Grant County PUD/Priest Rapids Coordinating Committee

Evaluation of Foraging Behavior, Dispersal, and Predation on ESA-listed Salmonids by Caspian Terns Displaced from Managed Colonies in the Columbia Plateau Region

2015 Final Annual Report

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This 2015 Final Annual Report has been prepared for the
Grant County PUD/Priest Rapids Coordinating Committee.

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EXECUTIVE SUMMARY

The primary objective of this study in 2015 was to monitor and evaluate management initiatives implemented to reduce predation on U.S. Endangered Species Act (ESA)-listed populations of salmonids (*Oncorhynchus* spp.) by Caspian terns (*Hydroprogne caspia*) nesting on Goose Island in Potholes Reservoir and on Crescent Island in the mid-Columbia River. Specifically, this study was designed to evaluate dispersal of Caspian terns dissuaded from nesting on Goose and Crescent islands and changes in Caspian tern predation rates (number consumed/number available) on juvenile salmonids as a consequence of management.

In January 2014, the U.S. Army Corps of Engineers – Walla Walla District (Corps) completed the *Inland Avian Predation Management Plan* (IAPMP). The goal of the IAPMP is to reduce Caspian tern predation rates on ESA-listed salmonids from the Columbia River Basin to less than 2% (per colony and per ESA-listed population) by redistributing Caspian terns from the two largest colony sites in the Columbia Plateau region (i.e. colonies on Goose Island in Potholes Reservoir and on Crescent Island in the mid-Columbia River) to sites outside the Columbia River Basin. In 2015, the Corps and the U.S. Bureau of Reclamation (BOR) implemented Phase II of the IAPMP by installing a variety of "passive nest dissuasion" materials prior to the 2015 nesting season that were designed to prevent Caspian terns from nesting on either island. An effort was also made to prevent nesting by the two species of gulls that nest abundantly on both islands (California gulls [*L. californicus*] and ring-billed gulls [*L. delawarensis*]), on the theory that nesting gulls would attract prospecting Caspian terns and could limit the efficacy of efforts to dissuade Caspian terns from nesting on the two islands. Once Caspian terns and gulls arrived on Goose and Crescent islands to initiate nesting, active nest dissuasion (i.e. human hazing) was used in an attempt to dissuade both Caspian terns and gulls from nesting anywhere on either island.

Despite the lack of suitable Caspian tern nesting habitat on Goose Island in 2015, some Caspian terns displayed persistent fidelity to the Pothole Reservoir area throughout the nesting season, likely due to the history of Caspian tern nesting on Goose Island since 2004 and the presence of a large breeding colony of gulls on the island that continued to attract prospecting Caspian terns to the site. Another factor that might explain the strong site fidelity of Caspian terns to the Potholes Reservoir area is the paucity of alternative Caspian tern colony sites in the vicinity. Caspian tern use of Goose Island for roosting and nesting during 2015 was largely limited to areas near the shoreline where passive nest dissuasion had not been installed. Active nest dissuasion (hazing), collection of any Caspian tern eggs that were discovered, and high rates of gull predation on newly-laid Caspian tern eggs were successful in preventing the formation of a Caspian tern colony on Goose Island in 2015. A total of 43 Caspian tern eggs were found on Goose Island and nearby islets in 2015, and these eggs were laid in 39 different nest scrapes. Seventeen Caspian tern eggs were collected under permit, 23 tern eggs were

depredated by gulls soon after they were laid, and three tern eggs ultimately produced chicks. In the end, only two pairs of Caspian terns nesting in separate areas of the island succeeded in hatching eggs and raising young on Goose Island and nearby islets in 2015.

Passive and active nest dissuasion techniques were successful in preventing nesting and roosting by both Caspian terns and gulls on Crescent Island in 2015. This result was somewhat unexpected because it was the first year that nest dissuasion was implemented at Crescent Island and because Caspian terns and gulls have nested consistently on Crescent Island for nearly three decades. One factor that likely contributed to the absence of nesting Caspian terns on Crescent Island was the use of closely-spaced fence rows of privacy fabric as passive dissuasion over much of the suitable Caspian tern nesting habitat on Crescent Island; similar fencing was not deployed at Goose Island due to shallow, rocky soils. Another factor was the successful dissuasion of all gulls from nesting on Crescent Island in 2015; gulls are breeding associates of Caspian terns and attract prospecting Caspian terns to nest near their colonies. At Goose Island, gull nesting could not be prevented using the passive and active dissuasion techniques at our disposal, whereas at Crescent Island gulls never habituated to our hazing techniques and abandoned Crescent Island to establish a new colony on Badger Island (located on the mid-Columbia River just one kilometer upstream from Crescent Island) in 2015. Similarly, Caspian terns displaced from Crescent Island were able to relocate to an alternative colony site on the mid-Columbia River, the Blalock Islands (70 river kilometers downriver from Crescent Island), where Caspian terns have nested in small numbers over the last decade.

The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2015 was 769 breeding pairs at five separate colonies (i.e. the Blalock Islands on the mid-Columbia River [677 breeding pairs], Twinning Island in Banks Lake [64 breeding pairs], Harper Island in Sprague Lake [10 breeding pairs], an unnamed island in Lenore Lake [16 breeding pairs], and Goose Island in Potholes Reservoir [2 breeding pairs]). The estimated total size of the breeding population of Caspian terns in the Columbia Plateau region in 2015 was similar to the estimated population size in 2014 (755 breeding pairs), but still generally lower than the numbers observed during 2000-2013. These results suggest that although nest dissuasion actions implemented on Goose and Crescent islands in 2015 were highly effective in reducing the numbers of Caspian terns nesting at these two colonies, formerly the largest Caspian tern colonies in the region, they did not result in a significant reduction in the total number of Caspian terns breeding in the region to date. This was due to the more than 10-fold increase in the number of Caspian tern nesting in the Blalock Islands in 2015 compared to 2014. The Blalock Islands colony in 2015 was similar in size to the largest Caspian tern colony recorded anywhere in the Columbia Plateau region since intensive monitoring began in 2000.

Juvenile salmonids made up 67.3% of the diet of Caspian terns nesting on the Blalock Islands in 2015; this is consistent with results from previous years for Caspian terns nesting at Crescent Island. However, a larger proportion of the salmonids in the Blalock

Islands tern diet were steelhead (34%) compared to the tern diet at Crescent Island. We estimated that Caspian terns nesting on the Blalock Islands consumed ca. 550,000 juvenile salmonids in 2015 (95% CI = 310,000 – 800,000), including ca. 240,000 steelhead (95% CI = 130,000 – 350,000). Steelhead consumption by terns nesting at the Blalock Islands colony in 2015 was likely greater than at either Crescent Island or Goose Island in any previous year for which results are available.

After two years of implementation of the IAPMP, satellite-tracking of tagged Caspian terns has indicated several broad categories of response to management: (1) stay and search or compete for nest sites in reduced habitat, (2) move to a nearby colony and attempt to nest there, returning to the colony of origin if nesting fails, (3) engage in a long distance dispersal to a more favorable colony, or (4) wander nomadically across the Columbia Plateau region or a much larger area. Terns tagged at Potholes Reservoir in 2014 or 2015 have generally stayed nearby and searched for nesting habitat, moved to nearby colonies (Banks Lake, Sprague Lake) and returned to Potholes Reservoir when those colonies failed, or wandered nomadically, often across large portions of Washington, Oregon, and northeastern California. Terns tagged at Crescent Island in 2015 primarily moved to a nearby colony (the Blalock Islands), but a few individuals exhibited long distance dispersal to the Columbia River estuary. In 2015, several tagged terns visited constructed islands in interior Oregon and northeastern California, and a few of these visits were sustained and suggested possible nesting attempts. We did not detect any movement of satellite-tagged terns to the newly constructed tern islands at Don Edwards NWR in the San Francisco Bay area during 2015.

Drought across the Pacific Northwest likely limited dispersal of Caspian terns from the Columbia Plateau region to the islands constructed in interior Oregon and northeastern California. Low flows in the Columbia River led to greater availability of nesting habitat at the Blalock Islands due to exposure of low-lying islands that terns nested on there. Low winter snowpack in interior Oregon and northeastern California resulted in low water levels and limited nesting and foraging habitat, particularly at Crump Lake in the Warner Valley and Malheur Lake in the Harney Basin. Expected relaxation of regional drought conditions in 2016 may make colony locations outside of the Columbia River Basin more attractive as nesting locations to prospecting terns displaced from the Columbia Plateau region by management.

Resightings of Caspian terns that were previously color-banded indicated that some terns exhibited site fidelity to the Potholes Reservoir area, while the Blalock Islands experienced a large influx of terns from the Crescent Island colony in 2015. Evaluation of inter-regional movements of Caspian terns in 2015 revealed net movements to the Columbia Plateau region from the managed colony at East Sand Island in the Columbia River estuary, as well as from the Corps-constructed alternative colony sites in interior Oregon and northeastern California; the latter two regions experienced severe drought in 2015.

Recoveries of passive integrated transponder (PIT) tags on Caspian tern colonies were used to estimate predation rates (percentage of tagged fish consumed by terns) to evaluate the efficacy of tern management initiatives to increase smolt survival in the region. PIT tag data were also used to evaluate smolt consumption rates by other piscivorous colonial waterbirds (e.g., California gulls, ring-billed gulls, American white pelicans [*Pelecanus erythrorhynchos*], double-crested cormorants [*Phalacrocorax auritus*]) on juvenile salmonids. Results indicate that management efforts to reduce the size of the Goose Island and Crescent Island Caspian tern colonies were successful in nearly eliminating predation by terns from these two colonies in 2015, with predicted Caspian tern predation rates ranging from < 0.1% to 1.5% (depending on the ESA-listed salmonid population) at Goose Island and < 0.1% (for all salmonid populations) at Crescent Island. This likely was the first time since the Crescent Island colony of Caspian terns formed in 1986 when no salmonid smolts were consumed by Caspian terns nesting on Crescent Island. Predation rates on juvenile salmonids by Caspian terns nesting on Goose Island were lower in 2015 than in 2014 (< 1% to 2.9%), the first year of tern management, and significantly lower than predation rates observed during 2007-2013, prior to tern management. For instance, predation rates by Goose Island terns on ESA-listed Upper Columbia River spring Chinook salmon and steelhead averaged 2.5% and 15.7%, respectively, during 2007-2013.

Despite a dramatic reduction in predation rates on smolts by Caspian terns nesting on Goose and Crescent islands in 2015, a significant increase in predation rates was observed for Caspian terns nesting at the Blalock Islands (John Day Reservoir) and at Twinning Island (Banks Lake), colonies where terns dissuaded from Goose and Crescent islands relocated following the implementation of management actions in 2015. Predation rates were highest on steelhead, with an estimated 8.2% (95% CI = 5.9–12.4%) of Upper Columbia River steelhead consumed by Blalock Islands terns and 2.6% (95% CI = 1.8–3.9%) of Upper Columbia River steelhead consumed by Twinning Island terns in 2015. These predation rates exceeded the IAPMP target goal of < 2% per ESA-listed salmonid population for these two tern colony sites. Predation rates by Caspian terns nesting at the Blalock Islands were also substantial for Snake River steelhead, with an estimated 8.0% (95% CI = 6.0–11.8%) consumed by terns in 2015, the highest predation rate on Snake River steelhead recorded for any Caspian tern colony in the Columbia Plateau region since 2007. Predation rates on salmon populations were significantly lower than those on steelhead populations, with predation rates of < 2.0% for all ESA-listed salmon populations evaluated in 2015. Predation rates by Caspian terns nesting at all colonies in the Columbia Plateau region combined during 2015 were similar to or higher than those observed in previous years due to the large and unprecedented number of Caspian terns (677 breeding pairs) that nested at the Blalock Islands in 2015.

Estimates of consumption rates of juvenile salmonids by gulls nesting at certain colonies in the Columbia Plateau region were also substantial in 2015, particularly consumption by California gulls nesting on Miller Rocks (The Dalles Reservoir), Island 20 (McNary

Reservoir), and the Blalock Islands. Similar to predation on smolts by Caspian terns, consumption rates by gulls were generally highest on steelhead populations relative to salmon populations, with the highest consumption rates observed on Upper Columbia River steelhead by gulls nesting on Miller Rocks (13.2%; 95% CI = 8.3–21.1%), Island 20 (7.9%; 95% CI = 5.2–12.0%), and the Blalock Islands (6.1%; 95% CI = 3.4–10.5%). Gull consumption rates of Snake River steelhead were also substantial (9.7% by gulls nesting on Miller Rocks), but lower than rates observed for Upper Columbia River steelhead in 2015. Consumption rates of salmon populations by gulls nesting at colonies in the Columbia Plateau region were generally < 2.0%, with the exception of consumption of Upper Columbia River spring Chinook salmon (3.5%; 95% CI = 2.1–6.0%) and Snake River sockeye salmon (7.4%; 95% CI = 4.1–13.1%) by gulls nesting on Miller Rocks. Consumption rates by gulls from colonies in the Columbia Plateau region during 2015 were significantly higher than those observed at the same gull colonies in previous years, with a roughly 2- to 5-fold increase observed at some gull colonies in 2015. Further research is needed to better understand the mechanisms that influence fish susceptibility to consumption by gulls and why consumption rates were significantly higher in 2015, a year of reduced river flows and increased water temperatures, compared with previous years. Regardless of the reasons, smolt consumption rates associated with certain gull colonies were comparable to or higher than predation rates associated with Caspian tern colonies in 2015, and were some of the highest consumption rates associated with any piscivorous waterbird colony in the Columbia Plateau region since 2007. Predation by American white pelicans nesting at the Badger Island colony was, however, low (< 1.0% per ESA-listed salmonid population), indicating that pelicans nesting at this colony posed little risk to smolt survival in 2015.

To better understand the spatial and temporal distribution of smolt consumption by piscivorous colonial waterbirds in the middle Columbia River (i.e. from the tailrace of Rock Island Dam to just upstream of the confluence with the Snake River), detections/recoveries of acoustic tags and PIT tags implanted in juvenile steelhead and sockeye salmon (i.e. double-tagged smolts) were used to evaluate predation rates, specifically within the Priest Rapids Project. Results were based on last known detections of live fish passing telemetry arrays, coupled with the recovery of PIT tags from these fish on nearby bird colonies. Results indicate that an estimated 2.7% (95% CI = 1.7–4.4%) and 2.3% (95% CI = 0.2–4.7%) of tagged steelhead were consumed by Caspian terns within the Wanapum and Priest Rapids developments, respectively. Predation rates in 2015 were significantly lower than those observed prior to implementation of the IAPMP (4.0–10.1% per development, depending on the year). Avian predation rates on double-tagged sockeye salmon in 2015 (the only year analyzed) were estimated at 1.2% (95% CI = 0.5–2.3%) and 0.7% (95 CI = 0.1–1.6%) in the Wanapum and Priest Rapids developments, respectively, indicating that avian predators posed little risk to tagged sockeye smolts traveling through the middle Columbia River in 2015. Reductions in the number of Caspian terns nesting within foraging distance of the Priest Rapids Project is likely a contributing factor to recent improvements in survival of juvenile salmonids, particularly survival of steelhead, in the middle Columbia River.

INTRODUCTION

Avian predation is a factor limiting the recovery of some salmonid populations from the Columbia River Basin that are listed under the U.S. Endangered Species Act (Collis et al. 2002; Lyons et al. 2011; Evans et al. 2012). Caspian terns (*Hydroprogne caspia*), double-crested cormorants (*Phalacrocorax auritus)*, American white pelicans (*Pelecanus erythrorhynchos*), California gulls (*Larus californicus*), and ring-billed gulls (*L. delawarensis*) have all been identified as predators of anadromous juvenile salmonids in the Columbia Plateau region. Of these avian predators, Caspian terns have been determined to have the highest per capita (per bird) predation rates on juvenile salmonids, especially steelhead, a salmonid species known to be particularly susceptible to tern predation (Collis et al. 2001; Antolos et al. 2005; Evans et al. 2012).

Caspian terns are colonial fish-eating waterbirds that nest along coastlines, in estuaries, and at inland sites on major rivers and lakes (Cuthbert and Wires 1999). The breeding season for Caspian terns is generally from April through July (Cuthbert and Wires 1999). Caspian terns are considered strictly piscivorous and forage by plunge-diving into the water to capture fish near the surface. Records of Caspian terns nesting in southeastern Washington in the Columbia Plateau region date back to 1929 (Kitchin 1930), when a small nesting colony of Caspian terns was observed on Moses Lake, Washington. Recently, Adkins et al. (2014) reported five different Caspian tern colonies in the Columbia Plateau region during 2004-2009, ranging in size from an average of six breeding pairs on Harper Island in Sprague Lake, Washington to an average of over 400 breeding pairs on Crescent Island in McNary Reservoir on the Columbia River.

The two largest Caspian tern colonies in the Columbia Plateau region during the 2013 nesting season were located on Goose Island in Potholes Reservoir, WA, with an average colony size of 404 breeding pairs during 2008-2013, and on Crescent Island in McNary Reservoir, with an average colony size of 391 breeding pairs during 2008-2013 (BRNW 2014a). Caspian terns nesting on Goose Island are known to commute at least 30 km from Potholes Reservoir to the mid-Columbia River to consume anadromous juvenile salmonids (Maranto et al. 2010). Since 2008, and prior to recent tern management activities on Goose Island, estimated predation rates (number consumed/number available) on ESA-listed steelhead and Chinook salmon from the Upper Columbia River populations have averaged 15.7% and 2.5%, respectively, with predation rates as high as 20% in some years (Evans et al. 2012; BRNW 2014a). Lyons et al. (2011) estimated that the annual population growth rate (λ) of Upper Columbia steelhead would be increased by 4.2% for hatchery-raised smolts and 3.2% for wild smolts, if predation by Caspian terns nesting at the Goose Island colony was eliminated and compensatory mortality did not occur.

