, Caleb Spiegel, Jason Tappa, Nicola Ventoini, and Carter Verhaeghe. Additional help both in and out of the field was provided by Riverdale High School, Annie Birnie, Mischa Connine, Amy Cook, Karen Courtot, Jonathan Erickson, Shealyn Friedrich, Nick Hatch, Day'e Hix, Bryan Kelly, Nina Koch, Samuel Loschl, Bob Magie, Matt Morris, Michael Morrow, Anne Mullan, Mathew Polzin, Lindsey Pounder, Julie Reynolds, David Roby, Terry Rowe, Tim Stentz, Brian Uher-Koch, Cory Van Stratt, and Darren Wiens. We are very grateful for the assistance, advice, and in-kind support from the following individuals: Kathy Courtright, Jan Cyrus, Barbie Gee, Sue Haig, Trish House, Kim Howard, Lynn Ketchum, Clem LaCava, Mark Lincoln, Bill Pearcy, Carl Schreck, and Jane Toliver with Oregon State University; Scott Dunmire, Rebecca Kalamasz, Chris Pinney, and Marvin Shutters, with the U.S. Army Corps of Engineers – Walla Walla District; Ralph Banse-Fay, Jim Beal, Kat Beal, Kitia Chambers, Geoff Dorsey, Daniel Farrar, with the U.S. Army Corps of Engineers – Portland District; Bob Willis with the U.S. Army Corps of Engineers – Northwest Division; Dave Askren, Brenda Heister, John Skidmore, and Dorothy Welch with the Bonneville Power Administration; Steve Duncan, Stacie Hensley, Kim Salarzon, Mike Strejc, Tudor Toader, and Lara Lippai with BPA Geospatial Services; Bruce Bergman and Trevor Gray with Bergman Photographic; Dave Marvin, and Carter Stein with Pacific States Marine Fisheries Commission; Brad Bortner, Chris Columbus, Jennifer Hoskins, Maura Naughton, Tami Tate-Hall, and Dave Wesley with the U.S. Fish and Wildlife Service; Gordon Axel, Blane Bellerud, Jennifer Bohannon, Dan Bottom, Mike Davison, Bob Emmett, John Ferguson, Tom Good, Bill Hevlin, Susan Hinton, Eric Hockersmith, David Kuligowski, Doug Marsh, Regan McNatt, Bill Peterson, Curtis Roegner, Ben Sandford, David Teel, Laurie Weitkamp, and Jen Zamon with NOAA Fisheries; Cody Arocho, Dave Gadwa, Katey Jones, Sharon Lind, Rosanna Tudor, Mike Tomseth, and Monty Price with Washington Department of Fish and Wildlife; Peg Boulay, Chris Carey, Ray Fiori, Craig Foster, Tom Friesen, Andrea Hanson, Joel Hurtado, Steve Jacobs, Tucker Jones, Wayne Morrow, Anne Mary Myers, David Nuzum, Michelle Schuiteman, Paul Scheerer, and Marty St. Louis with Oregon Department of Fish and Wildlife; Russ Kiefer with Idaho Department of Fish and Game; Blaine Parker with the Columbia River Inter-Tribal Fish Commission; Tommy King with USDA-National Wildlife Research Center, Mississippi State; Behr Turner with Grant County PUD; Richard Brown, John Stephenson, and Abby Welch with the Pacific Northwest National Laboratory; John Pease with the Dungeness Recreational Area; Frank Loge and Don Thompson with the University of California Davis; Nick Som and Manuela Huso with EcoStats, LLC); Aaron Turecek with AMT Geospatial Solutions; Dave Craig with Willamette University; Susan Crockford with Pacific ID; John Christensen with Sandpiper Technologies; Sue Schubel with Murre Maid Music Boxes; Jim and Nancy Henry with Mad River Decoys; Brad Cochran and Dave Smith with DSD Decoys; Brad Goldman with Gold Aero Flying Service; Jack Christopherson with Wilderness Air Charters; Burt Young with Oregon Sunstone Aviation; and the rangers, caretakers, and friends of the Dungeness National Wildlife Refuge.

LITERATURE CITED

Adkins, J.Y., and D.D. Roby. 2010. A status assessment of the double-crested cormorant (*Phalacrocorax auritus*) in western North America: 1998 – 2009. Report to U.S. Army Corps of Engineers, Portland, OR. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Adkins, J.Y., D.D. Roby, D.E. Lyons, Y. Suzuki, P.J. Loschl, K. Collis, and A.F. Evans. 2011. Colony size, nesting success, and limiting factors of piscivorous colonial waterbirds in the Columbia Plateau region, 2004-2009. Pages 8-37 *in* Roby, D.D. (ed.). Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

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

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

Banish, N.P., B.J. Adams, and R.P. Shively. 2009. Distribution of habitat associations of radio-tagged adult Lost River suckers and shortnose suckers in upper Klamath Lake, Oregon. Transactions of the American Fisheries Society. 138:153-168.

BRNW (Bird Research Northwest). 2004. Caspian tern nesting ecology and diet in San Francisco Bay and Dungeness National Wildlife Refuge. 2004 Annual Report submitted to the U.S. Fish and Wildlife Service, Region 1, Migratory Birds and Habitat Programs, Portland, OR. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2005a. Caspian Tern Research on the Lower Columbia River: 2004 Final Annual Report submitted to the Bonneville Power Administration and the U.S. Army Corps of Engineers – Walla Walla District. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2005b. Caspian Tern Nesting Ecology and Diet at Colony Sites on the Olympic Peninsula. 2005 Annual Report submitted to the U.S. Fish and Wildlife Service, Region 1, Migratory Birds and Habitat Programs, Portland, OR. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2006a. Caspian Tern Research on the Lower Columbia River: 2005 Final Annual Report submitted to the Bonneville Power Administration and the U.S. Army Corps of Engineers – Walla Walla District. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2006b. Observations of Caspian terns nesting at Dungeness National Wildlife Refuge and distribution of gull colonies in Puget Sound, Washington. 2006 Annual Report submitted to the U.S. Fish and Wildlife Service, Region 1, Migratory Birds and Habitat Programs, Portland, OR. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2007. Caspian Tern Research on the Lower Columbia River: 2006 Final Annual Report submitted to the Bonneville Power Administration and the U.S. Army Corps of Engineers – Walla Walla District. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2008. Caspian Tern Research on the Lower Columbia River: 2007 Final Annual Report submitted to the Bonneville Power Administration and the U.S. Army Corps of Engineers – Walla Walla District. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2009a. Caspian Tern Research on the Lower Columbia River: 2008 Final Annual Report submitted to the Bonneville Power Administration, U.S. Army Corps of Engineers – Walla Walla District, and the U.S Army Corps of Engineers – Portland District. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2009b. Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Interior Oregon: 2008 Final Annual Report submitted to the U.S Army Corps of Engineers – Portland District. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2010a. Caspian Tern Research on the Lower Columbia River: 2009 Final Annual Report submitted to the Bonneville Power Administration, U.S. Army Corps of Engineers – Walla Walla District, and the U.S Army Corps of Engineers – Portland District. Available on-line at www.birdresearchnw.org.

BRNW (Bird Research Northwest). 2010b. Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Interior Oregon: 2009 Final Annual Report submitted to the U.S Army Corps of Engineers – Portland District. Available on-line at www.birdresearchnw.org.

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

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

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

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

Emmet, R.L., G.K. Krutzikowski, P.J. Bently. 2006. Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998–2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids. Progress in Oceanography 68, 1-26.

Evans, A.F., N.J. Hostetter, K. Collis, D.D. Roby, D.E. Lyons, B.P. Sandford, R.D. Ledgerwood, and S. Sebring. 2011. A system-wide evaluation of avian predation on salmonid smolts in the Columbia River Basin based on recoveries of passive integrated transponder (PIT) tags. Pages 64-146 *in* Roby, D.D. (ed.). Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

FPC (Fish Passage Center). 2011. Fish Passage Center smolt passage index. Available on-line at www.fpc.org (October 2010).

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

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

Hostetter, N.J., A.F. Evans, K. Collis, and D.D. Roby. 2011. Susceptibility of juvenile steelhead (*Oncorhynchus mykiss*) to avian predation: The influence of individual fish characteristics and river conditions. Pages 147-178 *in* Roby, D.D. (ed.). Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Janney, E.C., R.S. Shively, B. H. Hayes, and P.M. Barry. 2008. Demographic analysis of Lost River sucker and shortnose sucker populations in upper Klamath Lake, Oregon. Transactions of the American Fisheries Society. 137:1812-1825.

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

Kress, S. W. 1983. The use of decoys, sound recordings, and gull control for re-establishing a tern colony in Maine. Colonial Waterbirds 6:185-196.

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

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

Lyons, D.E., D.D. Roby, J.Y. Adkins, P.J. Loschl, L.R. Kerr, T.K. Marcella, A.F. Evans, N.J. Hostetter, K. Collis, D.R. Kuligowski, and B.P. Sandford. 2011. Impacts of piscivorous birds on native anadromous fishes in the Mid-Columbia River. Pages 38-63 *in* Roby, D.D. (ed.). Impacts of avian predation on salmonid smolts from the Columbia and Snake rivers: A synthesis report to the U.S. Army Corps of Engineers Walla Walla District. Bird Research Northwest. Available on-line at www.birdresearchnw.org.

Maranto, C.J., T.P. Good, F.K. Wiese, and J.K. Parrish. 2010. Impact of the Potholes Reservoir Caspian tern breeding colony on out-migrating juvenile salmonids in the mid-Columbia River. Transactions of the American Fisheries Society 139:362-381.

Petersen, J.H., M.G. Mesa, J. Hall-Griswold, W.C. Schrader, G.W. Short, and T.P. Poe. 1990. Magnitude and dynamics of predators on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1989-1990. Contract DE-AI79-88BP91964, Bonneville Power Administration, Portland, Oregon.

Petersen, J.H., D.B. Jepsen, R.D. Nelle, R.S. Shively, R.A. Tabor, and T.P. Poe. 1991. System-wide significance of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1990. Contract DE-AI79-90BP07096, Bonneville Power Administration, Portland, Oregon.

Pochop, P.A., J.L. Cummings, and C.A. Yoder. 1998. Comparison of white mineral oil and corn oil to reduce hatchability in ring-billed gull eggs. Proceedings of the 18th Vertebrate Pest Conference, University of Nebraska, Lincoln, Nebraska.

PTAGIS. 2010. The Columbia Basin PIT Tag Information System. Available at on-line at www.ptagis.org (October 2010).

Purcell, M., G.G Mackey, E. LaHood, H.T Huber, and L. Park. 2004. Molecular methods for the genetic identification of salmonid prey from Pacific harbor seal (*Phoca vitulina richardsi*) scat. Fishery Bulletin 102:213-220.

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

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

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

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

Scoppettone, G.G., P.H. Rissler, D. Withers, and M.C. Fabes. 2006. Fish tag recovery from the American white pelican nesting colony on Anaho Island, Pyramid Lake, Nevada. Great Basin Birds 8:6-10.

Sebring, S.H., M. Morrow, R.D. Ledgerwood, B.P. Sandford, A.F. Evans, and G.M. Matthews. 2010. Detection of passive integrated transponder (PIT) tags on piscivorous avian colonies in the Columbia River basin, 2009. Annual report the U.S. Army Corps of Engineers Walla Walla District. NOAA Fisheries, Northwest Fisheries Science Center. Seattle, WA.

Seeb, L.W., A. Antonovich, M.A. Banks, T.D. Beacham, M.R. Bellinger, S.M. Blankenship, M.R. Campbell, N.A. Decovich, J.C. Garza, C.M. Guthrie III, T.A. Lundrigan, P. Moran, S.R. Narum, J.J. Stephenson, K.T. Supernault, D.J. Teel, W.D. Templin, J.K. Wenburg, S.F. Young, C.T. Smith. 2007. Development of a Standardized DNA Database for Chinook Salmon. Fisheries 32:540-552.

Tiller, B.L., I.D. Welch, J.E. Bernhard, and T.M. Degerman. 2003. Assessment of the extent of potential salmonid predation by American white pelicans in the pool and tailrace of McNary Dam 2002. 2002 Annual Report submitted to U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.

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

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

USFWS (U.S. Fish and Wildlife Service). 2006. Caspian tern management to reduce predation of juvenile salmonids in the Columbia River estuary: Record of Decision, November 2006. Migratory Birds and Habitat Programs, Portland, Oregon.

Van Doornik, D.M., D.J. Teel, D.R. Kuligowski, C.A. Morgan, and E. Casillas. 2007. Genetic analyses provide insight into the early ocean stock distribution and survival of juvenile coho salmon (Oncorhynchus kisutch) off the coasts of Washington and Oregon. North American Journal of Fisheries Management 27:220-237.

White, G.C., and K.P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46:120-138.

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

Zorich, N.A., M.R. Jonas, and P.L. Madson. 2010. Avian Predation at John Day Dam 2009: Estimated Fish Consumption Using Direct Observation With Diet Analysis. Report to USACE Walla Walla District.

PROJECT PUBLICATIONS AND SUBMITTED MANUSCRIPTS

Adrean, L.J., D.D. Roby, D.E. Lyons, K. Collis, and A.F. Evans. In review. Caspian tern (*Hydroprogne caspia*) predation on juvenile salmonids and other forage fishes in San Francisco Bay, California. Transactions of the American Fisheries Society.

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

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

Anderson, S.K., D.D. Roby, D.E. Lyons, and K. Collis. 2005. Factors affecting chick provisioning by Caspian terns nesting in the Columbia River estuary. Waterbirds 28:95-105.

Anderson, S.K., D.D. Roby, D.E. Lyons, and K. Collis. 2007. Relationship of Caspian tern foraging ecology to nesting success in the Columbia River estuary, Oregon, USA. Estuarine, Coastal, and Shelf Science 73:447-456.

Antolos, M., D.D. Roby, D.E. Lyons, S.K. Anderson, and K. Collis. 2007. Effects of nest density, location, and timing on breeding success of Caspian terns. Waterbirds 29:465-472.

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

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

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

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

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

Collis, K., D.D. Roby, K.W. Larson, L.J. Adrean, K. Nelson, A.F. Evans, D. Battaglia, D.E. Lyons, T. Marcella, and A. Patterson. In press. Trends in Caspian tern nesting and diet in San Francisco Bay: Conservation implications for terns and salmonids. Waterbirds.

Evans, A.F., D.D. Roby, K. Collis, B.M. Cramer, J.A. Sheggeby, L.J. Adrean, D.S. Battaglia, and D.E. Lyons. 2011. Recovery of coded wire tags on a Caspian tern colony in San Francisco Bay: A technique to evaluate impacts of avian predation on juvenile salmonids. North American Journal of Fisheries Management 31:79-87.

Hostetter, N.J., A. F. Evans, D. D. Roby, K. Collis, M. Hawbecker, B. P. Sandford, D. E. Thompson and F. J. Loge. 2011. Relationship of external fish condition to pathogen prevalence and out-migration survival in juvenile steelhead. Transactions of the American Fisheries Society 140: 1158-1171.

Hostetter, N.J., A. F. Evans, D. D. Roby, and K. Collis. In review. Susceptibility of juvenile steelhead (*Oncorhynchus mykiss*) to avian predation: The influence of individual fish characteristics and river conditions. Canadian Journal of Fisheries and Aquatic Sciences.

Lyons, D.E., D.D. Roby, and K. Collis. 2005. Foraging ecology of Caspian terns in the Columbia River estuary, USA. Waterbirds 28(3):280-291.

Lyons , D.E., D.D. Roby, and K. Collis. 2007. Foraging patterns of Caspian terns and double-crested cormorants in the Columbia River estuary. Northwest Science 81:91-103.

Lyons, E.E., and D.D. Roby. 2011. Validating growth and development of a seabird as an indicator of food availability: captive-reared Caspian tern chicks fed ad libitum and restricted diets. Journal of Field Ornithology 82(1):88-100.

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

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

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

Roby, D.D., K. Collis, and D.E. Lyons. 2005. Conservation and management for fish-eating birds and endangered salmon. Pp. 161-165 in C.J. Ralph and T.D. Rich (eds.). Bird conservation implementation and integration in the Americas: Proceedings of the Third International Partners in Flight Conference. USDA Forest Service Gen. Tech. Rep. PSW-GTR-191.

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

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

Wright, S.K., D.D. Roby, and R.G. Anthony. 2007. Responses of California brown pelicans to disturbances at a large Oregon roost. Waterbirds 30:479-487.

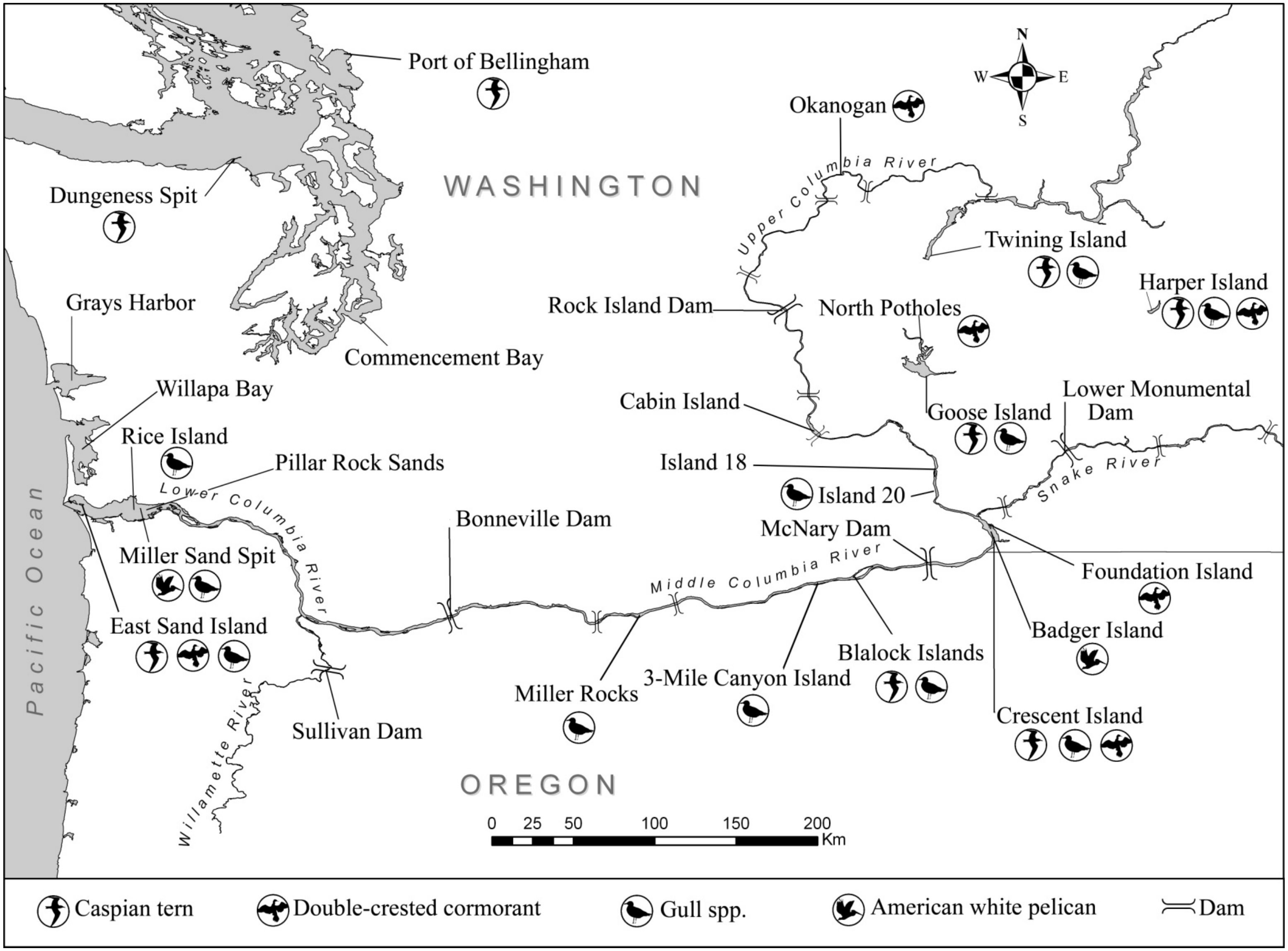
PROGRAM FUNDING

Funding for the work presented here was provided by the Bonneville Power Administration (BPA), the U.S. Army Corps of Engineers (USACE) - Portland District, and the U.S. Army Corps of Engineers - Walla Walla District; see below for the program funding support provided by each agency. In general, funding for work conducted in the Columbia River estuary was from BPA and the USACE – Portland District, funding for work conducted outside the Columbia River Basin was from the USACE – Portland District, and funding for work conducted on the Columbia Plateau region was from the USACE – Walla Walla District. We thank Dorothy Welch and John Skidmore (BPA), Scott Dunmire and Chris Pinney (USACE – Walla Walla District), and Paul Schmidt (USACE – Portland District) for their assistance in administering these contracts.

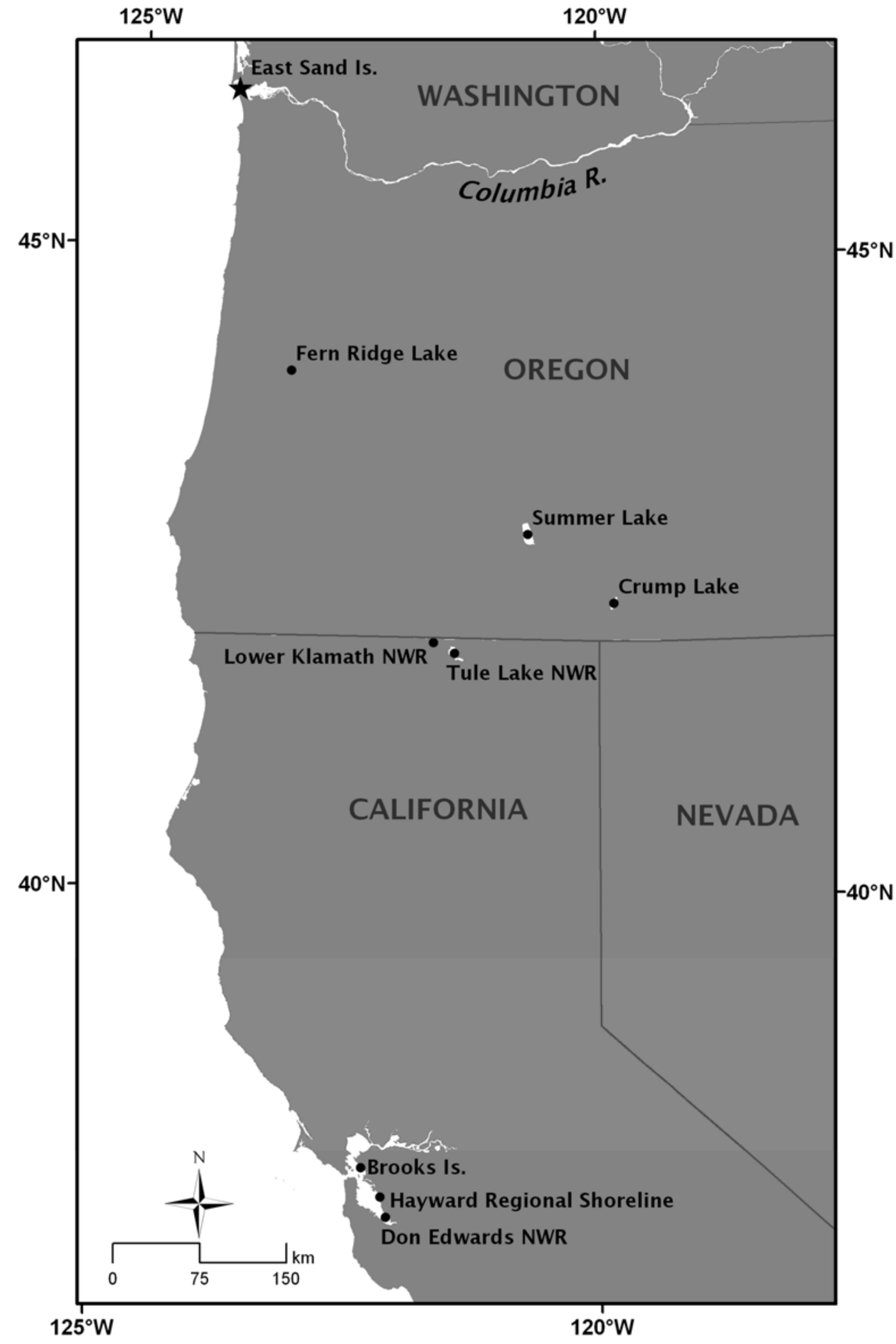
	Funding Contribution by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Caspian Terns			
1.1. Preparation and Modification of Nesting Habitat			
1.1.1. Columbia River Estuary		x	
1.1.2. Interior Oregon and Northeastern California		x	
1.2. Nesting Chronology, Colony Size, and Productivity			
1.2.1. Columbia River Estuary	x		
1.2.2. Columbia Plateau			x
1.2.3. Coastal Washington		x	
1.2.4. Interior Oregon and Northeastern California		x	
1.3. Diet Composition and Salmonid Consumption			
1.3.1. Columbia River Estuary	x		
1.3.2. Columbia Plateau			x
1.3.3. Coastal Washington		x	
1.3.4. Interior Oregon and Northeastern California		x	

	Funding Contribution by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Caspian Terns (cont.)			
1.4. Predation Rates Based on PIT Tag Recoveries			
1.4.1. Columbia River Estuary	x		
1.4.2. Columbia Plateau			x
1.4.3. Coastal Washington			
1.4.4. Interior Oregon and Northeastern California		x	
1.5. Color Banding and Band Resightings			
1.5.1. Columbia River Estuary	x		
1.5.2. Columbia Plateau			x
1.5.3. Coastal Washington		x	
1.5.4. Interior Oregon and Northeastern California		x	
Double-crested Cormorants			
2.1. Nesting Distribution and Colony Size			
2.1.1. Columbia River Estuary	x	x	
2.1.2. Columbia Plateau			x
2.1.3. Coastal Washington		x	
2.1.4. Interior Oregon and Northeastern California		x	
2.2. Nesting Chronology and Productivity			
2.2.1. Columbia River Estuary	x		
2.2.2. Columbia Plateau			x
2.2.3. Coastal Washington		x	
2.2.4. Interior Oregon and Northeastern California		x	
2.3. Diet Composition and Salmonid Consumption			
2.3.1. Columbia River Estuary	x	x	
2.3.2. Columbia Plateau			x
2.3.3. Coastal Washington			
2.3.4. Interior Oregon and Northeastern California			

	Funding Contribution by Agency		
	BPA	USACE Portland District	USACE Walla Walla District
Double-crested Cormorants (cont.)			
2.4. Predation Rates Based on PIT Tag Recoveries			
2.4.1. Columbia River Estuary	x		
2.4.2. Columbia Plateau			x
2.4.3. Coastal Washington			
2.4.4. Interior Oregon and Northeastern California		x	
2.5. Color Banding	x	x	
2.6. Management Feasibility Studies			
2.6.1. Techniques to Encourage Nesting	x		
2.6.2. Techniques to Discourage Nesting	x		
Other Piscivorous Waterbirds			
3.1. Distribution			
3.1.1. Columbia River Estuary	x		
3.1.2. Columbia Plateau			x
3.1.3. Coastal Washington	x		
3.1.4. Interior Oregon and Northeastern California		x	
3.2. Diet Composition			
3.2.1. Columbia River Estuary	x		
3.2.2. Columbia Plateau			x
3.2.3. Coastal Washington			
3.2.4. Interior Oregon and Northeastern California			
3.3. Predation Rates Based on PIT Tag Recoveries			
3.3.1. Columbia River Estuary	x		
3.3.2. Columbia Plateau			x
3.3.3. Coastal Washington			
3.3.4. Interior Oregon and Northeastern California		x	
Steelhead Susceptibility Study			x

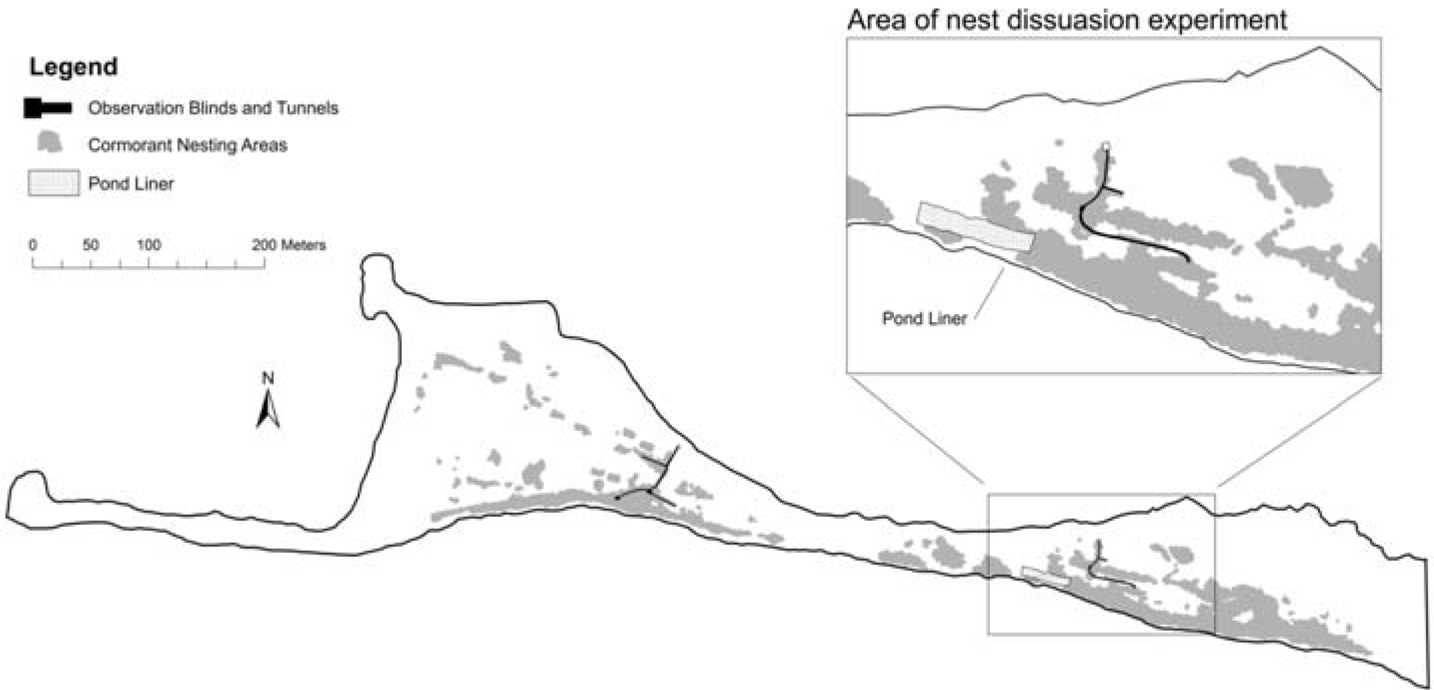


Map 1. Study area in the Columbia River basin and coastal Washington showing the locations of active and former breeding colonies of piscivorous colonial waterbirds mentioned in this report.



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

Map 3. Study area in interior Oregon and northeastern California and locations of piscivorous waterbird colonies mentioned in this report.



Map 4. Distribution of cormorant nests on western East Sand Island in the Columbia River estuary during the 2010 breeding season. Also shown are the locations of observation blinds and access tunnels, plus the area used for a nest dissuasion experiment (see text for details). In 2010, cormorants nested only on the western half of East Sand Island (shown here) and not elsewhere on the island.

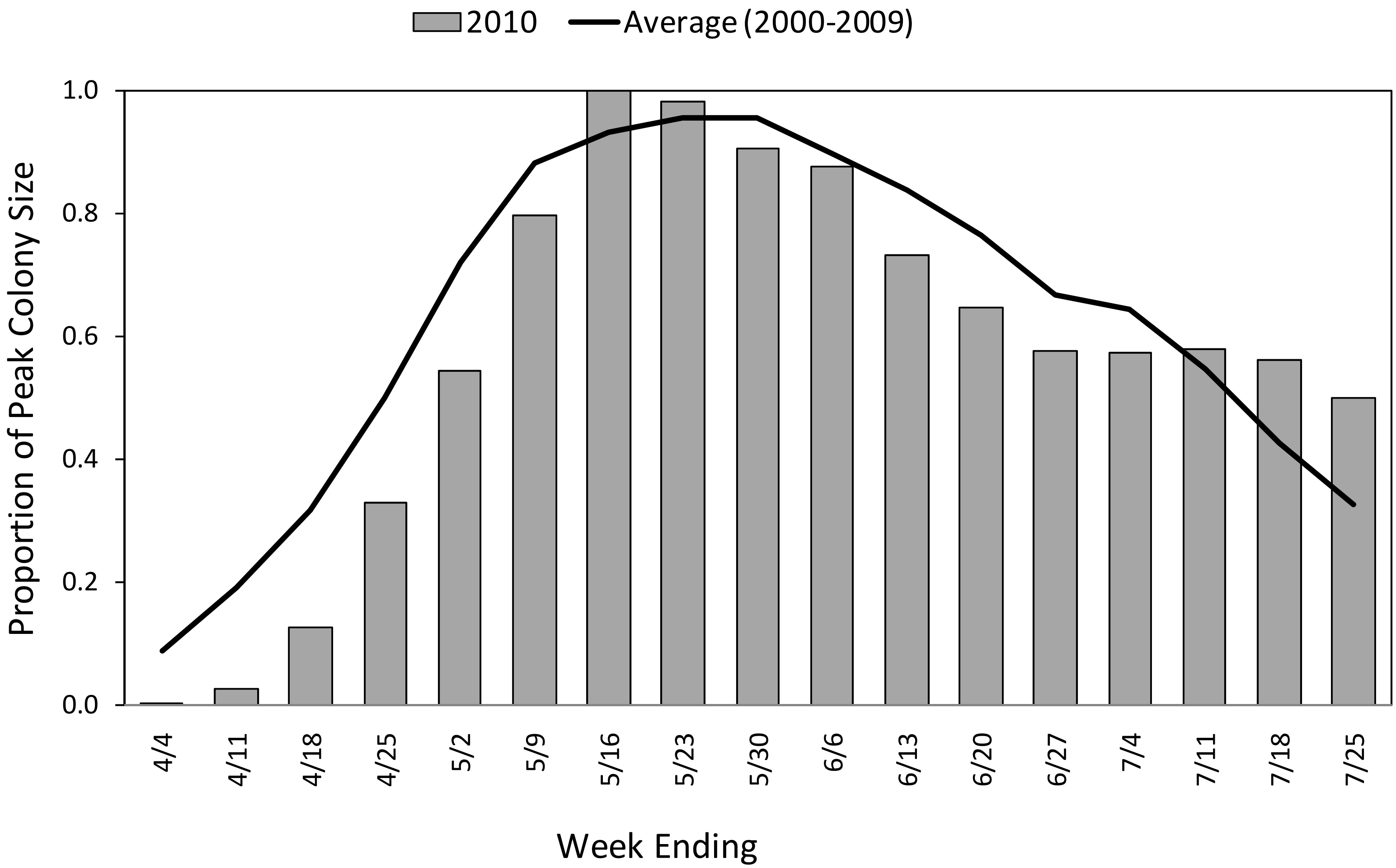


Figure 1. Weekly estimates from the ground of the number of adult Caspian terns on the East Sand Island colony during the 2010 nesting season, relative to peak colony attendance determined from counts of aerial photography taken late in incubation.

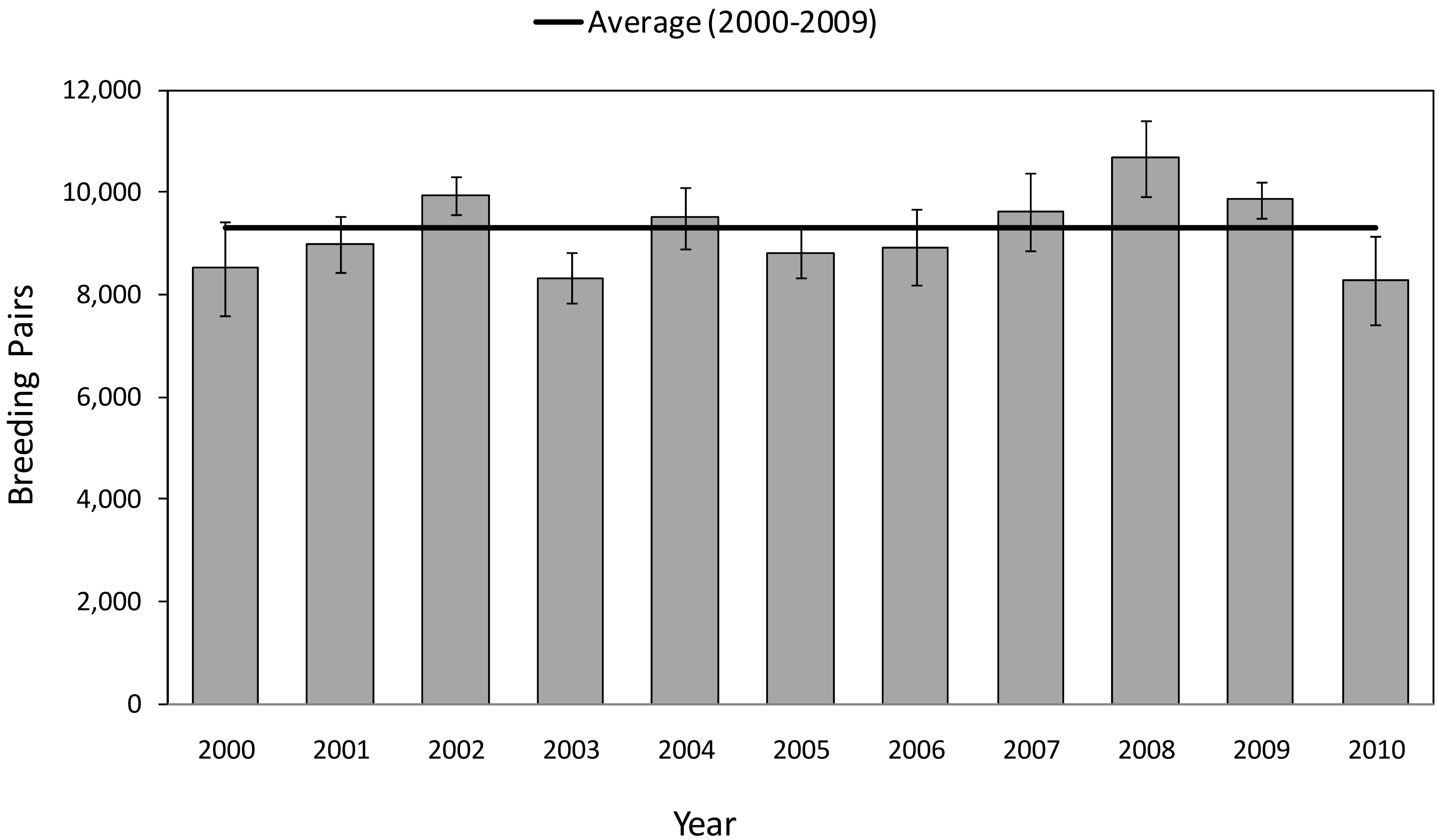


Figure 2. Caspian tern colony size on East Sand Island in the Columbia River estuary during 2000-2010. The error bars represent 95% confidence intervals for the number of breeding pairs.