Survival standards for juvenile salmonids established under the 2004 Biological Opinion for the Priest Rapids Project (Wanapum and Priest Rapids dams and associated reservoirs) require at least 93% survival for juvenile salmonids through each hydropower development (one dam and associated reservoir; NMFS 2004). To evaluate whether these standards were met, the Public Utility District No. 2 of Grant County, WA (GPUD) conducted salmonid survival studies within the Priest Rapids Project during 2008-2010 and again in 2014 and 2015. Survival studies utilized double-tagged (acoustic tag and passive integrated transponder [PIT] tag) smolts to track fish behavior (travel times and routes) and to estimate survival (Timko et al. 2011). Results indicated that survival standards for steelhead were not being met in the Priest Rapids Development (Priest Rapids Dam and associated reservoir) during 2008-2010 and in the Wanapum Development in 2010 (Thompson et al. 2012). Estimates of predation rates by Goose Island Caspian terns on steelhead smolts tagged and released by the GPUD during 2008-2010 ranged from 12.8% to 20.8% of available steelhead smolts below Rock Island Dam (Evans et al. 2013), indicating that predation by Caspian terns was a substantial source of smolt mortality within the Priest Rapids Project. Comparisons between total steelhead mortality and mortality caused by Caspian tern predation indicated that between 37% and 85% of all steelhead mortality in the Priest Rapids Project during 2008-2010 was attributable to predation by Caspian terns from the Goose Island colony (Evans et al. 2013).

Resource management agencies (i.e. U.S. Army Corp of Engineers – Walla Walla District [Corps] and U.S. Bureau of Reclamation [BOR]) are now implementing a management plan aimed at reducing the impacts of Caspian terns that nest in the Columbia Plateau region (i.e. colonies on Goose and Crescent islands) on the survival of ESA-listed salmonids, in particular, steelhead smolts originating from the upper Columbia River and lower Snake River. In 2014, the Corps and BOR began implementation of Phase I of the Inland Avian Predation Management Plan (IAPMP) (USACE 2014) by reducing nesting habitat and actively discouraging Caspian terns from nesting on Goose Island in Potholes Reservoir. Implementation of Phase II of the IAPMP began in 2015 by actively discouraging Caspian terns from nesting at both Goose Island (Potholes Reservoir) and Crescent Island (mid-Columbia River). Proposed management initiatives are focused on reducing Caspian tern predation on Columbia Basin salmonids without adversely affecting the Caspian tern population in western North America. Achieving these objectives will require (1) redistribution of Caspian terns from breeding colony sites in the Columbia Plateau region to multiple dispersed colony sites elsewhere within their breeding range (USFWS 2005; Collis et al. 2012) and (2) identifying specific sites on the mid-Columbia River where Caspian tern predation pressure on smolts is high and implementing measures (i.e. adaptive management) to protect smolts at those locales. Additionally, actions taken as part of the IAPMP are best considered in the context of Caspian tern management at the large breeding colony on East Sand Island in the Columbia River estuary and elsewhere in the Pacific Flyway. Actions taken on East Sand Island and elsewhere have the potential to cause changes in colony size and predation rates by Caspian terns nesting at colonies in the Columbia Plateau region. Efforts to better understand colony connectivity, dispersal, foraging locations, and impacts on survival of salmonid stocks (predation rates) by Caspian terns from managed colonies would be instrumental in determining the efficacy of management actions in 2015 and beyond.

The work described here is part of a comprehensive program to monitor and evaluate the efficacy of avian predation management initiatives implemented to improve survival of ESA-listed juvenile salmonids from the Columbia River Basin in 2015 (BRNW 2015b, 2015c, 2015d, 2016). This study is a continuation of work funded by the PRCC during 2013-2014 (BRNW 2014a, 2015a), with the aim of investigating the outcome of management initiatives implemented at the Caspian tern colonies on Goose and Crescent islands in 2015. Specifically, we evaluated (1) habitat use by prospecting Caspian terns in response to nest dissuasion activities, (2) colony size and nesting success of Caspian terns at all active colony sites in the Columbia Plateau region, (3) dispersal of terns from Goose and Crescent islands to foraging locations and nest sites both within and outside the region, (4) immigration and emigration rates of Caspian terns to and from the Columbia Plateau region, (5) diet and stock-specific predation rates on salmonid smolts by Caspian terns and other piscivorous colonial waterbirds nesting in the region, and (6) total mortality of steelhead and yearling Chinook salmon smolts in the Priest Rapids Project and the proportion of that mortality that was attributable to predation by Caspian terns and other piscivorous colonial waterbirds.

STUDY AREA

Research was conducted at Goose Island in Potholes Reservoir, WA and Crescent Island in McNary Reservoir, WA; these two Caspian tern colonies were slated for management activities in 2015 as part of the IAPMP. Research and monitoring was also conducted at un-managed bird colonies that pose a potentially significant risk to the survival of juvenile salmonids originating from the upper Columbia River, with emphasis on predation on smolts in the vicinity of the Priest Rapids Project (*Map 1*). Tagging and release of juvenile steelhead and yearling Chinook salmon to measure predation rates by Caspian terns and other piscivorous colonial waterbirds was conducted at Rock Island Dam, WA. Dispersal of Caspian terns from the Goose Island and Crescent Island colonies was evaluated via satellite telemetry and resighting of previously color-banded birds, including investigations of dispersal to other locations (1) in the Columbia Plateau region, (2) in the Columbia River estuary, and (3) outside the Columbia River Basin.

SECTION 1: MANAGEMENT ACTIONS

In 2015, the Corps) and BOR continued implementation of the IAPMP in order to reduce predation by Caspian terns on ESA-listed populations of salmonids from the Columbia

River Basin (USACE 2014). The primary objective for management in the second year of implementation of the IAPMP was to reduce the size of the Caspian tern breeding colonies on Goose Island and on Crescent Island to less than 40 breeding pairs each. To accomplish this task (and with funding from the Corps and BOR), the availability of suitable Caspian tern nesting habitat was reduced on both islands by installing a variety of “passive nest dissuasion” materials prior to the 2015 nesting season that were designed to preclude tern nesting over extensive areas on both islands. Ultimately, about 4.1 acres, or more than 85% of the upland area on Goose Island and its surrounding islets, were covered with passive nest dissuasion materials consisting of stakes, rope, and flagging. On Crescent Island, about 2.2 acres of potential Caspian tern nesting habitat were covered with passive nest dissuasion materials consisting of fence rows of privacy fabric and woody debris, as well as stakes, rope, flagging. On both islands, passive dissuasion was placed over all of the former Caspian tern nesting area, as well as all areas of open, sparsely-vegetated habitat that might be used by ground-nesting Caspian terns or gulls (*Larus* spp.). An effort was also made to prevent nesting by the two species of gulls that nest abundantly on both islands, California gulls and ring-billed gulls, on the theory that nesting gulls would attract prospecting Caspian terns and could limit the ability to dissuade Caspian terns from nesting on the two islands. Once Caspian terns and gulls arrived on Goose and Crescent islands to initiate nesting, active nest dissuasion (i.e. human hazing) was used to dissuade both Caspian terns and gulls from nesting anywhere on either island.

As was the case the previous year (BRNW 2014b), California and ring-billed gulls quickly adapted and acclimated to both the passive and active nest dissuasion implemented on Goose Island, and initiated nesting (laid eggs) despite our efforts. Once gulls laid eggs, hazing gulls that were attending eggs was precluded due to the risk of causing gull nest failure during hazing disturbance. As the area on Goose Island with active gull nests expanded, the opportunities to actively haze Caspian terns that were prospecting for nest sites on Goose Island declined. As a consequence, 43 Caspian tern eggs were found in 39 different nest scrapes on Goose Island and nearby islets in 2015. Seventeen of these Caspian tern eggs were collected under permit, 23 eggs were depredated by gulls soon after laying, and three eggs produced chicks. During the 2015 nesting season, two pairs of Caspian terns each succeeded in hatching eggs and raising a single young on Goose Island and nearby islets.

In contrast to Goose Island, passive and active nest dissuasion activities were successful in preventing nesting and roosting by both Caspian terns and gulls on Crescent Island in 2015. This result was somewhat unexpected because it was the first year that nest dissuasion activities were implemented at Crescent Island and because Caspian terns and gulls have nested consistently on Crescent Island for nearly three decades. This result may be explained by differences in the types of passive nest dissuasion materials used at the two islands and the close proximity of suitable alternative nesting habitat for both terns and gulls near Crescent Island as compared to Goose Island.

See BRNW (2015b) for additional details regarding the implementation of the IAPMP in 2015.

SECTION 2: DISPERSAL, FORAGING, & COLONY CONNECTIVITY

2.1. Satellite Telemetry

As one component of our efforts to assist with the evaluation of management to displace Caspian terns from colonies in the Columbia Plateau region during 2014, we captured Caspian terns at Goose Island (Potholes Reservoir) at the beginning of the breeding season and fitted them with satellite telemetry tags. These terns were tracked throughout the 2014 breeding season, and results suggested that the initial implementation of dissuasion efforts at Goose Island successfully shifted some Caspian tern foraging activity away from foraging areas in the Priest Rapids project that were used by terns previously nesting on Goose Island (BRNW 2015a). Presumably, this shift in foraging activity reduced Caspian tern predation rates on juvenile salmonids within those reaches. As a continuation and expansion of the research we conducted in 2014, we again monitored tern dispersal, foraging site use, and colony connectivity using satellite telemetry during the 2015 breeding season. We continued to follow those terns with actively transmitting tags that were captured at Goose Island in 2014, and we also supplemented the sample with additional terns captured and tagged at Crescent Island (in McNary Reservoir) and again at Goose Island at the beginning of the 2015 breeding season. Our objectives during the second year of the study were similar to those during the first year, specifically to (1) describe the responses of terns to the loss of nesting habitat at Goose Island during the second year of management at that site, (2) describe the responses of terns to the loss of nesting habitat at Crescent Island during the first year of management at that site, (3) quantify the foraging activity of all tagged terns that remained within the Columbia Plateau region and specifically within the Priest Rapids Project compared to pre-management, and (4) identify locations that terns displaced from their historical nesting colonies at Goose and Crescent islands might seek to relocate and nest. During the second year of the study, satellite telemetry data continued to be used to evaluate dispersal patterns of Caspian terns displaced through management actions associated with the IAPMP, and to identify areas where terns continued to forage on juvenile salmonids in the Columbia Plateau region.

<u>Methods:</u> Telemetry tags capable of transmitting to the ARGOS satellite network have been used to track the activity of a variety of species, including large waterbirds (e.g., Courtot et al. 2012) for many years. Recently, they have become small enough to be attached to medium-sized birds, including Caspian terns. Tags using the ARGOS satellite network deliver less location precision (ca. ± 1 km) than GPS-based technology (ca. ± 10s of m), but consume less power and consequently offer greater flexibility in tag lifetime and weight. By incorporating a small external solar panel to recharge the on-board battery, these tags can achieve extended lifetimes (> 1 year). Although the long life-span

of these solar-powered tags allowed for the continued monitoring of most Caspian terns tagged in 2014 during the 2015 breeding season, we also captured additional terns and fitted them with satellite tags at the beginning of the 2015 breeding season to supplement our sample of actively transmitting tags. In 2015, we again trapped terns at Goose Island, but also captured terns at Crescent Island prior to initiation of active dissuasion (hazing).

Tagging – Caspian terns were captured using a Netblaster compressed air-powered net launcher (Wildlife Control Supplies, East Granby, CT) at the former colony sites on Crescent Island in McNary Reservoir and Goose Island in Potholes Reservoir (*Map 1*). At Crescent Island, an approximately 15 m x 15 m area of earlier erected passive dissuasion material on the historical colony site (fencing, ropes, and flagging) was temporarily opened to allow for deployment of the net launcher. Capture efforts at Crescent Island began on 28 March and concluded on 2 April, and dissuasion materials were immediately reinstalled to cover the exposed trapping area following the last tern capture. At the Goose Island colony site, materials covering the colony to dissuade tern nesting (stakes, ropes, and flagging) were also temporarily moved aside to allow capture. Trapping at Potholes Reservoir was initiated on 04 April and concluded on 21 April, after which the dissuasion materials were immediately redeployed to cover the historical nesting area. Terns were captured and tagged in small groups throughout each of the two capture periods.

Satellite tags were manufactured by Microwave Telemetry Inc. (Columbia, MD) and programmed to operate on a 32-hour duty cycle, with 6 hours “on” and 26 hours “off”, transmitting at a 60-second repetition rate during the “on” period of each cycle. Each tag incorporated a small solar panel that recharged a battery allowing transmission during daylight or nighttime hours. Tags weighed 12.4 – 12.9 g, not including harness materials, and were ≤ 2.2% of body mass for all individual terns tagged (body mass of tagged terns ranged from 590 g to 720 g).

In 2015, all satellite tags were attached using a leg-loop harness attachment based on those previously used on south polar skuas (*Catharacta maccormicki*) and northern fulmars (*Fulmarus glacialis*; Mallory and Gilbert 2008), and successfully used on Caspian terns captured at Goose Island in 2014. Terns fitted with a leg-loop harness rapidly adjusted to carrying the tag and resumed normal behavior shortly, if not immediately, following release. At the beginning of the 2015 breeding season, 23 of the 29 satellite tags deployed in 2014 were still attached and transmitting data. We deployed 28 additional tags on terns captured at the Crescent Island colony site and 18 on terns captured at Potholes Reservoir.

We also collected 5-7 breast feathers from tagged terns for DNA-based gender identification (Avian Biotech International, Tallahassee, FL).

Data filtering and analysis – Raw position fixes of tagged terns were reported daily by the Argos System (CLS America, Inc., Largo, MD). We used the Douglas Argos-Filter Algorithm (Douglas et al. 2012) to remove spurious locations from the raw data, using criteria similar to other seabird satellite telemetry studies (e.g., Courtot et al. 2012). For example, consecutive locations that would have required flight speeds > 80 km/h were discarded. Across all tags, a median of 8 filtered locations were retained during each 6-hour "on" cycle (range: 1 – 14 locations).

Foraging Activity – To describe the response of tagged Caspian terns to the reduction in nesting habitat at Goose Island, we characterized their activity within three geographic extents of potential interest:

1. Foraging areas of terns nesting at Goose Island in the past, prior to tern management activities (*Map 2*)
2. Reaches of the Columbia and Snake rivers above The Dalles, OR defined by mainstem dams operated by the Public Utility District No. 2 of Grant County, WA (GPUD) and the Federal Columbia River Power System (FCRPS)
3. The Columbia Plateau region (*Map 2*)

To represent foraging areas of terns nesting at Goose Island in the past, we used results from a tagging study conducted at Goose Island in 2013 (BRNW 2014a). In that study, terns nesting at Goose Island were captured during the peak steelhead smolt outmigration period in May (FPC 2014) and fitted with tags that collected location data using the Global Positioning System (GPS) satellite network. We used a 95% contour interval for a kernel density estimate based on all GPS locations within 60 km of the colony, but excluding locations within 500 m of the colony. The resulting extent included foraging areas on the Columbia River (Wanapum and Priest Rapids developments, Hanford Reach), Potholes Reservoir, Moses Lake, and Scooteney Reservoir (*Map 2*).

To describe use of the Priest Rapids Project and FCRPS river reaches we used geographic extents for the Columbia and Snake rivers (available from the U.S. Geological Survey National Hydrography Dataset at nhd.usgs.gov) from The Dalles Dam (Columbia River rkm 309) upstream to Rock Island Dam (Columbia River rkm 729) and Lower Granite Dam (Snake River rkm 177). An additional buffer width of 5 km per side of the river was added to the river extent to account for tag location uncertainty.

Finally, to describe tern use of the broad region, we defined the Columbia Plateau region to include the Columbia Plateau ecoregion boundary (as defined by the U.S. Environmental Protection Agency's Level III ecoregion classifications at www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm), truncated at the Washington/Idaho border to the east, the Washington/Oregon border to the south, and The Dalles Dam to the west (*Map 2*). This extent captures all the areas of the upper Columbia Basin where anadromous salmonid smolts have been found to be susceptible to predation by Caspian terns, and includes all of the colony sites used in recent years

(Goose Island in Potholes Reservoir, Crescent and Badger islands in McNary Reservoir, the Blalock Islands in John Day Reservoir, as well as colonies on islands in Banks Lake and Sprague Lake; *Map 1*). As with the river reaches, an additional 5 km buffer was added to the extent to allow for tag location uncertainty.

For each of these geographic extents we quantified the presence of each tagged tern during the primary smolt outmigration period, based on 95% fish passage at Rock Island Dam, WA (FPC 2014, FPC 2015). Specifically, we considered a tagged tern to be present during a given on-cycle if any of the locations recorded were within the given geographic extent. For each tagged individual, we calculated the proportion of "on"-cycles in which the tern was present in each geographic extent.

To quantify the foraging activity of terns still using the Columbia River reaches of primary concern to GPUD (Priest Rapids Project), we calculated the proportion of daytime locations that fell within the Priest Rapids Reservoir (i.e. the primary focal area of interest in 2015), and within the combined Hanford Reach, Priest Rapids Reservoir, and Wanapum Reservoir area for the subset of tagged terns that reported locations within those river reaches during the peak smolt outmigration period. We then calculated two metrics of proportional use, which were used to (1) estimate the relative time these birds spent during daylight hours in these areas across all days of each smolt outmigration period and (2) examine the pattern of visitation on days when these birds were present (i.e. did birds make short, isolated visits or extended and/or repeated visits during the days they visited?). First, as a measure of the relative time birds spent in the areas of interest, we calculated the proportion of all daytime locations collected during the smolt outmigration period that were within these defined areas. Proportions were first calculated for each bird, then averaged across all birds. Second, to examine the pattern of visitation within days, we limited the dataset for each tagged bird to only days when the bird was tracked to the areas of interest. The proportional within day use was tabulated for each bird and then averaged across all birds.

These proportional use measurements allowed for a comparison to tracking results in 2013, when Caspian terns nesting at Goose Island in Potholes Reservoir (prior to the initiation of management in 2014) were fitted with short-duration high-sampling rate GPS tags. The GPS tags deployed in 2013 collected location fixes approximately every four minutes, whereas the satellite telemetry tags deployed in 2014 and 2015 collected location information every few hours, with gaps in the number and quality of location data depending on the configuration of ARGOS satellites and other factors. It should also be noted that in our annual comparisons of daily use, the GPS tags only provided location data over a 1-week period within the smolt outmigration period, whereas the satellite telemetry tags provided location data across the entire outmigration periods of 2014 and 2015.

To investigate potential differences in use of areas upstream of Richland, WA, between 2014 and 2015, we compared the behavior of terns satellite-tagged at Potholes

Reservoir in 2014 during the smolt outmigration in 2014 and 2015. Potential differences in proportional use measures between terns tagged in 2013 (GPS telemetry locations), 2014, and 2015 (ARGOS satellite telemetry locations) were examined using Wilcoxon Rank Sum Tests.

We also used kernel density estimates (KDE) in ArcMap GIS software (ESRI, Redlands, CA) and Geospatial Modeling Environment software (Spatial Ecology LLC) to investigate relative use patterns. First, we calculated the 50% and 90% utilization distributions to assess the daytime core use areas and region-wide use areas by all satellite-tagged terns tracked to the Hanford Reach, Priest Rapids Reservoir, and/or the Wanapum Reservoir during the 2014 and 2015 smolt outmigration periods. Second, we calculated the 50% utilization distribution within the Columbia Plateau region during the peak of the 2014 and 2015 smolt outmigration periods to examine changes in the core daytime use areas of terns tagged at Potholes Reservoir 2014 that had been tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir in each of those years. Third, we calculated the 50% and 90% utilization distribution of nighttime locations for all of the satellite-tagged terns within the Columbia Plateau region to examine the relative use of potential nesting locations in the Plateau region as overnight roosting sites. Lastly, we examined differences in spatial use by satellite-tagged terns that reported locations within the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir and those that did not by calculating the 50% and 90% utilization distributions for each group during the peak steelhead smolt outmigration period in 2015. All KDE were calculated using either daytime (05:30 to 20:30) or nighttime (20:31 to 05:29) locations with a location error estimate of < 1000 m during the smolt outmigration period. This method incorporated the relative frequency of all use for the respective locations, and better captured daytime foraging activity and nighttime roosting patterns.

Colony Associations – To assess the potential breeding response to habitat loss at Goose and Crescent islands, we characterized the association of tagged birds with known colony sites across the Pacific Northwest. We considered possible use of currently or recently active colony sites, including those in the Columbia Plateau region, western Washington, southern British Columbia, Oregon, and northerneastern California (*Map 3*). It was not possible to exhaustively identify and confirm nesting status at all of the various colony sites through site visits and visual monitoring; however, direct observations were made in some cases. Instead of relying exclusively on visual observations to confirm that a tagged tern was associated with a particular breeding colony, we used nighttime location data to infer associations of tagged terns with specific colony sites. Nighttime location data provided an incomplete record of activity, however, as location data were collected only during 2-5 nights per week due to the 32-hour duty cycle. We defined a tagged individual to be associated with a specific colony on a particular day of the season if it had been positively and consistently located within a 10-km buffer of that colony throughout a 9-night period and had not been located within 10 kms of any other colonies during those same 9 nights. This definition of colony association was consistent with limited visual observations at active colony sites that were regularly monitored (primarily East Sand Island in the Columbia River estuary and the Blalock Islands in John Day Reservoir).

Results and Discussion: We collected location data for 69 satellite-tagged Caspian terns during the 2015 breeding season. Of the 28 tags deployed on Caspian terns in 2014, 23 were still actively transmitting location data at the start of the 2015 breeding season. Of these, 22 migrated north from Mexico to the Columbia Plateau region prior to the 2015 breeding season, and one individual remained in southern Mexico throughout the breeding season. Of the 22 tagged terns that returned north, 12 were male and 10 were female.

Of the 18 terns tagged at Goose Island in 2015, six were male and 12 were female. Three of the 18 terns satellite-tagged at Goose Island in 2015 had been previously banded; all three were banded at Goose Island (two as adults in 2011 and one as a chick in 2006). All three of the previously banded terns had been confirmed breeding at Goose Island in either 2013 or 2014. One individual had been confirmed breeding at Goose Island in 2013 and at Crescent Island in 2014.

Of the 28 terns tagged at Crescent Island in 2015, 17 were male and 11 were female. Of these 28 satellite-tagged terns, 13 had been previously banded between 2003 and 2013; 10 had been banded at Crescent Island (eight as adults and two as chicks) and three had been banded at Goose Island (two as adults and one as a chick). All of the previously banded terns had been confirmed breeding on Crescent Island in either 2013 or 2014. One tern fitted with a satellite tag at Crescent Island had also been tagged with a GPS tag at Goose Island in 2013.

Of the 69 satellite-tagged terns tracked during the 2015 breeding season, five tags ceased to transmit data during the April-July breeding season; a tern carrying one of these tags was observed alive at Goose Island on 29 June, but the cause of tag failure could not be confirmed in the other four cases. The last days of transmission for these tags were 1 May, 8 May, 21 May, 2 June, and 7 July.

Tracking of satellite-tagged Caspian terns, followed by on-the-ground site visits, led to the discovery of several previously unknown roosts and two locations where eggs were laid in 2015 that had no previous history of Caspian tern nesting attempts. One of these sites was the Finley Islands, a pair of low-lying gravel islands in McNary Reservoir 7 km upstream of Crescent Island (near the unincorporated community of Finley, WA). Several tagged and numerous untagged terns were observed roosting on these islands early in the breeding season, and one tern egg was discovered at the site on 18 April. Terns later abandoned the site for unknown reasons. Similarly, several tagged terns and numerous untagged terns were observed roosting on a low-lying island at the Marsh Unit impoundment in Columbia National Wildlife Refuge (NWR), south of Potholes Reservoir and 5 km from Goose Island. Terns were observed to have two active nests with eggs at this site during the first week of May, both of which later failed.

Foraging Activity (Priest Rapids Project) – For terns tagged at Potholes Reservoir in 2014, the proportion of birds using areas upstream of Richland, WA (*Table 1*), was generally similar in both 2014 and 2015: 36% and 35% of terns in this group were observed to visit the Hanford Reach in 2014 and 2015, respectively; 50% and 43% were observed to visit Priest Rapids Reservoir; and 39% and 43% were observed to visit Wanapum Reservoir. In 2015, only a few birds tagged at Crescent Island were observed to have visited the Hanford Reach (7%) and Priest Rapids Reservoir (4%), and no birds from this group were observed to visit Wanapum Pool (0%). A much larger proportion of birds tagged at Potholes Reservoir used these reaches, however; 35% and 56% of terns tagged in 2014 and 2015, respectively, were observed to visit the Hanford Reach; 43% and 50% were observed to visit Priest Rapids Reservoir; and 43% and 44% were observed to visit Wanapum Reservoir. These proportions for terns tagged at Potholes Reservoir in 2014, Potholes Reservoir in 2015, and Crescent Island in 2015 are shown in *Table 2*.

Although a few terns tagged at Crescent Island were observed upstream of Richland, WA, and between a third and a half of terns tagged at Potholes Reservoir were tracked to the Hanford Reach and the Priest Rapids Project during the smolt outmigration in both 2014 and 2015, the above summary only describes the portion of individual tagged terns that were detected in the river reaches of interest one or more times during the smolt outmigration period; it does not consider the frequency of use (i.e. amount of time) for these areas. Of those terns with reported locations in river reaches of interest within the Priest Rapids Project, we found that, for the duration of the smolt outmigration period in 2014 and 2015, a relatively small and similar ($p = 0.59$; Wilcoxon Rank Sum Test) proportion of all daytime locations of tagged Caspian terns were within the Priest Rapids Reservoir (mean proportions were 10% and 9% in 2014 and 2015, respectively; *Table 3*). This was also true for the combined Hanford Reach, Priest Rapids Reservoir, and Wanapum Reservoir, although slightly higher in 2014 ($\overline{x}$ = 25%) than in 2015 ($\overline{x}$ = 19%; $p = 0.02$; Wilcoxon Rank Sum Test). However, on days when when tagged terns were detected visiting a river reach of interest in 2014 and 2015, the majority of their daytime locations were within that area. We found that the proportion of daytime locations at the Priest Rapids Reservoir, when birds were present on a given day, was similar between 2014 ($\overline{x}$ = 87%) and 2015 ($\overline{x}$ = 80% $p = 0.08$; Wilcoxon Rank Sum Test), but for the three combined reaches was statistically higher in 2014 ($\overline{x}$ = 89%) than in 2015 ($\overline{x}$ = 76%, $p = 0.009$; Wilcoxon Rank Sum Test).

A mean of 5% of the 2013 daytime locations of nesting Caspian terns tagged at Goose Island were within the Priest Rapids Reservoir during the smolt outmigration period, and a mean of 13% were within the combined Hanford Reach, Priest Rapids Reservoir, and Wanapum Reservoir during this period. Statistical tests suggested that the proportion of all daytime locations that were within the Priest Rapids Reservoir in 2014 ($\overline{x}$ = 10%) and 2015 ($\overline{x}$ = 9%) were greater than seen in 2013, prior to management ($\overline{x}$ = 5%), but the comparison lacked a high degree of confidence (i.e. $p = 0.06$ and $p = 0.12$ for comparisons between 2013 and 2014, and between 2013 and 2015, respectively;

Wilcoxon Rank Sum Tests). The average proportion of daytime locations at the three combined river reaches was higher in 2014 ($\overline{x}$ = 25%) than in 2013 ($\overline{x}$ = 13%, p = 0.007; Wilcoxon Rank Sum Test); there was also a suggestion that use in 2015 ($\overline{x}$ = 19%) was higher than in 2013 (p = 0.067; Wilcoxon Rank Sum Test). During 2014-15, on days when terns were tracked to these areas, a substantially higher proportion of their daytime locations were at the Priest Rapids Reservoir ($\overline{x}$ = 87% and 80% in 2014 and 2015, respectively) and the combined Hanford Reach, Priest Rapids Reservoir, and Wanapum Reservoir ($\overline{x}$ = 80% and 89%) than for tagged terns in 2013 ($\overline{x}$ = 17% for the Priest Rapids Reservoir and $\overline{x}$ = 28% for all three reaches combined). Fewer tagged terns used the Hanford Reach and Priest Rapids Project during 2014-2015 than during 2013, but their use was modestly greater on average, and much greater on days when they were present, during 2014-2015.

During the 2015 smolt outmigration period, tagged terns were active across the Columbia Plateau region, with core daytime use areas located at Priest Rapids Reservoir, Potholes Reservoir, Banks Lake, and the Blalock Islands in John Day Reservoir, as well as near the former Caspian tern colony at Crescent Island below the confluence of the Columbia and Snake rivers (*Map 4*). In contrast, the core use areas of tagged terns in 2014 were spread across a larger number of sites, with Wanapum Reservoir, Hanford Reach, and Sprague Lake identified as core use areas, in addition to the sites listed above (*Map 5*). Our KDE analysis suggests that tern foraging activity above Richland, WA, was spread across the Hanford Reach, Priest Rapids Reservoir, and Wanapum Reservoir relatively equally in 2014; however, tern foraging activity was more concentrated in the Priest Rapids Reservoir compared to the other two reaches in 2015 (*Map 6*).

Identification of PIT tag scanning locations – In-season satellite tracking data and analysis of tern foraging hotspots at river reaches within the FCRPS identified several locations that we then photographed during scheduled aerial surveys, visited by boat to monitor for breeding activity in-season, and later scanned after the breeding season for smolt PIT tags deposited by Caspian terns. Those locations included Cabin Island and Mud Island just upstream of the Priest Rapids Dam near the town of Desert Aire (*Map 7*), a low-lying island in Marsh Unit 1 of Columbia NWR (located 5 km south of Goose Island), and multiple sand and gravel bars within the Hanford Reach (see *Section 4.1*).

Overnight roosts – In 2015, the core overnight roosting sites (i.e. 50% utilization distribution; *Map 8*) of terns satellite-tagged at Potholes Reservoir in 2014 and 2015 were located at Goose Island in Potholes Reservoir, the Blalock Islands in John Day Reservoir, and Twinning Island at Banks Lake. The 90% utilization distribution also included Harper Island in Sprague Lake. The core overnight roosting site of terns satellite-tagged at Crescent Island in 2015 was centered on the Blalock Islands (*Map 9*), but the 90% utilization distribution included Goose Island in Potholes Reservoir, Twinning Island, Harper Island, and Badger and Foundation islands upstream of Crescent Island.

Foraging Activity (Columbia Plateau Region and Pre-Management Foraging Area for the Goose Island Colony) – The percentage of satellite-tagged terns that remained in the Columbia Plateau region and within the foraging area defined by of terns nesting at Goose Island prior to tern management activities (*Map 2*) varied week to week during the breeding season. However, during the period of peak smolt outmigration in 2015, 91% of the terns tagged at Potholes Reservoir in 2014 with actively transmitting tags reported locations somewhere in the Columbia Plateau region, and 87% were detected within the foraging area defined by the 2013 GPS tag study at Goose Island. During that same time period, 94% of the terns tagged at Potholes Reservoir in 2015 reported locations in the Columbia Plateau region and 83% were detected in the pre-management Goose Island foraging area. Of the terns tagged at Crescent Island, 89% were located in the Columbia Plateau region during the peak smolt outmigration, but only 18% were detected within the historical Goose Island foraging area. The percentages of terns tagged at Potholes Reservoir in 2014, Potholes Reservoir in 2015, and Crescent Island in 2015 that were located in the Columbia Plateau region and detected in the pre-management Goose Island foraging area are shown in *Table 4*.

Foraging Activity (FRCPS River Reaches) – Of all of the foraging areas within the FCRPS, John Day Reservoir was used during the peak smolt outmigration in 2015 by the largest percentage of terns tagged at Potholes Reservoir in 2014 (52%), which increased from 32% during the comparable period in 2014 (*Table 5*). The percentage of these terns that were detected at McNary Reservoir declined in 2015 (17%) compared to 2014 (29%), but use of the Snake River reach between Lower Monumental Dam and Lower Granite Dam was similar (17% in 2015 versus 18% in 2014). The John Day Reservoir also had the greatest proportional use by terns tagged at Crescent Island in 2015, with 89% of those terns detected somewhere within that reach during the peak smolt outmigration. During that same period, 50% of Crescent Island tagged tern were detected within McNary Reservoir, 14% within Ice Harbor Reservoir on the Snake River, and 18% within the river reach between Lower Monumental and Lower Granite dams on the Snake River. The terns tagged at Potholes Reservoir in 2015 used the river reaches downstream of Richland, WA, to lesser extent than they did those river reaches above Richland during peak smolt outmigration. Of the terns tagged at Potholes Reservoir in 2015, 44% were detected at John Day Reservoir, 22% at McNary Reservoir, and 17% were detected on the Snake River between Lower Monumental and Lower Granite dams (*Table 6*).

Colony Use and Association – Some of the satellite-tagged terns were not detected at the Priest Rapids Project during the 2015 steelhead smolt outmigration, and not all tagged terns remained in the Columbia Plateau region throughout the outmigration period. The 50% and 90% utilization distributions for tagged terns in Washington, Oregon, and California, both terns that were detected at the Priest Rapids Project and those that were not, are shown in *Maps 10 – 11*. The 90% utilization distribution highlights that both groups of satellite-tagged terns were using a network of active and historical colony sites within the Pacific Northwest, and were not restricted to the Columbia Plateau region. The greatest use tagged terns was near colony sites in the Columbia Plateau region, however, particularly for those tagged terns that were detected at the Priest Rapids Project.

During the peak of the smolt outmigration period in 2015, terns tagged at Goose Island in 2014 and 2015 were detected near Goose Island (57% and 72% of tagged individuals, respectively), at Marsh Unit 1 in Columbia NWR (43% and 50% of tagged individuals, respectively), near a previously used nesting site in northern Potholes Reservoir (22% and 11% of tagged individuals, respectively), at Twinning Island in Banks Lake (43% and 61% of tagged individuals, respectively), at Harper Island in Sprague Lake (9% and 22% of tagged individuals, respectively), at a new tern colony site on Lenore Lake (9% and 6% of tagged individuals, respectively), at the Finley Islands in McNary Reservoir (4% and 6% of tagged individuals, respectively), and at the Blalock Islands in John Day Reservoir (43% and 44% of tagged individuals, respectively).

Outside of the Columbia Plateau region, 22% of terns tagged at Potholes Reservoir in 2014 and 11% of terns tagged at Potholes Reservoir in 2015 were detected near tern colonies in southeastern Oregon and northeastern California. Also, 22% of terns tagged at Potholes Reservoir were detected near colonies in the Salish Sea region of coastal Washington and British Columbia. No terns tagged at Potholes Reservoir in 2015 were detected near colony sites in the Columbia River estuary, but 9% of terns tagged at Potholes Reservoir in 2014 were detected in the Columbia River estuary (*Table 7*).