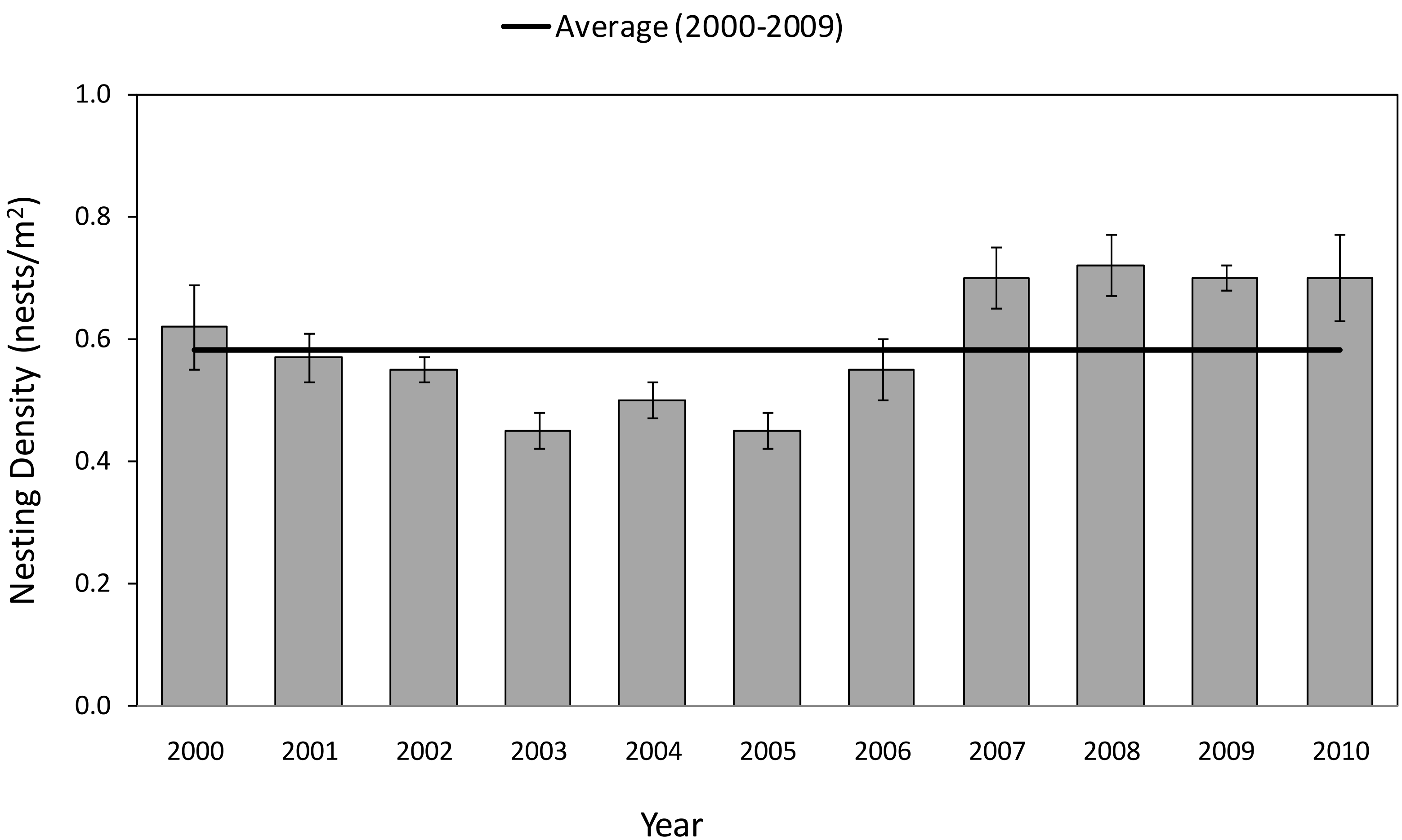


Figure 3. Caspian tern nesting density at the breeding colony on East Sand Island, Columbia River estuary during 2000-2010. The error bars represent 95% confidence intervals for nesting density.

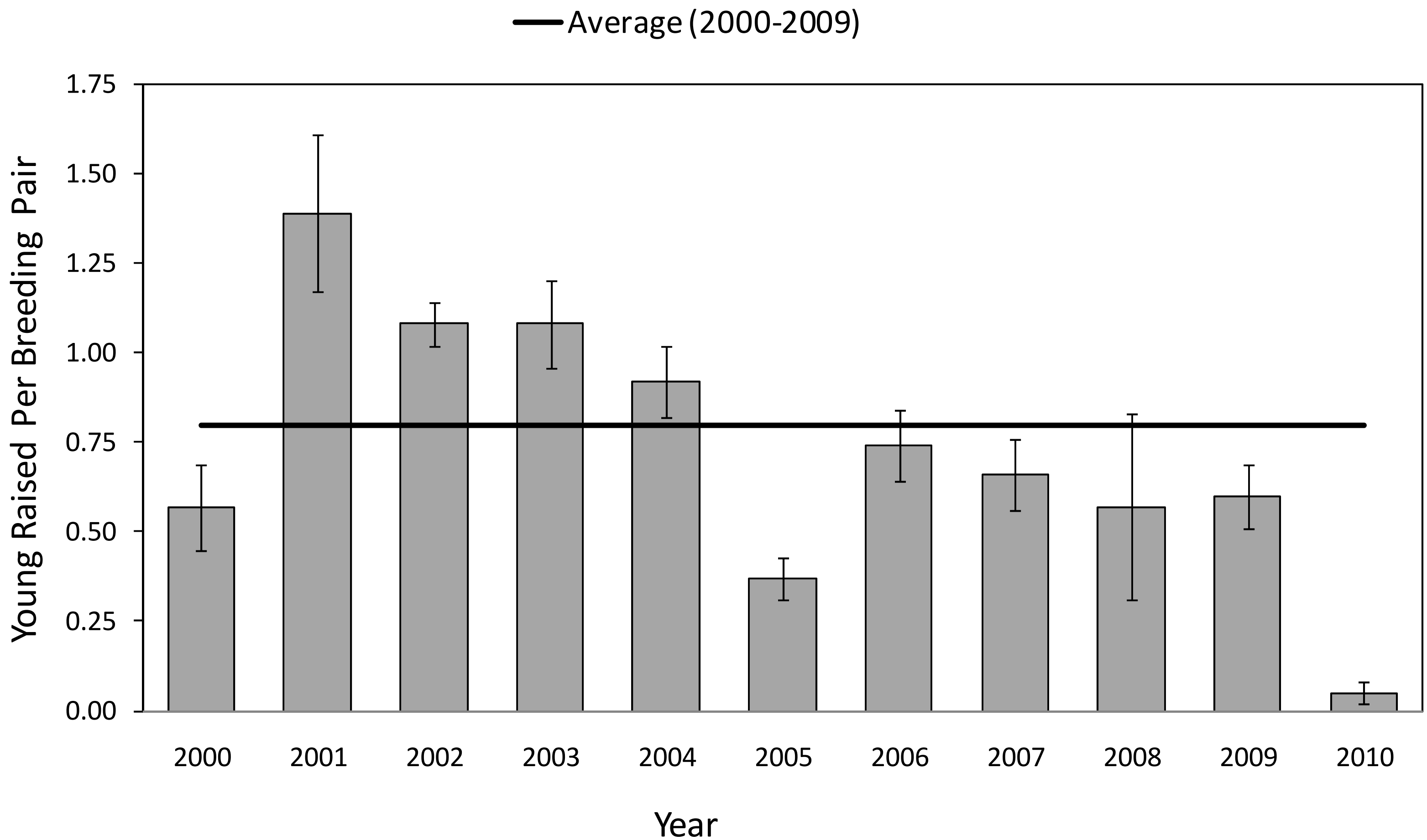


Figure 4. Caspian tern nesting success at the breeding colony on East Sand Island in the Columbia River estuary during 2000-2010. The error bars represent 95% confidence intervals for the number of young raised per breeding

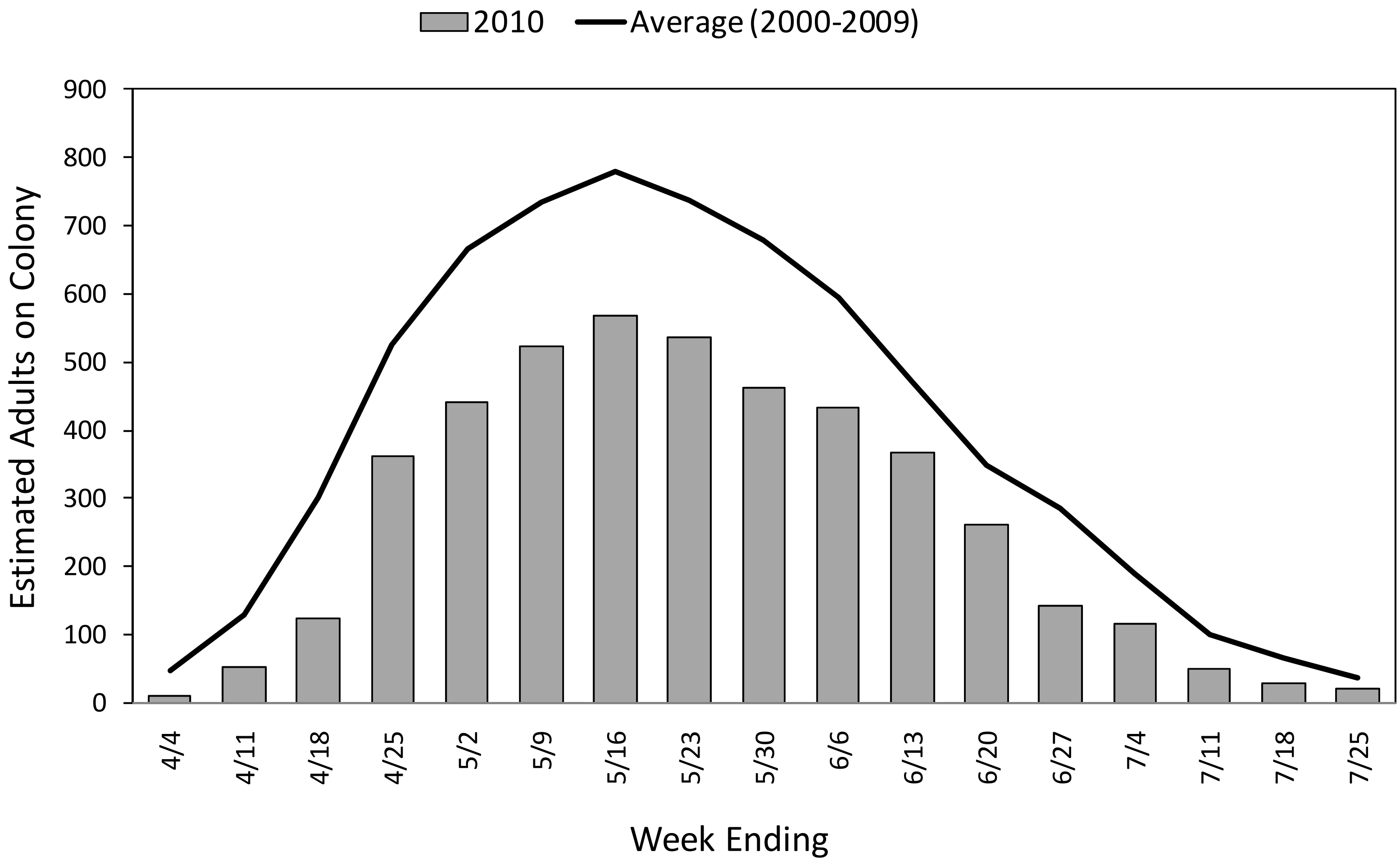


Figure 5. Estimates from the ground of the number of adult Caspian terns on the Crescent Island breeding colony on the mid-Columbia River, by week during the 2010 breeding season.

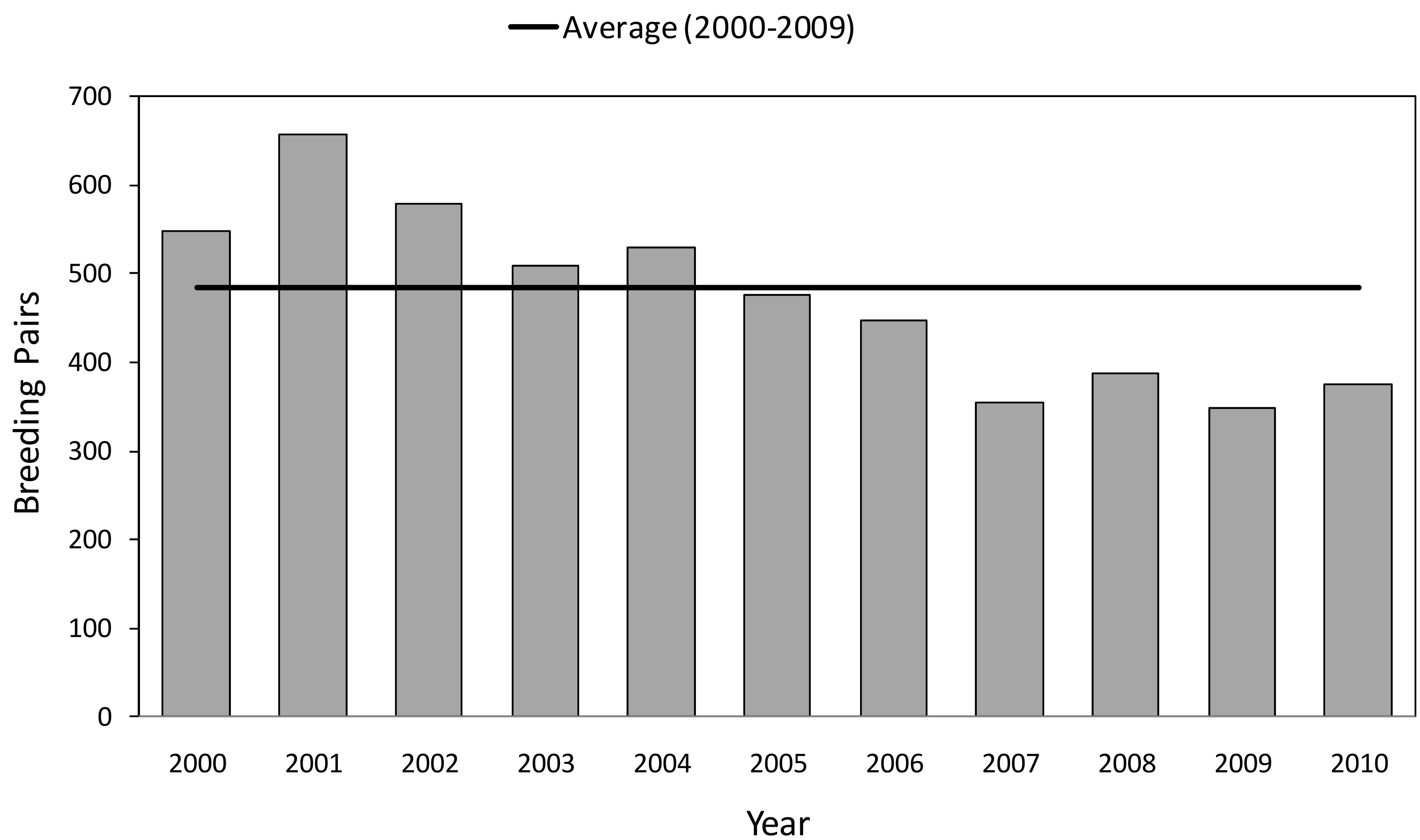


Figure 6. Size of the Caspian tern breeding colony on Crescent Island in the mid-Columbia River during 2000-2010.

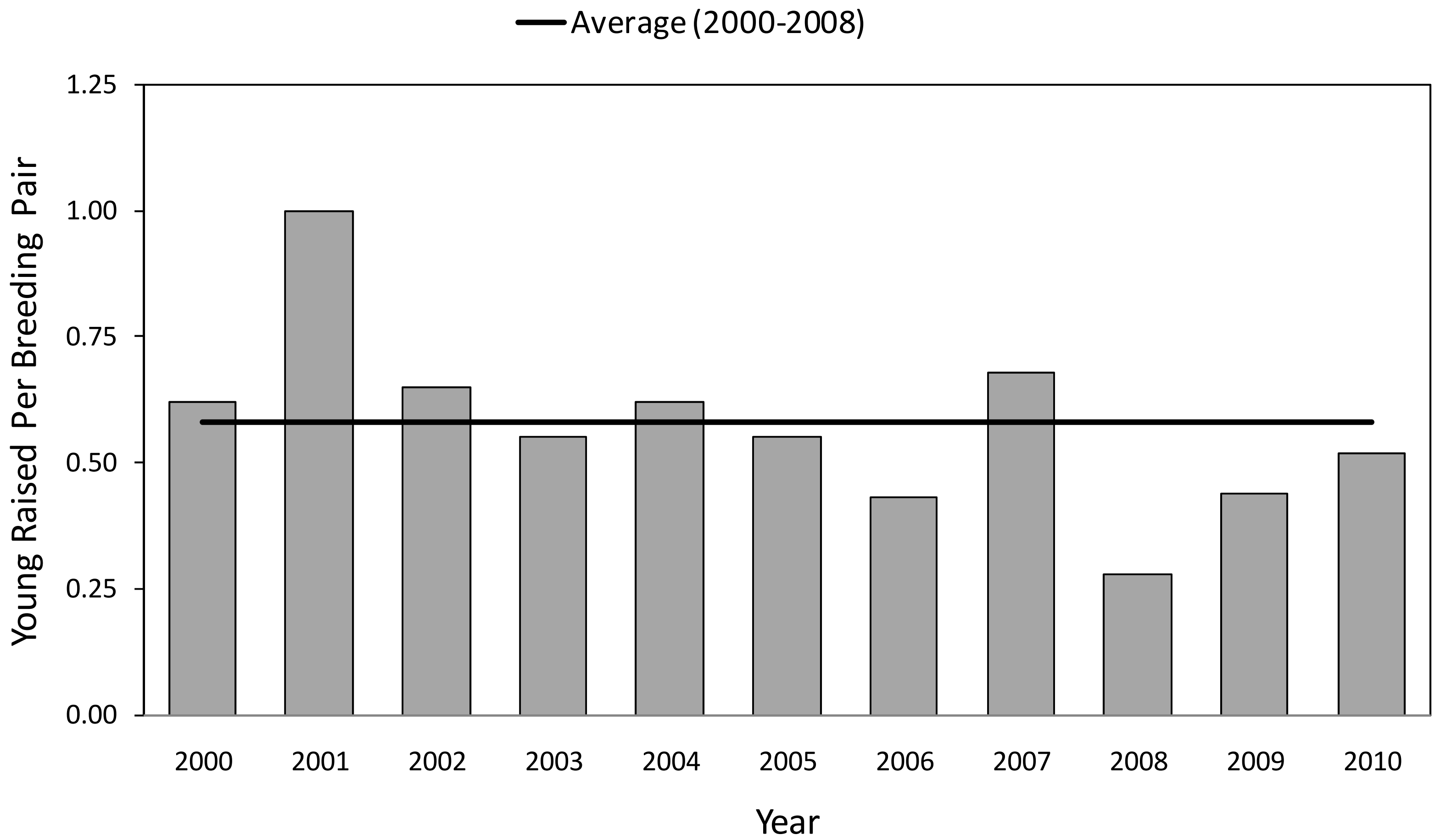


Figure 7. Nesting success of Caspian terns at the breeding colony on Crescent Island in the mid-Columbia River during 2000-2010.

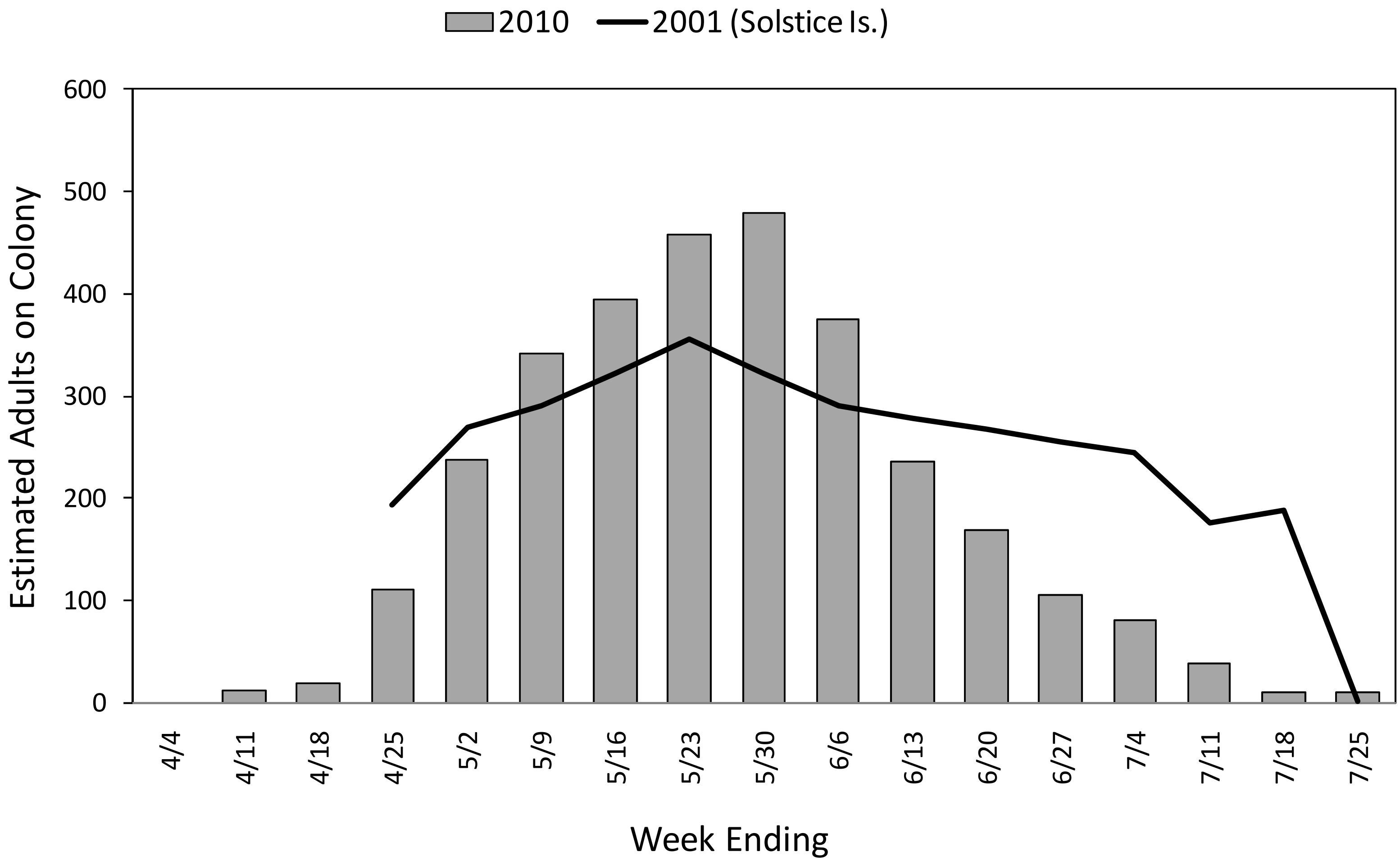


Figure 8. Estimates from the ground of the number of adult Caspian terns at the breeding colony on Goose Island in Potholes Reservoir, by week during the 2010 nesting season.

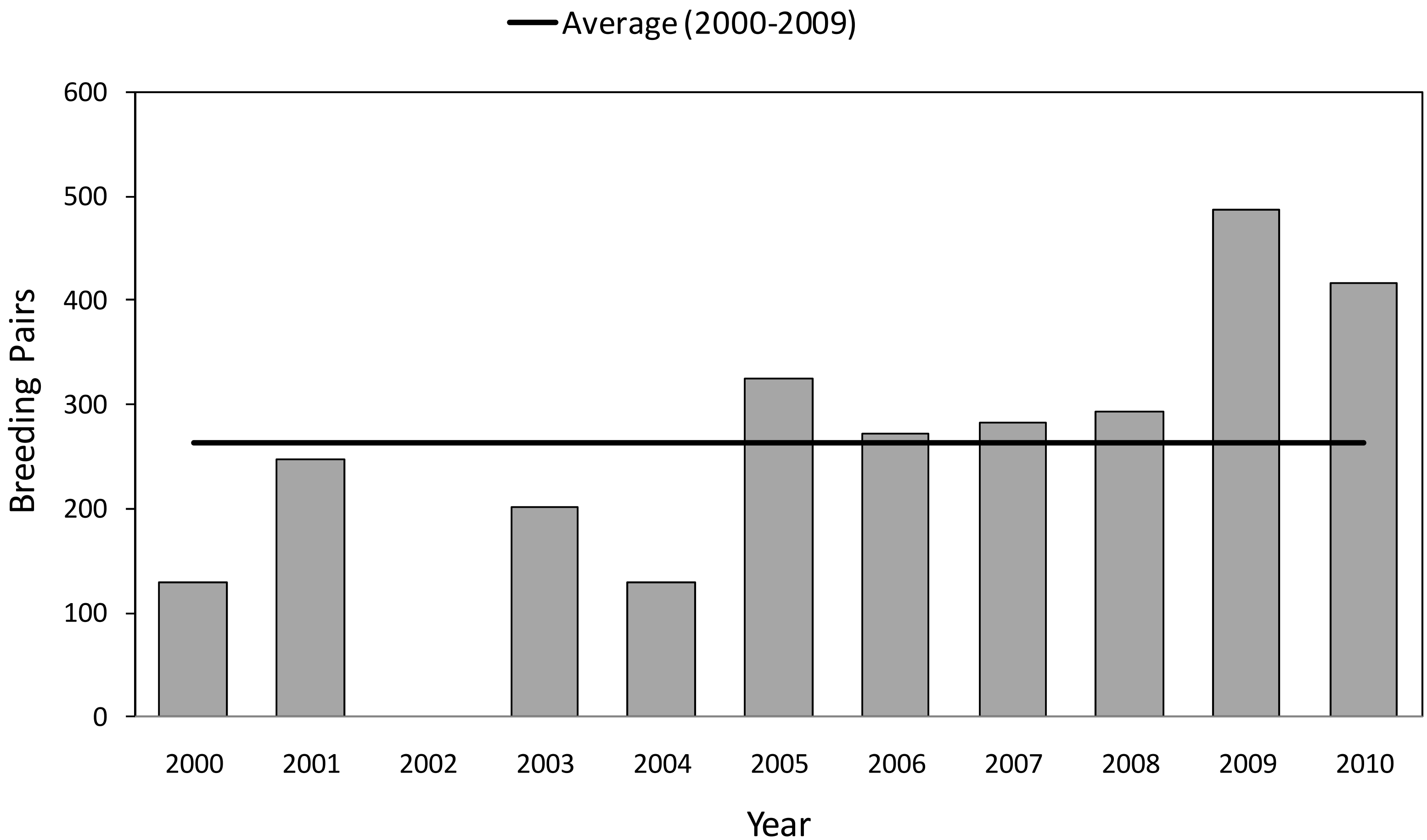


Figure 9. Size of Caspian tern breeding colony on Goose Island in Potholes Reservoir during 2000-2010. Colony size in 2002 is unknown.

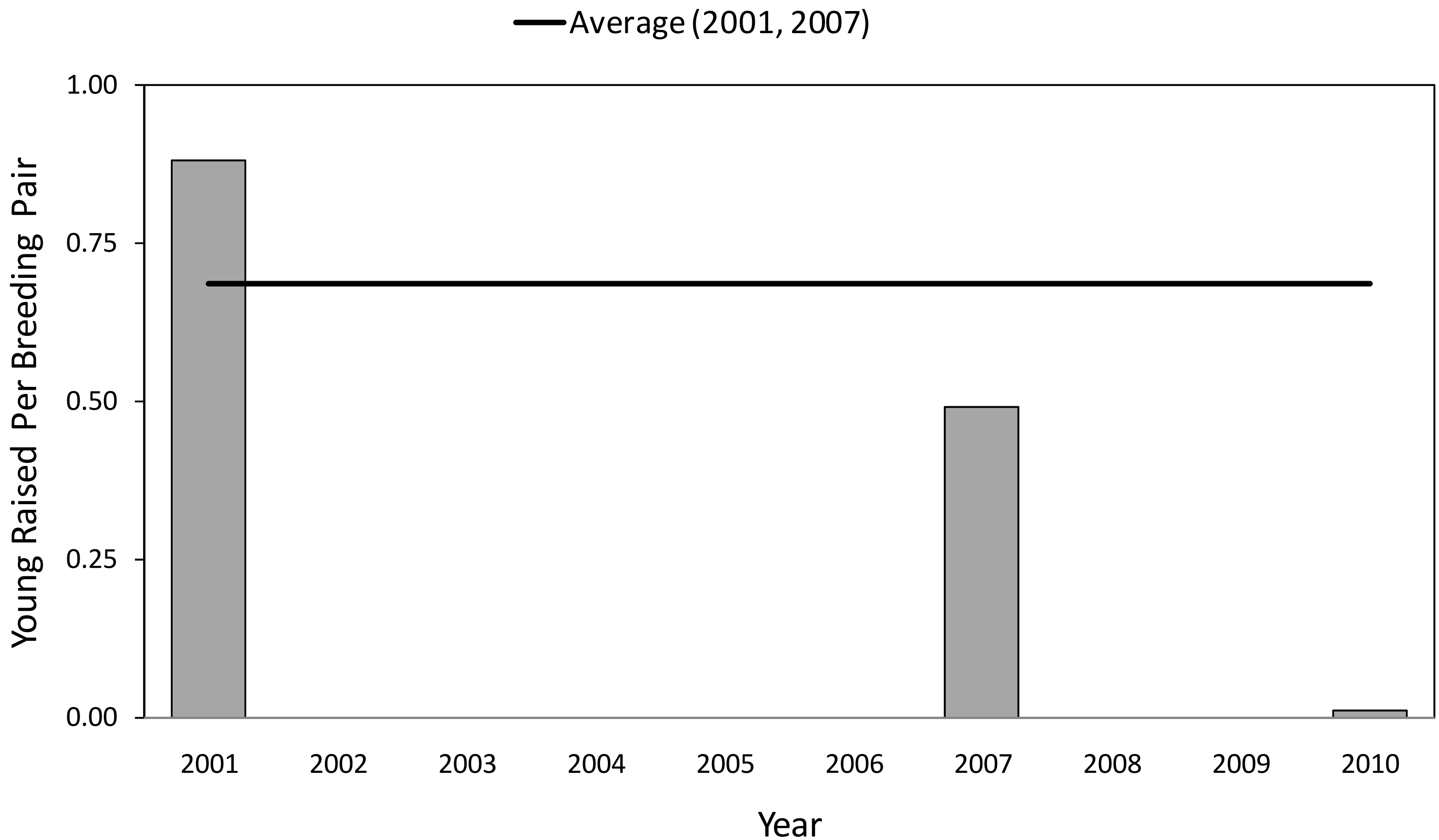


Figure 10. Caspian tern nesting success at the Goose Island breeding colony in Potholes Reservoir during 2001-2010. Nesting success during 2002-2006 and 2008-2009 is unknown.

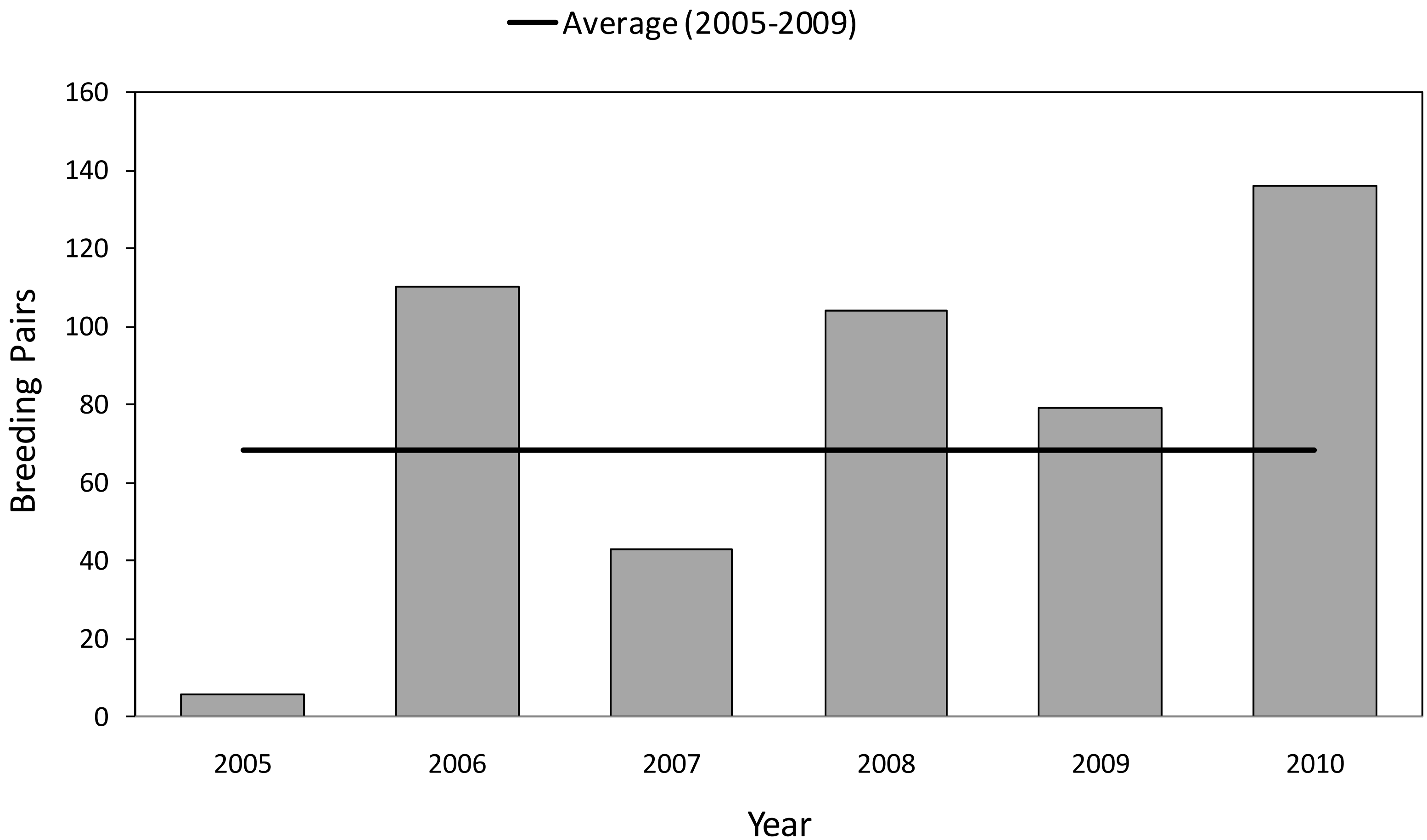


Figure 11. Size of the Caspian tern breeding colony at the Blalock Islands in the mid-Columbia River during 2005-2010.

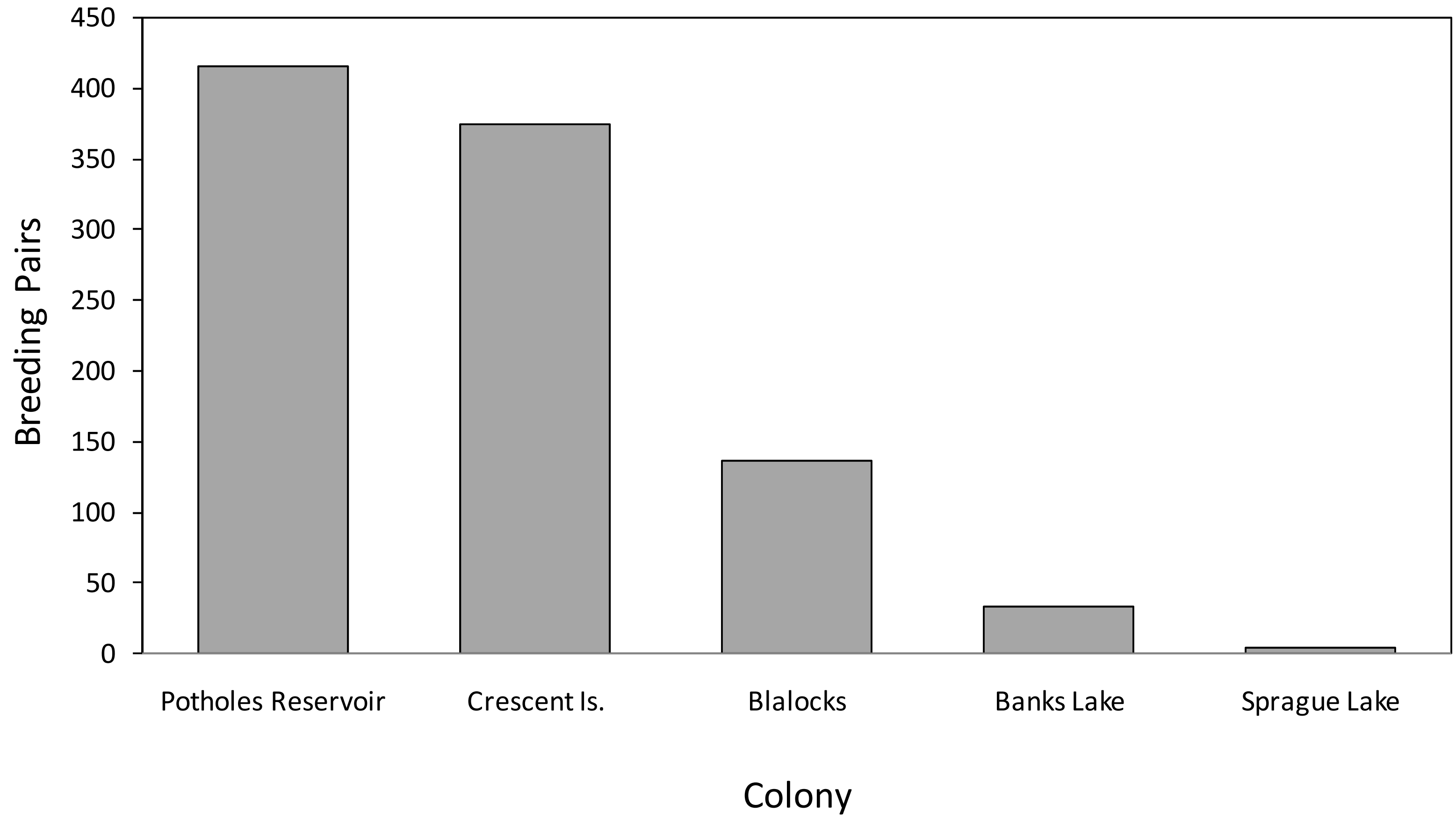


Figure 12. Sizes of Caspian tern breeding colonies at five sites in the Columbia Plateau region during the 2010 nesting season.