For terns tagged at Crescent Island in 2015, 86% were detected in the Blalock Islands in John Day Reservoir, 26% were detected near the Finley Islands in McNary Reservoir, 11% near Crescent Island in McNary Reservoir, 11% near Goose Island on Potholes Reservoir, 11% near Harper Island on Sprague Lake, 7% near Marsh Unit 1 in Columbia NWR, 7% near Twinning Island on Banks Lake, and 4% near the new tern colony on Lenore Lake. Outside of the Columbia Plateau region, 29% terns tagged at Crescent Island in 2015 were detected in the Columbia River estuary, 4% were detected near colonies in southeastern Oregon and northeastern California, and 4% near tern colonies in the Salish Sea region of coastal Washington and British Columbia. Regular and opportunistic monitoring at these alternative colony sites confirmed breeding activity by 14 of the 28 terns tagged at Crescent Island in 2015, and suggested that most terns that formerly nested at the Crescent Island colony moved to the Blalock Islands in 2015.

During 2014, the first year of tern management at the Goose Island colony, a Caspian tern nesting colony consisting of 156 breeding pairs formed on Northwest Rocks, a small rocky islet adjacent to Goose Island, Although there was some temporary dispersal of tagged terns away from Goose Island between mid-May and early June, many tagged terns remained associated with Goose Island and Northwest Rocks later in the nesting season (*Figure 1*). In 2015, Caspian terns were dissuaded from using Northwest Rocks as a satellite colony site, as well as at the main colony site on Goose Island, and only two pairs of Caspian terns successfully nested on Goose Island. Tagged terns continued to loaf at Goose Island during the day and roost on the island overnight, but none were actively nesting on Goose Island. Consequently, a smaller proportion of terns tagged at Potholes Reservoir demonstrated an association with Goose Island throughout the 2015 breeding season compared to 2014 (*Figure 2*). Nevertheless, a similar pattern of temporary dispersal away from Goose Island between mid-May and early June was again detected in 2015. The proportion of terns tagged at Potholes Reservoir that were associated with the colony at the Blalock Islands was greater in 2015 than in 2014, but was similar between years for the colonies at Sprague Lake and Banks Lake.

For the terns tagged at Crescent Island in 2015, the Blalock Islands provided the greatest attraction; about two-thirds of these terns were associated with the large colony at the Blalocks Islands during May (*Figure 3*). Several terns tagged at Crescent Island in 2015 also displayed sustained associations with the colony at East Sand Island in the Columbia River estuary, and to a lesser extent the small colony on Harper Island on Sprague Lake.

One tagged tern from Potholes Reservoir displayed a sustained association with the colony on a Corps-constructed island on Sheepy Lake, Upper Klamath NWR, CA, suggesting that the tern attempted to nest there. Two tagged terns, one each from Potholes Reservoir and Crescent Island, displayed sustained associations with the colony on a Corps-constructed island in Tule Lake NWR. One quarter to one third of tagged terns did not display a sustained association with any colony in 2015, however, suggesting either no nesting attempt or a very brief attempt.

Conclusions:

During 2015, satellite telemetry again proved to be a useful tool for documenting the response of Caspian terns to management at colonies in the Columbia Plateau region. Because passive and active dissuasion prevented Caspian terns from nesting on Crescent Island, and largely prevented terns from nesting on Goose Island, the sample of satellite-tagged terns helped identify patterns of breeding dispersal, the distribution of core foraging areas, and previously unknown locations where nesting attempts occurred in 2015, and may occur in the future. These observations of tern movements and space use were collected in near real time, which allowed for informed dialogue amongst regional resource managers. Data from satellite-tagged terns documented the continued presence of non-breeding terns within the Columbia Plateau region, data that would not otherwise have been available because observed terns could not be associated with a particular former breeding colony. Tracking satellite-tagged terns also facilitated locating alternative roosting sites where smolt PIT tag recovery efforts could be concentrated, documenting that non-breeding individuals were still contributing to mortality of juvenile salmonids in the study area.

Foraging Activity – Several measures of foraging activity within the Priest Rapids Project by satellite-tagged Caspian terns helped assess potential predation on juvenile salmonids: (1) The proportion of tagged Caspian terns that used the river reaches above

Richland, WA, during the smolt outmigration was approximately the same in 2014 and 2015; (2) 50% or less of terns tagged at Potholes Reservoir and < 10% of those tagged at Crescent Island were detected in the Priest Rapids Project or the Hanford Reach in 2015; (3) the Priest Rapids Project and the Hanford Reach were core day use areas in 2014, but only the Priest Rapids Reservoir was retained in the core day use area during 2015; (4) there was some evidence that those satellite-tagged terns that were detected at the Priest Rapids Project and the Hanford Reach in 2015 were spending more time there than did terns nesting at Potholes Reservoir during 2013, although only a fraction of satellite-tagged terns used these reaches during 2014 and 2015 (our best measure of time spent on these reaches was approximately twice in 2014 and 2015 what it was during 2013); and (5) on days when satellite-tagged terns were detected in the Priest Rapids Project and the Hanford Reach, they spent a larger proportion of the day on the river in 2014 and 2015 compared to 2013. These results suggest that many displaced terns have shifted their foraging away from the Priest Rapids Project, but the non-breeders that remained on the Columbia Plateau region still constituted a significant tern presence in the Project during 2014-15.

Colony associations – Analysis of sustained associations with known Caspian tern colonies indicated that the majority of satellite-tagged terns that nested in 2015 did so at locations within the Columbia Plateau region, primarily at the Blalock Islands colony, but also at the Banks Lake and Sprague Lake colonies. Several tagged terns were associated with the East Sand Island colony in the Columbia River estuary and with the Corps-constructed islands in the Upper Klamath Basin, but this was a minority of all tagged individuals. A large fraction of tagged terns (a quarter to a third) apparently did not make any sustained effort to breed during the 2015 nesting season.

Facilitation of PIT-tag recovery – The successful implementation of Caspian tern nest dissuasion at Goose and Crescent islands as part of the IAPMP reduced our ability to measure smolt predation rates by terns in the Columbia Plateau region (i.e. locations where non-breeding terns might deposit smolt PIT tags were less predictable). However, we were able to use the near real-time movement data from satellite-tagged terns to focus and direct our efforts to scan and recover smolt PIT tags deposited by Caspian terns away from the managed colonies in the Columbia Plateau region. Results from PIT tag recovery efforts at sites identified by satellite-tracking terns are described elsewhere in this report.

General – After two years of implementation of the IAPMP, satellite-tracking of tagged Caspian terns has indicated several broad categories of response to management: (1) stay and search or compete for nest sites in much reduced nesting habitat, (2) move to a relatively nearby colony and attempt to nest there, returning to the colony of origin if nesting fails, (3) engage in long distance dispersal to a more favorable colony site, or (4) wander nomadically across the Plateau region or a much larger area. Terns tagged at Potholes Reservoir in 2014-2015 have generally stayed nearby and searched for habitat, moved to nearby colonies (i.e. on Banks Lake, Sprague Lake) and returned to Potholes

Reservoir when those colonies failed, or wandered nomadically often across large portions of Washington, Oregon, and northeastern California. Terns tagged at Crescent Island in 2015 primarily moved to a nearby colony (the Blalock Islands), but a few individuals exhibited long distance dispersal to the Columbia River estuary. In 2015, several tagged terns visited Corps-constructed islands in interior Oregon and northeastern California, and a few tagged terns sustained these visits, suggesting possible nesting attempts. We did not detect any movement of satellite-tagged terns to the newly constructed tern islands at Don Edwards NWR in the San Francisco Bay area.

Ongoing drought across much of the Pacific Northwest likely limited Caspian tern dispersal from the Columbia Plateau region to the Corps-constructed tern islands in southeastern Oregon and northeastern California in 2015. Low Columbia River flows in 2015 enhanced availability of nesting habitat in the Blalock Islands on John Day Reservoir because low-lying islands were exposed. Low winter snowpack in interior Oregon and northeastern California resulted in low water levels and reduced nesting and foraging habitat, particularly at Crump Lake in the Warner Valley and Malheur Lake in the Harney Basin. Expected relaxation of regional drought conditions in 2016 may make colony locations outside of the Columbia River Basin more attractive as nesting locations to prospecting terns displaced by management.

2.2. Color Band Resightings

In 2015, we continued our efforts to resight previously color-banded Caspian terns at colonies in the Columbia Plateau region to help assess the consequences of various management initiatives implemented as part of the IAPMP (USACE 2014) and the Caspian Tern Management Plan for the Columbia River Estuary (USFWS 2005, 2006).

<u>Methods:</u> Caspian terns have been banded with a federal numbered metal leg-band and two colored plastic leg-bands on one leg, and a colored plastic leg-band engraved with a unique alphanumeric code on the other leg since 2005 (BRNW 2015a). Adult Caspian terns that were banded prior to the 2015 breeding season were resighted using binoculars and spotting scopes up to 7 days per week at Goose Island and up to 4 days/week at the Blalock Islands during the 2015 breeding season. As part of related but separate studies, resighting of previously-banded Caspian terns was also conducted at various sites in the Pacific Coast region during 2015 to evaluate movements of Caspian terns from the Goose Island and Crescent Island colony sites to sites outside the Columbia Plateau region. A data summary of banded Caspian terns resighted in 2015 is presented in a separate report (BRNW 2015b).

Multi-state analysis (Hestbeck et al. 1991, Brownie et al. 1993) in Program MARK (White and Burnham 1999) was used to estimate inter-regional movement probabilities of Caspian terns banded as adults during 2005-2014. Movement probabilities were estimated between three regions: the Columbia Plateau (including the Blalock Islands, Goose Island, and smaller colonies and loafing sites), the Columbia River estuary (including East Sand Island, Rice Island, and loafing sites), and Corps-constructed alternative colony sites (all the Corps-constructed tern islands in interior Oregon and northeastern California). *A priori* models were constructed to evaluate effects of transitions from one region to another and effects of year on movement probabilities. Models that incorporate location and year effects on resighting probabilities were included in this analysis, which allowed us to calculate unbiased probabilities of inter-regional movement rates despite resighting efforts that varied among locations and years. Akaike's Information Criterion (AIC) adjusted for small samples (AICc) was used to select the best model (Burnham and Anderson 2002) for estimating inter-regional movements. Based on movement probabilities between 2014 and 2015 from the best model, and the numbers of Caspian terns present at a colony in 2014, numbers of terns that moved between colonies from 2014 to 2015 were estimated.

Results and Discussion: A total of 222 previously color-banded Caspian terns were resighted in or near Potholes Reservoir, including on Goose Island, in 2015 (*Table 8*). The islands in northern Potholes Reservoir and in Marsh Unit 1 in Columbia National Wildlife Refuge are both within 10 km of Goose Island, and 10 of the 222 color-banded Caspian terns were resighted at one of those locations. Of the 222 banded Caspian terns that were resighted in or near Potholes Reservoir in 2015, 86% were previously banded at Goose Island, 7% were banded at Crescent Island (McNary Reservoir), 2% were banded at Sheepy Lake (Lower Klamath NWR, CA), 2% were banded at East Sand Island (Columbia River estuary), 1% were banded each at the Port of Bellingham (Puget Sound coast of Washington), at Brooks Island (San Francisco Bay), and at Crump Lake (Warner Valley, interior Oregon), and < 1% were banded at Malheur Lake in Malheur NWR, OR. (*Map 12*).

A total of 515 previously color-banded Caspian terns were resighted at the active Caspian tern breeding colony and loafing sites in the Blalock Islands (John Day Reservoir) during 2015 (*Map 12*; *Table 9*). Of these, 60% were previously banded at Crescent Island, 35% were banded at Goose Island-Potholes Reservoir, 2% were banded at East Sand Island, and 1% were banded each at the Port of Bellingham (WA), Sheepy Lake (CA), and Malheur Lake (OR), and < 1% were banded at Crump Lake (OR) (*Map 12*).

A total of 52 previously color-banded Caspian terns were resighted at a small colony on Twinning Island in Banks Lake. Of these, 81% were banded at Goose Island (Pothole Reservoir) and 19% were banded at Crescent Island (McNary Reservoir).

A total of 8 previously color-banded Caspian terns were resighted at a small colony on Lenore Lake, WA. Of these, 75% were banded at Goose Island (Potholes Reservoir) and 25% were banded at Crescent Island (McNary Reservoir) (*Map 12*).

In McNary Reservoir in the Columbia River, a total of five previously color-banded Caspian terns were resighted at non-breeding sites. One Caspian tern that was previously banded at Crescent Island was resighted at Borgans Island near Pasco, WA, two Caspian terns (one banded at Crescent Island and the other at East Sand Island) were resighted at the mouth of Snake River, and two Caspian terns (one banded at Crescent Island and the other at East Sand Island) were resighted at the Finley Islands (McNary Reservoir) (*Map 12*). At Priest Rapids Reservoir, four Caspian terns previously color-banded at Goose Island (Potholes Reservoir) were resighted loafing near Desert Aire. Five previously color-banded Caspian terns were resighted loafing at Cabin Island, also in Priest Rapids Reservoir (*Map 12*); however, positive identification of those banded individuals was not possible.

Of a total of 451 color-banded Caspian terns seen on Crescent Island in 2014, 262 terns (58%) were resighted elsewhere in 2015; some of these individuals were resighted at multiple locations in 2015. Of a total of 336 resighting records of these birds in 2015, 71% were resightings on the Blalock Islands, 9% were resightings in the Potholes Reservoir area, 8% were resightings on East Sand Island, 4% were resightings at Malheur Lake, 3% were resightings at Twinning Island (Banks Lake), 2% were resightings at Tule Lake NWR (CA), and 1% were resightings each in McNary Reservoir, Lenore Lake, East Link Impoundment at Summer Lake Wildlife Area (OR), and at an active colony on Rat Island in the Puget Sound, near Port Townsend, WA (*Map 12*; *Table 10*).

Of a total of 291 color-banded Caspian terns seen on Goose Island in 2014, 224 terns (77%) were resighted in 2015, either at Goose Island or elsewhere; some of these individuals were resighted at multiple locations in 2015. Of a total of 371 resighting records of these birds in 2015, 39% were resightings in the Potholes Reservoir area, 33% were resightings at the Blalock Islands, 10% were resightings at Twinning Island, 5% were resightings at Malheur Lake (OR), 4% were resightings each at East Sand Island (OR) and Tule Lake NWR (CA), 2% were resightings at Rat Island (WA), 1% were resightings each at Lenore Lake, an active tern colony in Everett (coastal Washington), and Priest Rapids Reservoir, and < 1% were resightings each at an active colony on Rice Island in the Columbia River estuary and at Sheepy Lake (CA) (*Map 12*; *Table 11*).

In summary, these results suggest that Caspian terns exhibited strong site fidelity to the Potholes Reservoir area, despite the second year of efforts to dissuade Caspian terns from nesting at Goose Island. Furthermore, band resightings in 2015 revealed where Caspian terns dissuaded from colonies on Goose and Crescent islands were recruited. The Blalock Islands experienced a large influx of nesting Caspian terns in 2015, both from the former colony on Crescent Island and the colony on Goose Island, but predominantly from Crescent Island. A much smaller influx of Caspian terns from Goose and Crescent islands was observed at other colonies in the Columbia Plateau region. Although the majority of Caspian terns that were dissuaded from nesting on Goose and Crescent islands remained in the Columbia Plateau region, some Caspian terns also dispersed to breeding or non-breeding sites along the coasts of Washington and Oregon, as well as to colonies in interior Oregon and northeastern California. These results offer some insight into locations where Caspian terns from the Columbia Plateau region would likely recruit back into the breeding population.

Out of 11 *a priori* models constructed in 2015, a model with transition (from one region to another) and year effects on inter-regional movement probabilities was selected as the best model, based on the smallest value of AICc. This model included an interaction term between transition and year effects, which allows movement probabilities to vary over years regardless of trends observed in other transitions. Movement probabilities of Caspian terns banded as adults from the Columbia Plateau region to the Columbia River estuary ranged from < 0.01% to 4.4% per year during 2006-2015, with the highest probability in 2015. This translates into an estimated movement of a total of 67 Caspian terns from the Columbia Plateau region to the Columbia River estuary (*Table 12*). Movement probability in the opposite direction was lower (1.4%) in 2015; however, because of the large size of the source colony at East Sand Island, estimated net movement of adult Caspian terns (the estimated number of terns that moved from one region to another, subtracted from the number of terns that moved in the opposite direction) from the Columbia River estuary to the Columbia Plateau in 2015 was 105 individuals. Although this number is small, it would partially off-set benefits to salmonids of tern management in the Columbia Plateau region and in the estuary because per bird predation rates on smolts are higher for terns nesting in the Columbia Plateau region compared to those nesting in the estuary, where marine forage fishes (anchovy, smelt, surfperch, etc.) tend to dominate the diet.

Based on the best model selected to estimate inter-regional movements (see *above*), movement probabilities of Caspian terns banded as adults from the Columbia Plateau region to the alternative colony sites on the Corps-constructed tern islands in interior Oregon and northeastern California ranged from < 0.01–10% per year during 2008-2015, with the highest probability in 2012 and 0.7% in 2015. This translates into an estimated movement of a total of 11 Caspian terns from the Columbia Plateau region to the Corps-constructed islands in 2015 (*Table 12*). Movement probabilities from colonies on the Corps-constructed islands to the Columbia Plateau region ranged from < 0.01% to 20% during 2009-2014, with the highest probability in 2014. The movement probability from the alternative colony sites to the Columbia Plateau remained high (19%) in 2015, despite management actions to prevent tern nesting at Crescent Island and Goose Island. Estimated net movement of adult Caspian terns from the Corps-constructed alternative colony sites to the Columbia Plateau region in 2015 was 282 individuals. The drought in interior Oregon and northeastern California during 2014 and 2015 not only made some of the Corps-constructed islands more accessible to terrestrial predators (e.g., raccoons), but also limited foraging habitat and prey availability within commuting distance for Caspian terns nesting on Corps-constructed islands (BRNW 2015a, 2015c). Two consecutive seasons (2014 and 2015) of high movement probability from the alternative colony sites to the Columbia Plateau region might have been partly due to available nesting habitat at Blalock Islands in John Day Reservoir and the strong fidelity by terns to Goose Island in Potholes Reservoir.