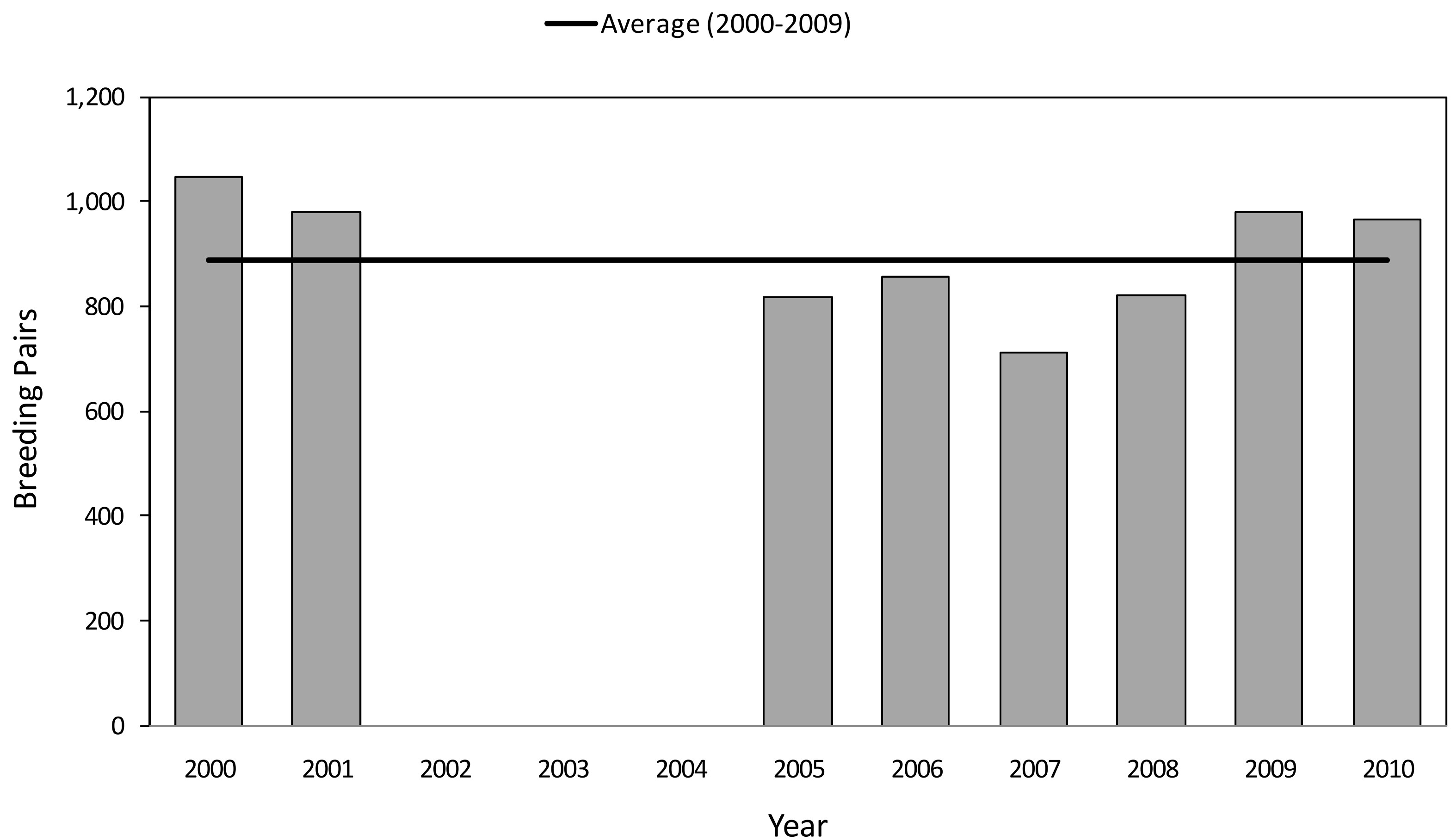


Figure 13. Total number of Caspian tern breeding pairs nesting at all colonies in the Columbia Plateau region during 2000-2010. Estimates of the number of breeding pairs were not available for all Caspian tern colonies in the Columbia Plateau region during 2002-2004.

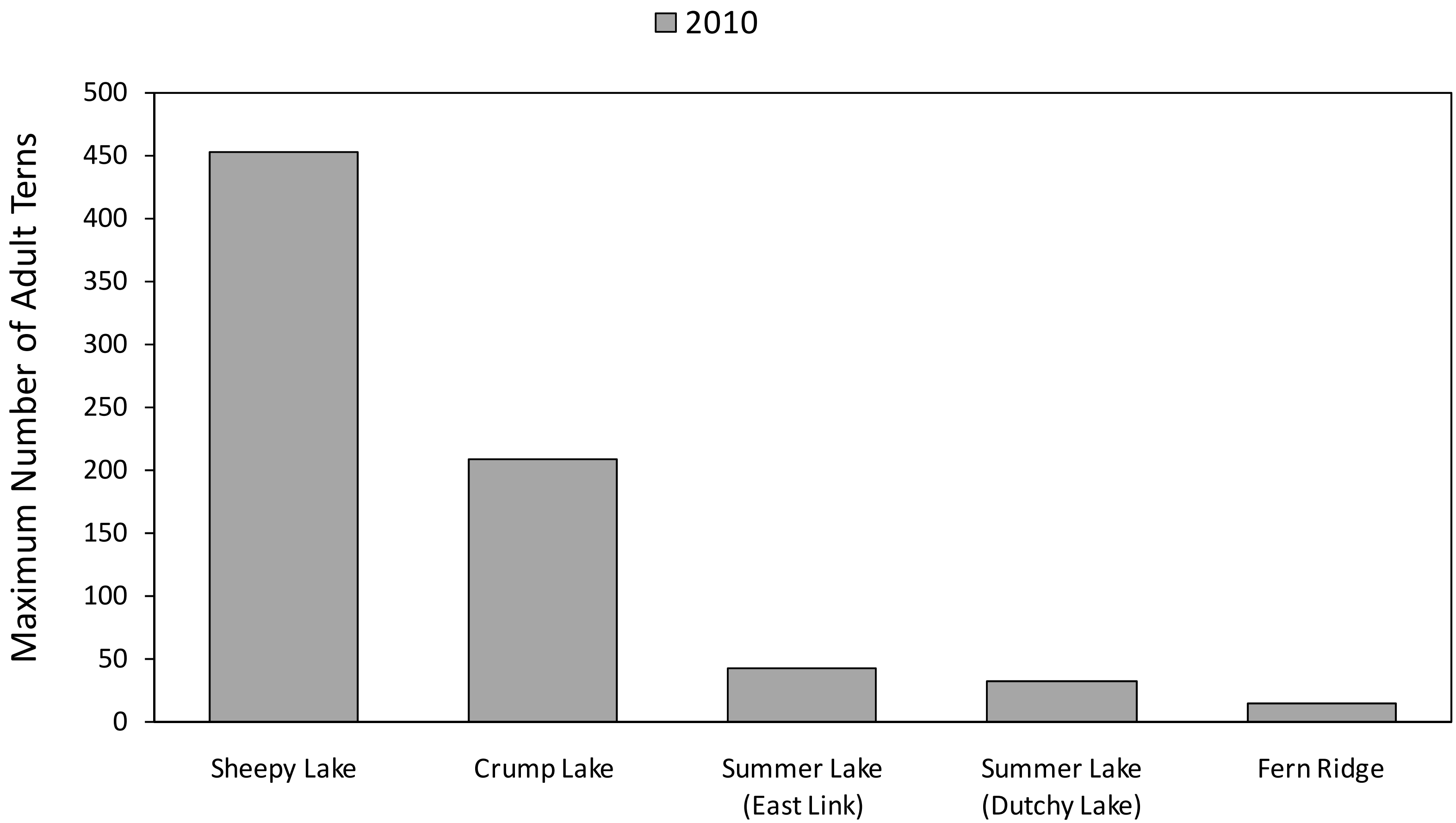


Figure 14. Maximum number of Caspian terns counted on tern islands recently constructed in interior Oregon and northeastern California in 2010. Caspian terns did not nest on the either the Fern Ridge Reservoir island or the Dutchy Lake island in 2010.

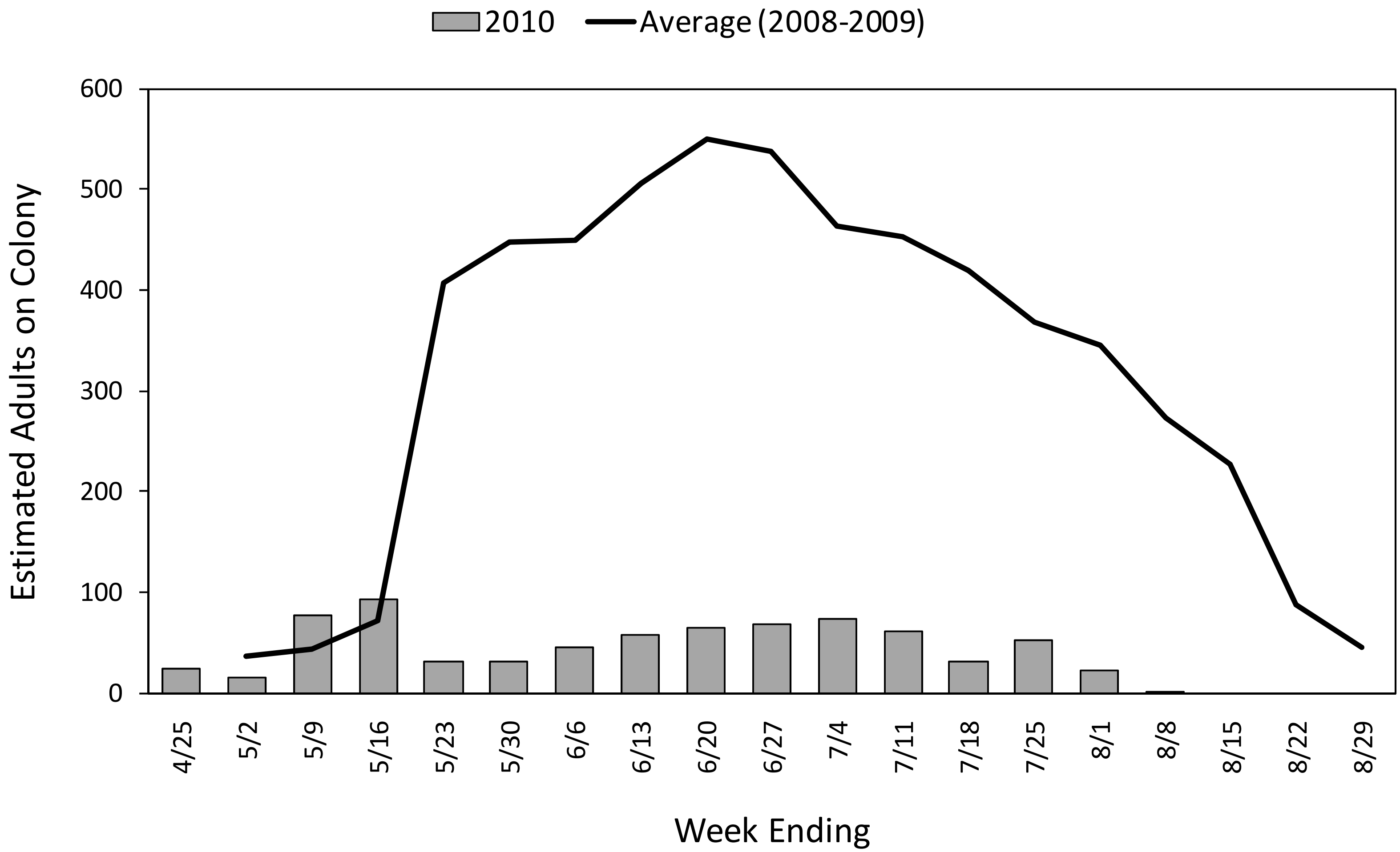


Figure 15. Estimates from the ground of the number of adult Caspian terns on the Crump Lake tern island in Warner Valley, Oregon, by week during the 2010 breeding season.

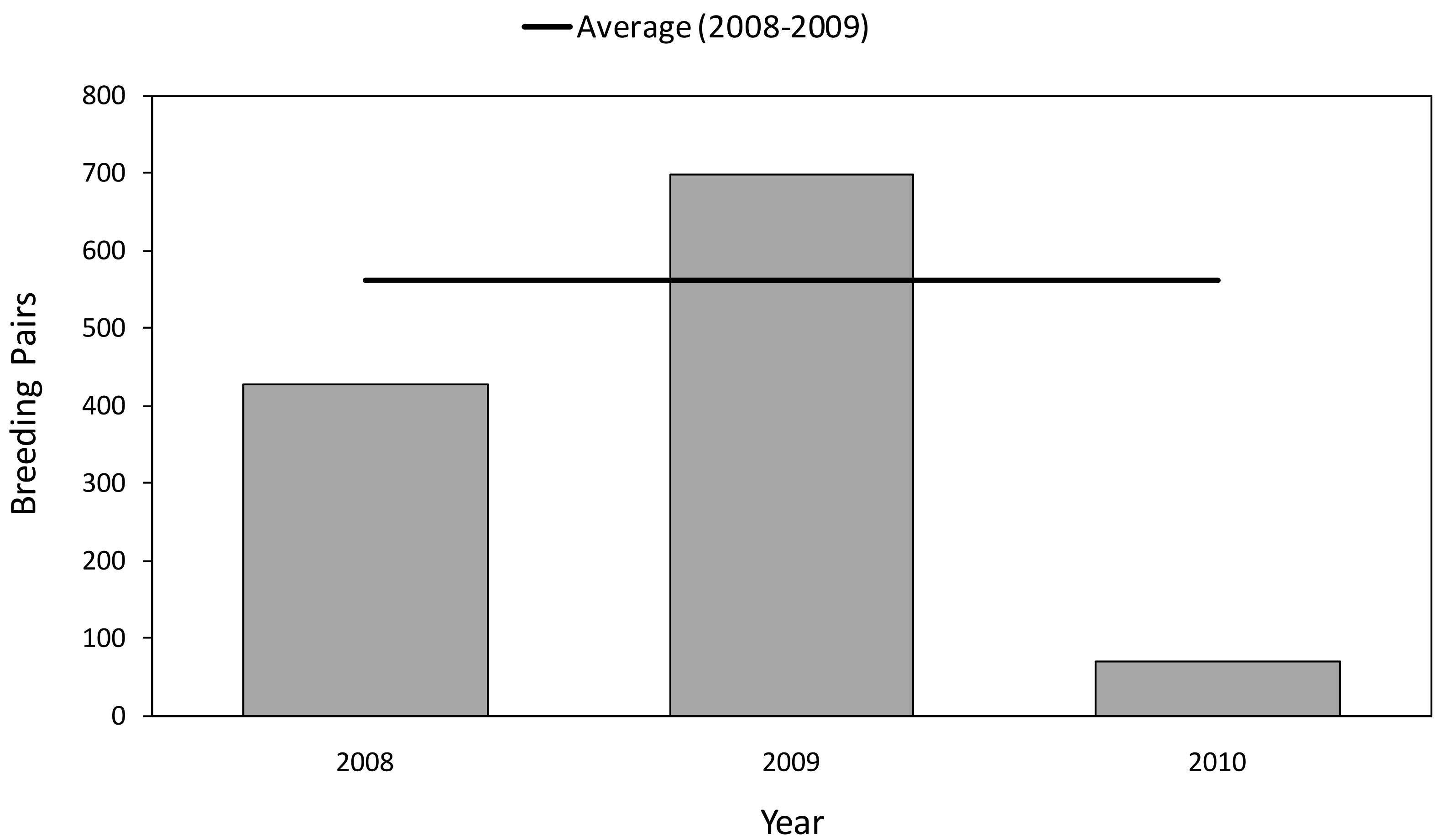


Figure 16. Size of the Caspian tern breeding colony on the Crump Lake tern island, Warner Valley, Oregon during the 2008-2010 nesting seasons.

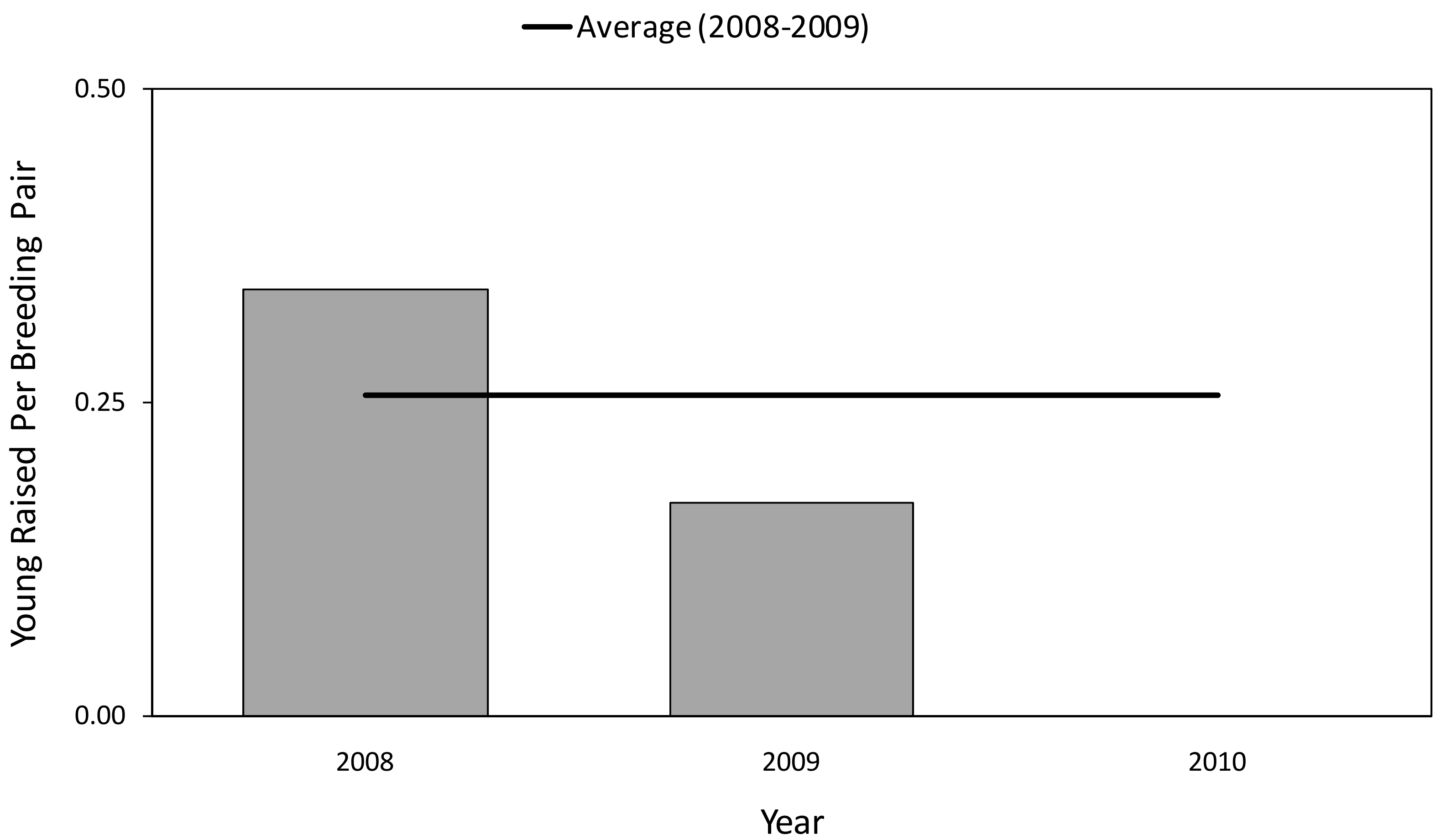


Figure 17. Caspian tern nesting success at the Crump Lake tern island in Warner Valley, Oregon during the 2008-2010 breeding seasons. Caspian terns failed to raise any young at the colony in 2010.

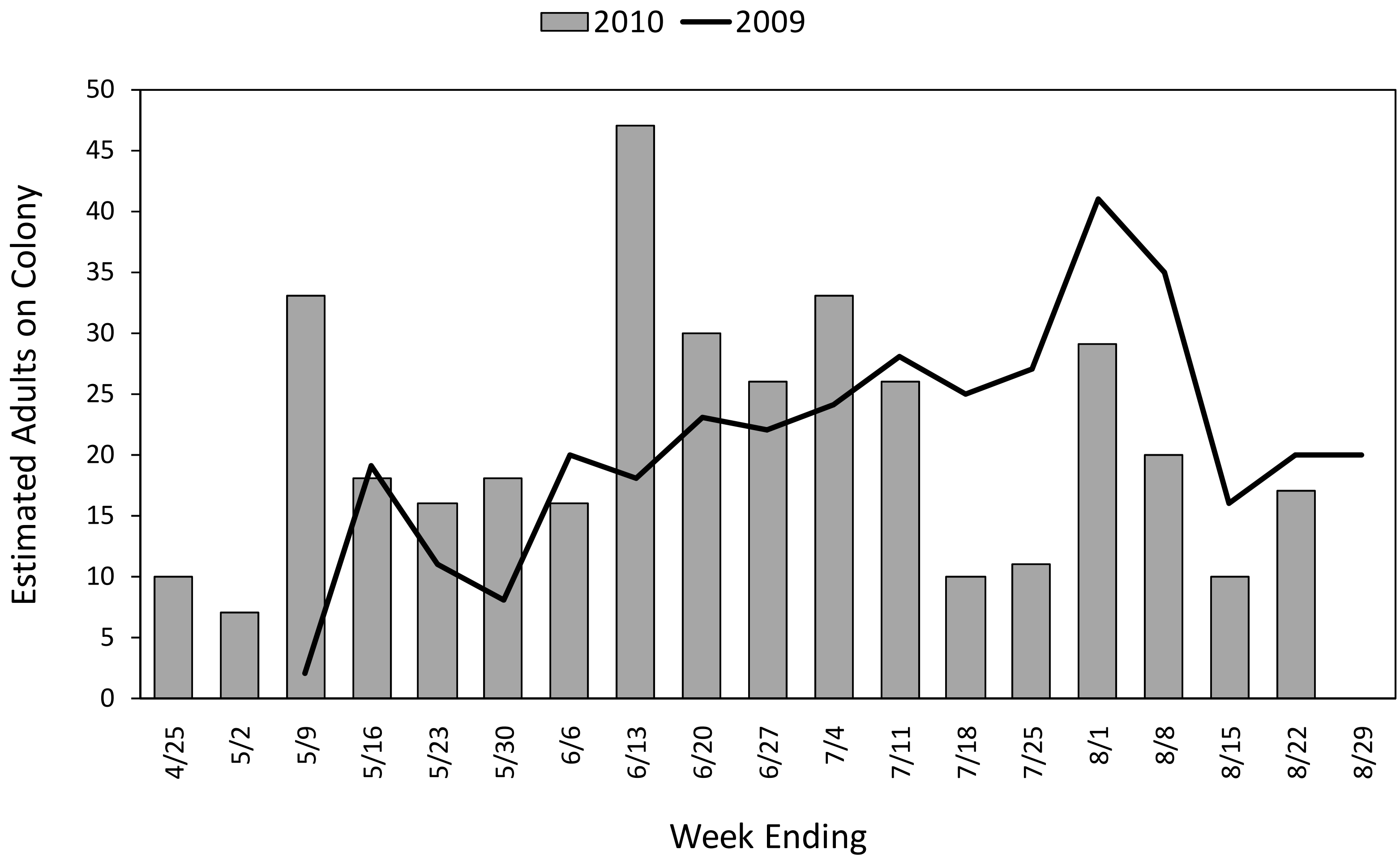


Figure 18. Estimates from the ground of the number of adult Caspian terns on the East Link and Dutchy Lake tern islands in Summer Lake Wildlife Area, Oregon, by week during the 2010 breeding season.

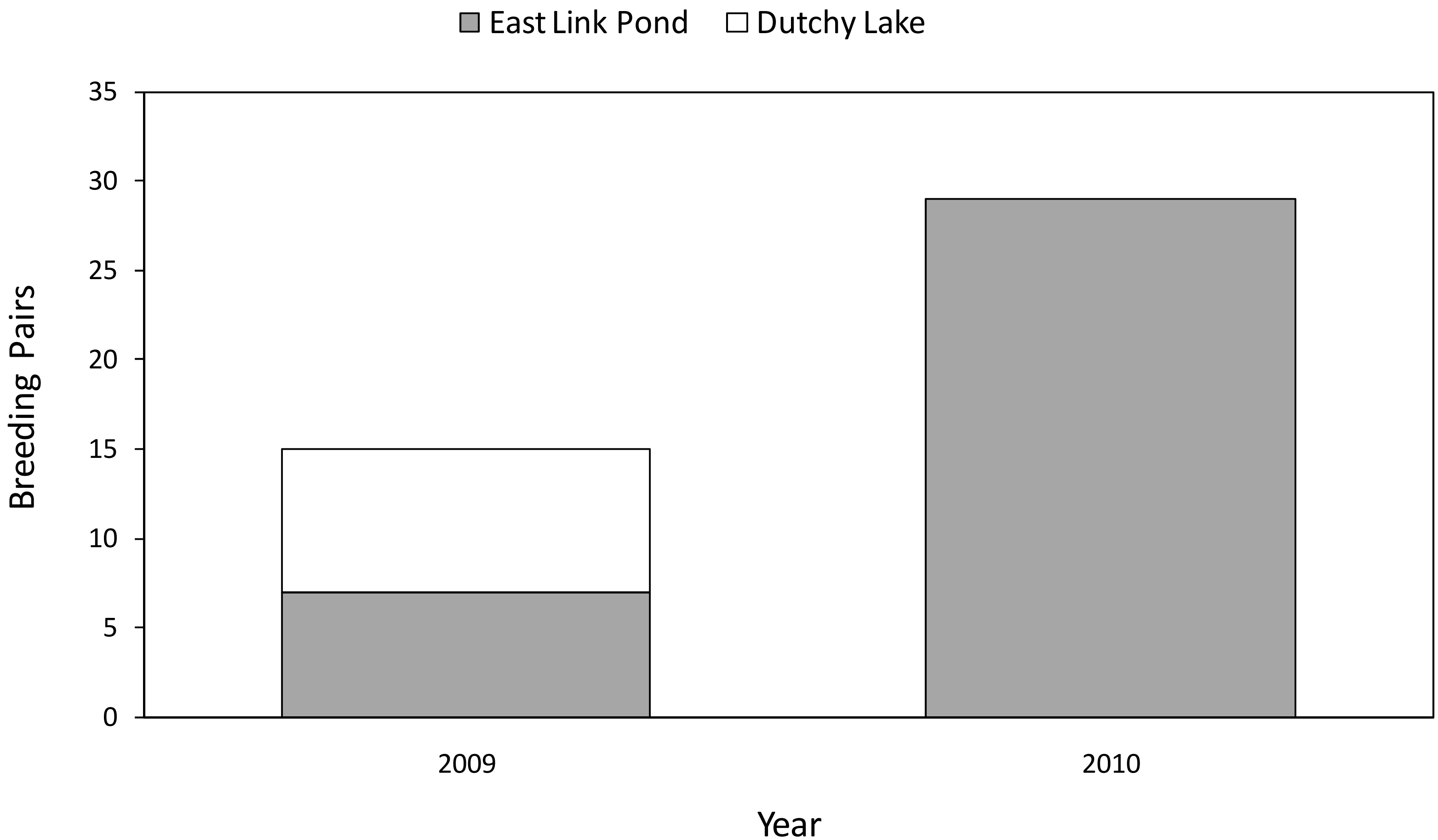


Figure 19. Size of Caspian tern breeding colonies on the East Link and Dutchy Lake tern islands in Summer Lake Wildlife Area during the 2009-2010 nesting seasons.

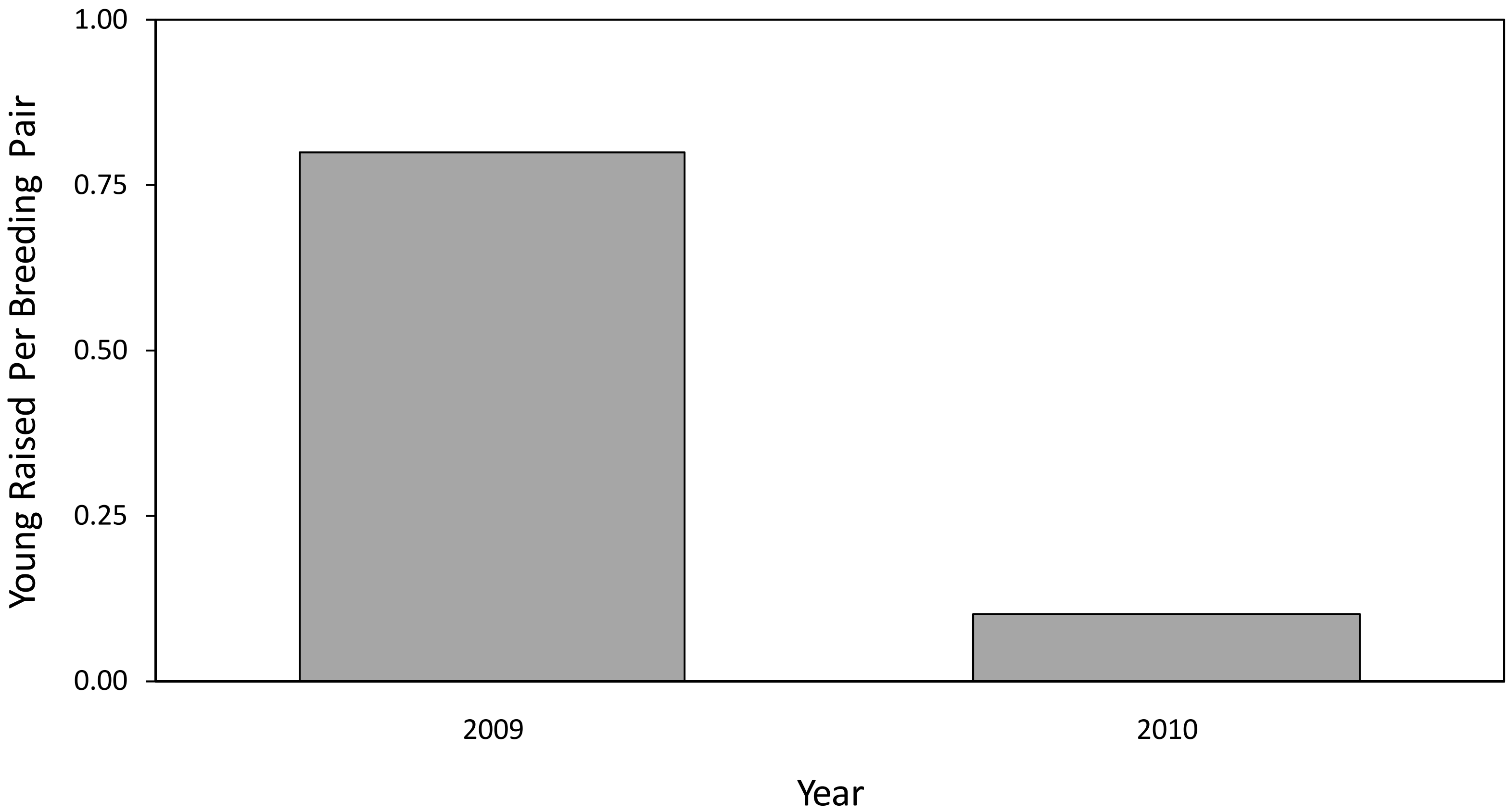


Figure 20. Caspian tern nesting success at the Summer Lake Wildlife Area tern islands (i.e., East Link and Dutchy Lake), Oregon during 2009-2010. Caspian terns did not nest on the Dutchy Lake tern island in 2010.

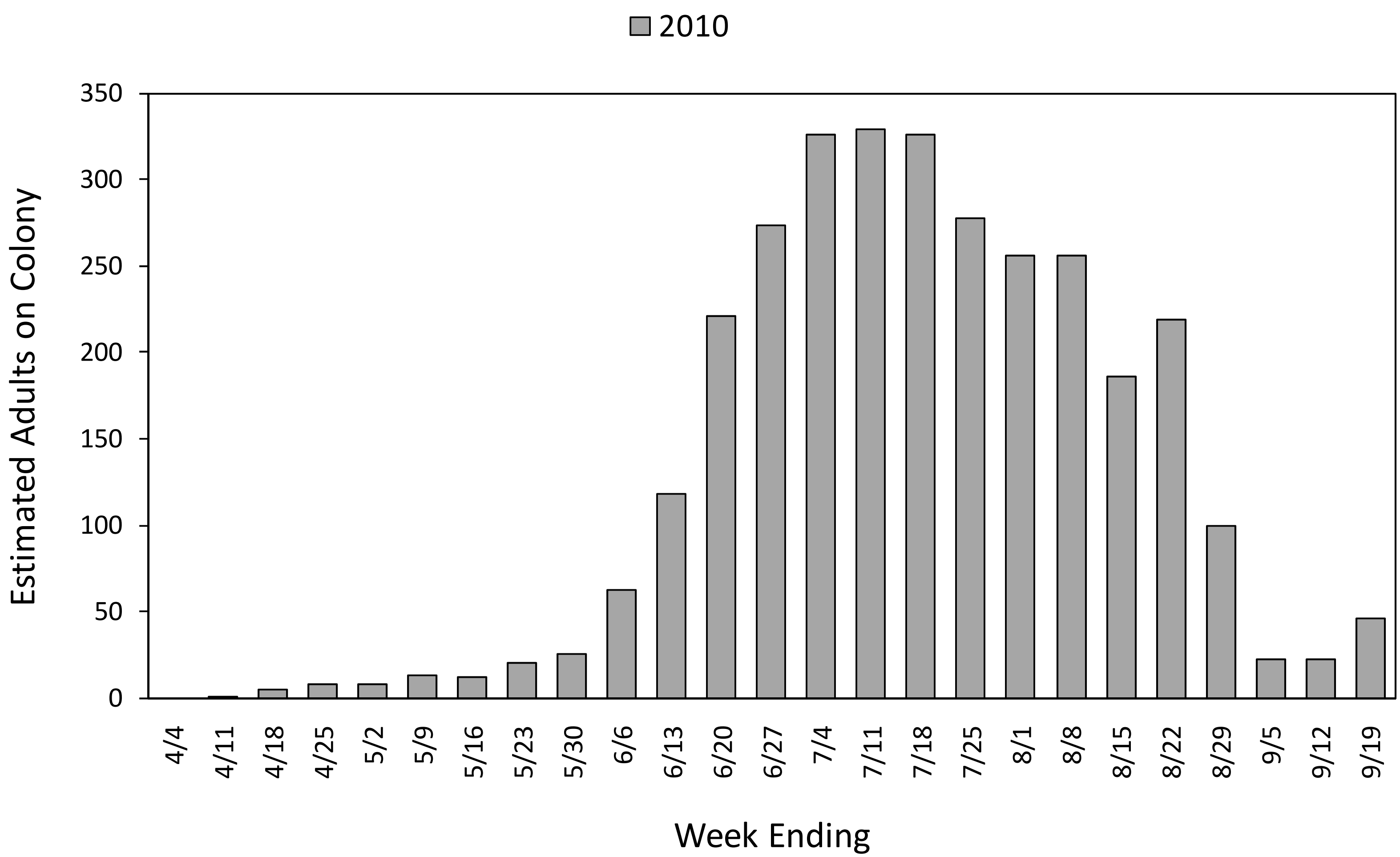


Figure 21. Estimates from the ground of the number of adult Caspian terns on the Sheepy Lake tern island in Lower Klamath NWR, California, by week during the 2010 breeding season.