SECTION 3: SYSTEM- & COLONY-LEVEL MONITORING

The geographic scope of the IAPMP includes the 10 "at-risk" sites identified in the IAPMP and other sites within the Columbia Plateau region where Caspian terns displaced from colonies on Goose and Crescent islands may relocate following management (USACE 2014). These alternative colony sites (hereafter referred to as "prospective sites") include islands where Caspian terns have recently nested (i.e. within the last two years), including the Blalock Islands (John Day Reservoir), Twinning Island (Banks Lake), Harper Island (Sprague Lake), and Lenore Lake. Prospective colony sites also include sites where Caspian terns have previously, but not recently, nested, including Miller Rocks (The Dalles Reservoir), Three Mile Canyon Island (John Day Reservoir), Badger Island (McNary Reservoir), Foundation Island (McNary Reservoir), Cabin Island (Priest Rapids Reservoir), and Solstice Island (Potholes Reservoir) (Adkins et al. 2014). Other prospective colony sites may have no history of Caspian tern nesting, but may be attractive as new colony sites because of the presence of other colonially nesting waterbirds, such as Island 20 in the Richland Islands complex on the Columbia River (*Map 1*).

Periodic monitoring was conducted at all of these prospective colony sites to help evaluate the consequences of management actions implemented on Goose and Crescent islands in 2015 to reduce or eliminate those Caspian tern colonies. We sought to assess whether reductions in colony size associated with dissuasion of Caspian tern nesting at Goose and Crescent islands was compensated by commensurate increases in Caspian tern colony size at alternative sites within the Columbia Plateau region, where Caspian terns may continue to consume significant numbers of ESA-listed juvenile salmonids (see *below*).

Monitoring was conducted both at the system-level (region-wide) and the colony-level. System-level monitoring consisted of periodic, carefully-timed aerial photography surveys in the Columbia Plateau region to locate both active and incipient Caspian tern breeding colonies. Colony-level monitoring was accomplished by field crews stationed at both Goose Island and Crescent Island, as well as by a mobile crew, which periodically visited all active Caspian tern colonies in the Columbia Plateau region. Colony-level monitoring was to evaluate the efficacy of nest dissuasion efforts on Goose and Crescent islands in preventing Caspian terns from nesting at these two colony sites, and to estimate colony size, nesting success, and other colony metrics at unmanaged Caspian tern colonies in the Columbia Plateau region. System- and colony-level monitoring in 2015 was completed with cost-sharing from the Corps and BOR (see BRNW 2015b for more details on the methods and results presented below).

Methods: Periodic aerial surveys were conducted from a fixed-wing aircraft (Cessna 205; Gold Aero Flying Service) to determine the distribution of Caspian terns (both nesting and roosting) along the Columbia River from Bonneville Dam to Chief Joseph Dam, and on the lower Snake River from the mouth of the Clearwater River to the confluence with the Columbia River, as well as at sites that are within Caspian tern foraging range (~90 km) of the mid-Columbia and lower Snake rivers (*Map 13*). The objective of aerial surveys was to identify all active Caspian tern nesting colonies and large roost sites within the region. Three aerial surveys of the Columbia Plateau region, each lasting two days, were conducted during the 2015 nesting season on the following schedule: (1) on 23-24 April, early in the incubation period, to check for the presence of newly formed colonies; (2) on 15-16 May, late in the incubation period, to estimate colony size (numbers of breeding pairs), colony area, and habitat types occupied by nesting Caspian terns, as well as identify late-forming colonies; and (3) on 24-25 June, at the onset of the fledging period, to assess overall nesting success at active Caspian tern colonies. Aerial surveys followed established methods, including reconnaissance surveys to search for new Caspian tern colonies and photographic surveys of sites where nesting Caspian terns were expected to be present. When Caspian terns were observed on the ground on substrate that was potentially suitable for nesting, oblique aerial photography was taken using a digital SLR camera with an image-stabilizing, zoom lens. When in-flight observations of Caspian terns or post-flight digital image inspection revealed a potential Caspian tern breeding colony, ground- or boat-based surveys were conducted to assess the breeding status of Caspian terns using the site.

The frequency of ground-based and boat-based surveys of Caspian tern colony sites identified during aerial surveys varied from several times a week to once a month, depending on location and the amount and type of Caspian tern nesting activity observed at the site. These surveys were conducted at each site throughout the breeding season to determine Caspian tern use of each island (i.e., roosting or nesting), seasonal colony/island attendance, nesting chronology, colony size, and the outcome of any nesting attempts (i.e. nesting success). Estimates of colony size and nesting success at these colonies were based on counts of active nests (i.e. adult terns in incubating posture on the colony) and fledging-age terns (i.e. black-capped chicks on or near the colony), respectively. Caspian tern colony size, measured as the number of active nests or breeding pairs, was based on the maximum number of incubating terns counted on the colony, which is observed late in the incubation period (late May). Colony size was estimated from counts of attended nests that were visible in oblique aerial photography, and verified using ground counts conducted during the same time period. Nesting success was estimated from ground counts of the maximum number of fledging-aged terns counted on the colony at the onset of the fledging period (late June – early July). These ground counts were made by researchers from observation blinds or vantages at the periphery of the tern colony.

<u>Results and Discussion:</u> Caspian terns were confirmed present at 26 different sites during aerial surveys conducted in the Columbia Plateau region during the 2015 nesting season (*Map 13*; BRNW 2015b). The majority of sites (n = 21) were loafing sites, with no signs of nesting activity, and most of those (n = 16) were located on the mid-Columbia River (*Map 13*; BRNW 2015b). At all but five sites where Caspian terns were observed

on the ground during aerial surveys, Caspian terns were on substrates that were not suitable for nesting (e.g., exposed rocks, mud flats, or gravel bars subject to periodic inundation); subsequent air, land, and boat-based surveys suggested that Caspian terns did not attempt to nest at any of these 21 sites (BRNW 2015b).

Nesting activity by Caspian terns was detectable during aerial surveys and in oblique aerial photography taken at five historical breeding sites in 2015: (1) Goose Island (main island) in Potholes Reservoir (see *above*), (2) the Blalock Islands on the mid-Columbia River, (3) Twinning Island in Banks Lake, (4) Harper Island in Sprague Lake, and (5) an unnamed island in Lenore Lake (*Map 1*). Subsequent land- and boat-based surveys confirmed that these five sites supported active Caspian tern breeding colonies in 2015.

Blalock Islands – The Blalock Islands are located on the Columbia River in the John Day Reservoir near the town of Irrigon, OR, and are managed by the U.S. Fish and Wildlife Service as part of Umatilla National Wildlife Refuge. The island group consists of several sizable, permanently vegetated islands, as well as numerous low-lying gravel islands and mudflats that were created by the John Day Dam impoundment.

The Blalock Islands have been the site of multiple breeding colonies of several species of piscivorous waterbird, including Caspian terns, Forster's terns, California gulls, ring-billed gulls, great blue herons, great egrets, and black-crowned night-herons. Nesting by Caspian terns on the Blalock Islands was first detected in 2005, when six pairs attempted to nest on Rock Island (BRNW 2015a; Adkins et al. 2014), a low-lying gravel and cobble island in the eastern Blalock Islands. The history of Caspian tern nesting in the Blalock Islands during 2005-2014 is characterized by small colonies (average = 56 breeding pairs; range = 6–136 breeding pairs) that moved frequently among islands (six different islands used for nesting during 2005-2014), and experienced poor nesting success. Nesting attempts by Caspian terns on the Blalock Islands typically failed or nearly failed to raise any young, either due to nest predation by mammalian or avian predators, or due to high water levels in John Day Pool during the incubation period that inundated nesting areas (BRNW 2015a).

In 2015, Caspian terns were first seen in the Blalock Islands on 25 March, when 10 roosting adults were observed on Sand Island. The first evidence of nesting by Caspian terns at the Blalock Islands during 2015 was observed on 19 April when 12 attended Caspian tern nests, including three with eggs, were counted on Middle Island, a small low-lying gravel island near Anvil Island. In the weeks that followed, Caspian tern nests were also confirmed on Long Island (26 April) and Southern Island (30 April), two more small, low-lying gravel island near Middle Island. As many as ca. 1,300 Caspian terns and 649 attended Caspian tern nests were counted during field visits to the Blalock Islands from 19 April to 15 August. Using vertical aerial photography collected on 20 May 2015, during the peak of breeding, a total of 677 pairs of Caspian terns were estimated to have active nests on these three small islands in the Blalock Group; this represents more than a 10-fold increase in colony size compared to the average colony size during 2005-

2014 (*Figure 4*). We estimated that 247 young Caspian terns fledged from the Blalock Islands colony in 2015, or an average productivity of 0.37 young raised per breeding pair, the highest Caspian tern nesting success ever observed at the Blalock Islands (BRNW 2015a). As in previous years, inundation of tern nests due to fluctuations in reservoir level was a factor limiting colony size and nesting success at the Blalock Islands in 2015.

Twinning Island – At the southern end of Banks Lake, near Coulee City, WA, two volcanic islands with thin topsoil provide nesting habitat for colonial waterbirds. These two sites, Goose Island and Twinning Island, are owned by the U.S. Bureau of Reclamation and managed in cooperation with the Washington Department of Fish and Wildlife.

From 1997 to 2005, Caspian terns that nested at Banks Lake used Goose Island, north of Twinning Island, where colony size ranged from 10 to 40 breeding pairs (Adkins et al. 2014). In 2005, Caspian terns began nesting on Twinning Island (also called Dry Falls Dam Island), which is located in Banks Lake just north of Dry Falls Dam. The colony at Twinning Island grew from less than 10 breeding pairs in 2005 to 67 breeding pairs in 2014 (BRNW 2015a). Also, there are large mixed species colonies of California and ring-billed gulls on both Goose and Twinning islands, with over 3,000 breeding individuals counted on each island in 2009 (BRNW 2015a). Recently, no young Caspian terns have been fledged from the colony at Twinning Island, likely due to human disturbance (the island is situated directly across from a popular boat launch), mammalian predators (the island is approximately 300 meters from the mainland), and competition and nest predation from gulls that also nest on the island (BRNW 2015a).

In 2015, Caspian terns were first seen on Twinning Island on 8 April, when one roosting tern was observed. The first evidence of nesting on Twinning Island was confirmed on 1 May when three attended Caspian tern nests were counted on the colony. As many as 131 Caspian terns and 64 attended Caspian tern nests were counted in subsequent visits to Twinning Island between 1 May and 2 July. Based on counts from oblique aerial photography, a total of 64 breeding pairs of Caspian terns attempted to nest on Twinning Island in 2015, similar to the estimated colony size in 2014 (67 breeding pairs; *Figure 5*; BRNW 2015a). In 2015, the first Caspian tern eggs were observed at the Twinning Island colony on 5 May; however, all Caspian tern nesting attempts at the island had failed by 10 June (BRNW 2015a). The primary cause of Caspian tern colony failure in 2015 was thought to be a combination of avian and mammalian nest predation.

Harper Island – Harper Island is a privately-owned island located near the southwestern end of Sprague Lake between the towns of Ritzville and Sprague in east-central Washington. The island is located about 48 km from the nearest section of the Snake River. Harper Island is a steep-sided, rocky island approximately 10 acres in area and covered by upland shrub habitat, sparse herbaceous vegetation, and bare rock.

Nesting by Caspian terns on Harper Island in Sprague Lake was first documented in the late 1990s, and Caspian terns have nested sporadically there ever since (Adkins et al. 2014). During 2005-2011, estimates of Caspian tern colony size on Harper Island were generally very small (< 10 breeding pairs), before increasing about 6-fold in 2012, and then declining again to just 8 breeding pairs in 2014 (BRNW 2015a). The island has also been home to a large California and ring-billed gull colony and a double-crested cormorant colony (BRNW 2015a). As was the case at Twinning Island in Banks Lake, no young Caspian terns were apparently fledged from the Harper Island colony during 2012-2014; the cause[s] of colony failure is not known (BRNW 2015a).

In 2015, Caspian terns were first seen on Harper Island on 16 May, when three attended nests were confirmed to be active. As many as 17 Caspian terns and 10 attended Caspian tern nests were counted during visits to Harper Island from 16 May to 8 July. A total of 10 breeding pairs of Caspian terns apparently attempted to nest on Harper Island in 2015, similar to the estimated colony size in 2014 (8 breeding pairs; *Figure 6*; BRNW 2015a). In 2015, egg-laying was not visually confirmed at the Harper Island Caspian tern colony prior to colony abandonment, which was confirmed on 5 July; the cause[s] of colony failure in 2015, as well as colony failure the previous year (BRNW 2015a), is not known.

Lenore Lake – In 2014, an incipient Caspian tern breeding colony was discovered on a small unnamed island on Lenore Lake (just north of Soap Lake, WA), where two breeding pairs of Caspian terns were detected among nesting gulls. This Caspian tern colony was active again in 2015, growing to 16 breeding pairs. Caspian terns were first observed breeding at Lenore Lake on 18 June, shortly after the Caspian tern colony at Twinning Island (located 23 km away) failed. In addition to Caspian terns, double-crested cormorants and ring-billed gulls also nested on this small island. Six young Caspian terns were fledged from the colony in 2015, while no Caspian terns fledged from the colony the previous year.

Columbia Plateau region – In total, an estimated 769 breeding pairs of Caspian terns nested at five different breeding colonies in the Columbia Plateau region during 2015 (*Figure 7*). All but one of the Caspian tern colonies that were active in the region during 2014 were active again in 2015; the lone exception was the Crescent Island colony, where nest dissuasion efforts were successful in preventing any Caspian terns from nesting in 2015 (*Figure 8*). The estimated total population of Caspian terns nesting in the Columbia Plateau region in 2015 (769 breeding pairs) was similar to the estimated population nesting in the region in 2014 (755 breeding pairs), but still lower than the average breeding population observed during 2000-2013 (*Figure 7*; BRNW 2015a). These results suggest that although the nest dissuasion actions implemented on Goose and Crescent islands in 2015 were effective in eliminating (Crescent Island) or greatly reducing (Goose Island) the numbers of Caspian terns nesting at those sites, they did not result in a significant reduction in the total number of Caspian terns breeding in the region compared to 2014. The reason for this result was the more than 10-fold increase in the number of Caspian terns nesting at the Blalock Islands in 2015 (677 breeding pairs) relative to the average colony size during 2005-2014 (56 breeding pairs; *Figure 8*). This was the largest Caspian tern breeding colony ever recorded at the Blalock Islands (*Figure 4*) and similar in size to the largest Caspian tern colony recorded anywhere in the Columbia Plateau region since intensive monitoring began in 2000 (BRNW 2015a).

SECTION 4: PREDATION RATES ON JUVENILE SALMONIDS

4.1. PIT Tag Recoveries

Passive integrated transponder (PIT) tags are placed in juvenile salmonids and other fishes to study their behavior and survival following release. PIT tags provide specific information on each individual fish, including the species, rearing-type (hatchery, wild), and migration timing of each fish. A portion of these PIT-tagged fish are consumed by avian predators, and a portion of the ingested tags are subsequently deposited (regurgitated or defecated) on avian nesting colonies. For more than a decade, recoveries of PIT tags on bird colonies have been used to estimate predation rates (percentage of available fish consumed by birds) and to compare the relative susceptibility of different fish species and fish populations to avian predators in the Columbia River Basin (Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005; Maranto et al. 2010; Evans et al. 2012; Sebring et al. 2013; Hostetter et al. 2015).

The over-all goal of the IAPMP is to reduce predation rates on ESA-listed juvenile salmonid populations (distinct population segments [DPSs] or evolutionarily significant units [ESUs]) by Caspian terns nesting at colonies in the Columbia Plateau region to < 2% per salmonid population (USACE 2014). The main objectives for collecting PIT tag data as part of this study were to (1) estimate colony-specific Caspian tern predation rates on ESA-listed salmonid populations, (2) assess relative differences in these predation rates prior to and following tern management actions, and (3) to evaluate the impacts of other colonial waterbird species (California gulls, ring-billed gulls, American white pelicans, and others) on smolt survival in the region. Comparisons between current and previous predation rates were made in the context of management initiatives for Caspian terns nesting on Goose Island in Potholes Reservoir, WA, and Crescent Island in McNary Reservoir, WA, as a means of evaluating the efficacy of those initiatives in achieving IAPMP goals. Predation rates at un-managed but high-risk Caspian tern colonies, such as the colony on the Blalock Islands in John Day Reservoir and on Twinning Island in Banks Lake (USACE 2014), were also compared and contrasted prior to and following management activities. Finally, because Caspian terns are not the only fish-eating colonial waterbird that consumes juvenile salmonids, estimates of predation rates for selected piscivorous waterbird colonies were evaluated as part of this study.

<u>Methods:</u> A description of the methods used to calculate predation rates from PIT tags recovered on bird colonies is provided below and can also be found in Evans et al.

(2012) and Hostetter et al. (2015). In general, predation rates were derived using the number of PIT tags found on a given bird colony from the number available passing dams, and then adjusting for the proportion of consumed tags deposited by birds on their nesting colony and subsequently detected by researchers following the nesting season (see *Figure 9* for a conceptual illustration).

Availability of PIT-tagged smolts – The number of PIT-tagged smolts available to birds was based on the number interrogated (detected alive) passing Rock Island Dam (middle Columbia River), Lower Monumental Dam (lower Snake River), or McNary Dam (lower Columbia River), whichever dam was the nearest upstream dam(s) to the bird colony of interest. PIT-tagged smolts were grouped by ESA-listed salmonid population based on the species, run-type, rearing-type, and origin of each PIT-tagged fish detected (Evans et al. 2012). The designation of salmonid populations followed that of NOAA (2014), which included both wild and hatchery-reared fish. Smolt availability to avian predators was limited to fish detected passing dams during 1 April to 31 July, which reflects the periods of overlap in active smolt out-migration and avian nesting in the region (Evans et al. 2012; Adkins et al. 2014). Detection data from each dam were retrieved from the regional salmonid PIT Tag Information System (PTAGIS) database maintained by the Pacific States Marine Fisheries Commission (www.ptagis.org; PTAGIS 2015).

Rock Island Dam (RIS) was a particularly important location for PIT-tagged fish used in this study because it represents the upper-most foraging range for Caspian terns nesting in Potholes Reservoir, WA (Maranto et al. 2010; Evans et al. 2012; BRNW 2014a). Due to the limited number of PIT-tagged smolts annually interrogated passing RIS (FPC 2015), we captured, PIT-tagged, and released steelhead and yearling Chinook smolts as part of this study to supplement numbers of smolts available for predation analyses. A detailed description of sampling methods used to PIT-tag smolts at RIS are presented in BRNW (2014a). In brief, steelhead and yearling Chinook salmon smolts were captured at the RIS fish trap, PIT-tagged (*Biomark* Model HPT12), and released into the tailrace to resume out-migration. Smolts were randomly selected for tagging (i.e. tagged regardless of their condition, origin, and size) and tagged in concert with, and in proportion to, the run-at-large to ensure that the tagged sample was representative of the smolt population passing the dam (tagged and untagged). In addition to PIT-tagging, data on the size (fork length and weight) and external condition (disease, body injuries, descaling, and fin damage obtained via high resolution photography; see Hostetter et al. 2011 for details) were collected from each fish.

Recovery of PIT tags on bird colonies – Electronic recovery of PIT tags on bird colonies followed the methods of Evans et al. (2012). In brief, portable pole-mounted antennas (*Biomark*, model HPR) were used to detect PIT tags *in situ* during August through November, after birds dispersed from the breeding colonies. PIT tags were detected by systematically scanning the entire area occupied by birds during the nesting season (referred to as a “pass”), with a minimum of two passes or complete sweeps conducted of the nesting area at each colony. The area scanned by researchers was determined based on aerial photography of the colony site and visits to the colony by researchers during the nesting season.

In addition to recovering tags on avian nesting colonies, tags were also recovered at several avian loafing sites used by piscivorous birds during the smolt out-migration period. These sites were selected based on areas where satellite-tagged Caspian terns were routinely detected during the smolt out-migration period (see *Section 2.1* for details). The same PIT tag recovery methods used at breeding colonies were used at avian loafing sites.

Not all PIT tags deposited by birds on their nesting colony are subsequently found by researchers after the nesting season. PIT tags can be blown off the colony during wind storms, washed away during rain storm or flood events, or otherwise damaged or lost during the course of the nesting season (Evans et al. 2012). Furthermore, the detection methods used to recover PIT tags on bird colonies are not 100% efficient, with some proportion of detectable tags missed by researchers during the scanning process. To address these factors, PIT tags with known tag codes were intentionally sown (hereafter referred to as "control tags") on bird colonies to quantify PIT tag detection efficiency (see *Predation Rate Calculation* below for details). The sowing of control tags was conducted during two discrete periods: (1) prior to the arrival of birds (March to April) and (2) immediately following the fledging of young (July to August). These periods were selected because they encompassed the time period when juvenile salmonids were out-migrating as well as the nesting season of birds at each colony. Control tags were haphazardly sown throughout the entire area occupied by nesting birds at each colony. The total number of control PIT tags sown varied by colony, with sample sizes ranging from 50 to 200 PIT tags per colony (see *Results and Discussion*).

Not all smolt PIT tags that are ingested by birds are subsequently deposited on their nesting colony (Hostetter et al. 2015). A portion of PIT tags implanted in depredated fish are stolen by other predators (kleptoparasitized), damaged and rendered unreadable during digestion, or are excreted off-colony at loafing or other areas utilized by birds during the nesting season. Studies to quantify PIT tag deposition rates for nesting Caspian terns, double-crested cormorants, and California and ring-billed gulls were conducted during 2004-2013. Results from these studies were used to infer deposition rates at bird colonies in 2015 (see *Results and Discussion*). A detailed description of methods and results from these PIT tag deposition experiments are presented in Hostetter et al. (2015). Briefly, salmonids implanted with a PIT tag of known code were fed to nesting birds during discrete periods of the day (morning, evening) and throughout the nesting season (April to July), with the number of ingested PIT tags subsequently found by researchers on the colony following the nesting season (August – October) used to estimate deposition rates by different avian species.

No data are available to evaluate PIT tag deposition rates by American white pelicans nesting on colonies in the Columbia River Basin. As such, we assumed a deposition probability of 1.0 for white pelican colonies, resulting in estimates of predation rate that are minimums (see *Predation rate calculations* below). There were also no deposition rate data available for tags deposited by birds at mixed-species colonies because the particular predator species at these sites was unknown.

Predation rate calculations – Predation rates were modeled independently for each bird colony and each salmonid population. The probability of recovering a PIT tag from a smolt on a particular colony was the product of the three rates described above (see also *Figure 9*), (1) the probability that an available fish was consumed (θ), (2) the probability that the consumed PIT tag was deposited on-colony (ϕ), and (3) the probability that the deposited PIT tag was detected on-colony (ψ):

$$k_i \sim Binomial(n_i, \theta_i * \phi * \psi_i)$$

where k_i is the number of smolt PIT tags recovered from the number available (n_i) in week *i*. The probable values of these parameters were modeled using a Bayesian approach. The detection efficiency (ψ_i) and predation rate(θ_i) were each modeled as a function of time. The rate, ψ_i, that a deposited tag that was consumed in week *i* is detected is assumed to be a logistic function of week. That is:

$$\psi_i = \beta_0 + \beta_1 * i$$

where β_0 and $\beta_1$are both derived from non-informative priors (normal [0, 1000]).

Weekly predation rate, θ_i, is modeled as a random walk process with mean μ_θ and variance σ_θ^2, where:

$$logit(\theta_i) = \mu_\theta + \sum_{w \le i} \varepsilon_w$$

and $\varepsilon_w \sim normal(0,\ \sigma_\theta^2)\ \forall\ w$. We placed non-informative priors on these two hyperparameters: ilogit(μ_θ) $\sim uniform(0,1)$ and $\sigma_\theta^2 \sim uniform(0,20)$. This allows each week (*i*) to have a unique predation rate (θ_i), while still sharing information among weeks to improve precision.

Informative Beta (α, β) priors were used to infer deposition rates (ϕ) for each bird species and colony (see *Results and Discussion*). The shape parameters for these prior distributions was assumed to be α = 16.20 and β = 6.55 for tern colonies, α = 33.71 and β = 183.61 for gull colonies, and α = 15.98 and β = 15.29 for cormorant colonies (Hostetter et al. 2015).

Annual predation rates were derived as the sum of the estimated number of PIT-tagged smolts consumed each week divided by the total number of PIT-tagged smolts last detected passing the nearest upstream dam with PIT tag interrogation capabilities.

$$\sum_{all\ i}(\theta_i * n_i) \Big/ \sum_{all\ i}(n_i)$$

The derived annual predation rate constitutes the estimated proportion of available PIT-tagged smolts consumed by birds nesting at a particular colony in a given year.

We implemented all predation rate models in a Bayesian framework using the software JAGS accessed through R version 3.1.2 (RDCT 2014). We ran three parallel chains for 50,000 iterations each and a burn-in of 5,000 iterations. Chains were thinned by 20 to reduce autocorrelation of successive Markov chain Monte Carlo samples, resulting in 6,750 saved iterations. Chain convergence was tested using the Gelman-Rubin statistic ($\hat{R}$; Gelman et al. 2004). We report results as posterior medians along with the 2.5 and 97.5 percentiles, which are referred to as 95% Credible Intervals (95% CI). Predation rates were only calculated for salmonid populations where ≥ 500 PIT-tagged salmonids were interrogated passing an upstream dam in a given year to avoid imprecise results that might arise from small sample sizes of available PIT-tagged smolts (Evans et al. 2012).

Results from this predation rate modeling procedure were based on the following assumptions:

A1. PIT-tagged smolts last detected passing the nearest upstream dam were available for consumption by piscivorous colonial waterbirds nesting downstream.

A2. The consumption of a PIT-tagged smolt by a piscivorous colonial waterbird represents a predation event, as opposed to the scavenging of a dead or moribund fish.

A3. The predation, deposition, and subsequent detection efficiency for PIT-tagged smolts are all independent probabilities.

A4. The detection efficiency for control PIT tags sown on-colony by researchers were equal to those for PIT tags naturally deposited by birds on-colony.

A5. The deposition rates for PIT tags that were measured by studies in previous years (Hostetter et al. 2015; see *Results and Discussion* for further details) were equal to those of smolt PIT tags consumed by birds during the current study year.

A6. PIT tags from consumed fish were egested by avian predators within one week of the PIT-tagged fish being detected passing an upstream dam.

A7. PIT-tagged fish were representative of non-tagged fish belonging to the same population and passing the same detection site (dam).

Detections of PIT-tagged salmonids at dams upstream of bird colonies were deemed the most appropriate measure of fish availability to avian predators given the downstream movement of smolts, the ability to standardize data across sites, and the ability to define unique groups of salmonids by a known location and passage date (Assumption A1). Assumption A1 assumes all PIT-tagged fish last detected passing a dam were alive and available to predators downstream. If large numbers of fish halted their out-migration or died immediately following passage and prior to reaching the foraging range of the bird colony, however, estimated predation rates would be biased low. Assumption A2 is very likely true in the case of PIT-tagged smolts consumed by Caspian terns, American white pelicans, and double-crested cormorants. The veracity of Assumption 2 with regard to consumption of PIT-tagged smolts by California or ring-billed gulls is questionable, however, because gulls are known to scavenge dead and moribund fish in the tailrace of hydroelectric dams, as well as kleptoparasitize dead smolts from predators like Caspian terns. Scavenging or kleptoparasitism of dead or moribund PIT-tagged smolts would result in estimated predation rates by gulls that are biased high. The proportion of PIT-tagged smolts consumed by gulls that represent a predation event vs. a scavenging or kleptoparasitism event is not known, and is likely to vary among gull breeding colonies.

The fate of each PIT tag implanted in a smolt is assumed to be independent (Assumption A3). Lack of independence among PIT-tagged fish could potentially bias predation rates and overinflate credibility intervals. Detection efficiency estimates (Assumption A4) were generally high (see *Results and Discussion*), suggesting that any possible violations of Assumption A4 would have little effect on estimates of predation rates at most colonies. Deposition rate data collected during 2004-2013 (when multiple estimates of deposition rates were measured for each species of avian predator) showed no evidence of inter- or intra-annual trends in deposition rates (Assumption A5; Hostetter et al. 2015).

Assumption A6 relates to the use of the last date of live fish detection as a proxy for the date a PIT tag was deposited on a bird colony. This assumption needs to be only roughly true because detection efficiency did not change dramatically on a weekly basis. Assumption A7 relates to inference regarding the susceptibility to consumption of a PIT-tagged fish as it relates to that of all fish (tagged and untagged) from the same population. There are few empirical data to support or refute Assumption A7, except that the run-timing and abundance of PIT-tagged fish is often in agreement with the run-timing and abundance of untagged fish passing dams in the Columbia River Basin. In the case of Upper Columbia River steelhead and Upper Columbia River spring Chinook salmon sampled at RIS, fish were intentionally PIT-tagged in concert with the run passing the dam as part of this study to better ensure that a representative sample of fish were available for predation analyses.

<u>Results and Discussion:</u> Numbers of PIT-tagged smolts used in predation analyses varied by ESA-listed salmonid population and interrogation/release sites (Rock Island Dam, Lower Monumental Dam, McNary Dam). In general, numbers of PIT-tagged smolts originating from the Snake River were greater than those originating from the Upper Columbia River. Numbers of available PIT-tagged fish exceeded the 500 minimum

needed to generate reliable predation rate estimates for all ESA-listed populations, with the exception of Snake River sockeye last detected passing Lower Monumental Dam (n = 486).

A total of 7,069 steelhead smolts (5,105 hatchery, 1,964 wild) and 5,763 yearling Chinook salmon smolts (5,376 hatchery, 387 wild) were captured, PIT-tagged, and released at Rock Island Dam (RIS) as part of this study. Fish were tagged and released from 12 April to 11 June 2015. Fish were tagged in concert with, and in proportion to, the run-at-large (*Figure 10*), with sampling effort peaking in May for both species. Only 832 previously PIT-tagged steelhead and 367 previously PIT-tagged Chinook salmon were recaptured at the RIS trap, indicating that in the absence of our tagging project, inadequate numbers of fish would have been available for analyses of avian predation rates in 2015. All of the steelhead smolts PIT-tagged at RIS as part this study were ESA-listed Upper Columbia River steelhead. Not all of the yearling Chinook salmon smolts PIT-tagged at RIS, however, were from the ESA-listed spring-run because non-listed summer-run hatchery Chinook salmon are also released as yearlings into the middle Columbia River. Based on unique markings (a combination of fin clips and coded wire tags), a minimum of 606 of the yearling Chinook salmon smolts PIT-tagged at RIS were known ESA-listed spring-run Chinook, while the remaining fish were a mixture of ESA-listed spring-run and non-listed summer-run Chinook salmon.

Mean fork lengths were 192 mm (standard deviation [SD] = 24 mm) and 140 mm (SD = 18 mm) for steelhead and yearling Chinook salmon, respectively, tagged at RIS in 2015 (*Figure 11*). An evaluation of external smolt condition indicated that relative to prior years (2008-2014 for steelhead and 2013-2014 for yearling Chinook salmon), both species arrived at RIS in reduced condition in 2015 (*Figure 12*). Roughly 30% and 9% of steelhead and yearling Chinook salmon, respectively, had moderate-to-severe external signs of damage and disease (defined as presence of body wounds, > 20% descaling, fungal or viral infections, and/or > 50% fin damage; Hostetter et al. 2011). External body injuries were the most prevalent indicator of condition anomalies for both species, observed in 24% and 7% of steelhead and yearling Chinook salmon, respectively, in 2015. Similar to 2013-2014, yearling Chinook salmon captured at RIS generally arrived in better condition than steelhead, with relatively few descaled, diseased, or individuals with severe fin damage observed in 2015.

A total of 11 breeding colonies and 5 loafing sites were scanned for smolt PIT tags following the 2015 nesting season (*Map 14* and *Table 13*). From these locations, a total of 17,830 PIT tags from 2015 migration-year smolts (Chinook salmon, coho salmon, sockeye salmon, and steelhead combined) were recovered (*Table 13*). The vast majority of tags were recovered from breeding colonies (n = 17,120 or 96% of all recovered tags; *Table 13*). Of the breeding colony sites evaluated, the largest numbers of smolt PIT tags were found on the Blalock Islands Caspian tern colony (n = 7,294), followed by the Miller Rocks gull colony (n = 3,851), and the Island 20 gull colony (n = 1,164; *Table 13*). Of the loafing sites evaluated, the largest numbers of PIT tags were found on the Blalock

Islands (n = 382), followed by Mud Island (n = 147) just upstream of Priest Rapids Dam, and Marsh Unit 1 in Columbia NWR near Potholes Reservoir (n = 107; *Map 14* and *Table 13*). Both Mud Island and Marsh Unit 1 were sites routinely visited by satellite-tagged Caspian terns (see *Section 2.1*), but other piscivorous waterbird species (e.g., California gulls, American white pelicans, Forster's terns, and double-crested cormorants) may have also used these sites during the 2015 smolt out-migration period.

A total of 7,298 PIT tags from 2015 migration year smolts were recovered on two un-managed Caspian tern colonies (i.e. Blalock Islands and Twinning Island) following the nesting season, representing 43% of all smolt PIT tags recovered from bird breeding colonies in 2015 (*Table 13*). We did not attempt to recover PIT tags from the managed Caspian tern colonies (i.e. Goose Island and Crescent Island) in 2015 due to the paucity of nesting terns at each site; instead, predation rates by terns at these sites were predicted based on the number of terns observed at each site and estimated per capita (per bird) predation rates calculated in previous years (see *below* for further explanation). In comparison, a total of 9,222 smolt PIT tags were recovered from other piscivorous waterbird colonies, including gull colonies (five different colonies), American white pelican colonies (one colony), and mixed-species colonies (three different colonies) following the 2015 nesting season (*Table 13*). Of these, the majority of tags (n = 6,995 or 76%) were recovered from the five gull colonies (*Table 13*).

Caspian tern predation rates at managed colonies – Efforts to prevent Caspian terns from forming a colony on Goose Island in Potholes Reservoir through active and passive nest dissuasion methods were mostly successful in 2015 (see *Section 1*). In total, 39 Caspian terns nests were initiated and 43 tern eggs were laid, with only two breeding pairs successfully rearing young (see *above*). Most (40) of the tern eggs laid on Goose Island persisted for less than a day before they were either depredated by gulls (23 tern eggs) or collected by researchers (17 tern eggs) under permit. Despite the lack of sustained Caspian tern nesting attempts on Goose Island in 2015, adult terns were routinely observed roosting on Goose Island outside areas with passive nest dissuasion prior to and following daily hazing. On average, 28 adults (equivalent to 14 breeding pairs) were observed on Goose Island each week throughout the smolt out-migration period. Due to the paucity of sustained Caspian tern nesting attempts and the lack of a defined colony area for terns on Goose Island, PIT tag recovery was not conducted at Goose Island following the 2015 nesting season.