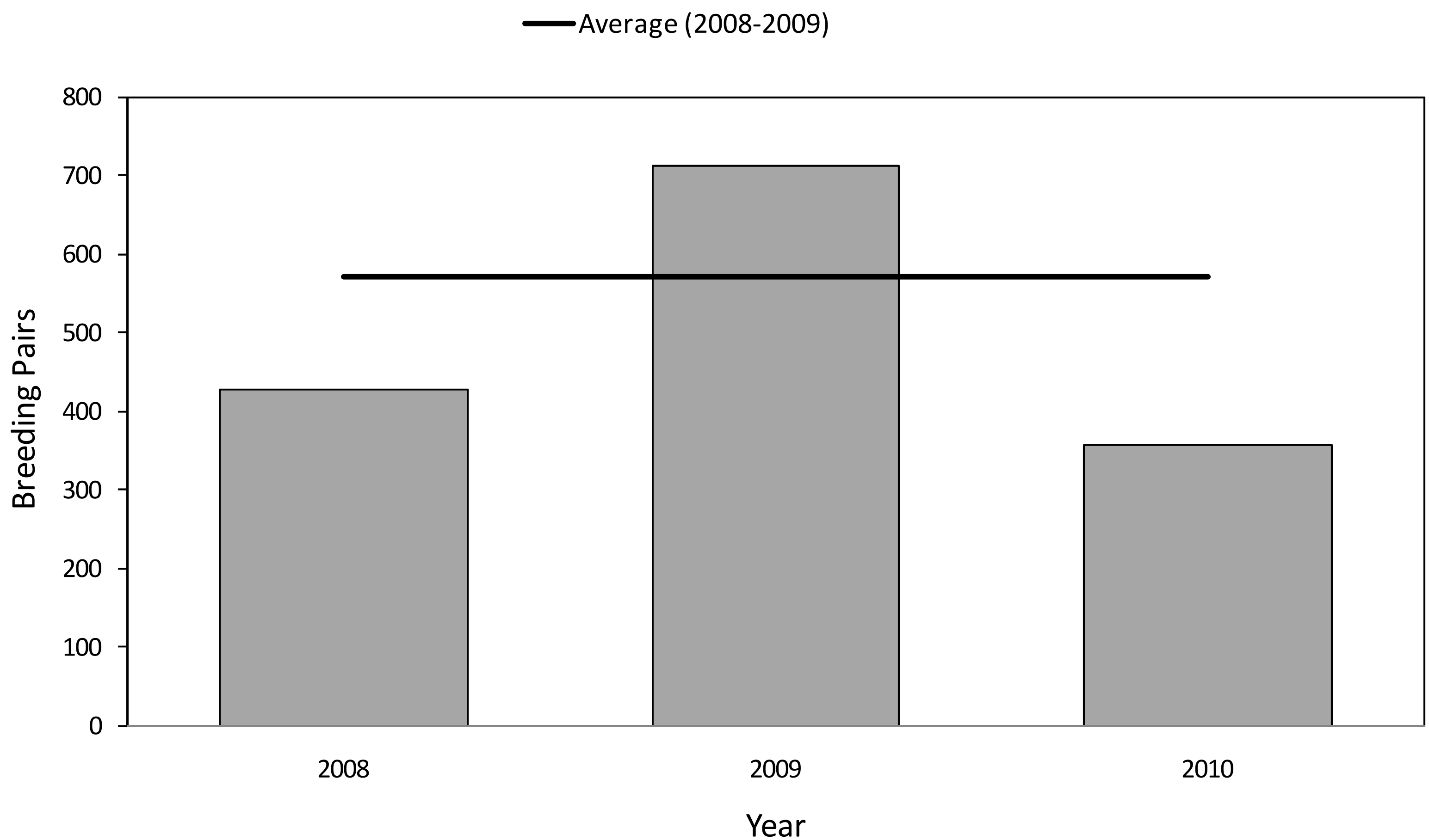


Figure 22. Total number of Caspian tern breeding pairs nesting at new tern islands in interior Oregon and northeastern California during the 2008-2010 nesting seasons.

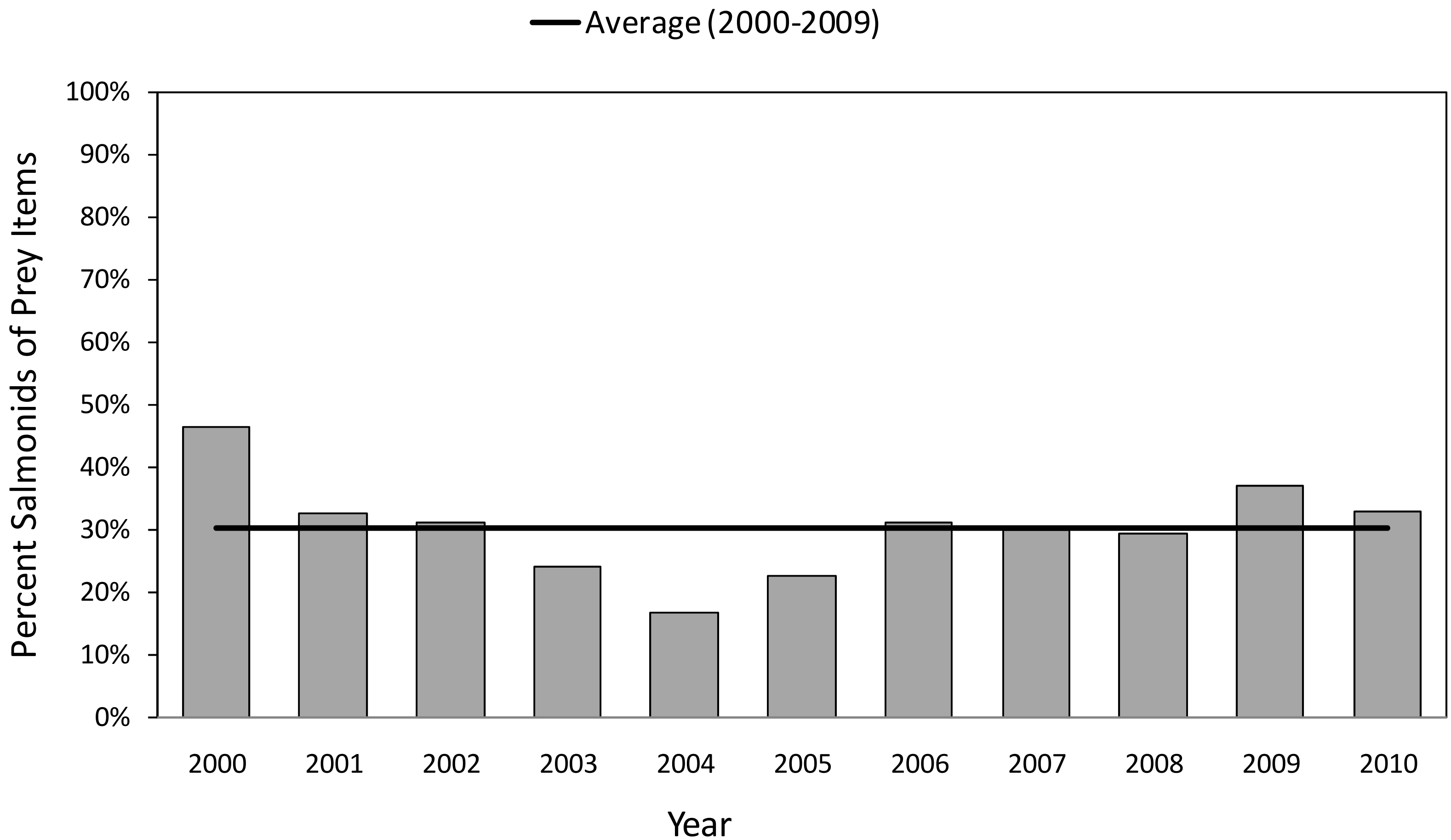


Figure 23. Average annual proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island in the Columbia River estuary during 2000-2010.

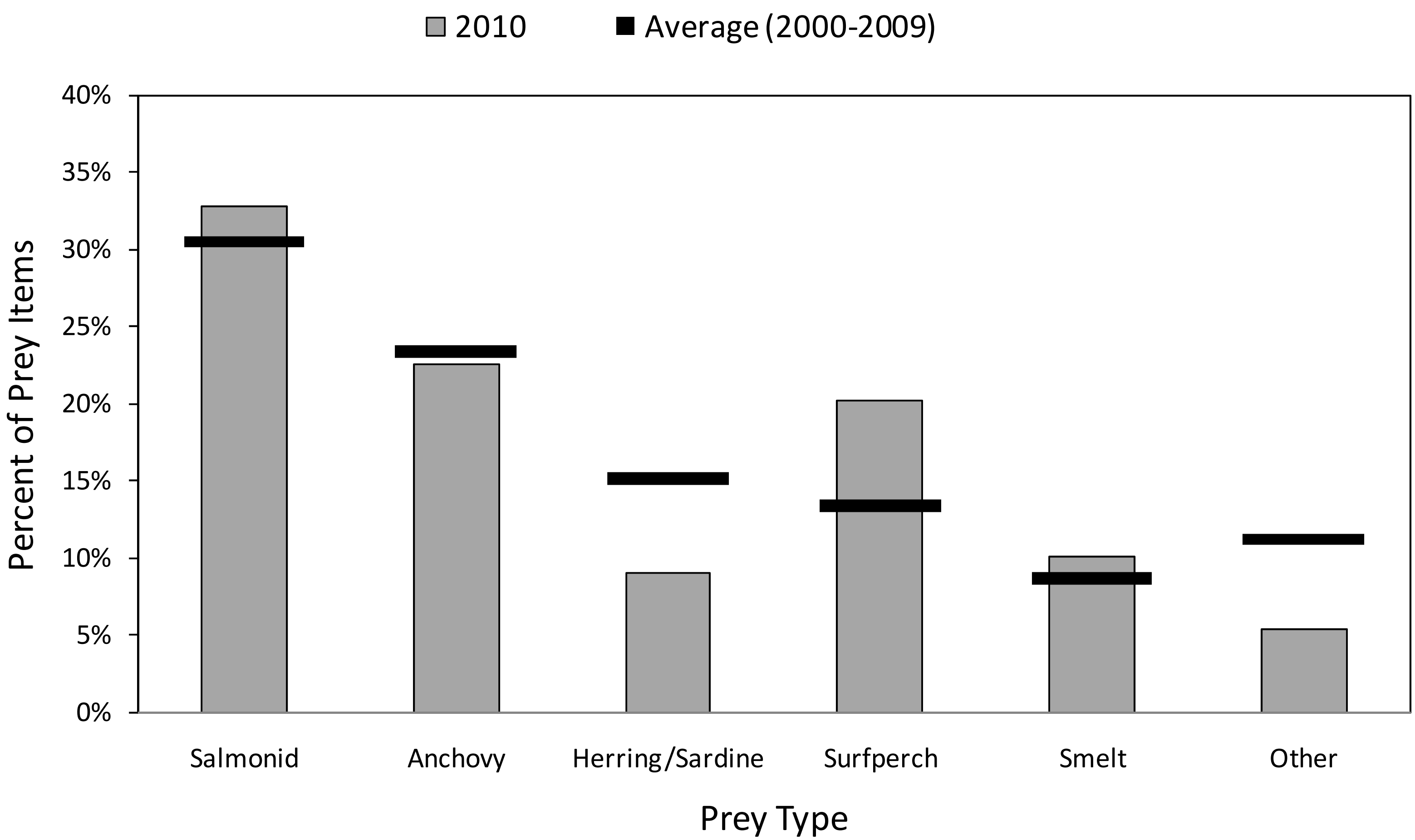


Figure 24. Diet composition of Caspian terns nesting on East Sand Island in the Columbia River estuary during the 2010 nesting season.

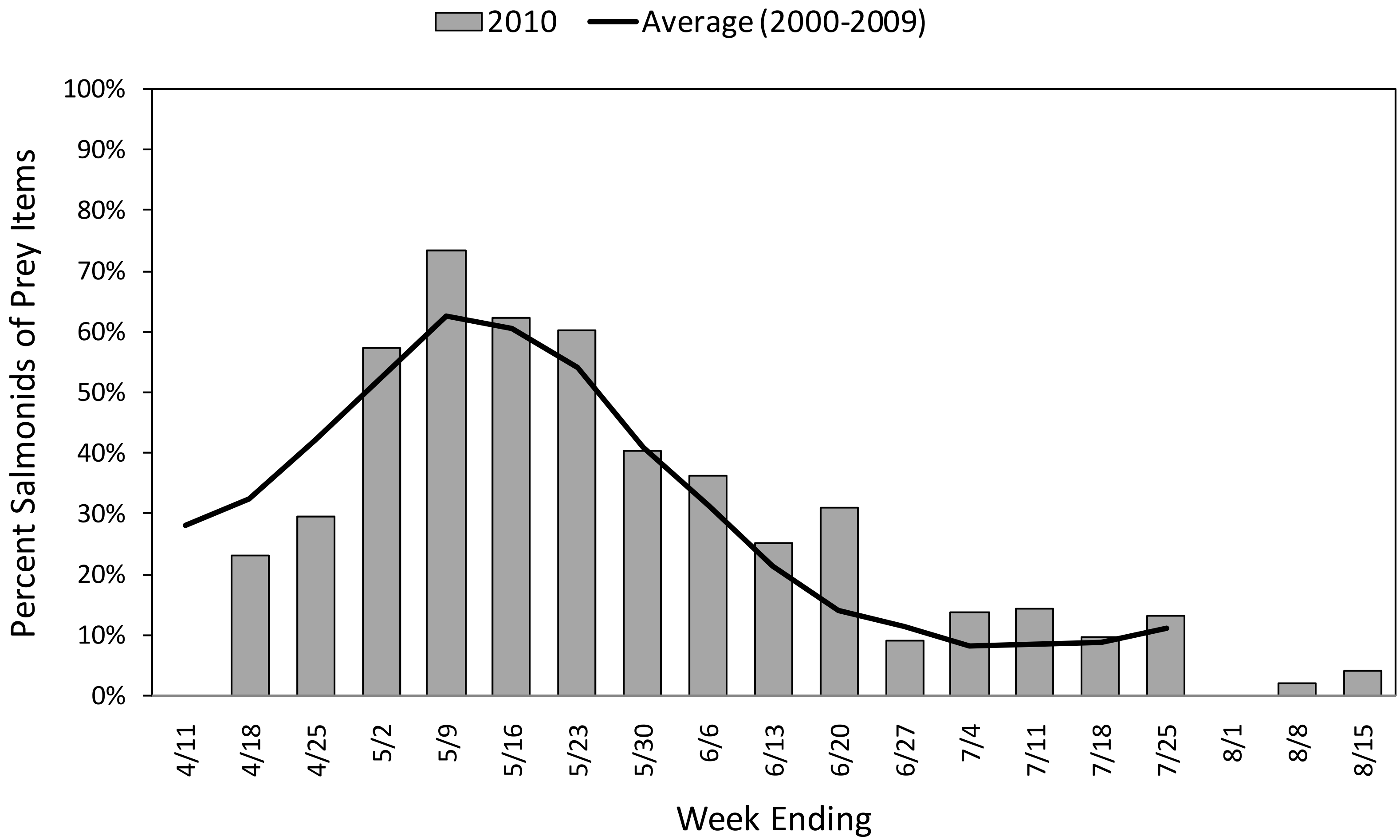


Figure 25. Proportion of juvenile salmonids in the diet of Caspian terns nesting on East Sand Island in the Columbia River estuary, by week during the 2010 nesting season.

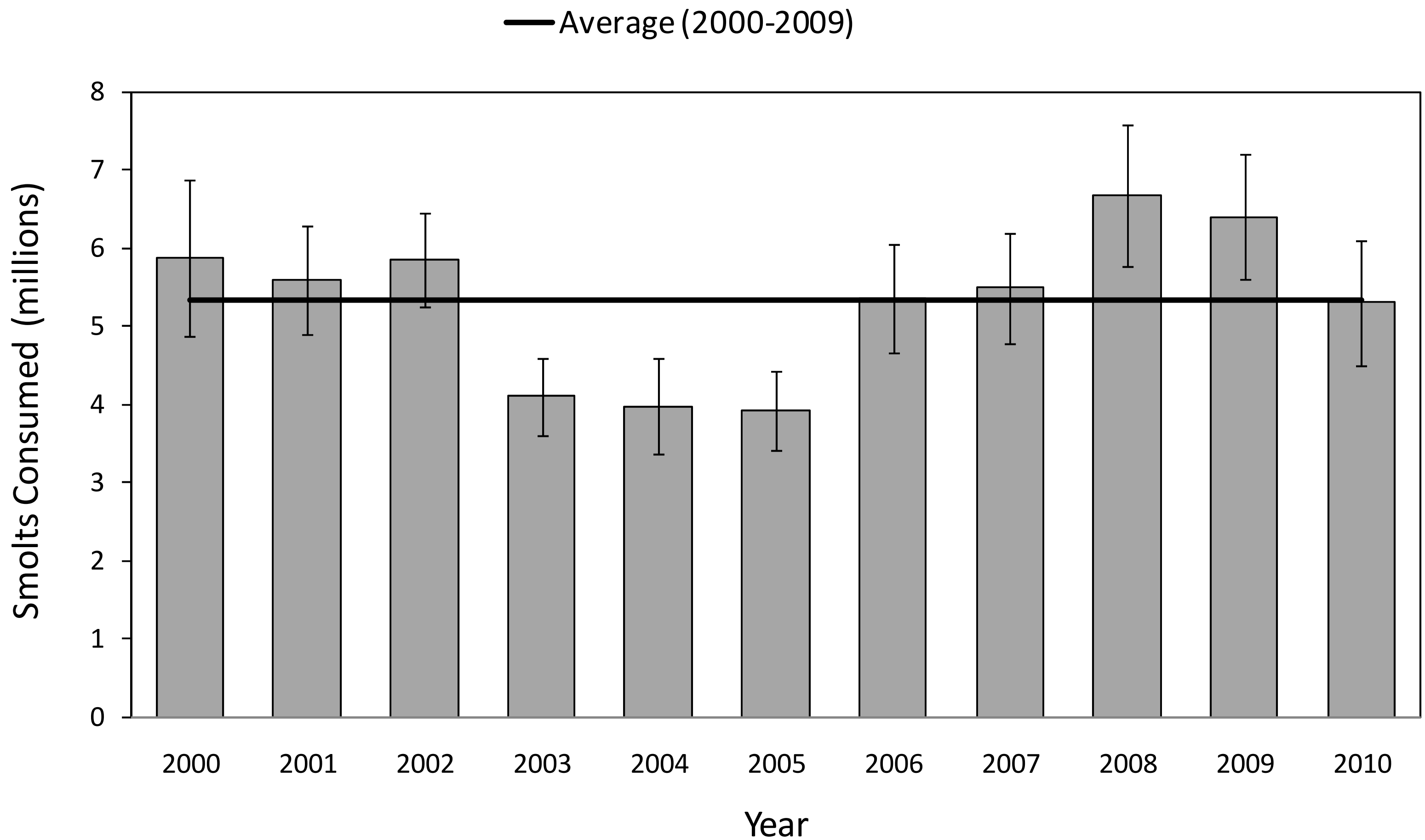


Figure 26. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting on East Sand Island in the Columbia River estuary during the 2000-2010 nesting seasons. Error bars represent 95% confidence intervals for the number of smolts consumed.

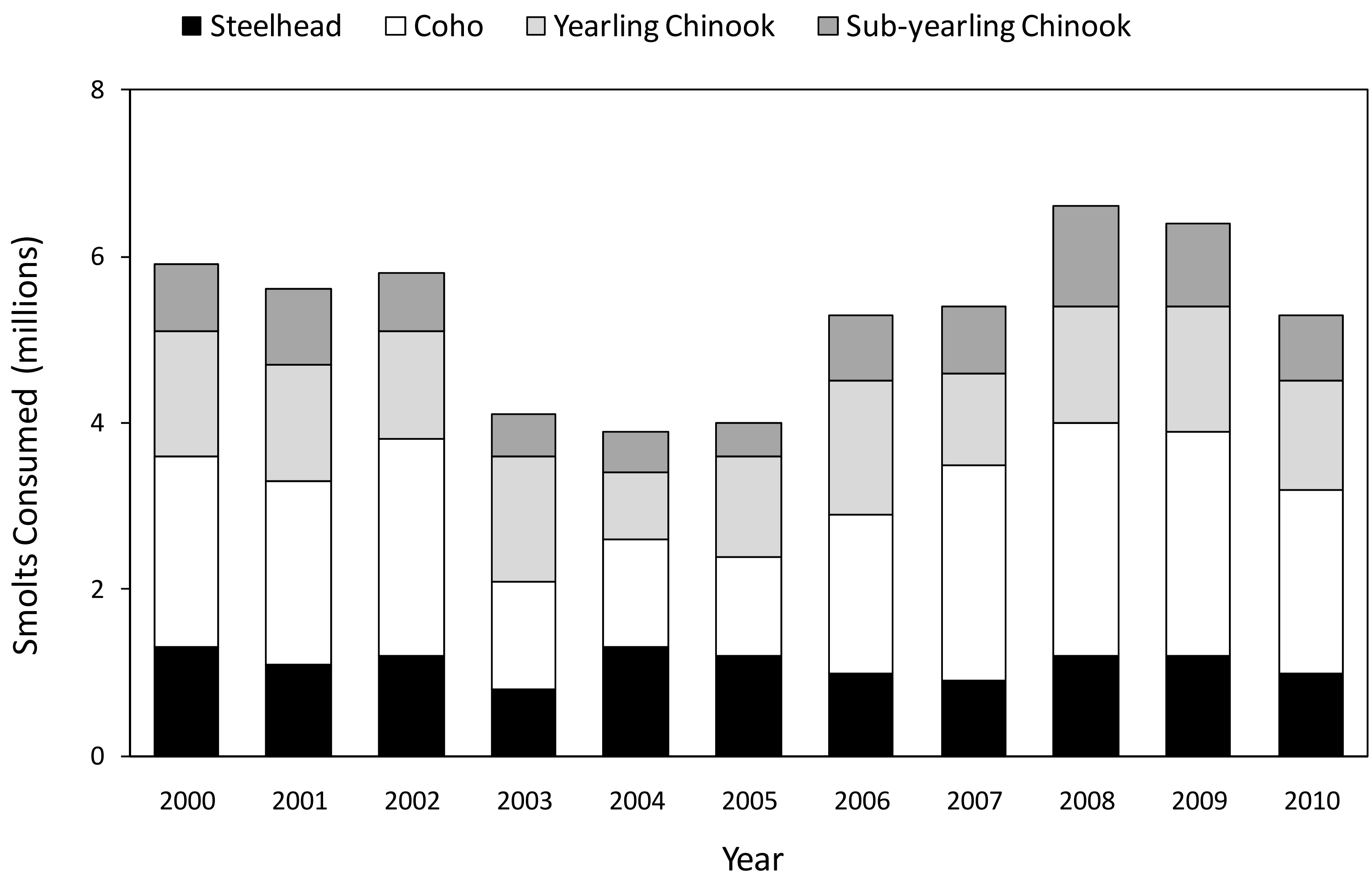


Figure 27. Estimated total annual consumption of four species/run types of juvenile salmonids by Caspian terns nesting on East Sand Island in the Columbia River estuary during the 2000-2010 nesting seasons.

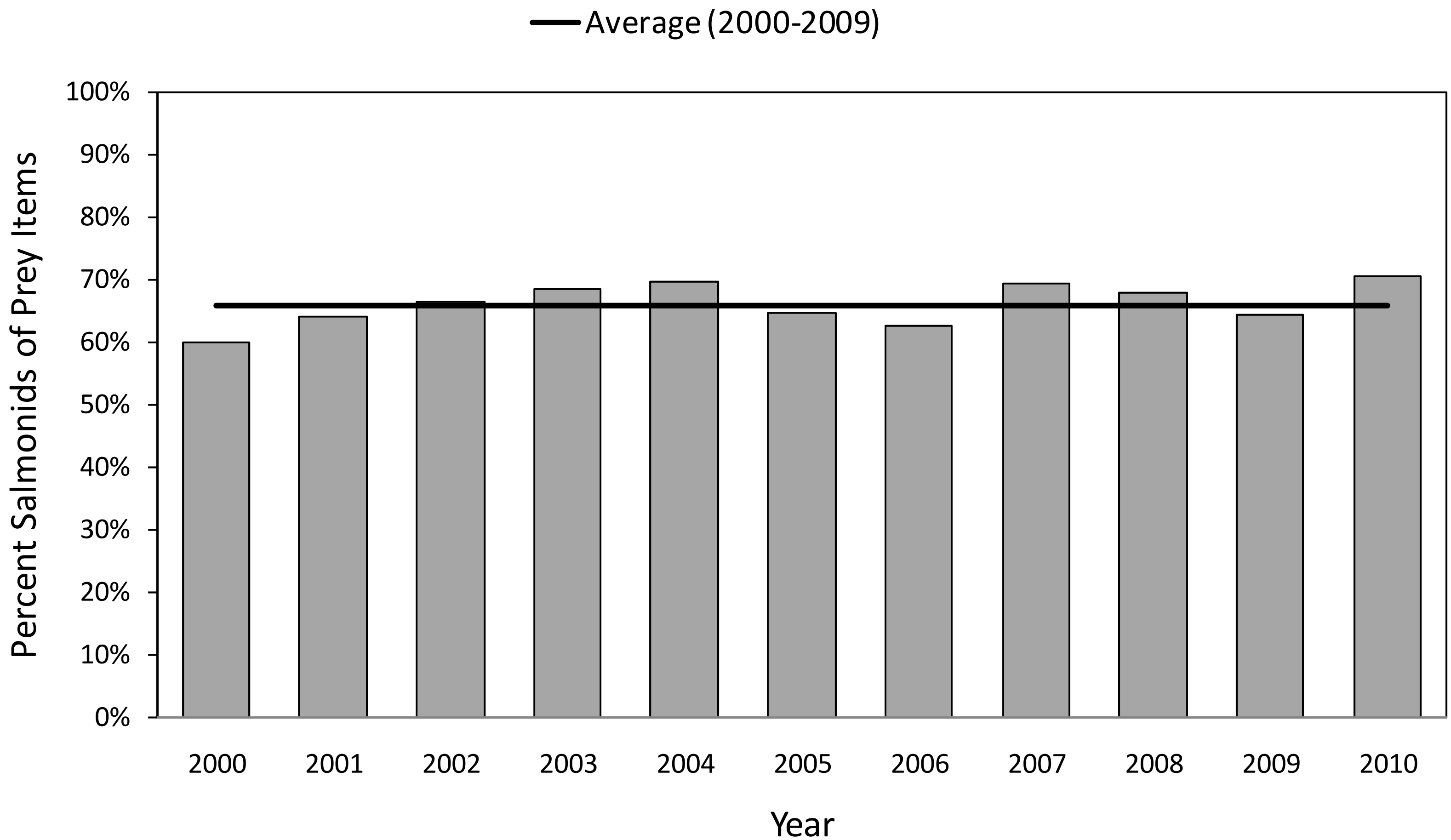


Figure 28. Average annual proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island, mid-Columbia River, during the 2000-2010 breeding seasons.

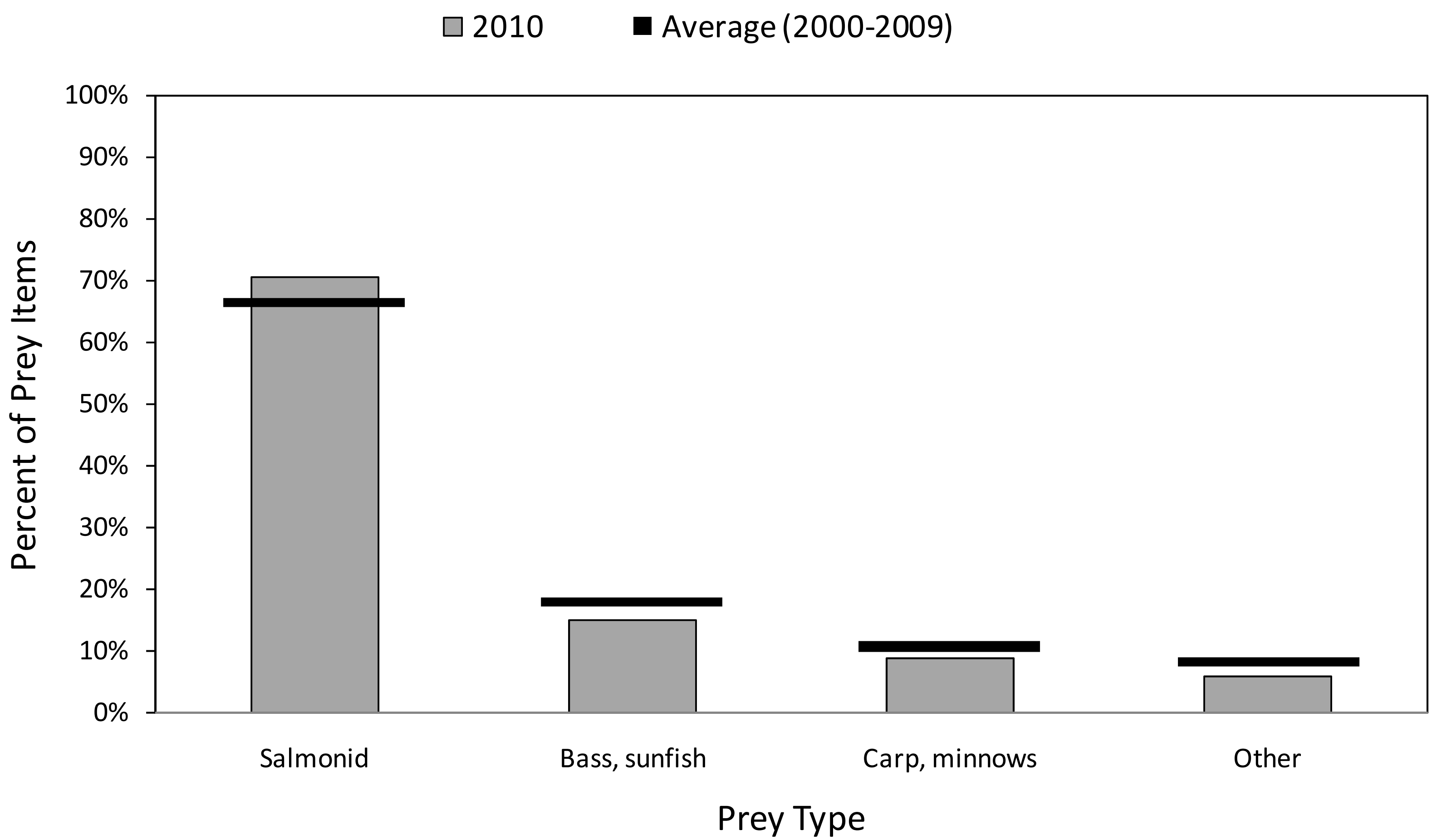


Figure 29. Diet composition of Caspian terns nesting on Crescent Island in the mid-Columbia River during the 2010 breeding season.

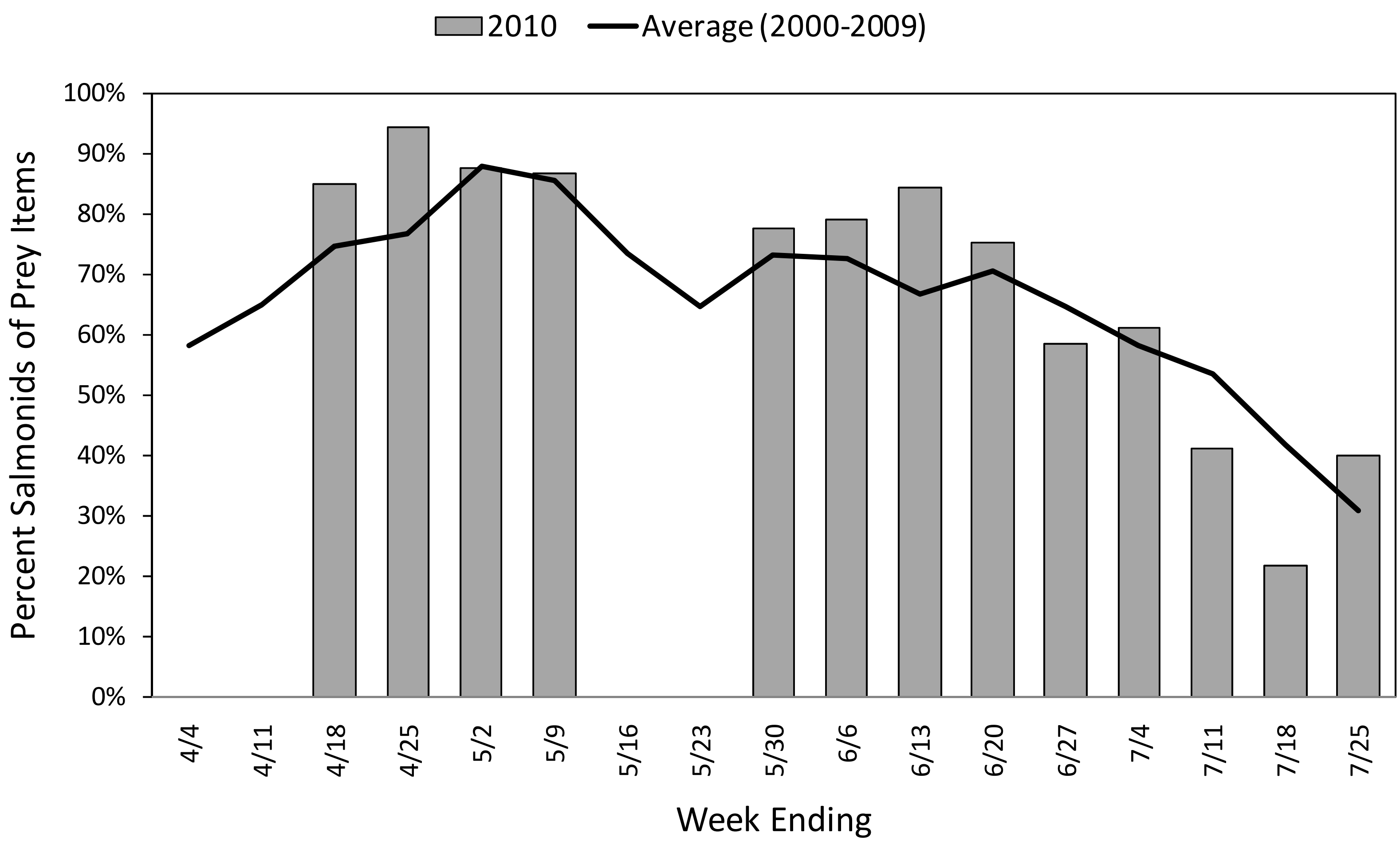


Figure 30. Proportion of juvenile salmonids in the diet of Caspian terns nesting on Crescent Island in the mid-Columbia River during the 2010 breeding season, by week. No diet data were collected for the weeks ending on 5/16 and 5/23. Diet composition data were not collected during two weeks in mid-May to avoid disturbing an incipient satellite colony of Caspian terns that formed on the landing beach, and subsequently failed.

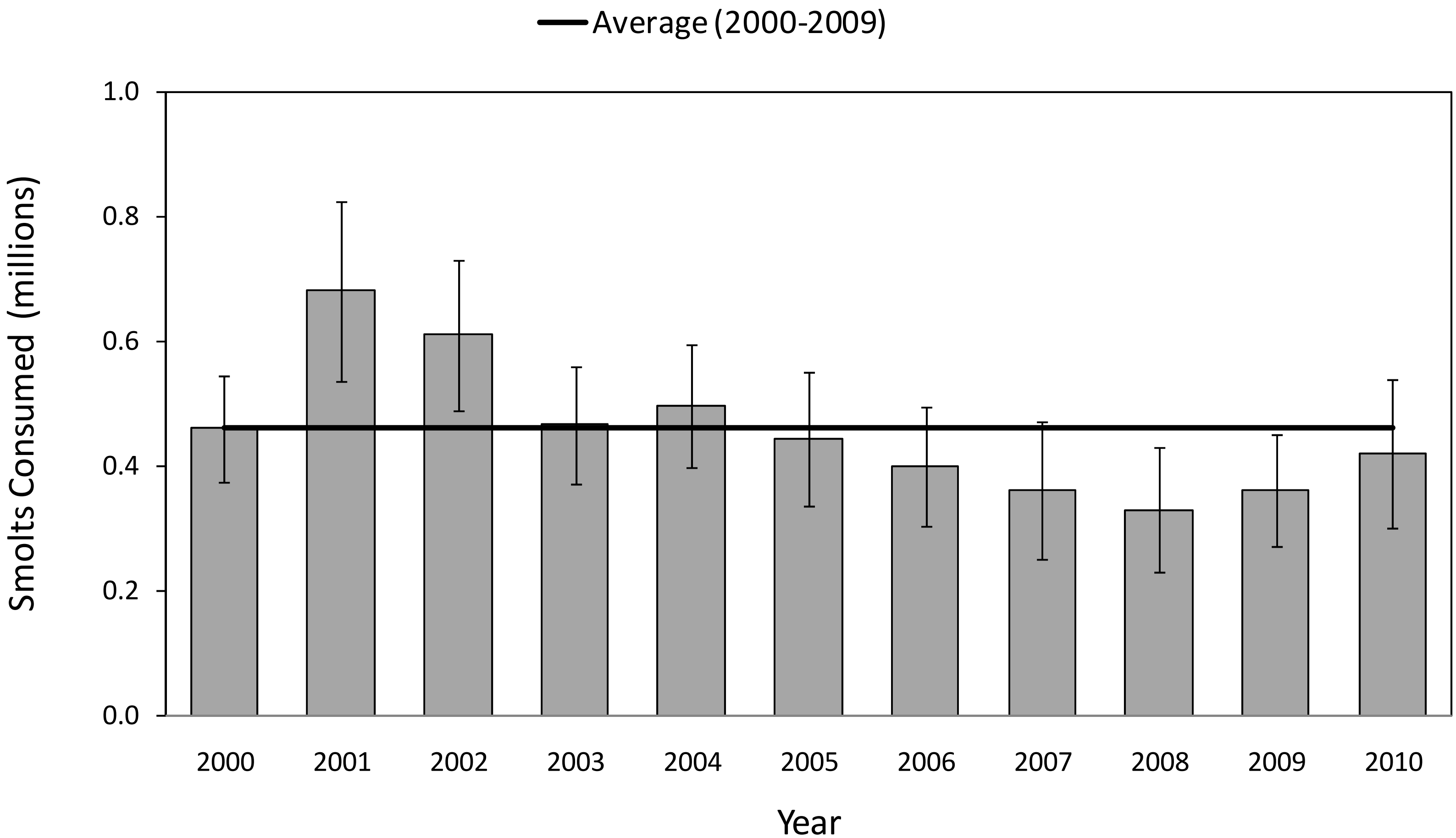


Figure 31. Estimated total annual consumption of juvenile salmonids by Caspian terns nesting on Crescent Island in the mid-Columbia River during the 2000-2010 breeding seasons. Error bars represent 95% confidence intervals for the number of smolts consumed.