In lieu of actual PIT tag recoveries and for the purposes of providing a rough estimate of predation rates by Caspian terns present at Goose Island in 2015, we used information on the number of adult terns observed on Goose Island during the 2015 nesting season (14–39 breeding pairs, see *above*), coupled with per capita (per bird) predation rate estimates from 2008-2014 (based on actual PIT tag recovery efforts in those years) to predict Goose Island Caspian tern predation rates in 2015 (BRNW 2015b). Using this approach, BRNW (2015b) predicted that between 0.5% (based on 14 nesting pairs) and 1.5% (based 39 nesting pairs) of upper Columbia River steelhead were consumed by

Goose Island terns in 2015. By comparison, the average pre-management predation rate on Upper Columbia River steelhead by terns nesting on Goose Island was 15.7% (95% CI = 14.1–18.9%) during 2007-2013 (*Table 14*). For both colony size scenarios (14 pairs vs. 39 pairs), predicted Caspian tern predation rates on Upper Columbia River steelhead were below the IAPMP target goal of < 2%. Predicted predation rates on all other ESA-listed salmonid populations, including Upper Columbia River spring Chinook salmon, by Goose Island terns were < 0.2% in 2015, far below IAPMP target goals. In 2014, following the first year of tern management on Goose Island, predation rates were estimated at 2.9% (95% CI = 1.9–5.1%), with 156 breeding pairs persisting throughout the nesting season. Collectively, results indicated that management efforts in 2014 and 2015 aimed at reducing the size of the Goose Island tern colony have resulted in lower predation rates on ESA-listed salmonids, particularly on steelhead.

The Caspian tern colony at Crescent Island was completely eliminated in 2015, the first year that nest dissuasion activities were implemented at that site. There were no (zero) Caspian tern nests initiated and no Caspian tern adults observed, nesting or roosting, on Crescent Island during the smolt out-migration period. As such, PIT tag recovery was not conducted and the predation rates of Crescent Island terns on salmonid smolts were presumably small, if not non-existent, in 2015. By comparison, prior to management actions on Crescent Island, predation rates averaged 3.9% (95% CI = 3.5–4.6%) and 2.4% (95% CI = 2.2–2.8%) on Snake River and Upper Columbia River steelhead, respectively, during 2007-2014 (*Table 14*). Predation rates on salmon populations by Crescent Island terns prior to management were generally lower than those on steelhead, but benefits to salmon were also achieved in 2015 relative to previous years (*Table 14*).

In summary, analyses of smolt predation rates at managed Caspian tern colonies indicated that the IAPMP target goal of achieving predation rates less than 2% per ESA-listed salmonid population were met in 2015. Reduction in the size of the Caspian tern colony on Goose Island in 2015 suggests that predation rates on Upper Columbia River steelhead were significantly reduced compared with both 2014, the first year of management, and prior to management activities during 2007-2013. Similarly, a lack of Caspian tern nesting or roosting on Crescent Island resulted in predation rates of < 0.1% for all ESA-listed salmonid populations evaluated in 2015, a significant decrease relative to pre-management impacts. Presumably, this marks the first time since the Crescent Island colony was formed in the 1986 when no salmonid smolts were consumed by Caspian terns nesting on Crescent Island.

Caspian tern predation rates at unmanaged colonies – Following the nesting season, a total of 7,294 PIT tags from 2015 migration year smolts were recovered on the Blalock Islands Caspian tern colony (*Map 1 and Map 14*), the largest number of tags recovered on any individual bird colony in 2015 (*Table 13*). Recoveries of control PIT tags sown on the Blalock Islands colony indicated that detection efficiency ranged from 53% to 91% for PIT tags deposited between 1 April and 31 July 2015 (*Table 15*). Based on previous studies that empirically measured deposition rates for Caspian terns (Hostetter et al. 2015), deposition rates were estimated to be 71% (95% CI = 51–89%; *Table 16*).

Predation rates by Caspian terns nesting at the Blalock Islands were highest on steelhead populations, with estimated predation rates of 8.2% (95% CI = 5.9–12.4%) and 8.0% (95% CI = 6.0–11.8%) on Upper Columbia River steelhead and Snake River steelhead, respectively (*Table 17*). Predation rates on salmon populations by Blalock Island terns were significantly lower than those on steelhead, ranging from 0.4% (Snake River fall Chinook salmon) to 1.4% (Snake River spring/summer Chinook salmon; *Table 17*). Higher predation rates by Caspian terns on juvenile steelhead compared with salmon species are well documented in the published literature (Collis et al. 2001; Ryan et al. 2003; Evans et al. 2012). Possible explanations for the greater susceptibility of juvenile steelhead to tern predation include differences in the size (length) and behavior of steelhead compared with other salmonid species; steelhead smolts are generally larger and more surface-oriented compared with salmon smolts (Beeman and Maule 2006). Surface orientation is believed to render fish more vulnerable to predation by terns, gulls, and American white pelicans, species that forage in the top meter of the water column (Evans and Knopf 1993; Winkler 1996; Cuthbert and Wires 1999).

The overall number of smolt PIT tags recovered and the associated estimates of predation rates, particular on steelhead, by Caspian terns nesting on the Blalock Islands were significantly higher in 2015 compared with 2007-2014 (*Table 14*). In fact, impacts on steelhead smolts by Caspian terns nesting on the Blalock Islands were some of the highest recorded at any Caspian tern colony in the Columbia Plateau region since 2007 (*Table 14*). Significantly higher predation rates on smolts by terns nesting on the Blalock Islands in 2015 were due to the colony's much larger size in 2015 (677 breeding pairs) compared with previous years (average of 59 breeding pairs during 2007-2014). Data from Caspian terns satellite-tagged at Goose and Crescent islands in 2015 confirms connectivity between these two managed colonies and the colony in the Blalock Islands, with satellite-tagged terns displaced from Goose Island and, especially, Crescent Island relocating to nest on the Blalock Islands in large numbers in 2015 (see *Section 2.1*).

Following the nesting season, 604 PIT tags from 2015 migration year smolts were recovered on the Twinning Island Caspian tern colony (*Map 14*; *Table 13*). Recoveries of control PIT tags sown on Twinning Island to measure detection efficiency indicated that detection efficiency ranged from 58% to 87% for PIT tags deposited between 1 April and 31 July 2015 (*Table 15*). Based on previous studies that empirically measured deposition rates for Caspian terns (Hostetter et al. 2015), deposition was estimated at 71% (95% CI = 51–89%; *Table 16*).

Predation rates indicate that an estimated 2.6% (95% CI = 1.8–3.9%) of Upper Columbia River steelhead was consumed by Caspian terns nesting on Twinning Island in 2015 (*Table 18*), a rate that exceeds the < 2% target goal or threshold of the IAPMP (USACE 2014). Predation rates were below the threshold for all other ESA-listed populations, however, including Upper Columbia River spring Chinook salmon, with a predation rate of just 0.1% (95% CI = <0.1–0.9%; *Table 18*) by terns nesting on Twinning Island in 2015. It should be noted that these estimates are based on fish last detected alive in the tailrace of Rock Island Dam and that the tailrace of Rock Island Dam is roughly 70 km southwest of Twinning Island, with the closest reach of the middle Columbia River upstream of Rock Island Dam, roughly 50 km west of Twinning Island. Consequently, predation rates by Twinning Island Caspian terns that are based on smolt availability below Rock Island Dam may be underestimated to an unknown degree.

Predation rates on Upper Columbia River steelhead by Twinning Island Caspian terns were higher in 2015 (2.6%) compared with both 2014 (1.2%; the first year of tern management at Goose Island in Potholes Reservoir) and prior to implementation of the IAPMP (average of 0.1% during 2009-2012; *Table 14*). The number of terns attempting to nest on Twinning Island has also increased following tern management activities in the region, including terns that were initially satellite-tagged at Goose Island and relocated to nest on Twinning Island (see *Section 2.1*) during 2014-2015. Based on these findings, predation rates by terns nesting at Twinning Island on ESA-listed steelhead have increased since management was initiated and now exceed the IAPMP threshold. The productivity of terns nesting at the island has generally been low (few or no young raised each year), however, suggesting that Twinning Island may not be a suitable long-term colony site for Caspian terns. Nevertheless, Caspian terns nesting on Twinning Island consumed an appreciable number of Upper Columbia River steelhead, including fish within the Priest Rapids Project (see *Section 4.2* for additional details).

In summary, predation rates on ESA-listed salmonid populations by Caspian terns nesting on the Blalock Islands and, to a lesser extent, by Caspian terns nesting on Twinning Island were significantly higher than those observed during 2007-2014. At the Blalock Islands, increases in predation rates were commensurate with the increase in the size of the tern colony, with the colony size increasing from an average of 59 breeding pairs during 2007-2014 to 677 breeding pairs in 2015. Results suggest that predation rates by Caspian terns nesting on the Blalock Islands in 2015 were comparable to or higher than those of Caspian terns nesting on Crescent Island or Goose Island prior to the implementation of the IAPMP for most, but not all, of the salmonid populations evaluated. Consequently, the increased predation rates on salmonid smolts by Caspian terns nesting on the Blalock Islands and on Twinning Island likely offset the benefits to juvenile salmonid survival achieved by the reduction in the number of Caspian terns nesting on Crescent and Goose islands in 2015.

Gull consumption rates – Unlike Caspian terns, gulls are known to consume dead or moribund juvenile salmonids, and to kleptoparasitize (steal fish from) other piscivorous waterbirds, such as Caspian terns. Consequently, smolt PIT tag recoveries on gull colonies are more indicative of gull consumption rates of PIT-tagged smolts, rather than predation rates *per se*.

A total of 3,851 PIT tags from 2015 migration year smolts were recovered on the Miller Rocks gull colony following the nesting season (*Map 14*; *Table 13*). Detection efficiency ranged from 74% – 95% for tags deposited between 1 April and 31 July *(Table 15*). Based on previous studies that empirically measured deposition rates for California and ring-billed gulls (Hostetter et al. 2015), deposition rates were estimated to be 15% (95% CI = 11–21%; *Table 16*).

Smolt consumption rates by gulls nesting on Miller Rocks were the highest of any piscivorous waterbird colony in the Columbia Plateau region that was evaluated in 2015 (*Table 17* and *Table 18*). With the sole exception of consumption rates on Snake River spring/summer Chinook salmon (1.7%; 95% CI = 1.1–2.6%), consumption rates were greater than 2% for all salmonid populations evaluated. The highest recorded consumption rates by gulls nesting at Miller Rocks were 13.2% (95% CI = 8.3–21.1%) for Upper Columbia River steelhead and 9.7% (95% CI = 6.6–14.6%) for Snake River steelhead (*Table 17*). Unlike many of the other gull colonies evaluated, where consumption rates of salmon stocks were generally low, an estimated 7.4% (95 CI = 4.1–13.1%) of Snake River sockeye salmon and 3.5% (95% CI = 2.1–6.0%) of Upper Columbia River spring Chinook salmon were consumed by Miller Rocks gulls in 2015 (*Table 17*).

Consumption rates of smolts by gulls nesting on Miller Rocks are some of the highest observed for any piscivorous waterbird colony in the Columbia Plateau region since system-wide, multiple avian predator studies were first initiated in 2007 (Evans et al. 2012; BRNW 2013; BRNW 2014a; Evans et al. *in press*). For example, predation rates by Caspian terns nesting at Crescent Island averaged 3.9% and 1.1% on Snake River steelhead and Snake River sockeye, respectively, during 2007-2014 (*Table 14*). Hostetter et al. (2015) reported that consumption rates by gulls nesting at some colonies in the Columbia Plateau region were higher than previously reported in the published literature because previous estimates did not include a measure of on-colony PIT tag deposition rates. Data from BRNW (2014a) indicate that PIT tag deposition rates can be low for gulls because gulls macerate PIT tags in their gizzards following ingestion, resulting in a small fraction of ingested PIT tags being egested on-colony in readable/detectable condition. High smolt consumption rates by gulls nesting at some colonies (e.g., Miller Rocks) are associated with the large size of most gull colonies (an order of magnitude greater number of breeding pairs than nearby tern and cormorant colonies) and behavioral flexibility to exploit temporally available food sources (Ruggerone 1986; Winkler 1996).

Consumption rates of smolts by gulls nesting on Miller Rocks were higher in 2015 compared with the rates observed at the same colony in previous years. For example, Hostetter et al. (2015) estimated consumption rates on steelhead by Miller Rocks gulls averaged 6% (range = 3.9–10.0%) annually during 2008-2013. In comparison, an estimated 9.7% and 13.2% of Snake River and Upper Columbia River steelhead, respectively, were consumed by gulls nesting on Miller Rocks in 2015 (*Table 17*).

A total of 1,164 PIT tags from 2015 migration year smolts were recovered on the Island 20 gull colony (*Map 14*; *Table 13*). Recoveries of control PIT tags sown on the Island indicated that detection efficiency ranged from 78% to 89% for PIT tags deposited between 1 April and 31 July 2015 (*Table 15*). Based on previous studies that empirically measured deposition rates for California and ring-billed gulls (Hostetter et al. 2015), deposition rates were estimated to be 15% (95% CI = 11–21%; *Table 16*).

Consumption rates of salmonid smolts by gulls nesting on Island 20 were highly variable in 2015, ranging from a high of 7.9% (95% CI = 5.3–12.0%) for Upper Columbia River steelhead to a low of 0.3% (95% CI = < 0.1–2.1%) for Snake River fall Chinook salmon. In 2015, consumption rates by Island 20 gulls for both Upper Columbia River steelhead and Snake River steelhead (3.6%; 95% CI = 1.7–6.9%) were the highest observed among colonies of piscivorous waterbirds within foraging range of McNary Reservoir (based on colony location and species-specific foraging ranges; Evans et al. *in press*) (*Table 18*). Consumption rates of smolts by Island 20 gulls in 2015 were significantly higher than those observed in previous years (BRNW 2014a; BRNW 2015a). For example, BRNW (2015a) estimated that gulls nesting on Island 20 consumed an estimated 1.6% (95% CI = 0.9–2.9%) of Upper Columbia River steelhead in 2014. Although there was evidence that colony size (number of adults present on-colony) increased in 2015 (16,558 adults) compared with 2014 (14,475 adults), higher consumption rates in 2015 (i.e. a 5-fold increase in the estimated consumption rate on Upper Columbia River steelhead in 2015 relative to 2014) cannot be explained by changes in colony size alone.

Two separate gull colonies were present within the Blalock Islands complex in 2015, one on Anvil Island and the other on Straight Six Island. A total of 943 and 64 PIT tags from 2015 migration year smolts were recovered on Anvil Island and Straight Six Island, respectively (*Table 13*). Detection efficiency ranged from 85% to 98% on Anvil Island and from 72 to 98% on Straight Six Island (*Table 15*). Based on previous studies that empirically measured deposition rates for California and ring-billed gulls (Hostetter et al. 2015), deposition rates were estimated to be 15% (95% CI = 11–21%) for both colonies (*Table 16*).

Of the two gull colonies in the Blalock Islands, smolt consumption rates were significantly higher for gulls nesting on Anvil Island, with the highest rates observed on Upper Columbia River steelhead (6.1%; 95% CI = 3.4–10.5%) and Snake River steelhead (2.4%; 95% CI = 1.4–4.0%). In comparison, consumption rates by gulls nesting on Straight Six Island were < 1.0% for all salmonid populations evaluated in 2015 (*Table 17*). Of the salmon populations evaluated, consumption rates were highest on Snake River sockeye, with an estimated 1.1% (95% CI = 0.2–3.2%) consumed by gulls nesting on Anvil Island (*Table 17*). Two possible reasons for the higher smolt consumption by gulls nesting on Anvil Island compared to gulls on Straight Six Island are (1) differences in colony size (5,915 adult gulls counted on Anvil Island; 1,457 adult gulls counted on Straight Six island) and (2) differences in gull species composition (Anvil Island was dominated by nesting California gulls and Straight Six Island was dominated by nesting ring-billed gulls). Data from Hostetter et al. (2015) indicated that per capita (per bird) consumption of juvenile salmonids was greater for gull colonies dominated by California gulls compared to those dominated by ring-billed gulls. This difference in smolt consumption rates between the two gull species is likely due to differences in body size and energy requirements (Winkler 1996), as well as the proportion of the diet that consists of fish (Collis et al. 2002), both of which are greater for California gulls compared to ring-billed gulls.

Similar to trends observed at other gull colonies in the Columbia Plateau region in 2015, smolt consumption rates by gulls nesting on the Blalock Islands (Anvil Island and, to a lesser extent, Straight Six Island) in 2015 were significantly higher than those observed at the Blalock Islands gull colonies in previous years (BRNW 2015a; Hostetter et al. 2015). For example, in 2014 consumption rates of Upper Columbia River and Snake River steelhead by gulls nesting on Anvil Island were estimated at 2.3% (95% CI = 1.0–4.6%) and 1.4% (0.8–2.4%), respectively, about a half to a third of the rates observed in 2015.

A total of 973 PIT tags from 2015 migration year smolts were recovered on an area of Badger Island that was used exclusively by nesting gulls in 2015 (*Map 14*; *Table 13*). Control tags sown on the island after the nesting season indicated a detection efficiency of 94% (*Table 15*). Based on previous studies that empirically measured deposition rates for California and ring-billed gulls (Hostetter et al. 2015), deposition rates were estimated to be 15% (95% CI = 11–21%; *Table 16*).

Smolt consumption rates by gulls nesting on Badger Island ranged from a high of 4.1% (95% CI = 2.6–6.4%) for Upper Columbia River steelhead to a low of 0.1% (95% CI = <0.1–0.5%) for Snake River spring/summer Chinook salmon (*Table 18*). Like gulls nesting on Island 20, consumption rates were significantly higher for steelhead populations compared to salmon populations (*Table 18*). Estimates of consumption rates for gulls nesting at this colony in 2015 are likely underestimates because no measure of pre-season detection efficiency was possible; the Badger Island gull colony, which consisted of about 3,740 breeding adults, formed for the first time in 2015. Although there is no proof of what colony gulls that nested on Badger Island in 2015 originated from, it is likely that most, if not all, were gulls that previously nested on Crescent Island (6,404 adult gulls counted on Crescent Island in 2014; BRNW 2015a); dissuasion activities associated with the IAPMP completely eliminated the gull colony on Crescent Island in 2015 (see *Section 1*).