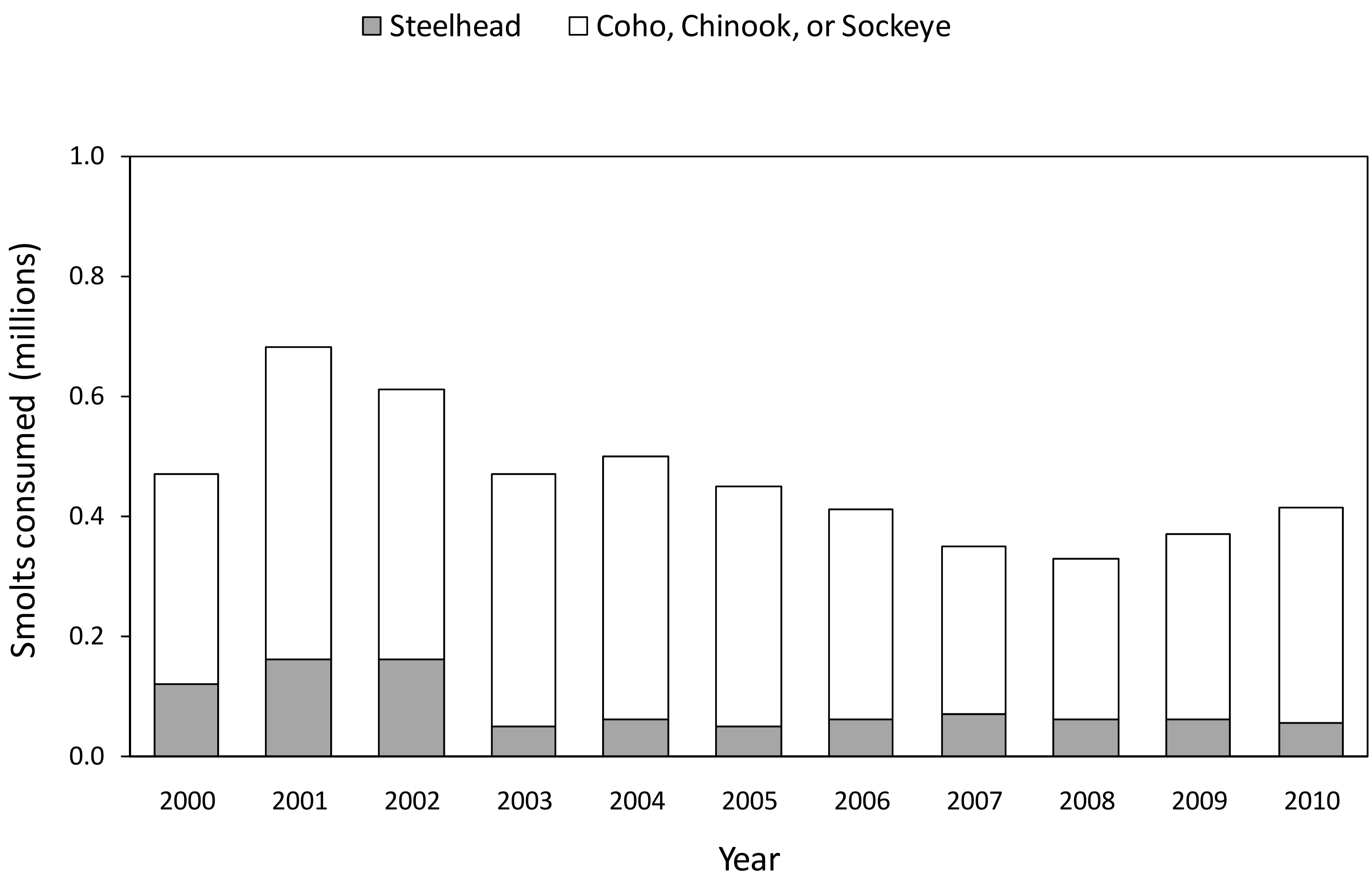


Figure 32. Estimated total annual consumption of steelhead and salmon (coho, Chinook, and sockeye) by Caspian terns nesting on Crescent Island in the mid-Columbia River during the 2000-2010 breeding seasons. Estimates are based on fish identified in tern bill-loads on-colony and bioenergetics calculations.

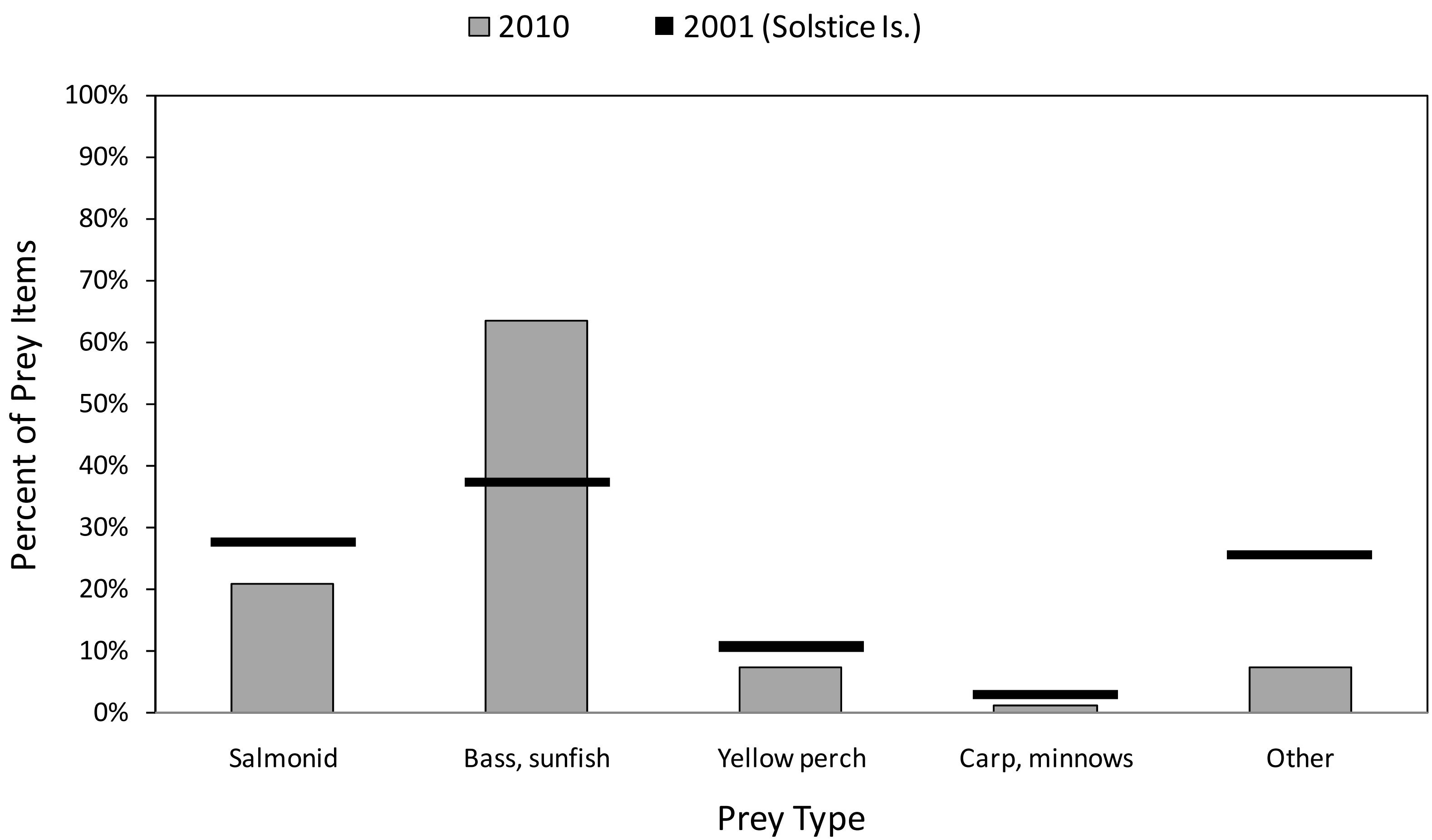


Figure 33. Diet composition of Caspian terns nesting on Goose Island in Potholes Reservoir during the 2010 breeding season. Comparison data are from 2001, when the Caspian tern colony on Potholes Reservoir was on Solstice Island. Diet composition was based on fish identified in tern bill-loads on-colony.

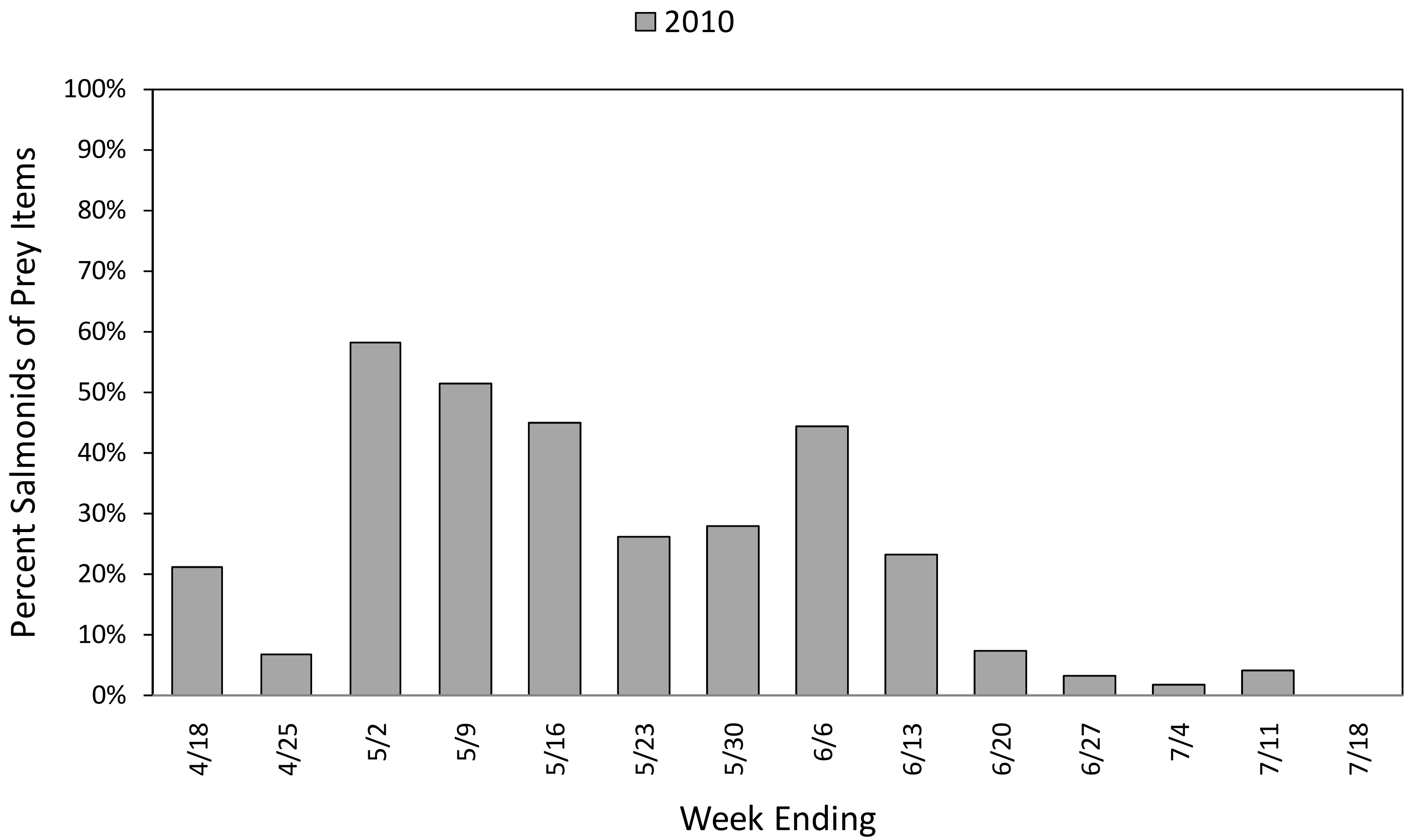


Figure 34. Proportion of juvenile salmonids in the diet of Caspian terns nesting on Goose Island in Potholes Reservoir during the 2010 breeding season, by week.

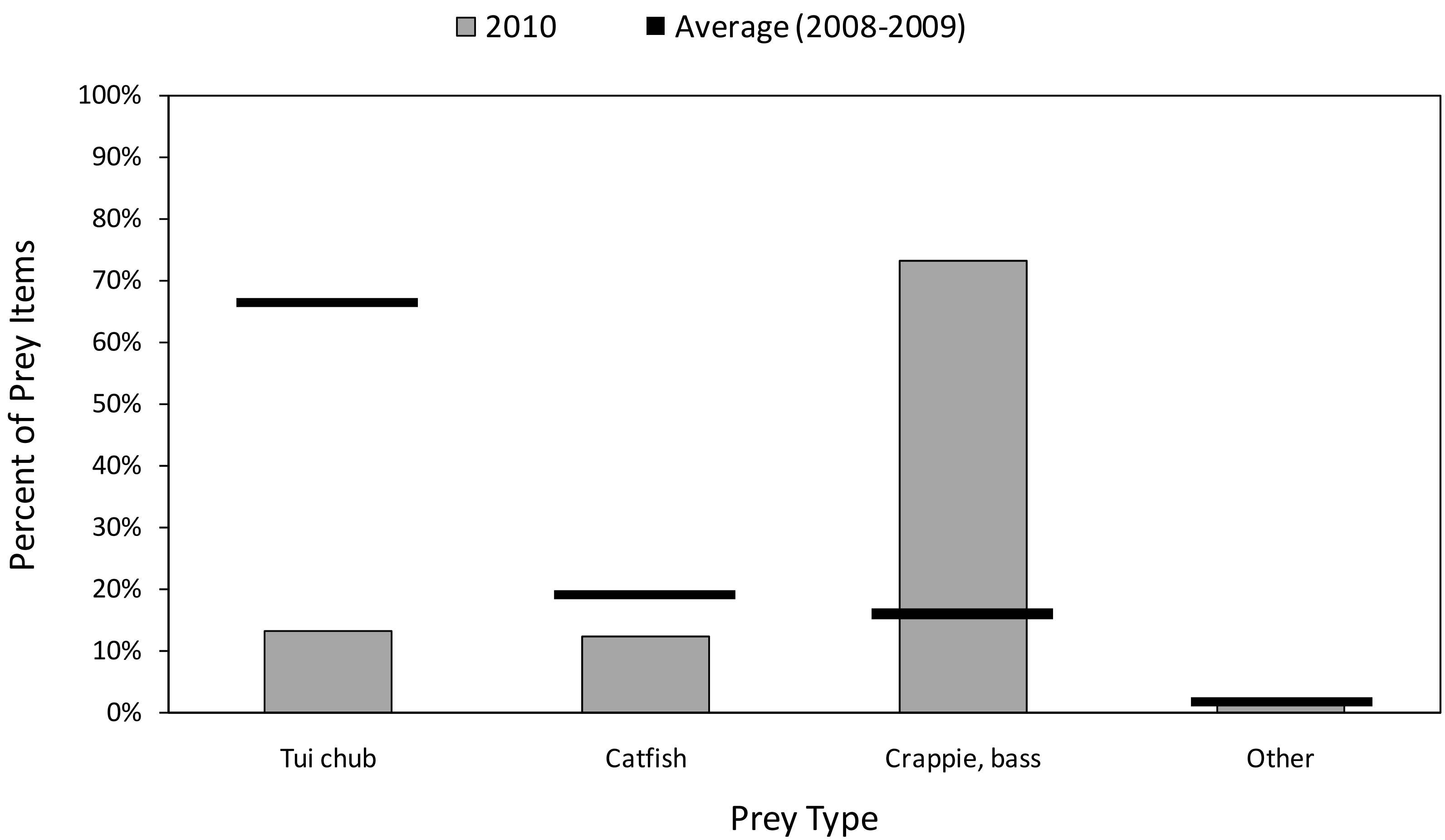


Figure 35. Diet composition of Caspian terns nesting on Crump Lake tern island, Warner Valley, Oregon during the 2010 breeding season.

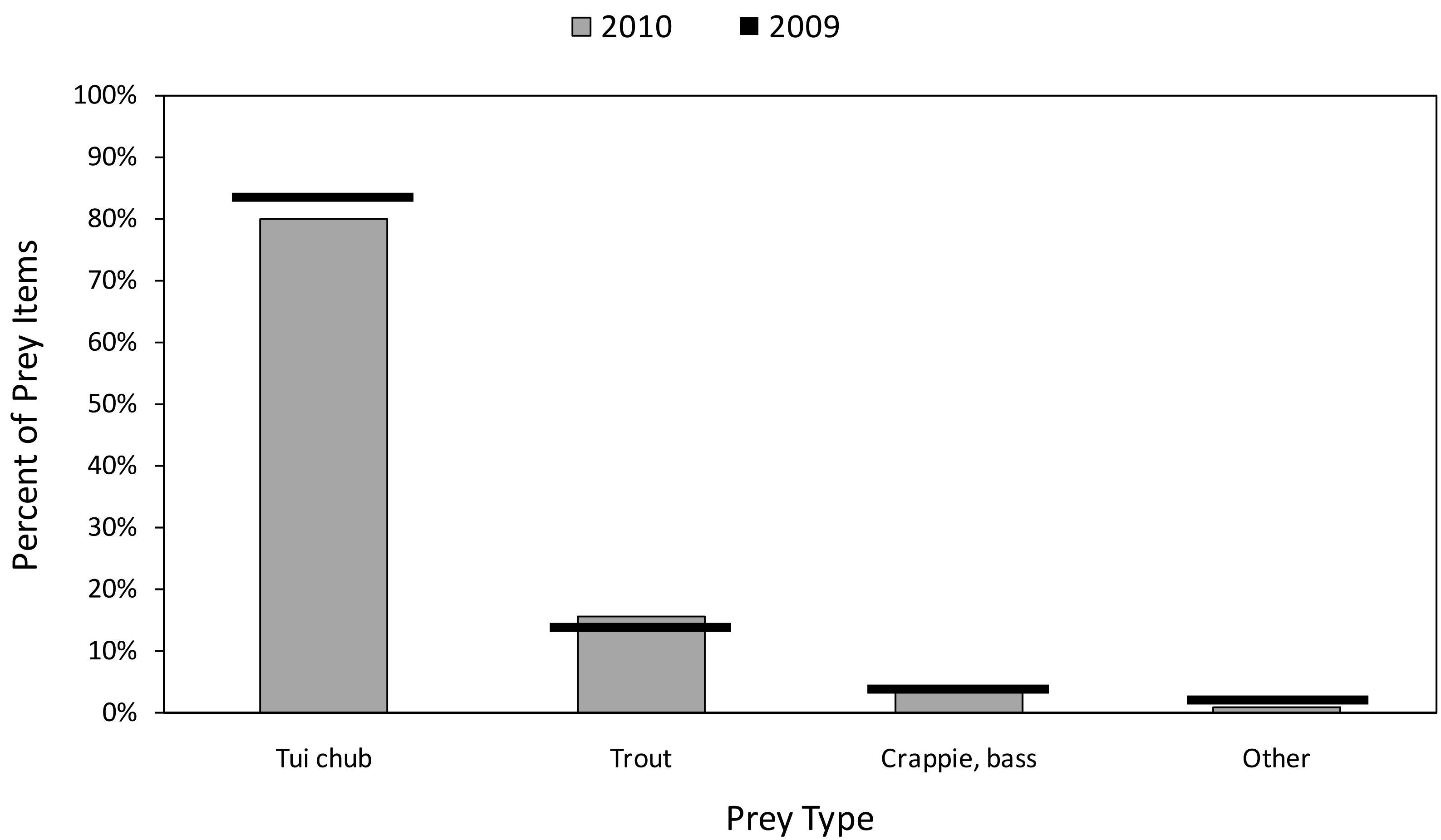


Figure 36. Diet composition of Caspian terns nesting on the Summer Lake Wildlife Area tern islands (East Link and Dutchy Lake) during the 2010 breeding season.

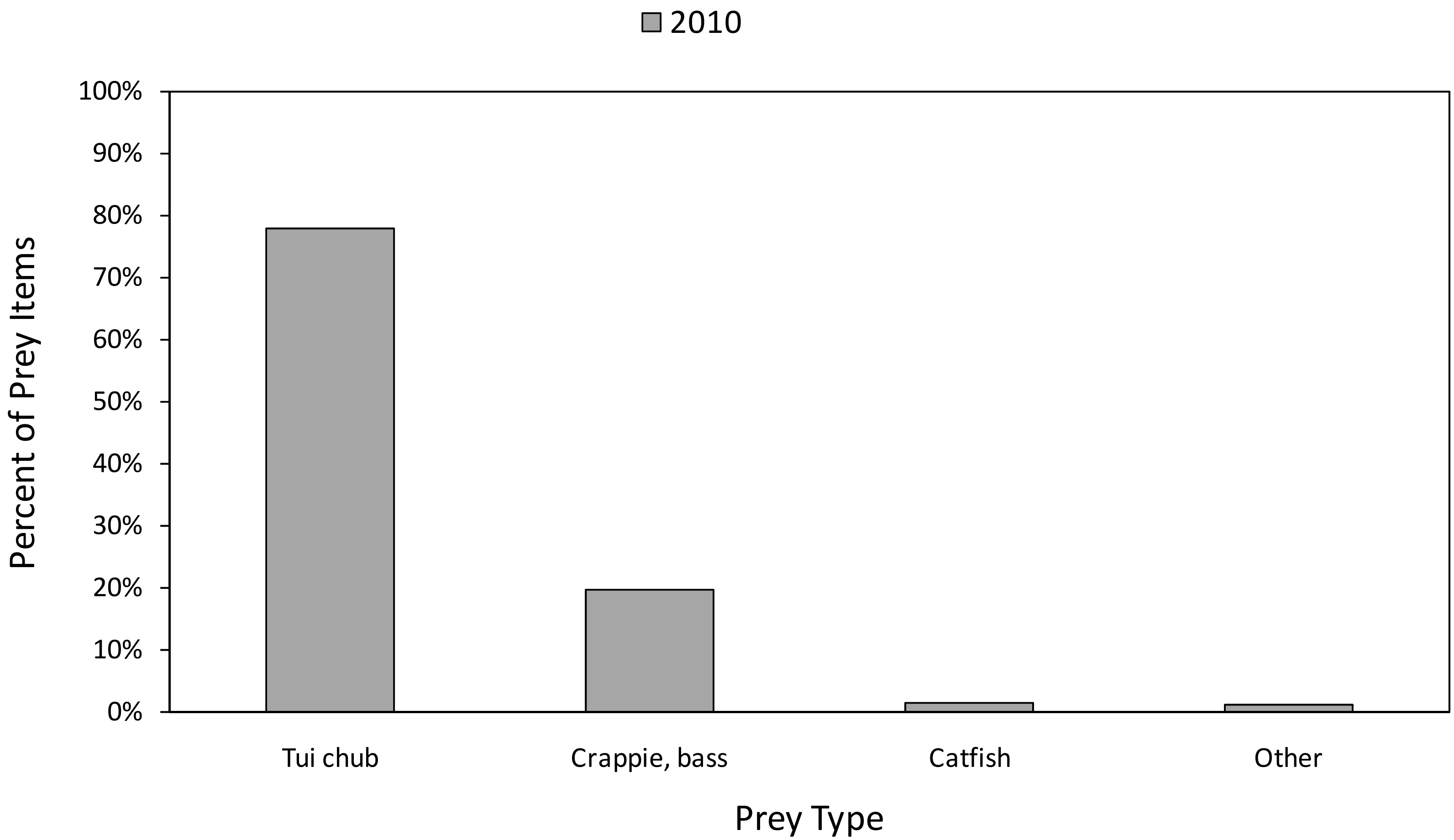


Figure 37. Diet composition of Caspian terns nesting on the Sheepy Lake tern island in Lower Klamath NWR, California during the 2010 breeding season.

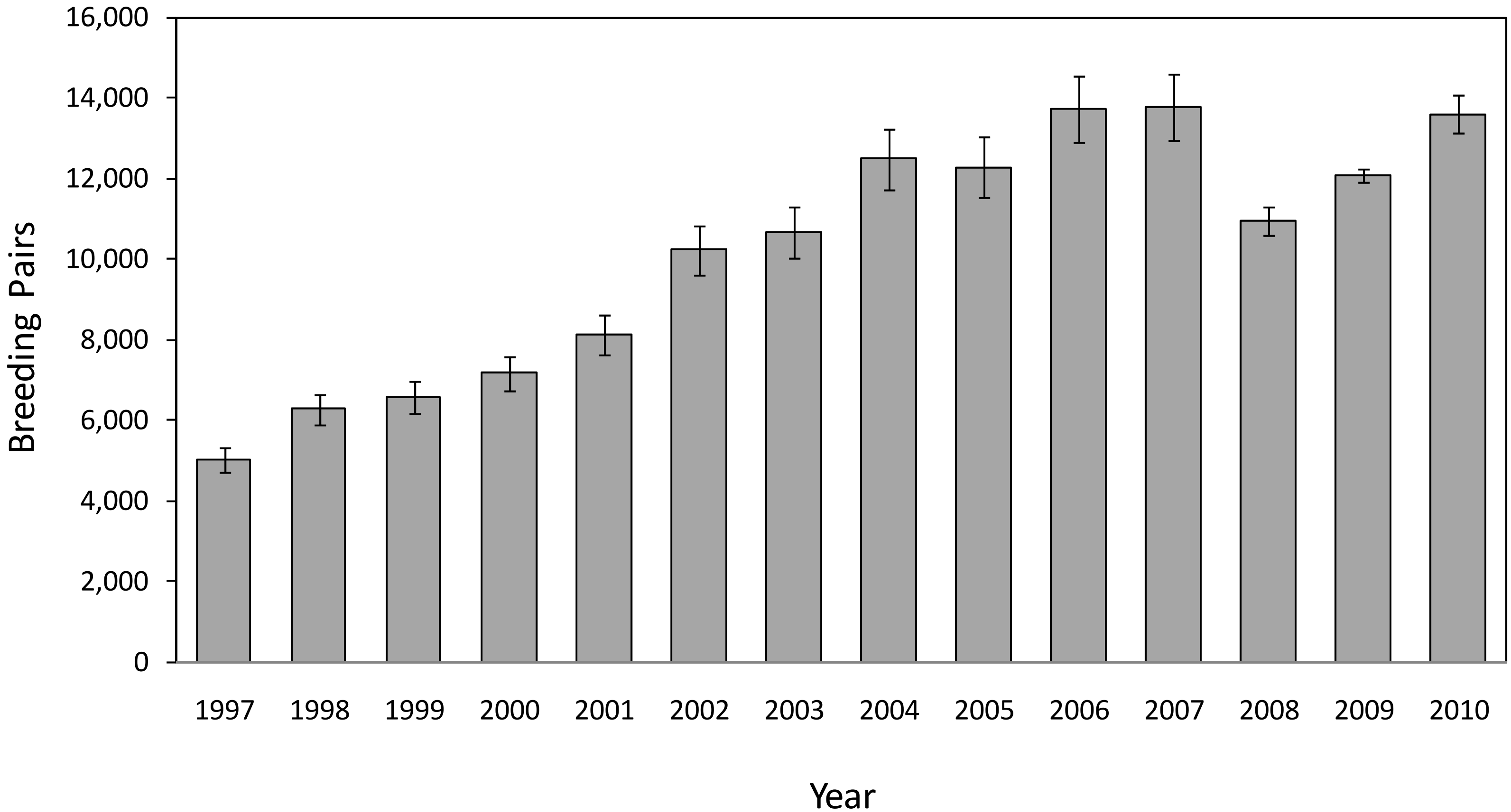


Figure 38. Colony size for double-crested cormorants nesting on East Sand Island in the Columbia River estuary during the 1997-2010 breeding seasons. Error bars represent 95% confidence intervals for the number of breeding pairs.

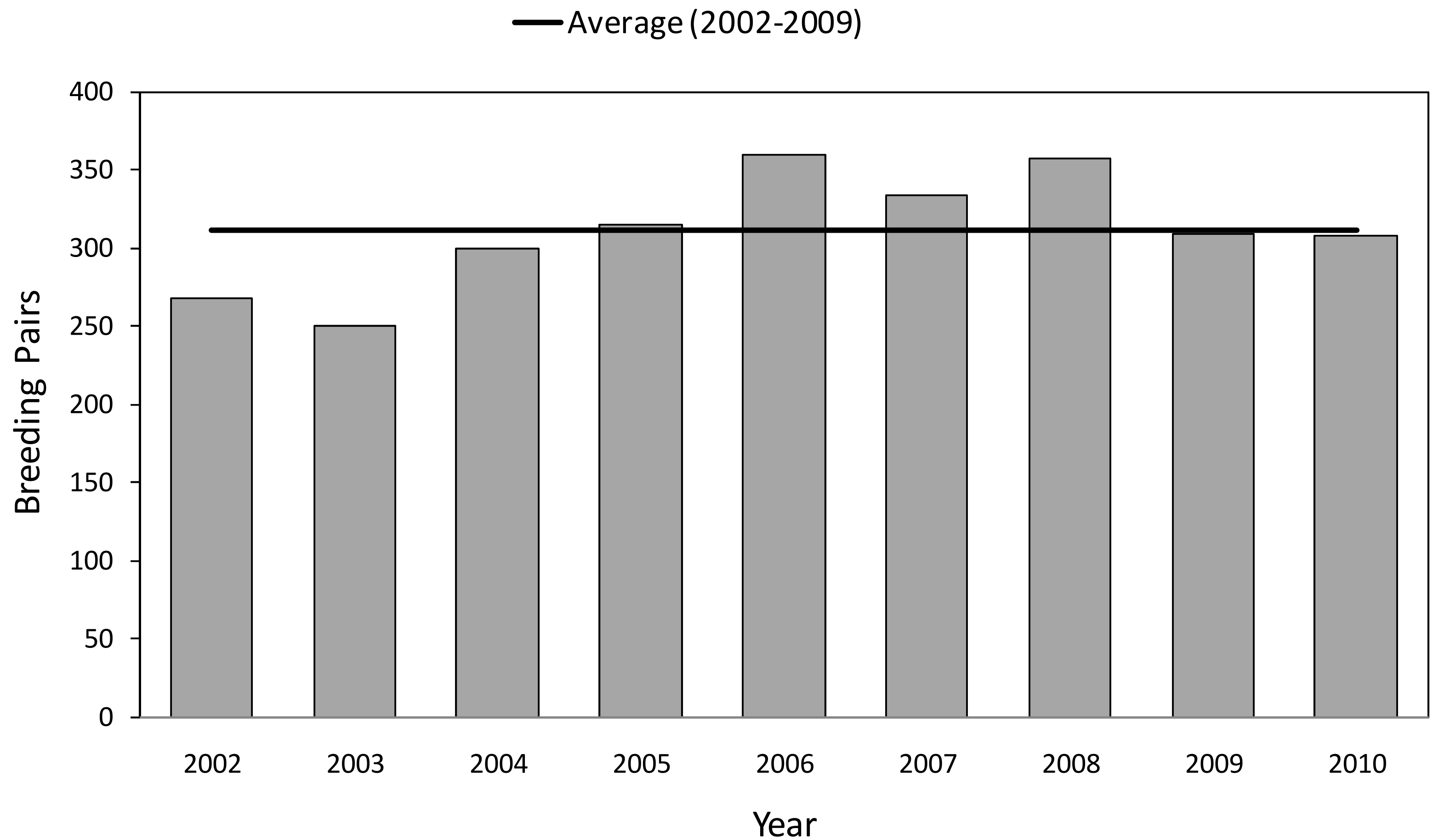


Figure 39. Colony size for double-crested cormorants nesting on Foundation Island in the mid-Columbia River during the 2002-2010 breeding seasons.

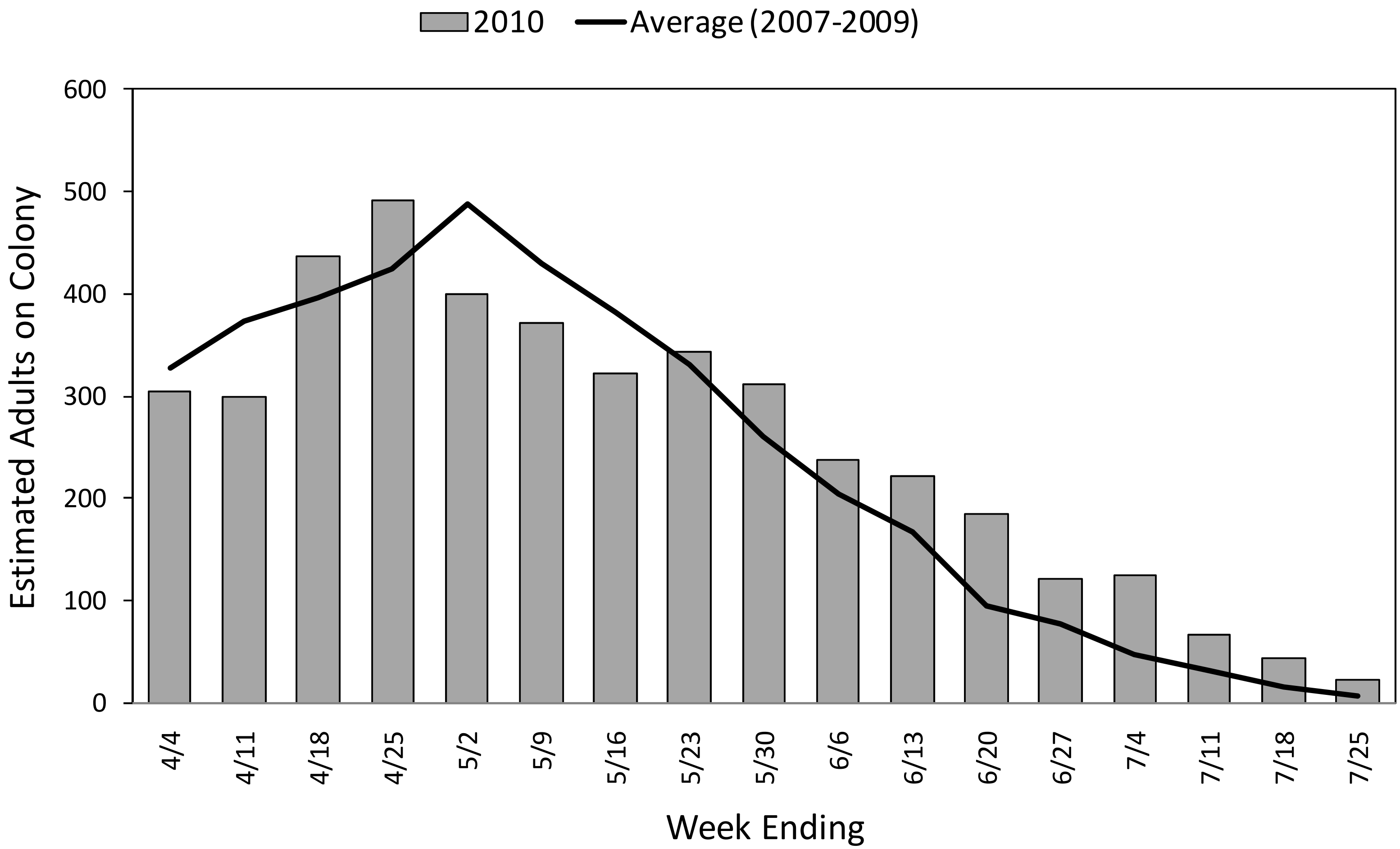


Figure 40. Weekly estimates from the ground of the number of adult double-crested cormorants on the Foundation Island colony in the mid-Columbia River during the 2010 breeding season.

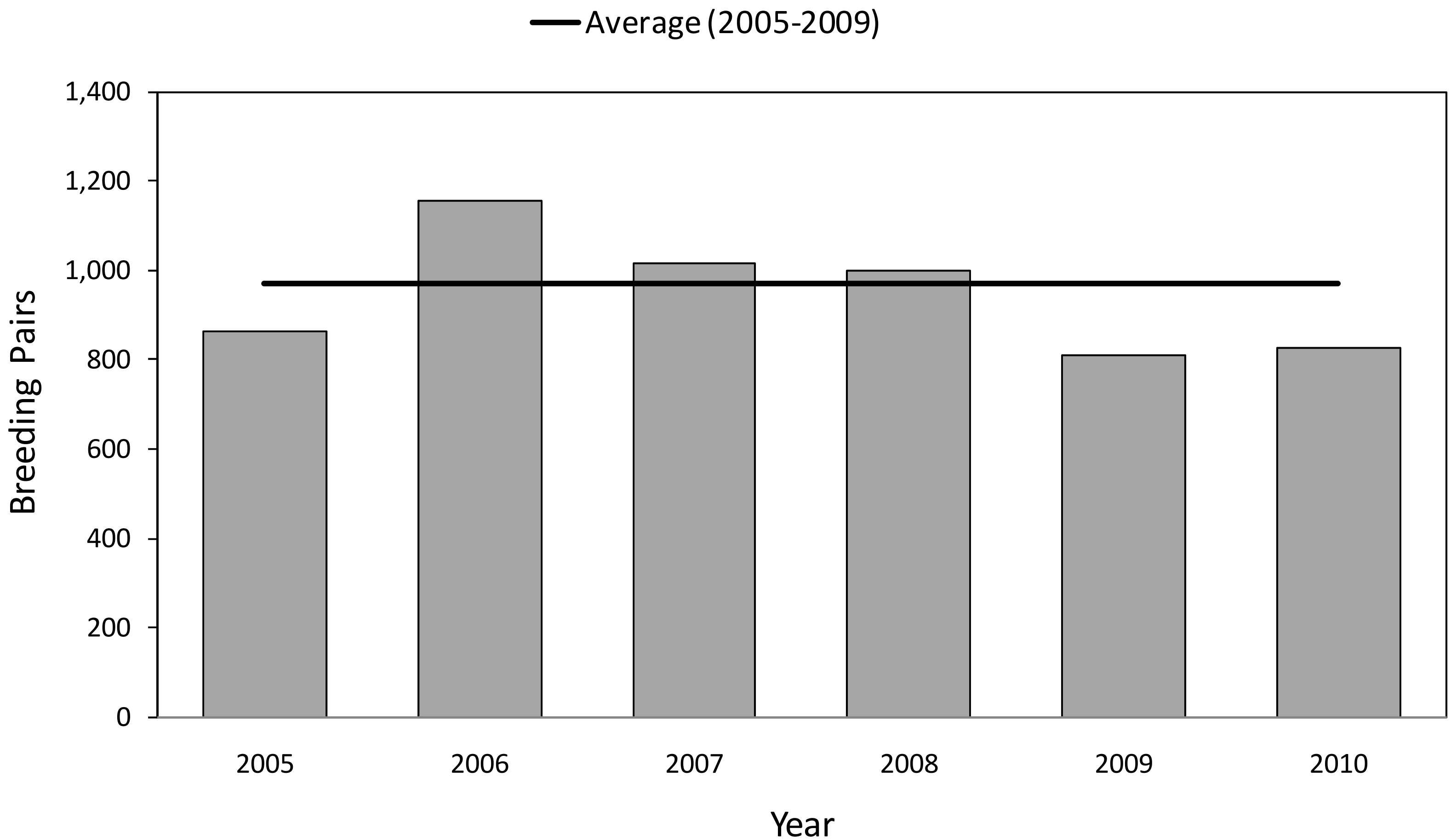


Figure 41. Size of the colony of double-crested cormorants nesting in the North Potholes Reserve, Potholes Reservoir during the 2002-2010 breeding seasons.

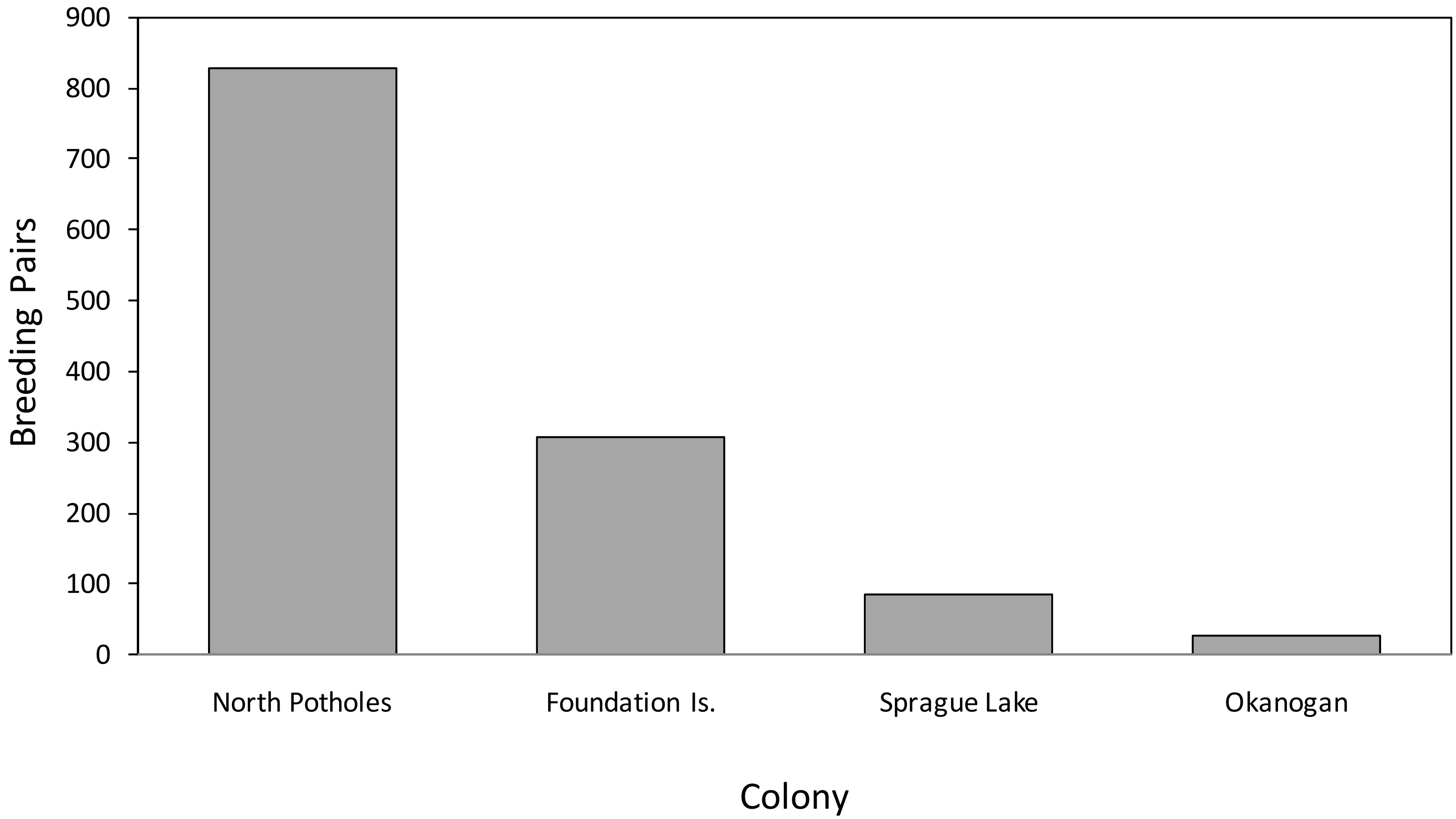


Figure 42. Size of the double-crested cormorant colonies in the Columbia Plateau region during the 2010 breeding season.

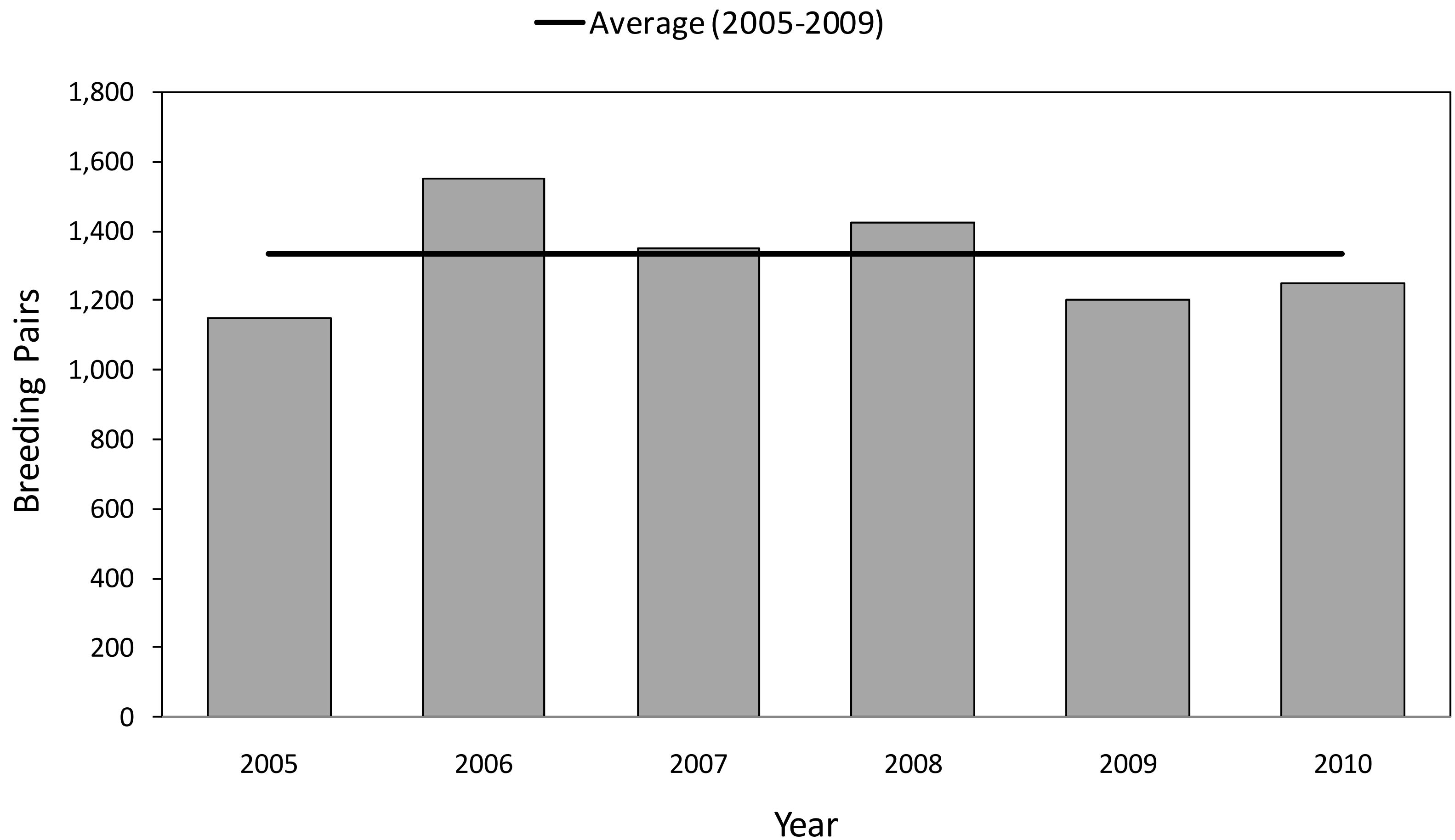


Figure 43. Total number of double-crested cormorant breeding pairs nesting at colonies in the Columbia Plateau region during the 2005-2010 nesting seasons.

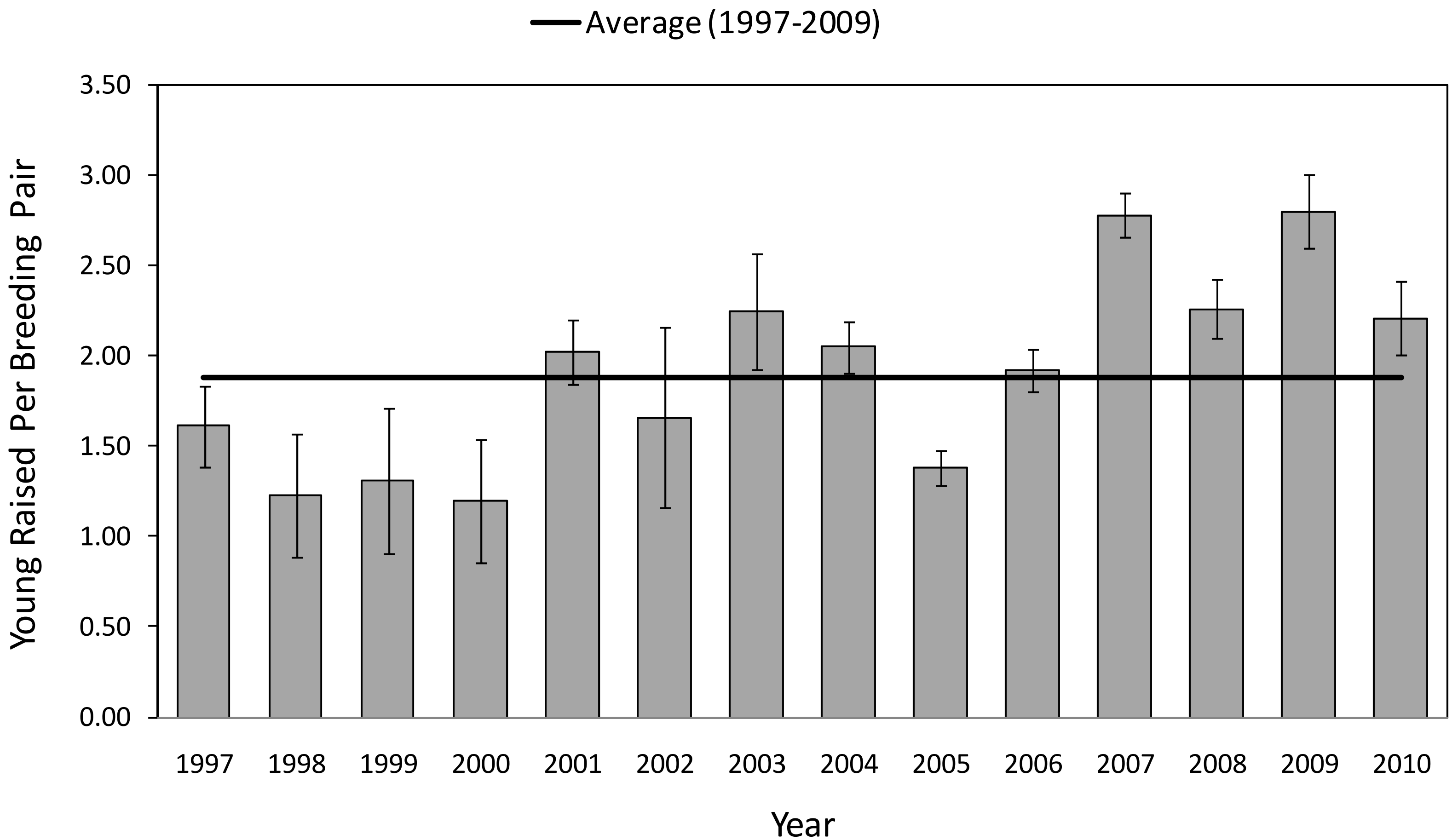


Figure 44. Double-crested cormorant nesting success at the East Sand Island colony in the Columbia River estuary during the 1997-2010 breeding seasons. Error bars represent 95% confidence intervals for the average number young raised per breeding pair.

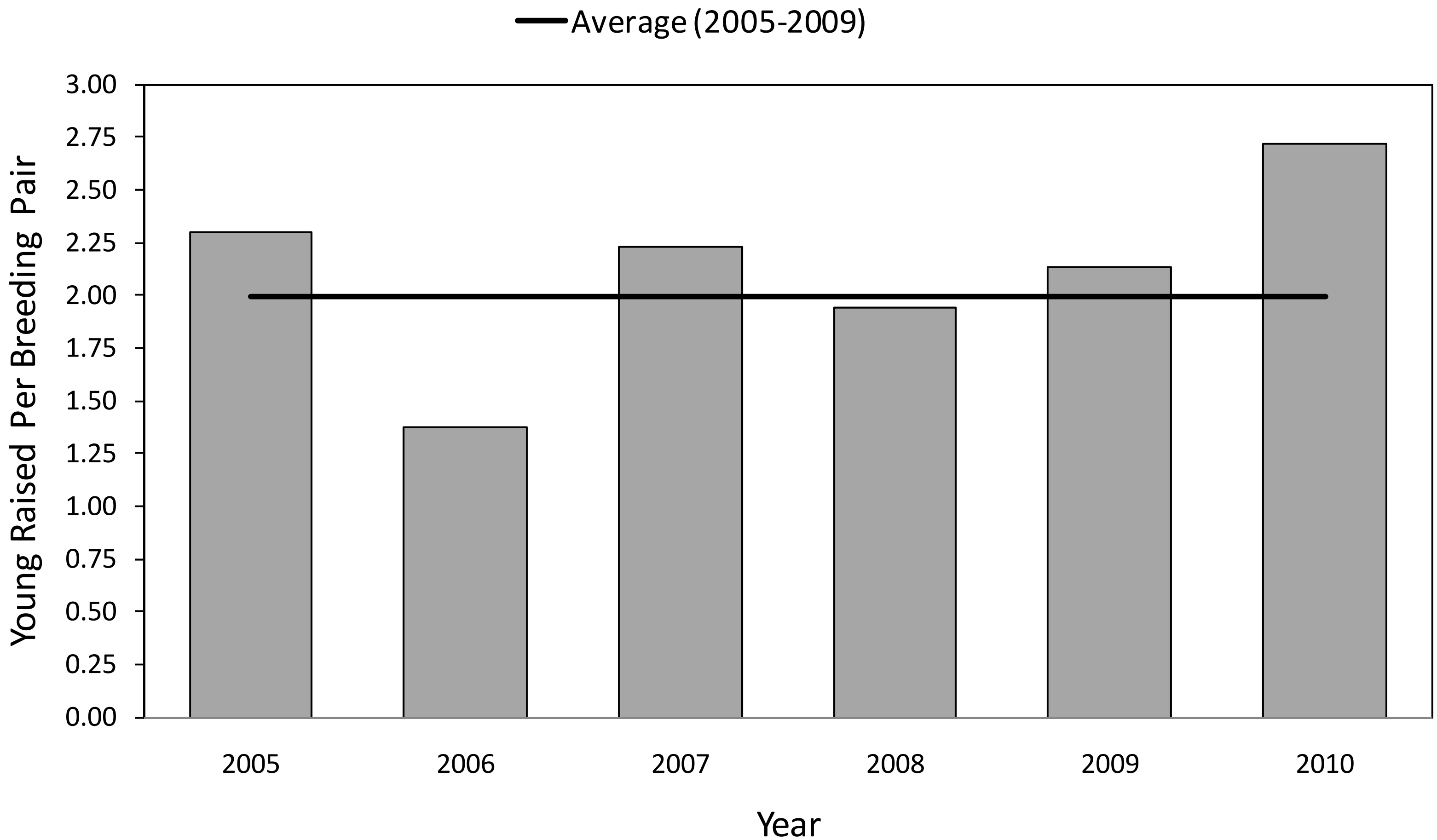


Figure 45. Double-crested cormorant nesting success at the Foundation Island colony in the mid-Columbia River during the 2005-2010 breeding seasons. Average productivity in 2010 was 2.64 young raised per breeding pair.

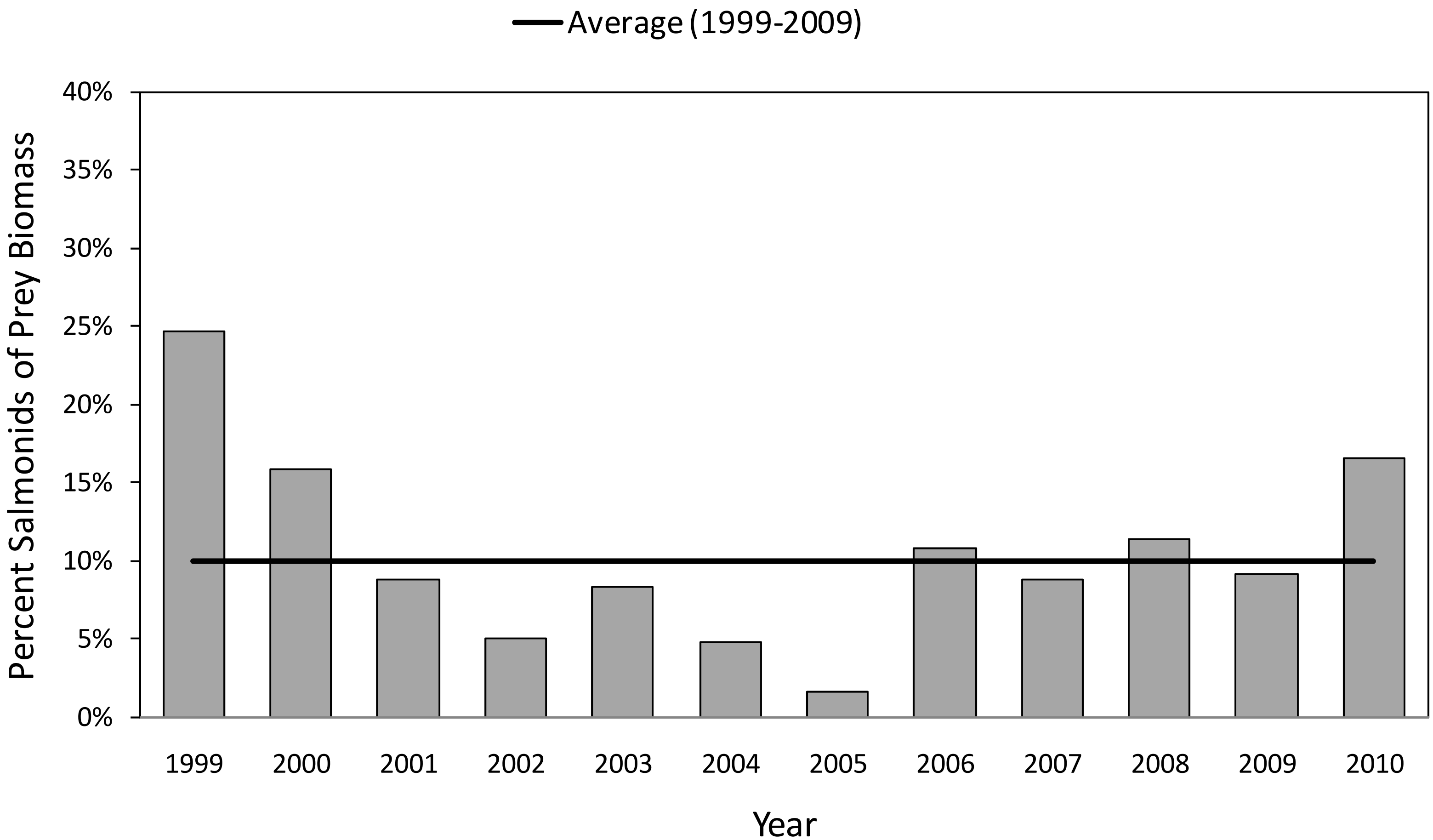


Figure 46. Average annual proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island in the Columbia River estuary during the 1999-2010 breeding seasons.

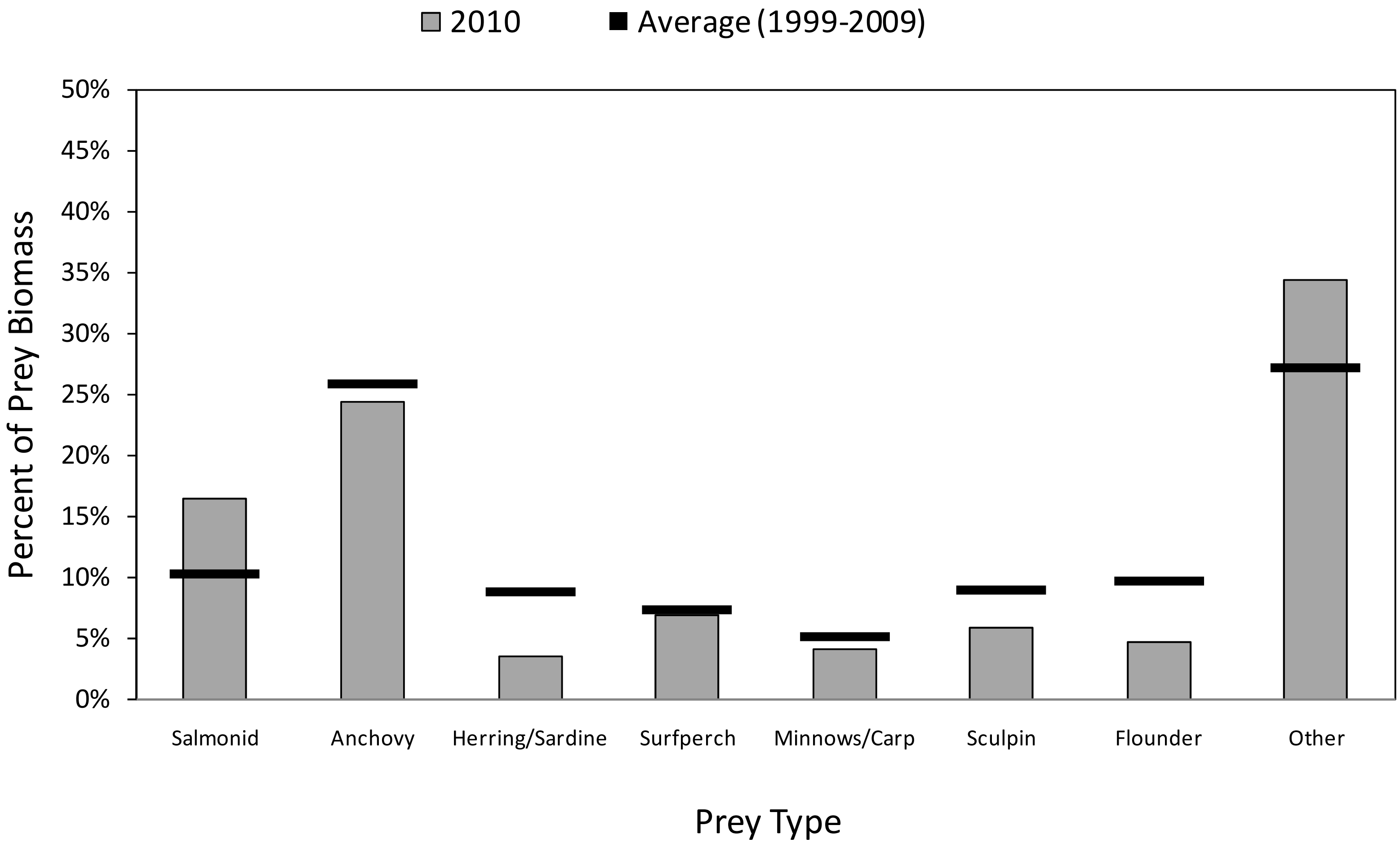


Figure 47. Diet composition of double-crested cormorants nesting on East Sand Island in the Columbia River estuary during the 2010 breeding season.

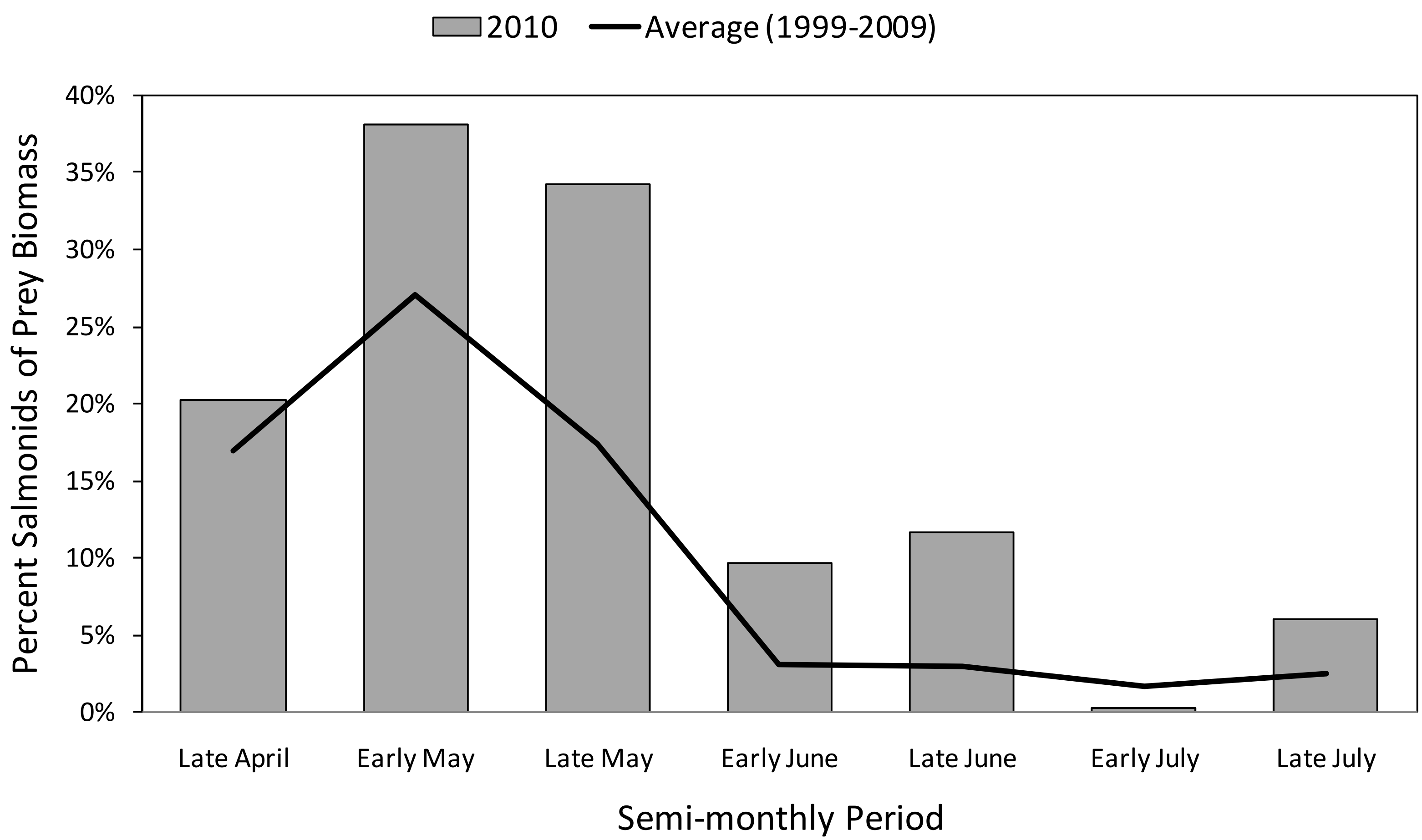


Figure 48. Seasonal trend in the proportion of juvenile salmonids in the diet of double-crested cormorants nesting on East Sand Island in the Columbia River estuary during the 2010 breeding season, by half-month period.

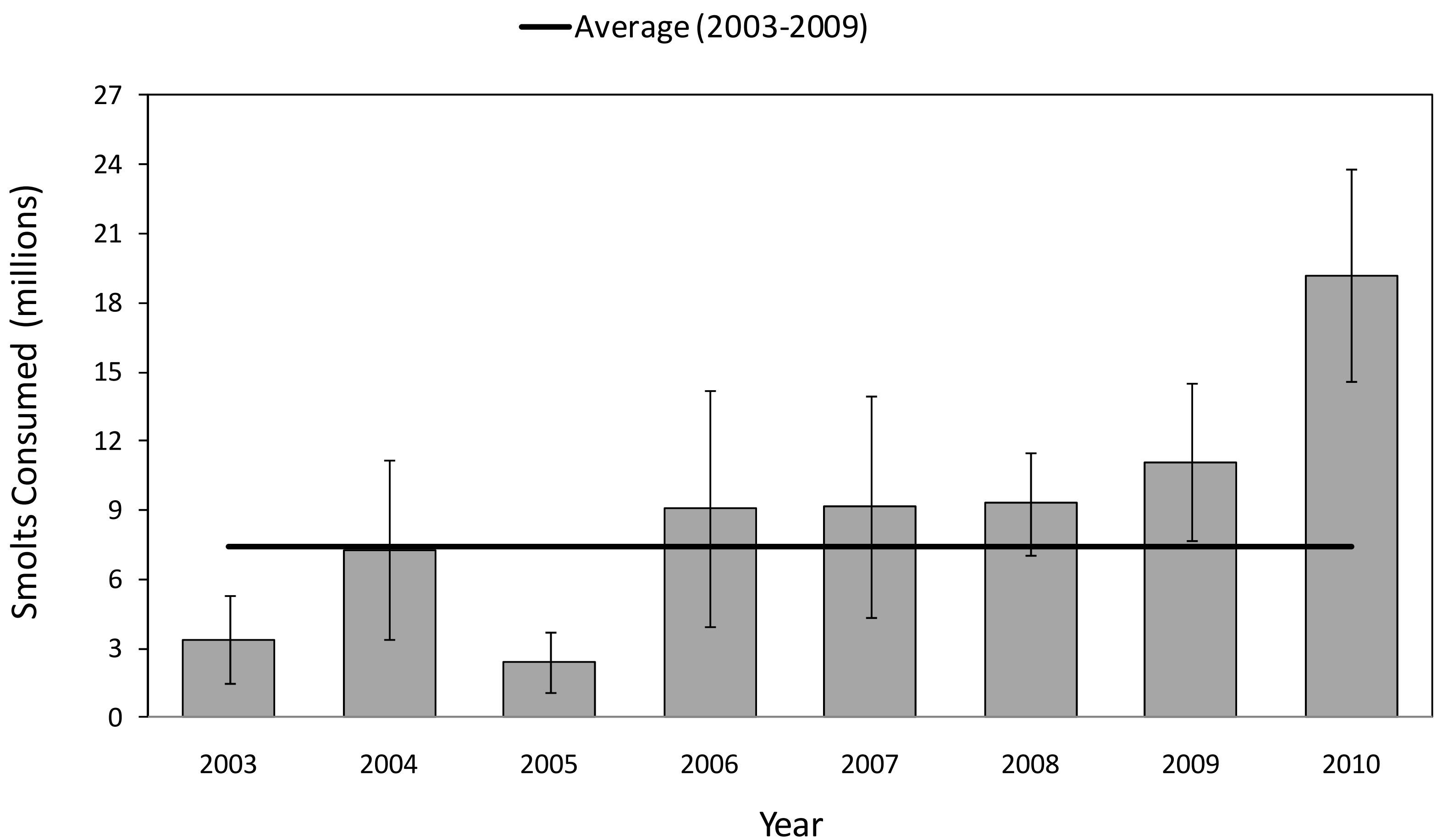


Figure 49. Estimated total annual consumption of juvenile salmonids by double-crested cormorants nesting on East Sand Island in the Columbia River estuary during the 2003-2010 breeding seasons. Error bars represent 95% confidence intervals for the number of smolts consumed.

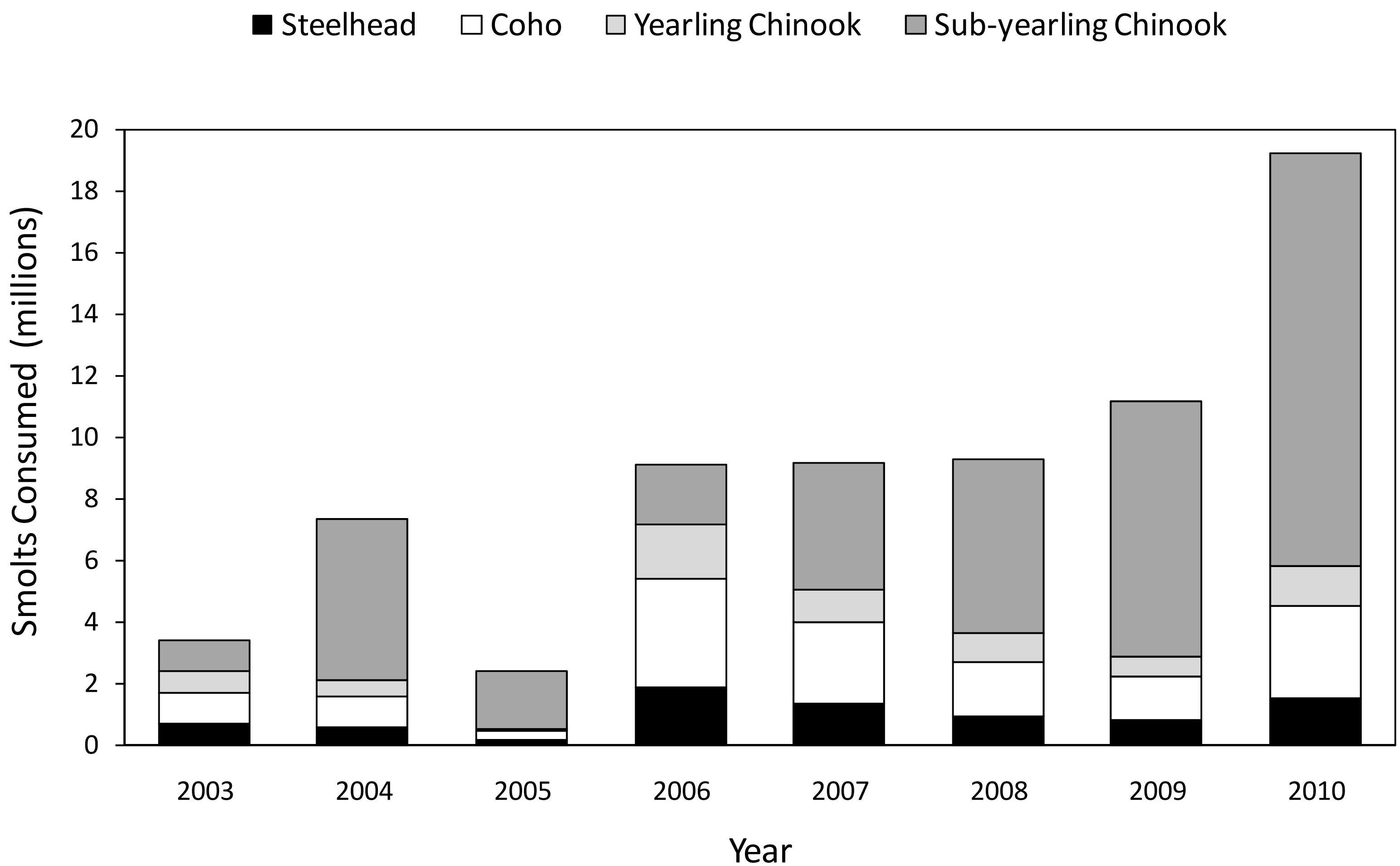


Figure 50. Estimated total annual consumption of four species/run types of juvenile salmonids by double-crested cormorants nesting on East Sand Island in the Columbia River estuary during the 2003-2010 breeding seasons.

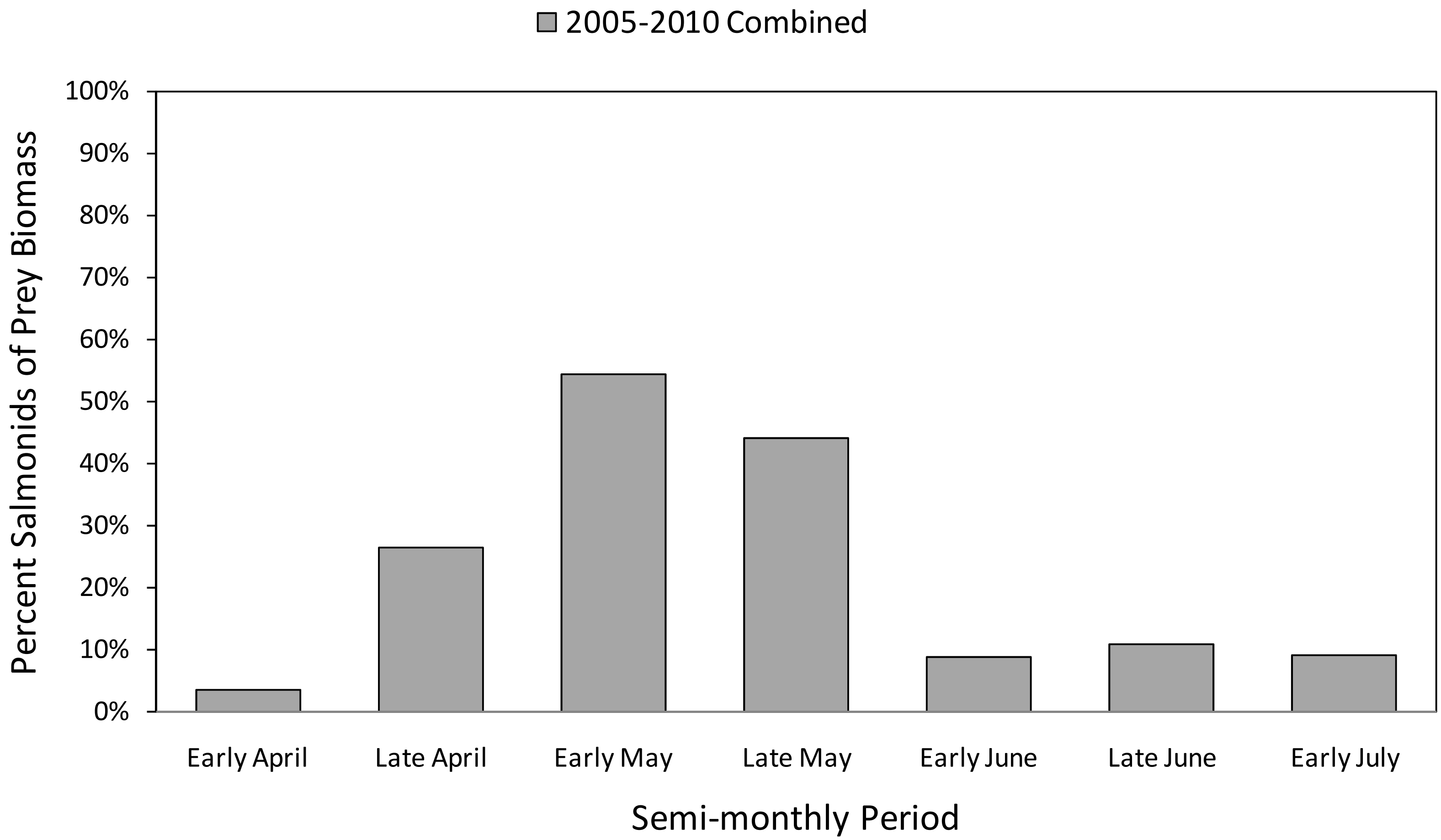


Figure 51. Average proportion of juvenile salmonids in the diet of double-crested cormorants nesting on Foundation Island in the mid-Columbia River during the 2005-2010 breeding seasons, by half-month period. Diet samples collected during the six-season study period are combined.

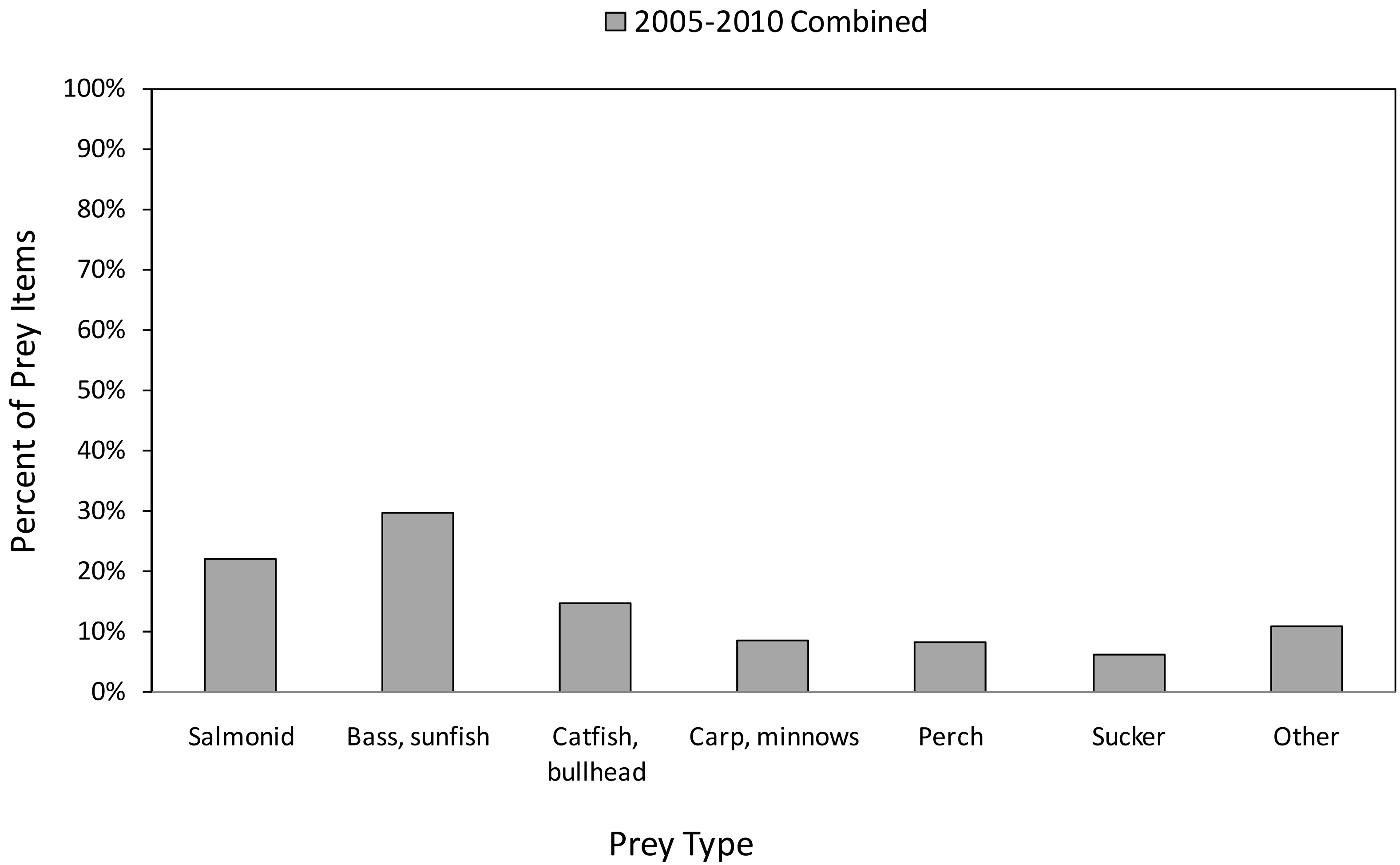


Figure 52. Diet composition of double-crested cormorants nesting on Foundation Island in the mid-Columbia River during the 2005-2010 breeding seasons. Diet samples collected during the six-year study period are combined.

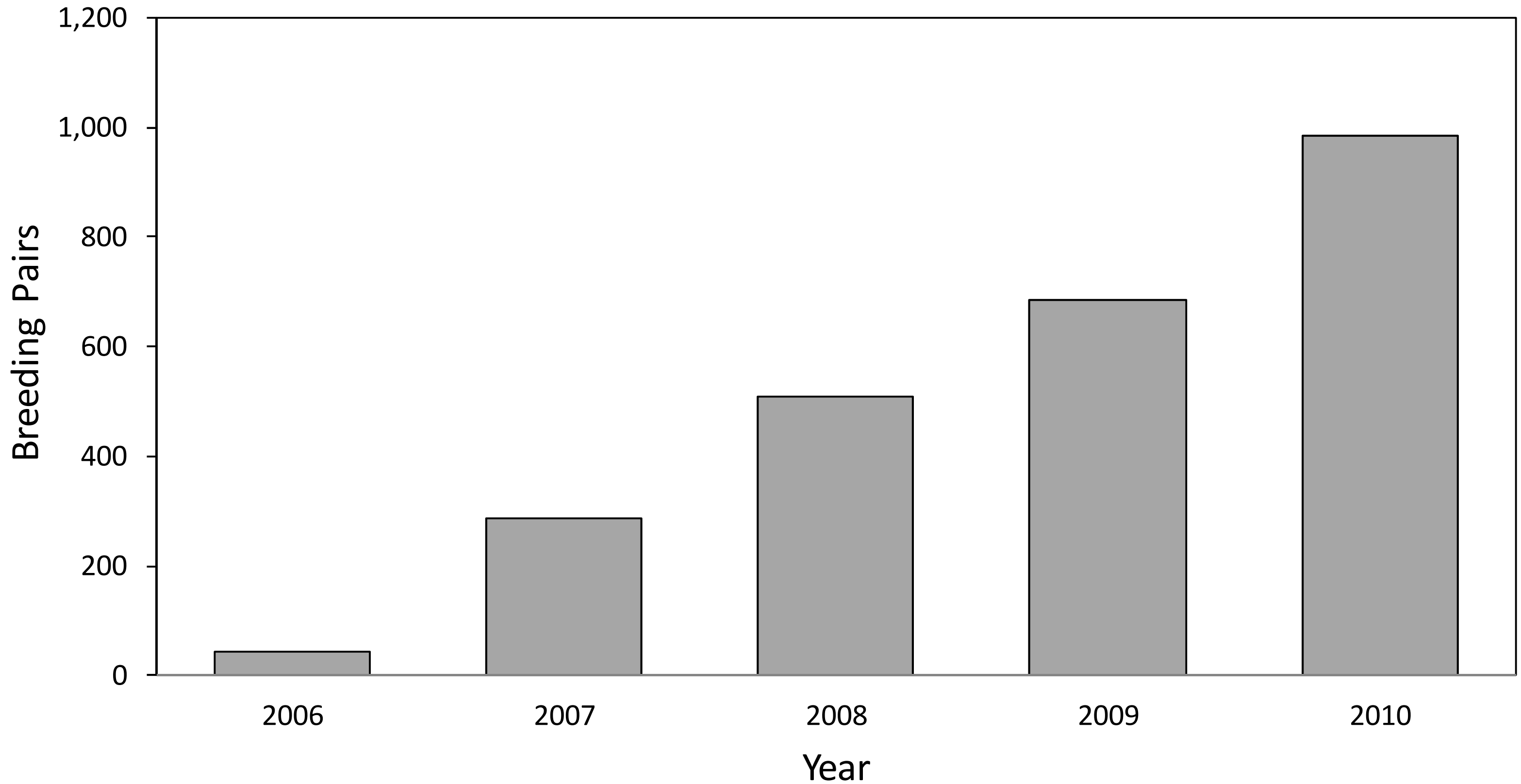


Figure 53. Size of the Brandt's cormorant breeding colony on East Sand Island in the Columbia River estuary during the 2006-2010 nesting seasons.

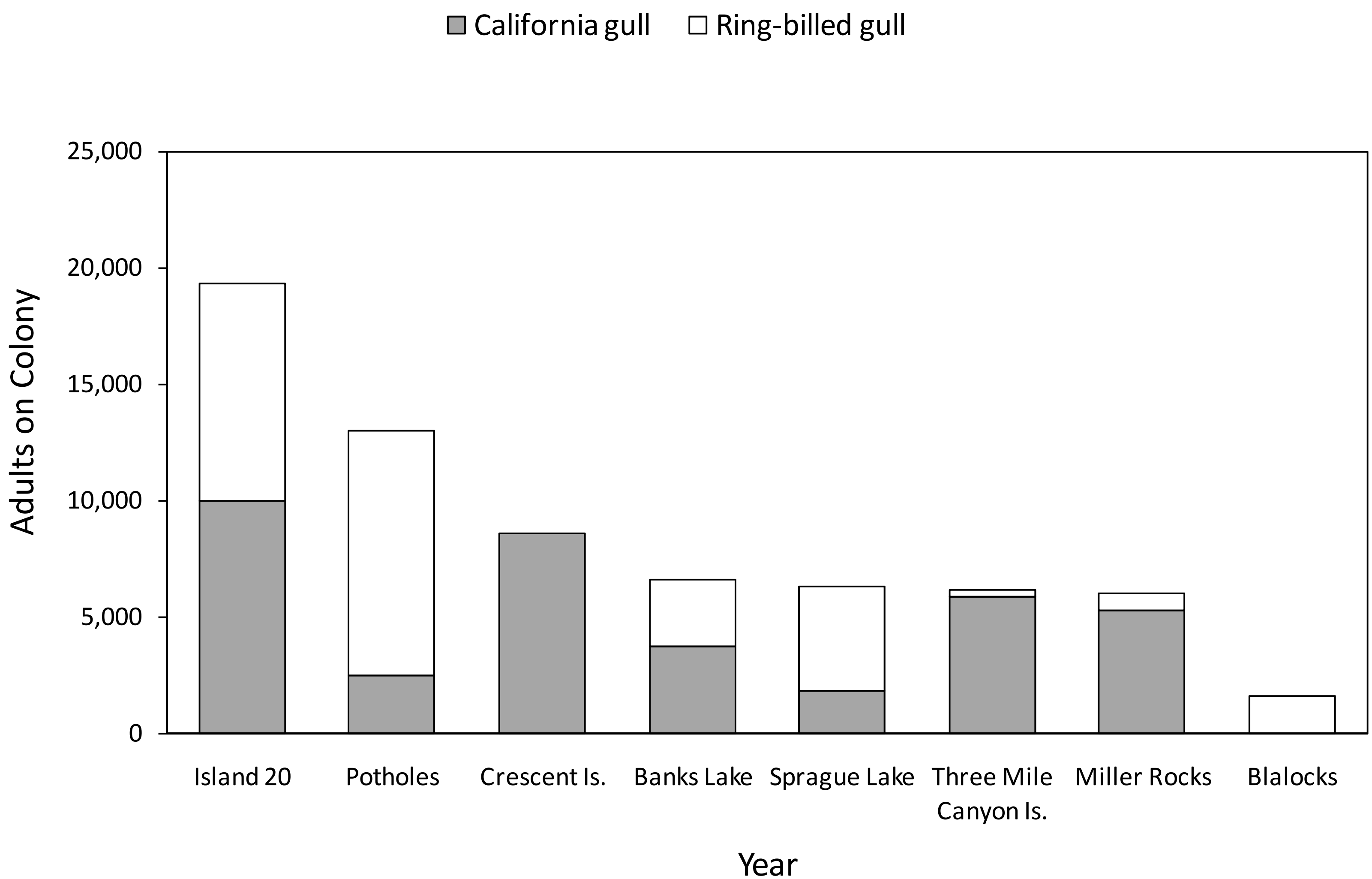


Figure 54. Numbers of adult California and ring-billed gulls counted on aerial photography of eight different colonies in the Columbia Plateau region during the 2009 nesting season. Photography was taken late in the incubation period.

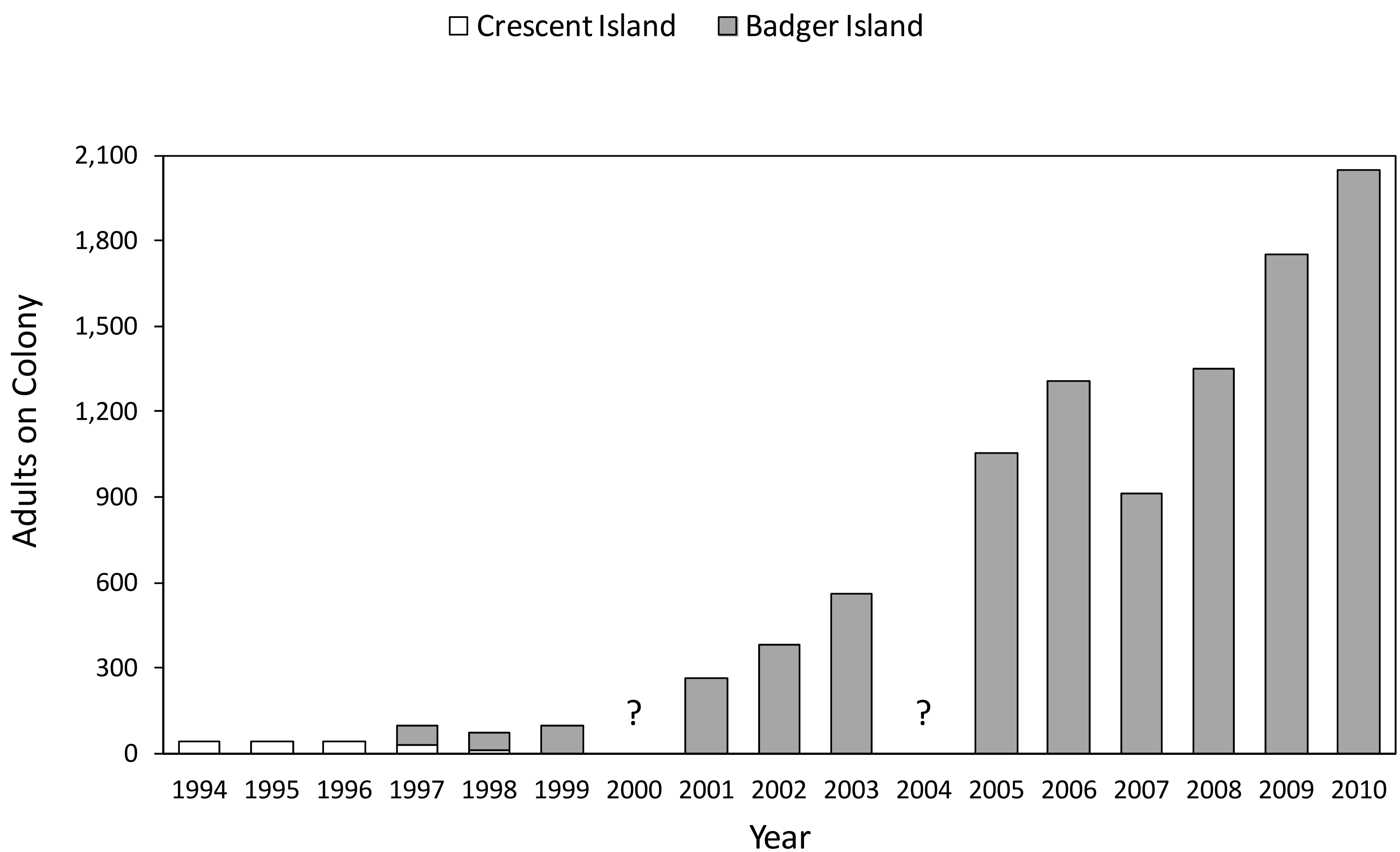


Figure 55. Numbers of American white pelicans counted in aerial photography of two colonies on the mid-Columbia River, Badger Island and Crescent Island, during the 1994-2010 breeding seasons. Photography was taken late in the incubation period. Numbers of pelicans on the Badger Island colony were not determined in 2000 and 2004. Number of pelicans counted on photography from 2010 averaged 2,048 individuals.

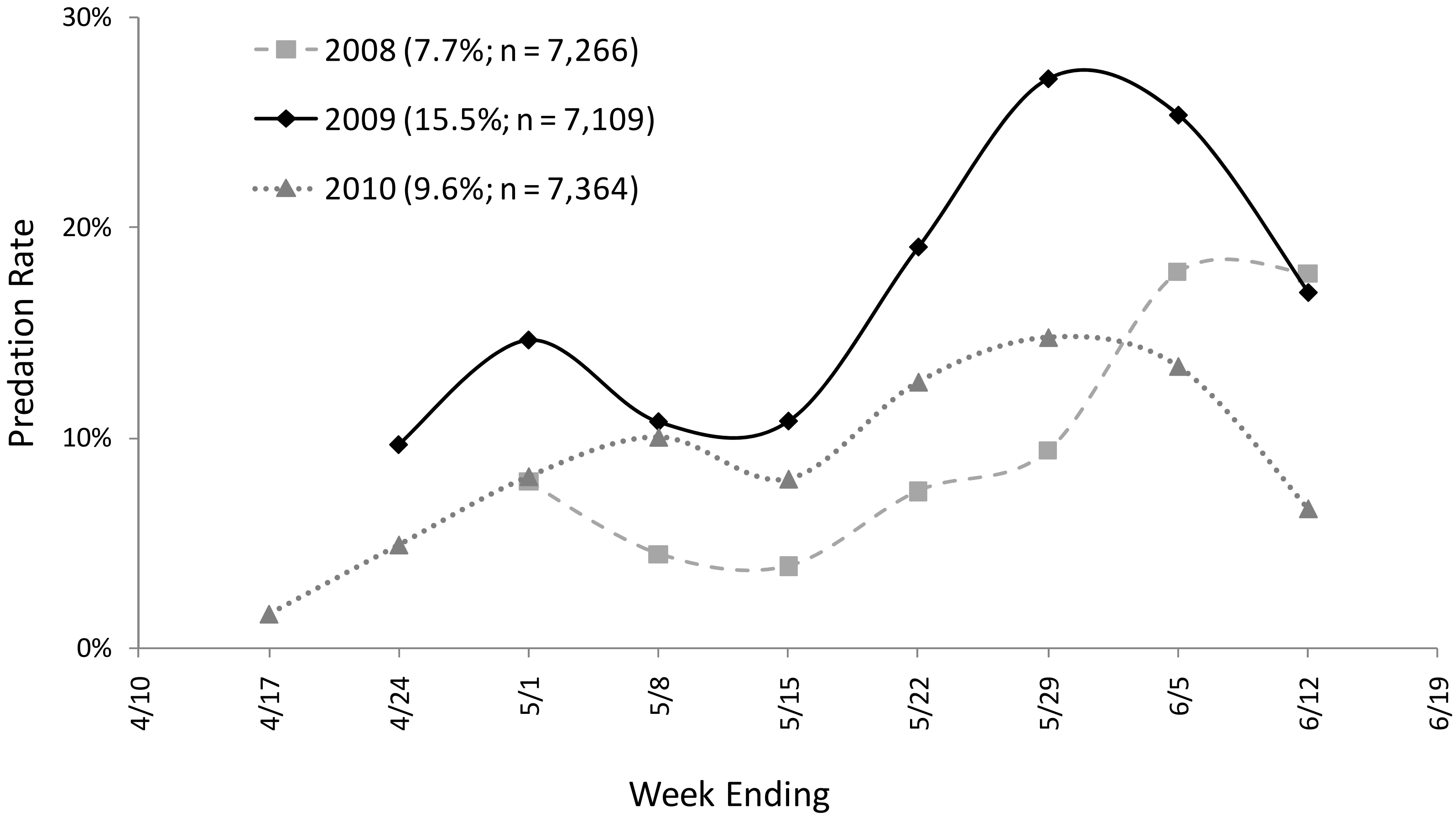


Figure 56. Estimated predation rates by week of PIT-tagged Upper Columbia River steelhead (released at Rock Island Dam on the upper Columbia River) by Caspian terns nesting at the colony on Goose Island in Potholes Reservoir. Estimates are separated by migration year, with annual predation rates and number of PIT-tagged steelhead released in parentheses. Predation rates were corrected for bias due to on-colony PIT tag detection efficiency (see Table 2), but not for deposition rates, and therefore are minimum estimates.

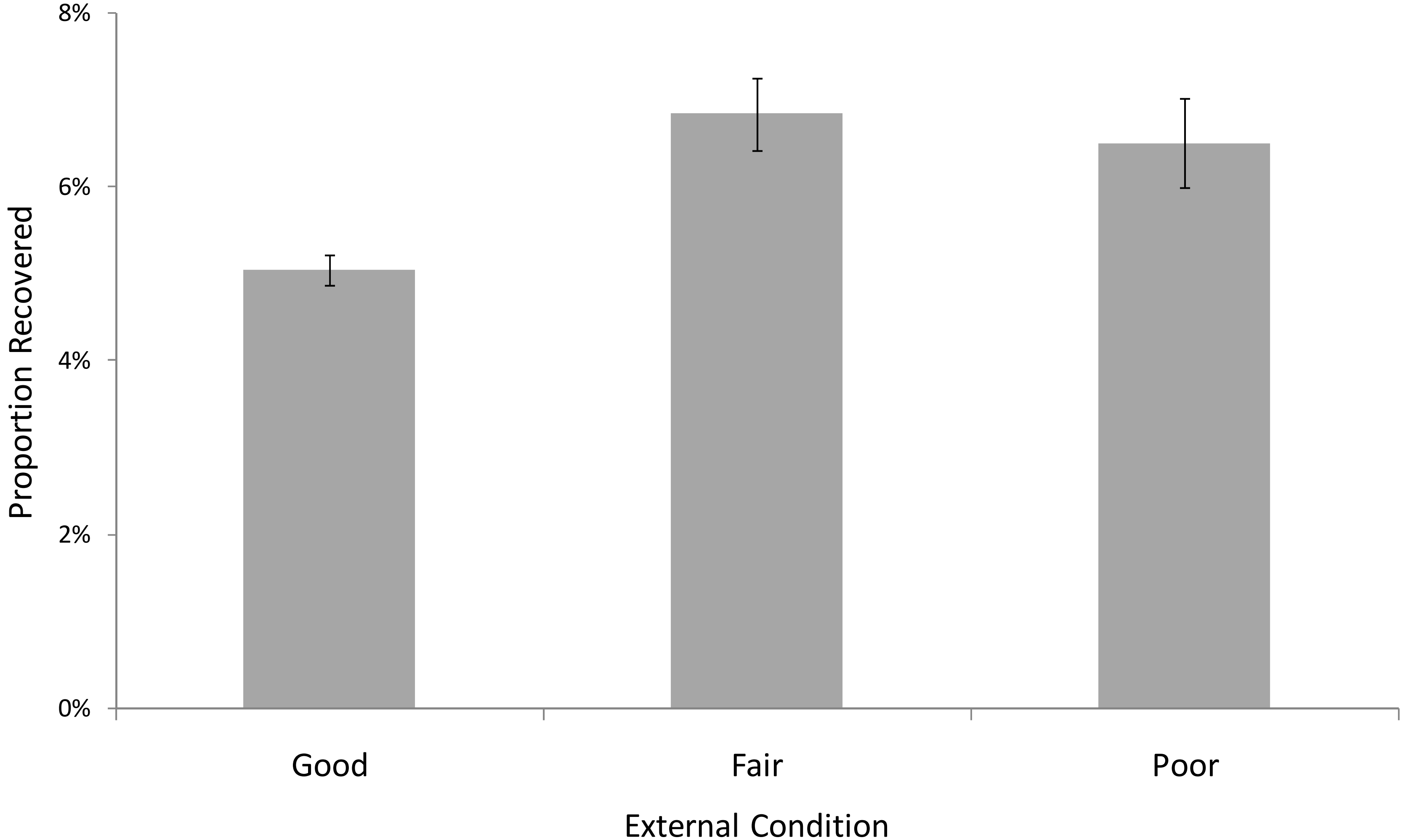


Figure 57. Percentage of steelhead smolts PIT-tagged and released at Rock Island Dam on the upper Columbia River during 2008-2010 (n = 21,739 steelhead) that were subsequently recovered on the Caspian tern breeding colony on Goose Island in Potholes Reservoir, as a function of the external condition of the smolt at the time of release. Error bars represent one standard error.

Table 1. Caspian tern nesting island construction that has been completed to date as part of the federal agencies' Caspian Tern Management Plan for the Columbia River estuary (USFWS 2005, 2006).

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

Table 2. Number of juvenile salmonid (Chinook, coho, and sockeye salmon, and steelhead) PIT tags recovered and deposited on bird colonies in the Columbia River basin during the 2010 breeding season. The number of PIT tags deposited on-colony was estimated based on a correction factor for average PIT tag detection efficiency (standard deviation). Piscivorous waterbird breeding colonies include American white pelicans (AWPE), Brandt's cormorants (BRAC), Caspian terns (CATE), double-crested cormorants (DCCO), and California and ring-billed gulls (Gulls).

			Salmonid PIT Tags		
River Segment	Location	Colony	Recovered	Est. Deposited	Detection Efficiency
Estuary	East Sand Island	CATE	35,862	42,693	84.0% (9.4)
		DCCO	24,554	32,308	76.0% (13.4)
		BRAC	199	240	83.0% (21.2)
The Dalles Pool	Miller Rocks	Gulls	3,784	5,045	75.0% (21.2)
John Day Pool	Blalock Islands	CATE	1,099		NA
McNary Pool	Crescent Island	CATE	6,253	8,337	75.0% (30.2)
		Gulls	3,148	4,010	78.5% (14.8)
	Badger Island	AWPE	2,319	3,113	74.5% (14.8)
	Foundation Island	DCCO	5,343	8,481	63.0% (3.7)
Off-river	Potholes Reservoir	CATE	4,405	7,595	58.0% (32.4)
	Banks Lake	CATE	110	183	60.0% (53.7)

Table 3. Estimated minimum predation rates (95% c.i.) of PIT-tagged salmonid smolts last detected at Bonneville Dam on the Columbia River or Sullivan Dam on the Willamette River by avian predators nesting at colonies on East Sand Island (ESI) in the Columbia River estuary. Colonies include Caspian terns (CATE), double-crested cormorants (DCCO), and Brandt's cormorants (BRAC). The species (sockeye, Chinook, coho, steelhead), run type (spring, summer, fall, winter), and river-of-origin (UCR for upper Columbia River, SR for Snake River, MCR for middle Columbia River, WR for Willamette River) for each PIT-tagged stock are provided, along the number of PIT-tagged smolts interrogated at Bonneville or Sullivan dams (N).

		Predation Rates			
Stock	N	ESI CATE	ESI DCCO	ESI BRAC	All
SR Sockeye	1,382	1.1% (0.5-1.7)	1.2% (0.6-1.9)	<0.1%	2.2% (1.4-3.1)
UCR Sockeye	828	0.3% (0.0-0.8)	1.7% (0.7-2.8)	<0.1%	2.0% (1.0-3.2)
SR Spring Chinook	31,087	2.6% (2.3-2.8)	2.7% (2.4-3.0)	<0.1%	5.3% (4.9-5.7)
UCR Spring Chinook	9,057	2.1% (1.8-2.4)	1.6% (1.3-2.0)	<0.1%	3.7% (3.3-4.2)
MCR Spring Chinook	15,518	3.5% (3.1-3.9)	2.3% (2.0-2.6)	<0.1%	5.8% (5.3-6.3)
SR Summer Chinook	6,634	1.6% (1.3-2.0)	2.4% (2.0-2.9)	<0.1%	4.0% (3.5-4.7)
UCR Summer Chinook	11,540	1.4% (1.1-1.6)	1.8% (1.5-2.2)	<0.1%	3.2% (2.9-3.7)
SR Fall Chinook	17,974	0.5% (0.4-0.6)	1.9% (1.7-2.2)	<0.1%	2.5% (2.2-2.7)
UCR Fall Chinook	2,159	1.7% (1.1-2.3)	2.7% (1.9-3.6)	<0.1%	4.4% (3.4-5.5)
MCR Fall Chinook	3,336	2.0% (1.5-2.6)	11.1% (9.7-12.6)	<0.1%	13.2% (11.7-14.8)
SR Coho	939	7.4% (5.6-9.5)	3.4% (2.1-4.8)	<0.1%	10.8% (8.5-13.2)
UCR Coho	5,089	3.8% (3.2-4.4)	2.0% (1.5-2.5)	<0.1%	5.8% (5.1-6.6)
SR Summer Steelhead	40,023	9.9% (9.3-10.6)	3.7% (3.4-4.1)	<0.1%	13.7% (13.0-14.4)
UCR Summer Steelhead	12,312	9.8% (9.0-10.5)	3.4% (2.9-3.8)	<0.1%	13.2% (12.3-14.0)
MCR Summer Steelhead	8,395	8.5% (7.7-9.4)	3.9% (3.4-4.5)	<0.1%	12.5% (11.5-13.5)
WR Summer Steelhead	3,112	5.8% (4.8-6.9)	3.5% (2.7-4.3)	<0.1%	9.3% (8.0-10.6)
MCR Winter Steelhead	2,105	8.9% (7.6-10.4)	2.4% (1.6-3.2)	0.1% (0-0.2)	11.3% (9.8-13.0%)

Table 4. Estimated minimum predation rates (95% c.i.) on PIT-tagged salmonid smolts last detected at Lower Monumental Dam on the lower Snake River or Rock Island Dam on the upper Columbia River by avian predators nesting on islands in McNary Pool or in Potholes Reservoir. Colonies include Caspian terns nesting on Crescent Island (CI CATE), Caspian terns nesting on Goose Island, Potholes Reservoir (GI CATE), double-crested cormorants nesting on Foundation Island (FI DCCO), California and ring-billed gulls nesting on Crescent Island (CI GULL), and American white pelicans nesting on Badger Island (BI AWPE). The species (sockeye, Chinook, and coho salmon, and steelhead), run type (spring, summer, fall, winter), and river-of-origin (UCR for upper Columbia River, SR for Snake River) for each PIT-tagged stock are provided, along the number of PIT-tagged smolts interrogated at Lower Monumental or Rock Island dams (N).

		Predation Rates					
Stock	N	CI CATE	GI CATE	FI DCCO	CI GULL	BI AWPE	All
SR Sockeye	568	0.9% (0.2-1.9)	<0.1%	1.7% (0.5-3.1)	<0.1%	<0.1%	2.6% (1.1-4.2)
UCR Sockeye	4,104	0.2% (0.0-0.3)	0.3% (0.1-0.6)	<0.1%	0.1% (0.0-0.2)	<0.1%	0.5% (0.3-0.9)
SR Spring Chinook	6,609	0.3% (0.2-0.5)	<0.1%	0.8% (0.6-1.1)	0.2% (0.1-0.3)	<0.1%	1.3% (1.0-1.7)
UCR Spring Chinook	929	0.4% (0.0-1.0)	1.0% (0.2-2.0)	<0.1%	<0.1%	<0.1%	1.5% (0.5-2.6)
SR Summer Chinook	1,953	0.2% (0.0-0.5)	<0.1%	0.6% (0.2-1.0)	0.1% (0.0-0.2)	0.1% (0.0-0.4)	1.0% (0.5-1.5)
UCR Summer Chinook	2,180	0.1% (0.0-0.2)	0.2% (0.0-0.4)	<0.1%	0.1% (0.0-0.2)	<0.1%	0.3% (0.1-0.6)
SR Fall Chinook	38,709	0.7% (0.6-0.8)	<0.1%	0.4% (0.3-0.5)	<0.1%	0.1% (0.0-0.1)	1.1% (1.0-1.3)
SR Summer Steelhead	10,950	2.8% (2.4-3.2)	<0.1%	1.3% (1.0-1.6)	0.6% (0.4-0.7)	0.3% (0.2-0.4)	4.9% (4.4-5.5)
UCR Summer Steelhead	7,732	1.2% (1.0-1.6)	9.6% (8.3-11.3)	0.1% (0-0.2)	1.1% (0.8-1.4)	0.1% (0.0-0.2)	12.1%(10.8-13.8)

Table 5. Estimated minimum predation rates (95% c.i.) of PIT-tagged salmonid smolts last detected at McNary Dam on the middle Columbia River by avian predators nesting in the John Day or The Dalles pools. Colonies include Caspian terns (CATE) nesting on the Blalock Islands (BI) and California and ring-billed gulls (GULL) nesting on Miller Rocks (MR). The species (sockeye, Chinook, and coho salmon, and steelhead), run type (spring, summer, fall, winter), and river-of-origin (UCR for upper Columbia River, SR for Snake River, MCR for middle Columbia River) for each PIT-tagged stock are provided, along the number of PIT-tagged smolts interrogated at McNary Dam (N).

		Predation Rates		
Stock	N	BI CATE*	MR GULL	All*
SR Sockeye	1,327	0.1%	0.6% (0.2-1.1)	0.7%
UCR Sockeye	1,789	<0.1%	0.4% (0.1-0.7)	0.4%
SR Spring Chinook	40,079	<0.1%	0.3% (0.2-0.3)	0.3%
UCR Spring Chinook	10,456	<0.1%	0.3% (0.2-0.4)	0.3%
MCR Spring Chinook	1,222	0.1%	0.8% (0.2-1.4)	0.8%
SR Summer Chinook	12,050	<0.1%	0.3% (0.2-0.4)	0.3%
UCR Summer Chinook	9,934	0.1%	0.2% (0.1-0.3)	0.2%
SR Fall Chinook	29,587	<0.1%	0.1% (0.1-0.2)	0.2%
UCR Fall Chinook	3,350	<0.1%	0.2% (0.0-0.4)	0.2%
UCR Coho	2,570	0.1%	0.5% (0.2-0.9)	0.6%
SR Summer Steelhead	17,805	0.6%	1.4% (1.2-1.6)	2.0%
UCR Summer Steelhead	3,974	0.6%	1.1% (0.7-1.4)	1.7%
MCR Summer Steelhead	858	0.5%	0.5% (0.0-1.1)	1.0%

** No estimate of detection efficiency was available for the Caspian tern colony on the Blalock Islands during 2010. Predation rates are therefore minimums as the estimate represents the proportion of tags recovered, unadjusted for detection efficiency and without confidence intervals.*

Table 6. Total numbers of Warner, Lost River, shortnose, and Klamath largescale suckers PIT-tagged and released since 1995 that were subsequently recovered on bird colonies in the Warner Basin and the Upper Klamath Basin during 2008-2010. The numbers of tags recovered are specific to the year(s) the tags were recovered by researchers, which is not necessarily the same year the fish was consumed by a bird. Some suckers could not be identified to the level of species (Unid). Colony sites with mixed species of avian predator are islands where multiple species of piscivorous colonial waterbirds nested in close proximity to one another and it was not possible to associate a PIT-tagged sucker with a single species of avian predator. Mixed species consisted primarily of American white pelicans and double-crested cormorants, although other piscivorous waterbirds (great blue herons, great egrets, ring-billed gulls, California gulls, and possibly others) may have been present and could have deposited sucker PIT tags on the island. Blank cells represent zeros.

				PIT Tags Recovered by Sucker Species				
Basin	Location	Predator	Year (s)	Warner	Lost River	Shortnose	Largescale	Unid
Warner	Crump Lake Tern Island	Caspian tern	2008-2010	1				
Warner	Pelican Island, Pelican Lake	Mixed Species	2010	15				
Klamath	Sheepy Lake Floating Tern Island	Caspian tern	2010					
Klamath	Sheepy Lake Tule Mat Island	Mixed Species	2009		1	2		
Klamath	Clear Lake Refuge Islands	Mixed Species	2009-2010		63	203	45	13
Klamath	Upper Klamath Refuge Islands	Mixed Species	2009-2010		38	41	16	13

Table 7. Minimum consumption rates of PIT-tagged Warner, Lost River, and shortnose suckers by avian predators nesting at several colonies in the Upper Klamath Basin and Warner basin during the 2009 and 2010 breeding seasons. Release and recovery periods include all suckers released within a year of the tag being recovered on a bird colony. Release sites were within the lake or a tributary of the lake. With the exception of suckers at Crump Lake, juvenile suckers could not be identified to the level of species (Unid). Breeding colonies on Crump Lake tern island and Sheepy Lake tern island were of Caspian terns. Colonies on all other islands consisted primarily of American white pelicans and double-crested cormorants, although other piscivorous waterbirds (great blue herons, great egrets, ring-billed and California gulls, and others) were present in small numbers and could have deposited sucker PIT tags on the island. NA indicates that data are not available for that colony, that year. Blank cells represent zeros.

				Percent (number) of PIT-Tagged Suckers Recovered on Bird Colonies					
Release Period	Recovery Period	Release Site	Sucker Species	Crump Lake tern is.	Pelican Lake is.	Clear Lake is.	Upper Klamath is.	Sheepy Lake tule is.	Sheepy Lake tern is.
Spr. 09	Fall 09	Crump Lake	Warner		NA				NA
Spr. 09	Fall 09	Upper Klamath Lake	Lost River		NA	0.1% (6)	0.1% (7)	< 0.1% (1)	NA
Fall 08	Fall 09	Clear Lake			NA	1.6% (2)			NA
Spr. 09	Fall 09	Upper Klamath Lake	Shortnose		NA	0.3% (4)	0.3% (5)	< 0.1% (1)	NA
Fall 08	Fall 09	Clear Lake			NA	1.4% (11)			NA
Spr. 09	Fall 09	Upper Klamath Lake	Juvenile (Unid)		NA		3.6% (6)		NA
Spr. 10	Fall 10	Crump Lake	Warner		6.7% (4)			NA	
Spr. 10	Fall 10	Upper Klamath Lake	Lost River					NA	
Fall 09	Fall 10	Clear Lake						NA	
Spr. 10	Fall 10	Upper Klamath Lake	Shortnose					NA	
Fall 09	Fall 10	Clear Lake				0.3% (5)		NA	
Spr. 10	Fall 10	Upper Klamath Lake	Juvenile (Unid)					NA	

Table 8. Percentages of steelhead tagged and released at Rock Island Dam (n = 7,364; upper Columbia River) recovered on breeding colonies of piscivorous waterbirds in the Columbia River basin during 2010. Percentages are listed separately for wild and hatchery-raised steelhead. Recovery percentages were corrected for bias due to on-colony PIT tag detection efficiency (see Table 3), but not for steelhead survival to the vicinity of the bird colony or for off-colony deposition of PIT tags, and therefore are minimum estimates.

Location	Island	Nesting Bird Species	Hatchery	Wild	All
Banks Lake	Twining Island	Caspian terns	0.1%	0.0%	0.1%
Potholes Reservoir	Goose Island	Caspian terns	10.9%	5.9%	9.6%
McNary Pool	Crescent Island	Caspian terns	1.3%	0.9%	1.2%
		California gulls	1.2%	0.7%	1.1%
	Foundation Island	Double-crested cormorants	0.1%	0.0%	0.1%
	Badger Island	American white pelicans	0.1%	0.1%	0.1%
John Day Pool	Blalock Island	Caspian terns[a]	0.3%	0.2%	0.3%
The Dalles Pool	Miller Rocks	California/ring-billed gulls	0.6%	0.6%	0.6%
Estuary	East Sand Island	Caspian terns	6.2%	3.2%	5.4%
		Double-crested cormorants	1.6%	1.2%	1.5%
		Brandt's cormorants	0.0%	0.0%	0.0%
ALL			22.7%	12.6%	20.0%

[a] *No PIT tag detection efficiency estimate for this tern colony was available in 2010*

APPENDIX 1:

Recovery of Salmonid Coded Wire Tags on the Brooks Island Caspian Tern Colony in San Francisco Bay during 2010

This summary report has been prepared for the
U.S. Army Corps of Engineers – Portland District
for the purposes of assessing project accomplishments.
This report is not for citation without permission of the authors.

By

Allen F. Evans[1], Daniel D. Roby[2], Ken Collis[1], Bradley M. Cramer[1], Nathan Hostetter[1], and Daniel S. Battaglia[2]

[1]Real Time Research, Inc., 52 Southwest Roosevelt Avenue, Bend, Oregon 97702, USA

[2] U.S. Geological Survey - Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University, Corvallis, Oregon 97331, USA

SUMMARY

We recovered coded wire tags (CWTs) from a Caspian tern (*Hydroprogne caspia*) breeding colony on Brooks Island in central San Francisco Bay, California to evaluate predation on juvenile salmonids (*Oncorhynchus* spp.*)* originating from the Sacramento and San Joaquin rivers. A sample of colony substrate representing 6.3% of the nesting area used by terns yielded 590 salmonid CWTs from fish released and subsequently consumed by terns in 2010. This value expands to an estimated 15,793 CWTs (95% confidence interval = 12,139 to 19,447 CWTs) once adjustments are made to account for tag loss and the amount of tern nesting substrate not sampled for CWTs.

CWTs recovered from the Brooks Island tern colony indicate that hatchery-raised Chinook salmon (*O. tshawytscha*) trucked to and released in eastern San Pablo Bay (northern San Francisco Bay; approximately 25 kilometers from Brooks Island) were significantly more likely to be consumed by terns than Chinook salmon that migrated naturally in-river. Smolts released from net pens in eastern San Pablo Bay were over 400 times more likely to be recovered on the tern colony compared to naturally migrating smolts. Of the 590 CWTs found on the tern colony, 588 or 99.6% were from net pen released fish. Fall-run and ESA-listed spring-run Chinook salmon were more susceptible to tern predation compared to winter-run and late fall-run Chinook run-types because fall-run and spring-run smolts were released from net pens during the tern nesting season (April to July). None of the approximately 180,000 wild Chinook salmon that were marked with CWTs and released in-river were recovered on the Brooks Island tern colony, suggesting impacts to the survival of wild Chinook salmon populations in the region were negligible. None of the approximately 200,000 hatchery-raised winter-run (ESA-listed) Chinook salmon that were marked with CWTs and released in-river were subsequently recovered on the tern colony. Overall (all Chinook run-types and release strategies combined), we estimate that ca. 0.1% of the approximately 11.4 million Chinook salmon marked with CWTs and released into the basin in 2010 were consumed by a Caspian tern and the tag deposited on the Brooks Island colony.

Results from the 2010 study were very similar to those from 2008 and 2009, and indicated that Brooks Island Caspian tern predation on Chinook smolts is almost exclusively limited to hatchery-reared fish trucked to and released via net pens into eastern San Pablo Bay. Data from two Caspian tern colonies (Eden Landing and Steven's Creek) in southern San Francisco Bay collected following the 2009 nesting season indicated that very few Chinook salmon, regardless of release location (in-river or bay) or rearing-type (hatchery or wild), were consumed by Caspian terns. After adjusting for tag loss and the area of tern nesting substrate sampled by researchers, we estimated that just 179 (95% CI: 146 to 212) CWTs from Chinook salmon were consumed and deposited on-colony by Caspian terns nesting at colonies in southern San Francisco Bay, a remarkably low number given the millions of Chinook salmon smolts annually marked with CWTs and released. Results from this study indicated a strong association between a colony's distance from the Sacramento and San Joaquin River delta and smolt mortality; Caspian terns nesting at colonies in southern San Francisco Bay have a much lower impact on smolt survival than Caspian terns nesting on Brooks Island in central San Francisco Bay.

INTRODUCTION

Each year millions of anadromous juvenile salmonids (*Oncorhynchus* spp.) originating from the Sacramento and San Joaquin rivers are implanted with coded wire tags (CWTs) prior to their release as smolts (RMISD 1977). A CWT is a small (ranging from 0.5 to 2.1 mm in length, 0.25 mm in diameter) piece of stainless steel wire emblazoned with a numeric code. CWTs are implanted in the nasal cartilage of fish and provide a variety of information on each fish, including (but not limited to) species, stock, run, rearing-type (hatchery or wild), release date, and release location. The Regional Mark Processing Center, which is operated by the Pacific States Marine Fisheries Commission, provides coordination and maintains a centralized database for information on all salmonids marked with CWTs in the Pacific Region of North America (RMISD 1977).

The management of piscivorous bird colonies in the Pacific Northwest is a component of regional plans to recover salmonid populations that are listed under the U.S. Endangered Species Act (ESA; NOAA Fisheries 2008). Caspian terns that nest in the Columbia River estuary on East Sand Island have been found to consume millions of juvenile salmonids annually (Lyons et al. 2010). As a result, a plan entitled "*Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary*" was developed to reduce impacts on salmonids from Caspian terns nesting in the Columbia River estuary by redistributing a portion of the East Sand Island tern colony – the largest of its kind in the world – to newly created or enhanced alternative colony sites in Oregon and California (USFWS 2005, 2006). Some of the potential alternative colony sites in California are in San Francisco Bay. Caspian terns have been nesting on Brooks Island in San Francisco Bay for over 20 years (Strong et al. 2004) and Brooks Island is currently the location of the largest Caspian tern colony in the San Francisco Bay area. The above-mentioned Caspian Tern Management Plan seeks to expand the available nesting habitat for terns in San Francisco Bay to accommodate terns displaced from East Sand Island. The potential expansion of the Caspian tern breeding population in San Francisco Bay may be controversial, however, due to the rapidly declining status of Chinook salmon (*O. tshawytscha*) and steelhead trout (*O. mykiss*) populations from the Central Valley of California that are listed under the ESA (Yoshiyama et al. 1998; Good et al. 2005). As such, data on the number and percentage of salmonid smolts consumed by Caspian terns nesting at colonies in San Francisco Bay would be a valuable source of information to determine the efficacy of expanding Caspian tern colonies in the Bay area as part of the Caspian Tern Management Plan.

In 2010, we continued a study initiated in 2008 to assess the impact of Caspian terns on salmonid smolts in San Francisco Bay by recovering smolt CWTs on the Brooks Island tern colony. Data collected from the Brooks Island colony in 2008 indicated that Caspian terns were almost exclusively consuming hatchery-reared Chinook salmon smolts that were being trucked to and released into nearby San Pablo Bay (northern San Francisco Bay; approximately 25 kilometers from Brooks Island) during the tern nesting season (Evans et al. 2011). In 2009, we expanded the study to include the recovery of CWTs from Caspian tern colonies at Eden Landing and Steven's Creek, located in southern San Francisco Bay. Results from the 2009 study indicated a strong association between a colony's distance from the Sacramento and San Joaquin River delta and smolt mortality, with Caspian terns nesting at colonies in southern San Francisco Bay having a much lower impact on smolt survival than terns nesting on Brooks Island in the central Bay.

The primary objective of the 2010 study was to continue to monitor the impact of the Brooks Island tern colony on salmonid smolts marked with CWTs. Research was limited to Brooks Island in 2010 because very few terns were documented nesting at other colony sites in the Bay Area.

METHODS

The number of Caspian terns nesting at Brooks Island was determined from aerial photography of the colony taken during the peak of egg incubation in May 2010. The photography was analyzed to estimate the number of breeding pairs on-colony. Nesting density (pairs/m^2) at the colony in 2010 was estimated based on the average nesting density of terns observed on Brooks Island in 2008 (ca. 1.2 breeding pairs/m^2) and 2009 (ca. 1.0 breeding pairs/m^2). This approach was necessary because multiple counts of the tern colony were not conducted in 2010 and because the digital photography of the colony in 2010 was not geo-referenced.

Samples of the nesting substrate used by Caspian terns at Brooks Island were removed and searched for CWTs (see Evans et al. 2011 for a detailed description of the methods used to recovery CWTs). Briefly, plots containing nesting substrate were haphazardly selected within the area occupied by nesting Caspian terns. Substrate was removed from 30 individual 1-m^2 plots (hereafter referred to as “plots”) in August of 2010, following the tern nesting season. Each individual sample included substrate to a depth of approximately 5 cm. Substrate from each plot was placed in a 5-gallon plastic bucket. The contents of each bucket were then ground using a mortar mixer paddle and drill to break up guano and other large, compacted material. Material was then screened (3-mm mesh) to remove shell fragments, rocks, bones, and other large debris. Processed material was then placed into a 50 cm (length) x 45 cm (width) metal funnel that poured the material over a vibrating trough. As the substrate moved through the trough, ferrous material was removed by a 20 cm (length) x 15 cm (width) x 5 cm (depth) ceramic and rare-earth (neodymium) magnet that was place at the end of the trough. An illuminated magnifying glass was then used to locate CWTs that were stuck to the magnet. Once recovered from the surface of the magnet, CWTs were cleaned with isopropyl alcohol and read using a specially-designed MagniViewer© microscope (Northwest Marine Technology, Shaw Island, Washington).

In order to quantify the efficiency of our CWT extraction technique, we sowed CWTs with known tag codes into four discrete 1-m^2 plots on the tern colony prior to the nesting season (March; hereafter referred to as “pre-season”) and after the nesting season (August; hereafter referred to as “post-season”). Equal numbers of test tags (n = 15 per plot) were sown in each plot during each release period (pre-season and post-season). To further assess the efficiency of processing CWTs, test tags were also sown directly into the 5-gallon buckets containing pre-processed substrate samples. Here, too, equal numbers of test tags (n = 10 per plot) were sown into randomly-selected buckets of pre-processed substrate samples. The sowing of test tags was done under the premise that not all CWTs deposited by terns on-colony were subsequently recovered by researchers. For example, tags could be blown off the colony during wind or rain storms, buried deeper than 5 cm, washed away during high tides or other flooding events, or otherwise damaged or lost (Evans et al. 2011). Furthermore, it is reasonable to suspect that some of the recovered tags within the substrate samples were lost during the extraction process.

Detection efficiency estimates (percentage of sown test tags subsequently recovered) were analyzed relative to the release location (on-colony versus in buckets) and release date (pre-season or post-season) to describe spatial and temporal variation in detection efficiency.

Impacts on Salmonid Survival

Data regarding the number, species, rearing-type (hatchery or wild), run-type (fall, late-fall, winter, or spring), and release location of salmonids marked with CWTs in the Sacramento and San Joaquin rivers were obtained by querying the Regional Mark Information Systems Database (RMISD 1977) on 20 February 2011. Salmonid release locations were placed in one of three categories, based on the distance from San Francisco Bay and the release strategy employed by fishery agencies in the region: (1) releases directly into the Sacramento River or a tributary of the Sacramento River (hereafter referred to as the "In-river" release group), (2) releases into the Sacramento-San Joaquin River delta (hereafter referred to as the "Delta" release group), or (3) releases into the Bay (hereafter referred to as the "Bay" release group; Figure A.1). Bay released fish were released into eastern San Pablo Bay (in northern San Francisco Bay) from net pens maintained by the Fisheries Foundation of California; specifically, the fish were trucked from the hatchery, placed in a net pen for salt water acclimation, and then towed out to release points in eastern San Pablo Bay (FFC 2008).

Data Analysis

Analysis of the impacts of Caspian tern predation on survival of juvenile salmonids was limited to smolts marked with CWTs and released during the 2010 migration year (i.e., fish assumed to be out-migrating to the Pacific Ocean between December 2009 and July 2010). The numbers of CWT fish released (by species, rearing-type, and location) were compared to the numbers on the Brooks Island tern colony to generate minimum consumption and predation rate estimates. Chi-square tests and odds ratio comparisons (Ramsey and Schafer 1997) were used to evaluate the relative susceptibility to tern predation of fish from different run-types and release locations under the null hypothesis that fish were consumed in proportion to their availability at release.

The total number of salmonid CWTs deposited by Caspian terns on the Brooks Island colony was estimated by calculating the number of CWTs within sampled plots and multiplying this value by the total estimated area of nesting substrate used by Caspian terns on Brooks Island. Estimates were then adjusted or corrected for CWT detection efficiency by dividing the number of tags recovered by the average on-colony detection efficiency value obtained based on the recovery of test tags. A measure of precision (95% confidence interval) was obtained by applying the variation in detection efficiency (standard error of the mean) observed from test tags released on-colony to all recovered tags from that colony. This approach assumes the fate (tag loss) and detection probability of test tags was representative of salmonid tags naturally deposited by birds during the 2010 nesting season. Finally, the total number of CWTs deposited on the Brooks Island Caspian tern colony during 2008-2010 (from results presented in BRNW 2010 and Evans et al. 2011) were compared to the number deposited by terns nesting on Eden Landing and Steven's Creek (southern San Francisco Bay; Figure 1) in 2009.

RESULTS

We estimated that 430 pairs of Caspian terns nested on Brooks Island (Figure A.1) in 2010. Based on a presumed nesting density of 1.1 pairs m^2 (average of the 2008 and 2009 nesting season), Caspian terns utilized 473 m^2 of habitat during the 2010 nesting season. A total of 30 m^2 of nesting habitat from the tern colony was sifted for CWTs following the breeding season in August, representing 6.3% of the estimated nesting habitat utilized by terns in 2010 (Table A.1). From the 30 m^2 of nesting substrate, a total of 1,035 salmonid CWTs were recovered. Of these, 590 or 57.0% were from fish tagged and released into the Sacramento or San Joaquin rivers during the 2010 migration year, while the remaining 445 tags were from older releases (prior to 2010) of Sacramento/San Joaquin fish or from fish released out-of-basin. The oldest confirmed CWT recovered was from a fall-run Chinook salmon released into the Sacramento River in 2000.

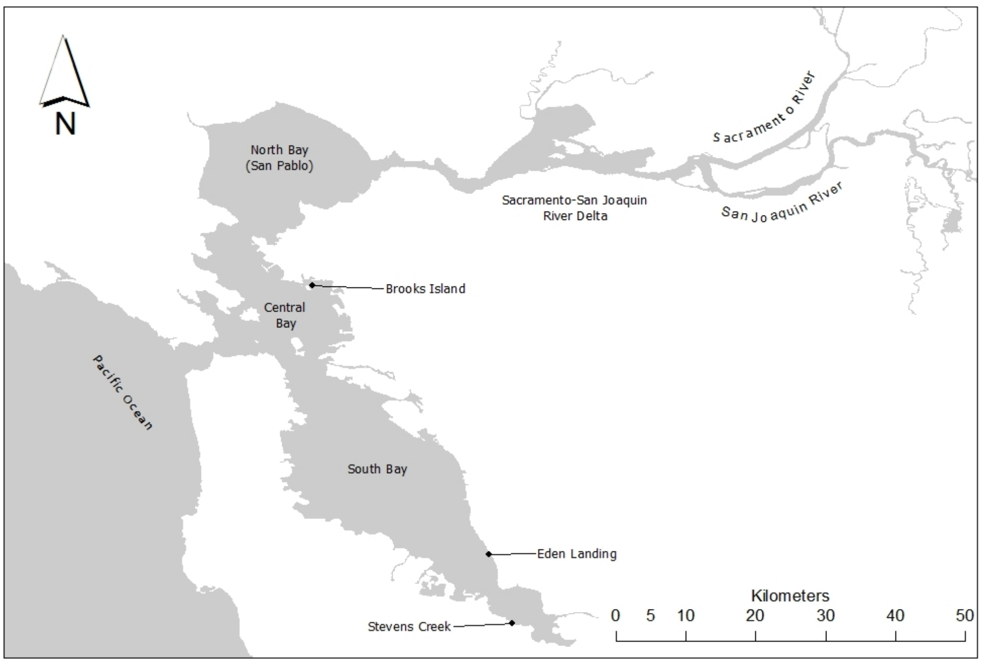


Figure A.1: Map of San Francisco Bay, California. Brooks Island is located in central San Francisco Bay, with the Sacramento and San Joaquin rivers entering the Bay from the northeast. Eden Landing and Steven's Creek are located in southern San Francisco Bay.

Detection efficiency of test tags intentionally sown on the tern colony prior to and after the nesting season averaged 59.2% (n = 120; Table A.1). Differences between pre-season (ca. 28.3%; n = 60) and post-season (ca. 90.0%; n = 60) detection efficiency were observed, with detection efficiency positively associated with the tag's release or sow date. Detection efficiency of test tags placed in 5-gallon buckets of pre-processed substrate was high, with 93.0% (n = 100) of sown tags subsequently recovered. Consequently, most of the loss of CWTs deposited on the Brooks Island Caspian tern colony occurred prior to, or during, the sampling of nesting substrate and not as a result of processing the material (i.e., the grinding, sifting, and removal of tags with magnets).

Based on the total amount of nesting substrate that was searched for CWTs at Brooks Island, average on-colony detection efficiency, and the total number of 2010 migration year salmonid tags recovered, we estimate that terns deposited 15,793 (95% c.i. = 12,139 to 19,447) CWTs from juvenile salmonids during the 2010 nesting season (Table A.1).

Table A.1: Salmonid coded wire tag (CWT) recovery on the Brooks Island Caspian tern colony in 2010. The estimated total number of CWTs deposited by terns was based on the area of used nesting substrate sampled by researchers and the detection efficiency of test tags sown on-colony. All CWTs were from Chinook salmon released into the Sacramento and San Joaquin rivers as smolts during the 2010 out-migration. SE is the standard error of the mean average detection efficiency and CI is the 95% confidence interval.

Colony	Breeding Pairs	Total Nesting Area (m^2)	Sampled Nesting Area (m^2)	CWTs Recovered	Detection Efficiency (SE)	Est. CWTs Deposited (± 95% CI)
Brooks	430	473	30	590	59.2% (11.8)	15,793 (3,654)

In 2008 and 2010, CWT recovery was limited to the Caspian tern colony on Brooks Island. In 2009, however, the Brooks Island colony and two tern colonies in southern San Francisco Bay, at Eden Landing and Steven's Creek (Figure A.1), were searched for CWTs. Results indicated that predation on smolts marked with CWTs by Caspian terns nesting in southern San Francisco Bay were negligible, with an estimated 179 CWT smolts deposited by terns nesting at either the Eden Landing (114 CWT smolts) or Steven's Creek (65 CWT smolts) colonies (Table A.2).

Table A.2: Salmonid coded wire tag (CWT) recoveries on three different Caspian tern colonies located in central or southern San Francisco Bay during 2008-2010. The estimated annual number of CWTs deposited by terns on each colony was based on the area of used nesting substrate sampled by researchers and the detection efficiency of test tags sown on each colony in each year. CWTs were from Chinook salmon released into the Sacramento and San Joaquin rivers as smolts in each out-migration year.

Colony	Location	Study Year	No. CWTs Deposited
Brooks	Central Bay	2008, 2009, 2010	23,445 (mean)
Eden Landing	South Bay	2009	114
Steven's Creek	South Bay	2009	65

Impacts on Salmonid Survival

Approximately 11.4 million Chinook salmon from the Sacramento and San Joaquin rivers were marked with CWTs and released during the 2010 migration year (Table A.3). The vast majority of CWT fish were from hatcheries (11.2 million or 98.4% of all CWT fish), and of the hatchery CWT fish, the majority were fall-run Chinook salmon (8.9 million or 78.5% of all CWT fish). Of the remaining marked hatchery fish, 2.1 million were spring Chinook salmon (ESA-listed fish produced by the Feather River Hatchery), 0.2 million were late-fall Chinook salmon, and 0.2 million were winter Chinook salmon (ESA-listed fish produced by Coleman National Fish Hatchery). In addition to hatchery fish, 0.2 million wild fall-run Chinook salmon (from Butte Creek, a tributary of the Sacramento River) were marked with CWTs and released in 2010 (Table A.3). Virtually all (> 99%) of the hatchery-reared spring, winter, and late-fall Chinook salmon released in 2010 were marked with CWTs. By comparison, only 33% of hatchery-reared fall Chinook salmon released in the basin were tagged with CWTs. In addition to the approximately 19 million non-CWT hatchery fall Chinook released, approximately 1.5 million non-tagged hatchery winter-run steelhead were also released in 2010. Unfortunately, the lack of CWT steelhead precludes the use of CWT recoveries on bird colonies to evaluate impacts of avian predation on survival of steelhead from the Sacramento River, an ESA-listed population.

Of the 590 CWTs recovered from 2010 migration year Chinook smolts, 412 or 69.8.0% were from fall-run Chinook salmon (Table A.3), indicating a relatively high susceptibility to Caspian tern predation for this run-type. Spring-run Chinook smolts were also susceptible, with CWTs from 178 spring-run Chinook recovered on-colony (Table A.3). No CWTs from hatchery-reared winter-run Chinook, hatchery late-fall Chinook, or wild fall-run Chinook salmon were recovered on the Caspian tern colony in 2010. Overall (all run-types combined), < 0.1% (590/11,398,725) of all CWT Chinook salmon released in the basin were recovered on the Brooks Island Caspian tern colony in 2010 (Table A.3). This proportion increases to ca. 0.1% (15,793/11,398,725) after adjustments are made for detection efficiency and the proportion of the total area of the Caspian tern colony that was sampled for CWTs (Table 3).

Of the 590 CWTs from 2010 migration year smolts recovered on the Brooks Island tern colony, 588 or 99.6% were from fish trucked to and released into eastern San Pablo Bay via net pens. Only 1 CWT or 0.2% was from a Delta release group and another CWT or 0.2% was from an In-river release group (Table A.3). The odds of recovering a CWT from a Chinook salmon released in San Pablo Bay were 16 times greater (95% c.i. = 2 to 113 times greater) and 481 times greater (95% CI: 68 to 3,418) than recovering a CWT from a Chinook salmon released into the Delta or In-river groups, respectively ($P < 0.0001$ for both comparisons). A difference between the Delta and In-river release groups was also noted, with Delta released Chinook salmon being 30 times more likely (95% c.i. = 2 to 480 times more likely) than an In-river released Chinook to be recovered on the tern colony, although this comparison is limited to asingle on-colony CWT for each release group.

After accounting for differences in release location, Bay released spring Chinook salmon were more susceptible to predation from Caspian terns than Bay released fall Chinook salmon, with spring-run Chinook two times (95% c.i. = 1.7 to 2.4 times) more likely to end up on the Brooks Island tern colony than Bay released fall Chinook salmon ($P < 0.01$). The small numbers of CWTs recovered from In-river and Delta released Chinook smolts ($N = 2$; all run-types combined) precludes statistical comparisons among different run-types from these two release groups.

Table A.3: Coded wire-tagged (CWT) Chinook salmon from the Sacramento and San Joaquin rivers released as smolts that were subsequently recovered on the Brooks Island Caspian tern colony following the 2010 nesting season. In-river fish were released directly into the Sacramento River or a tributary of the Sacramento River between 135 and 615 river kilometers (Rkm) upstream of San Pablo Bay. Delta fish were released into sloughs below the confluence of the Sacramento and San Joaquin rivers between 80 and 95 Rkm upstream of San Pablo Bay. Bay fish were released directly into San Pablo Bay, northern San Francisco Bay.

Salmonid Species / Run-type by Release Strategy	Number Released	Release Month	Recovered (deposited)	% Recovered (deposited)
Bay Releases				
Hatchery Spring Chinook	1,058,635	April -May	178 (4,764)	< 0.01 (0.45)
Hatchery Fall Chinook	5,026,351	April - June	410 (10,973)	< 0.01 (0.22)
Delta Releases				
Hatchery Fall Chinook	154,685	April - June	1 (28)	< 0.01 (< 0.01)
In-River Releases				
Hatchery Winter Chinook	184,462	January		
Hatchery Spring Chinook	1,030,377	April		
Hatchery Fall Chinook	3,592,803	April - June	1 (28)	< 0.01 (< 0.01)
Hatchery Late-Fall Chinook	172,642	Dec. - Jan.		
Wild Fall Chinook	178,770	Jan. - March		
ALL	11,398,725		590 (15,793)	< 0.01 (0.14)

DISCUSSION

Results of this study demonstrate that CWTs implanted in juvenile salmonids can be recovered from a Caspian tern colony and used to evaluate impacts of this colonial piscivore on survival of juvenile salmonids. Efforts to recover fish tags after birds have left the breeding colony avoids disturbing the birds during the breeding season, which can negatively affect nesting success and, in some cases, cause colony abandonment (Ellison and Cleary 1978; Tremblay and Ellison 1979; Burger 1984). Furthermore, the use of fish tag recoveries to assess the diet of piscivorous waterbirds avoids either lethal collection or live capture and handling of chicks or adults to collect diet samples.

Detection efficiency trials aimed at quantifying the rate of CWT loss and missed detections suggest that a large percentage (ranging from 10% to 72%) of the CWTs deposited on the tern colony were not detected by researchers. Data also indicates that tag detection is associated with deposition date, with tags that have been on the colony for longer periods of time less likely to be recovered by researchers at the end of the tern nesting season. The detection efficiency of CWTs associated with the processing of substrate samples (i.e., the passing of colony substrate over magnets) was quite high (> 90% of test tags sown), suggesting that the methods used were effective at finding the vast majority of CWTs within the collected substrate. By measuring the detection efficiency of CWTs sown on-colony and by knowing the proportion of the total tern colony area that was sampled for CWTs, adjustments can be made to estimate the total number of CWTs deposited by terns on the colony during the nesting season (Evans et al. 2011). Predation rates on different groups of salmonids marked with CWTs can then be estimated by dividing the estimated total number of CWTs deposited on-colony by the total number of tags released. It is important to note, however, that the total number of CWTs deposited on a tern colony is not a proxy for the total number of CWT smolts consumed because an unknown proportion of CWTs are deposited off-colony (e.g., at loafing or staging sites not associated with the birds' nesting site), and we have no method of estimating this proportion (Evans et al. 2011). As such, values presented here represent minimums. Despite this caveat, our results regarding the relative susceptibility of CWT salmonid smolts from the Sacramento and San Joaquin rivers should not be biased due to either the loss of CWTs deposited on-colony or the off-colony deposition of ingested CWTs.

Impacts on Salmonid Survival

Overall, a very small percentage (ca. 0.1% or 15,793/11,398,725) of available CWTs from juvenile Chinook salmon from the Sacramento and San Joaquin rivers were estimated to have been deposited on the Brooks Island colony by Caspian terns during the 2010 breeding season. Of the fish consumed by terns, there was over-whelming evidence that smolts released directly into San Pablo Bay from net pens were the most susceptible, with CWTs from the Bay release group of fish 30 and 481 times more likely to be deposited than CWTs from Delta or In-river smolt release groups, respectively. The proximity of the net pen release locations in eastern San Pablo Bay to Brooks Island in central San Francisco Bay (~ 25 km), the timing of releases (during daylight hours), the duration of releases (April to June), and the large numbers of hatchery-reared juvenile salmonids in each net pen release are all likely contributing factors to the much higher susceptibility of the Bay release group to predation from Caspian terns nesting at Brooks Island. Previous studies have shown that Caspian terns tend to forage on the most available prey-types near the breeding colony when raising young (Lyons et al. 2005). Furthermore, hatchery-reared juvenile Chinook salmon have been shown to be more susceptible to Caspian tern predation as compared to their wild counterparts (Collis et al. 2001; Ryan et al. 2003).

Of the various run-types of CWT Chinook salmon from the Sacramento San Joaquin rivers (spring, winter, fall, and late-fall), fall-run and spring-run Chinook salmon were the most susceptible to predation by Brooks Island Caspian terns; 100.0% of all recovered CWTs were from these two run-types. By number, fall-run Chinook were the most commonly deposited CWT on Brooks Island, with 11,029 of 15,793 CWTs being fall-run Chinook. There was some evidence, however, that spring-run Chinook were more susceptible than fall-run Chinook relative to their availability at release. This finding is contrary to data collected in 2008 and 2009, when fall-run Chinook released from net pens were both the most numerous and the most susceptible run-type to predation by Brooks Island Caspian terns (Evans et al. 2010; Evans et al. 2011). It is not known why net pen released spring-run Chinook were depredated at a higher rate than net pen released fall-run Chinook in 2010. Differences in release timing, release numbers, fish behavior, or the size of spring-run Chinook relative to fall-run Chinook may be important.

Because this finding was limited to 2010 and the relative magnitude of the difference between run-types was small, however, it may not be a biologically meaningful difference.

Data presented here suggest that the impacts of Caspian terns on survival of wild or naturally-produced juvenile Chinook salmon from the Central Valley of California were minimal in 2010. Similar to results from 2008 and 2009, none of the wild fall-run Chinook salmon marked with CWTs and released in the Sacramento River were subsequently recovered on the Brooks Island Caspian tern colony. Furthermore, a very small number (N = 1) and proportion of all Chinook salmon released in-river were recovered on Brooks Island, a finding that supports the conclusion of minimal impacts to survival of wild fish because all wild Chinook salmon in the region (tagged and un-tagged) migrate in-river. Life history data on wild Chinook salmon populations from the Sacramento River (i.e., winter- and spring-run Chinook) indicate that the timing of smolt out-migration from stream to estuary is primarily between November and May (Yoshiyama et al. 1998), a period that only partially over-laps with the Caspian tern nesting season in the Bay Area. Conversely, both wild and hatchery fall-run Chinook salmon out-migrate to the estuary between March and July (Yoshiyama et al. 1998; Weber and Fausch 2004) and hatchery spring-run Chinook are released between April and May, periods that completely over-lap with the Caspian tern nesting season.

Differences in fish size, density, and behavior may also limit the impact of Caspian tern predation on survival of wild Chinook salmon smolts relative to their counterparts that are raised in hatcheries. Weber and Fausch (2004) reported that hatchery-reared Chinook salmon released into the upper Sacramento River were larger (fork length), emigrated later, and were more numerous than wild Chinook salmon of the same run-type. Data aimed at evaluating the in-river survival and timing of ocean entry – as opposed to emigration timing to the estuary – by wild and hatchery-reared smolts from the Sacramento and San Joaquin rivers would assist in quantifying and evaluating differences in susceptibility to Caspian tern predation between wild and hatchery-reared Chinook smolts.

Unfortunately, we were unable to evaluate the susceptibility of juvenile steelhead relative to the susceptibility of juvenile Chinook salmon to predation by Caspian terns because steelhead were not marked with CWTs during 2008-2010. Data from Caspian tern colonies in the Columbia River basin suggest that steelhead smolts are particularly susceptible to Caspian tern predation (Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005). Observations of the species of fish being delivered by Caspian terns to the Brooks Island colony (Caspian terns capture and deliver in their bills whole fish to their mates and young) in 2008 and 2009 indicated that only a small percentage were steelhead (ca. 2.5% in 2008 and ca. 1.7% in 2009). Whether these steelhead belonged to the threatened Central Valley or Central California Coast ESUs or to one of the other non-listed steelhead ESUs in the region is unknown, but the overall impact of Caspian terns on steelhead survival in San Francisco Bay is likely minimal given the scarcity of steelhead observed in the diet of Caspian terns nesting at Brooks Island.

In conclusion, results presented here provide over-whelming evidence that of the juvenile salmonids consumed by Caspian terns, the vast majority were hatchery-reared Chinook salmon that were being released *en masse* into eastern San Pablo Bay from net pens. Of these tern-depredated net pen fish, the majority were un-listed fall-run Chinook, although spring-run

Chinook (an ESA-listed species) were also being consumed. Data collected from Caspian terns nesting on islands in southern San Francisco Bay in 2009 indicated that terns consumed very few Chinook salmon smolts, regardless of the fish's run-type, rearing-type, or release location. The lack of CWTs from wild Chinook salmon or in-river migrating Chinook salmon supports the conclusion that impacts to the survival of naturally-produced salmonid smolts by Caspian terns nesting at colonies in the Bay Area were minimal.

ACKNOWLEDGMENTS

This project was funded by the U.S. Army Corps of Engineers (USACE), Portland District. We especially want to thank Paul Schmidt for his assistance and support during this study. We thank Kevin Neimela and Patricia Brandes from the U.S. Fish and Wildlife Service, Armando Quinones and Clint Garman from the California Department of Fish and Game, and Kari Burr from the Fisheries Foundation of California for providing support and information on CWT smolt releases. We thank Gary Shugart of the University of Puget Sound for providing initial guidance on ways to recover CWTs from tern nesting substrate. We are grateful to Steve Bobzien of East Bay Regional Parks District for granting access to Brooks Island and for his long-standing support of this research. A special thanks to our field crews for their assistance in recovering CWTs as part of this study.

REFERENCES

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

BRNW (Bird Research Northwest). 2010. Caspian Tern Nesting Ecology and Diet in San Francisco Bay and Interior Oregon: 2009 Final Annual Report submitted to the U.S Army Corps of Engineers – Portland District. Available on-line at www.birdresearchnw.org/.

Burger, J. 1984. Colony stability in least terns. Condor 86:61-67.

Collis, K., D.D. Roby, D. E. Lyons, Y. Suzuki, J.Y. Adkins, L. Reinalda, C. Hand, N. Hostetter, A.F. Evans, and M. Hawbecker. 2007. Research, monitoring, and evaluation of avian predation on salmonid smolts in the lower and mid-Columbia River: 2006 final season summary. Available: http://birdresearchnw.org. (September 2009).

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

Ellison, L.N., and L. Cleary. 1978. Effects of human disturbance on breeding of double-crested cormorants. Auk :510-517.

Evans, A.F. D. Roby, K. Collis, B. Cramer, J. Sheggeby, L. Adrean, D. Battaglia, and D. Lyons. 2011. Recovery of coded wire tags on a Caspian tern colony in San Francisco Bay: A technique to evaluate impacts of avian predation on juvenile salmonids. North American Journal of Fisheries Management. 31:79-87.

FFC (Fisheries Foundation of California). 2008. San Francisco Bay estuary acclimation of Central Valley hatchery raised Chinook Salmon Project, 2008 Final Report. Available from the Fishery Foundation of California. Elk Grove, CA.

Good, T.P., R.S. Waples, and P. Adams. (editors). 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. Technical memorandum NFMS-NWFSC-66, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.

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

NOAA Fisheries. 2008. Biological opinion, Endangered Species Act section 7(a)(2) consultation: consultation on remand for operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(1)(A) permit for Juvenile Fish Transportation Program. Seattle, Washington. Available: https://pcts.nmfs.noaa.gov/pls/pcts-pub/pcts_upload.summary_list_biop?p_id=27149. (September 2009).

Ramsey, F.L., and D.W. Schafer. 1997. The statistical sleuth. Duxbury Press, Belmont, California.

RMISD (Regional Mark Information System Database). Continuously since 1977. Regional Mark Processing Center, Pacific States Marine Fisheries Commission, Portland, Oregon. Available: http://www.rmpc.org. (August 2009.)

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

Strong, C.M., L.B. Spear, T.P. Ryan, and R.E. Dakin. 2004. Forster's Tern, Caspian Tern, and California Gull colonies in San Francisco Bay: Habitat use, numbers and trends, 1982-2003. Waterbirds 27:411-423.

Tremblay, J., and L.N. Ellison. 1979. Effects of human disturbance on breeding of black-crowned night herons. Auk: 364-369

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

USFWS (U.S. Fish and Wildlife Service). 2006. Record of Decision: Caspian tern management to reduce predation of juvenile salmonids in the Columbia River estuary, Final Environmental Impact Statement. U.S. Fish and Wildlife Service, Migratory Birds and Habitat Programs, Portland, OR.

Weber, E.D., and K.D. Fausch. 2004. Abundance and size distribution of ocean-type juvenile Chinook salmon in the upper Sacramento River margin before and after hatchery releases. North American Journal of Fisheries Management 24:1447-1455.

Yoshiyama, R.M., F.W. Fisher, and P.B. Moyle. 1998. Historical abundance and declines of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.