In summary, consumption rates by gulls from some breeding colonies were similar to or greater than the highest predation rates by Caspian terns from colonies in the Columbia Plateau region during 2015. Results from this study and those of Hostetter et al. (2015) and Evans et al. (*in press*) suggest that some, but not all, of the gull colonies in the Columbia Plateau region could pose a significant risk to smolt survival in the mid-Columbia River.

The reasons for higher smolt consumption rates by gull from certain colonies in 2015 compared with previous years is not known, but warrants further investigation given the levels observed at some colonies in 2015. There was evidence that the numbers of gulls nesting on Island 20, Anvil Island, and Miller Rocks were higher in 2015 compared with 2014 (BRNW 2015a), although increases in colony sizes (ca. 10% to 25% increases in the number of adults counted, depending on the colony) were not commensurate with increases in smolt consumption rates (ca. 200% to 500% increases, depending on the colony and salmonid population). In addition to colony size, other factors could explain increased smolt susceptibility to gull consumption in 2015 compared with previous years. For example, several measures of the river environment during the 2015 outmigration period suggest that smolts experienced some of the poorest conditions for survival in recent years. Daily water temperatures measured at McNary Dam were consistently higher in 2015 than daily averages during 2005-2014 (FPC 2015). In addition, daily outflow rates at McNary Dam were consistently lower in 2015 compared to those recorded during 2005-2014 (DART 2016). Consequently, measures of water transit time indicate that smolt travel times in 2015 were greater on average than in recent years (FPC 2015), potentially exposing fish to avian predators for longer periods of time. Evans et al. (*in press*) observed that gulls disproportionately consumed smolts near dams and hypothesized that smolts may be more vulnerable near dams as a result of (1) increased smolt travel times or delayed migration in the forebay of dams, (2) smolt morbidity or mortality associated with dam passage, or (3) smolts being temporarily stunned or disoriented by hydraulic conditions in the tailrace of dams. Gull consumption of smolts, however, is not limited to foraging near dams, with gulls consuming substantial numbers of smolts from open reservoirs as well (Evans et al. *in press*).

In addition to abiotic factors, such as river flow rate and water temperature, there was also evidence that smolts were in reduced external condition (disease, injuries, descaling) during the 2015 outmigration compared with previous years. Although similar studies are lacking for gulls, these factors (both biotic and abiotic) have previously been linked to higher avian predation rates on smolts by Caspian terns and double-crested cormorants nesting at colonies in the Columbia River Basin (Hostetter et al. 2012; BRNW 2014a). Finally, the number of gulls observed foraging in the tailrace of The Dalles Dam was greater in 2015 than that observed during 2012-2014, including increased foraging underneath avian exclusion wires near the spillway of the dam (B. Cordie, USACE Biologist, pers. comm.). Additional research to better understand the mechanisms that influence smolt susceptibility to gull consumption, such as river flows, water temperatures, degraded fish condition, and changes in gull colony size, seem warranted given the potential magnitude of smolt mortality associated with gull colonies in the Columbia Plateau region.

American white pelican predation rates – A total of 973 PIT tags from 2015 migration year smolts were recovered on the Badger Island American white pelican colony (*Table*

13). Control tags sown on the island after the nesting season indicated a detection efficiency of 66% (*Table 15*). No deposition rate data for American white pelicans nesting on Badger Island currently exist, so even after an adjustment for detection efficiency, estimated predation rates represent minimums for smolt losses to Badger Island pelicans during the 2015 nesting season.

Minimum smolt predation rate estimates for Badger Island pelicans were < 0.3% for all ESA-listed salmonid populations evaluated (*Table 18*). Minimum predation rate estimates in 2015 were very similar to those recoded during 2007-2013, with white pelican predation rates generally less than 0.5% in all years (Evans et al. 2012; BRNW 2013). It should be noted, however, that estimates of white pelican predation rates presented here and by Evans et al. (2012) do not incorporate smolt PIT tag loss due to off-colony deposition. In a study of trout predation by nesting American white pelicans in Idaho, Teuscher et al. (2015) estimated that deposition and detection efficiency of PIT-tagged trout consumed < 200 km from a pelican colony was approximately 30% (range = 10–60%). Applying this correction factor to the raw, unadjusted number of Upper Columbia River and Snake River PIT-tagged fish recovered on Badger Island, however, would not dramatically change estimates of predation rates, as predation rates would still be < 1.0% for these salmonid populations.

There is some evidence that predation rates by American white pelicans on smolts originating from the middle Columbia River, particularly sub-yearling Chinook salmon, may differ than those of smolts originating from upper Columbia and Snake rivers. For example, during 2010-2014 predation rates on Yakima River summer/fall Chinook salmon last detected at Prosser Dam (Yakima River; Rkm 76) ranged from 2.2% (95% CI = 1.6–3.0%) to 6.5% (95% CI = 5.2–8.0%), roughly 2-5 times greater than predation rates on Yakima River spring Chinook salmon and steelhead (BRNW, unpubl. data). These results should be interpreted cautiously, however, as summer/fall Chinook salmon originating from the Yakima River represent a small proportion of the overall ESU. Additional research on smolt predation rates by Badger Island white pelicans should consider factors that potentially make smolts out-migrating from smaller tributaries more susceptible to pelican predation (e.g., low flows, diversion dams, fish congregating in shallow water habitats; Evans et al. 2012; Hostetter et al. 2012).

In addition to PIT tags from juvenile anadromous salmonids, we continued to find PIT tags from adult anadromous salmonids on the Badger Island white pelican colony; 22 PIT tags from adult salmonids tagged in 2015 were recovered on the Badger Island pelican colony after the 2015 nesting season. PIT tags were from adult sockeye salmon (n = 12), adult steelhead (n = 7), and adult Chinook salmon (n = 3 jack salmon) tagged at the Bonneville Dam fishway during upstream migration or as post-spawn steelhead (kelts) returning to the ocean. Fish ranging in size from 480 mm fork length (sockeye salmon tagged at Bonneville Dam fishway) to 695 mm fork length (steelhead tagged at Bonneville Dam fishway) were consumed by Badger Island pelicans.

Mixed-species predation rates – Two small breeding colonies of double-crested cormorants and great blue herons (*Ardea herodias*) were present on two adjacent islands in the Hanford Reach of the middle Columbia River during the 2015 nesting season (*Map 14; labeled as "Hanford Reach sites"*). These colonies were located on islands at a sharp bend in the river just above White Bluffs at ca. Rkm 601. Most nests at one of these colonies were of double-crested cormorants, but great blue heron nests were also present, so tags recovered on the ground underneath trees containing nests could not be assigned to a particular species of avian predator. The other small colony was used only by great blue herons. A total of 171 PIT tags from 2015 migration year smolts were recovered on the mixed-species breeding colony. No measures of detection or deposition rates were available, however, resulting in minimum estimates of predation rates. Minimum predation rates were < 0.3% for all salmonid populations evaluated, with predation rates on Upper Columbia River spring Chinook salmon (0.2%; 95% CI = < 0.1–0.7%) the highest observed (*Table 18*). If deposition and detection rates were similar to those measured at other cormorant colonies in the region in previous years (i.e. cormorants nesting on nearby Foundation Island in McNary Reservoir), best estimates of predation rates would be approximately 2-3 times higher than those reported here. Even with these adjustments, however, predation rates would still be < 1.0% for all salmonid populations evaluated in 2015.

A small mixed-species colony of Caspian terns (16 breeding pairs) and double-crested cormorants (39 breeding pairs) formed in 2015 at a small gull colony on an un-named island in Lenore Lake, located east of the middle Columbia River and south of Banks Lake (*Map 14*). Due to a infrequent in-season surveys at this site and the close proximity of the three species of piscivorous waterbirds nesting on the island, we could not assign each scanned tag to a particular species of avian predator. However, only one PIT tag (n = 1) from a 2015 migration year smolt was recovered on the nesting island following the breeding season. No data on detection or deposition rates were available for this colony, but because just a single smolt PIT tag was found, predation rates were apparently negligible. Minimum predation rate estimates were < 0.1% for all salmonid populations evaluated (*Table 18*).

The formation of a new gull colony on Badger Island in 2015 (see *above*) resulted in a section of the island where American white pelicans and gulls nested in close proximity to one another, forming a mixed-species colony area where PIT tags recovered by researchers after the nesting season could not be assigned to a particular species of avian predator. A total of 1,068 PIT tags from 2015 migration year smolts were recovered on this mixed-species area of the colony following the nesting season (*Table 13*). Control tags sown on the island after the nesting season indicated a detection efficiency of 66% (*Table 15*). Again, no data on deposition rates are available for this mixed-species area of the colony, so predation rates represent minimum estimates of smolt losses.

Minimum predation rates by the mixed-species area of the colony on Badger Island were similar to minimum predation rate estimates for the Badger Island American white pelican colony, with < 0.4% of each available salmonid population consumed (*Table 18*).

The total smolt consumption rate by colonial waterbirds (gulls and pelicans combined) nesting on Badger Island in 2015 was the highest observed since PIT tag scanning on the island was first conducted in 2007 (Evans et al. 2012). The increase in smolt consumption rates in 2015 compared with previous years is primarily associated with the newly established gull colony on Badger Island. Because most, and perhaps all, of the gulls nesting on Badger Island in 2015 were likely from the former gull colony on nearby Crescent Island, however, some of the impact of gull predation on smolt survival in McNary Reservoir may have simply shifted from the Crescent Island colony to the Badger Island colony in 2015.

Cumulative avian consumption rates – The representative smolt tagging that occurred at Rock Island Dam (RIS) in 2015, as well as the dam's geographic location – the farthest upstream sampling location used in this study – provides an opportunity to evaluate cumulative (all piscivorous waterbird colonies combined) avian consumption rates on steelhead and yearling Chinook salmon tagged as part of this study. These results can provide valuable insights regarding the overall magnitude of colonial waterbird predation on juvenile salmonids out-migrating through the Priest Rapids Project, the Hanford Reach, and the Federal Columbia River Power System (FCRPS; Richland, WA, to Bonneville Dam). Methods to calculate cumulative avian predation/consumption rates were the same as those described above, with the exception that these rates were not adjusted for downstream survival of fish to the foraging vicinity of each bird colony. For example, consumption rates by gulls nesting at Miller Rocks (Rkm 331 in The Dalles Reservoir) in cumulative estimates of avian consumption rates were based on the number of PIT-tagged smolts available in the tailrace of Rock Island Dam (Rkm 729) and not the number available in the tailrace of McNary Dam (Rkm 429), as presented elsewhere in this report. This approach standardizes fish availability for all evaluated bird colonies within the Columbia Plateau region, resulting in a cumulative measure of avian consumption rates of steelhead and yearling Chinook salmon during out-migration from Rock Island Dam to Bonneville Dam, for those bird colonies included in this study. Because Rock Island Dam (RIS) is considered the start of the migration corridor for ESA-listed Upper Columbia River steelhead and Upper Columbia River spring Chinook salmon (NOAA 2014), consumption rates are considered to be for the entire smolt outmigration period within the Priest Rapids Project, the Hanford Reach, and the FCRPS.

Results indicated that cumulative avian consumption rates were consistently greater on steelhead released into the tailrace of RIS compared with yearling Chinook salmon, with steelhead consumed at a higher rate at each of the 11 piscivorous waterbird colonies evaluated in 2015 (*Table 19*). This finding is consistent with differences in the relative susceptibility of steelhead versus salmon to avian predation observed in other salmonid populations during 2015 (e.g., Snake River steelhead versus Snake River spring/summer

Chinook salmon; *Table 17* and *Table 18*). A discussion of factors that influence the greater susceptibility of steelhead to avian predation compared with salmon is provided above.

In 2015, cumulative avian consumption rates indicated that 40.1% (95% CI = 34.0–47.9%) and 9.4% (95% CI = 6.9–13.0%) of the PIT-tagged steelhead and yearling Chinook salmon, respectively, released into the tailrace of Rock Island Dam were consumed within the Priest Rapids Project, the Hanford Reach, and the FCRPS by piscivorous waterbirds nesting at colonies evaluated in this study (*Table 19*). For both salmonid species (steelhead and yearling Chinook salmon), the majority of the consumption occurred by birds from colonies located downstream of McNary Dam (Rkm 470). For steelhead, the majority of the consumption by birds was due to gulls nesting on Miller Rocks (11.6% of released fish) and Caspian terns nesting on the Blalock Islands (7.4% of released fish; *Table 19*). For yearling Chinook salmon, the majority of of the consumption by birds was due to gulls nesting on Miller Rocks (6.2% of released fish; *Table 19*). These estimates do not account for other sources of mortality (piscine predation, dams, disease, or other sources) that occurred during out-migration from Rock Island Dam to the vicinity of each bird colony, suggesting that consumption by birds from these 11 colonies was a substantial source of smolt mortality, possibly the single greatest source of mortality, for these smolts during out-migration from RIS to Bonneville Dam in 2015. Evans et al. (*in press*) also documented that avian consumption of steelhead and yearling Chinook salmon was substantial compared with other documented sources of smolt losses during out-migration. For example, avian consumption estimates reported herein are significantly higher than those reported for piscine predators (generally < 5% per reservoir; Ward et al. 1995, Thompson et al. 2012) and passage mortality of smolts associated with individual dams (generally < 4% per dam; Muir et al. 2001, Skalski et al. 2002; Timko et al. 2011).

Cumulative avian consumption rates of steelhead based on releases of PIT-tagged fish into the tailrace of Rock Island Dam in 2015 were the highest observed since estimates were first generated in 2008 (BRNW 2013; BRNW 2015a). For example, cumulative consumption rates of steelhead PIT-tagged and released at RIS by piscivorous waterbirds nesting at colonies upstream of Bonneville Dam were < 35% (range = 21–35%) during 2008-2014, which saw high predation rates by Caspian terns nesting on Goose Island in Potholes Reservoir in some years (11–22%, depending on the year; BRNW 2013; BRNW 2015b), a colony where smolt predation rates were dramatically reduced in 2015. The primary reason for increased cumulative avian consumption rates of steelhead in 2015 was increased consumption by gulls nesting at Miller Rocks (11.6%), gulls nesting at Island 20 (7.7%), and Caspian terns nesting at the Blalock Islands (7.4%), colonies which account for the majority of steelhead consumption due to birds breeding at the colonies evaluated in 2015 (*Table 19*). Despite the finding that cumulative avian consumption rates of steelhead smolts in 2015 were the highest so far recorded, avian consumption rates of steelhead were below average for birds from colonies upstream of McNary Dam, primarily due to reduced predation rates from Caspian terns nesting on Goose and Crescent islands in 2015.

The cumulative avian consumption rates within the Priest Rapids Project, the Hanford Reach, and the FCRPS are minimums because the consumption by non-breeding birds and non-colonial or semi-colonial piscivorous waterbirds, such as common mergansers (*Mergus merganser)*, black-crowned night-herons (*Nycticorax nycticorax)*, large grebes (*Aechmophorus* spp.), and others were not investigated as part of this study. While non-colonial or semi-colonial waterbird species are known to consume juvenile salmonids in the Columbia River Basin, their predation rates on smolts have been shown to be far less than those of colonial waterbirds (Parrish 2006; Wiese et al. 2008), primarily because of smaller numbers of breeding adults in populations of non-colonial and semi-colonial species of piscivorous waterbirds relative to their colonial counterparts in the Columbia Plateau region. The impact on smolt survival of non-breeding colonial waterbirds, such as Caspian terns dissuaded from nesting on Goose Island that resided in the region but did not attempt to nest in 2015, is unknown and could account for a measurable level of losses for out-migrating smolts in the Priest Rapids Project.

Finally, the results presented here do not include the predation rates by piscivorous colonial waterbirds nesting in the Columbia River estuary during 2015, most notably Caspian terns and double-crested cormorants that nested on East Sand Island. These results will be reported elsewhere (BRNW 2016), but estimates of predation rates from previous years indicate that the combined impact on smolt survival of predation by Caspian terns and double-crested cormorants nesting on East Sand Island is significant, ranging from 7.0% to 12.2% of the steelhead PIT-tagged and released at Rock Island Dam during 2008-2013 (BRNW 2014a).

4.2. JSATS Analysis

Spatially-explicit measures of avian predation and consumption of juvenile salmonids may be essential for evaluating the efficacy of Caspian tern management to increase smolt survival within the Priest Rapids Project (Wanapum and Priest Rapids dams and associated reservoirs). For example, reductions in the numbers of Caspian terns nesting on Goose Island and Crescent Island should result in increases in smolt survival, if displaced terns relocate to and forage in out-of-basin locations following emigration from these two colonies (see *Section 2*). To address this critical question and to document where (spatially) and when (temporally) within the Priest Rapids Project fish were depredated by Caspian terns or consumed by other piscivorous colonial waterbird species, we collaborated with researchers conducting Juvenile Salmonid Acoustic Telemetry System (JSATS) survival studies on steelhead and sockeye salmon smolts in 2015. Because acoustic-tagged (AT) fish are also PIT-tagged (i.e. double tagged), we can estimate the location within the river where tagged smolts were consumed by birds based on last know locations of live fish passing hydrophone arrays prior to consumption by birds. More specifically, the objectives of this task were to: (1) calculate avian consumption rates of juvenile steelhead and sockeye salmon at different spatial- and temporal-scales within the Priest Rapids Project and (2) quantify unaccounted for mortality (total mortality – mortality associated with consumption by piscivorous colonial waterbirds) at these same spatial and temporal scales. Collectively, results were used to identify where smolt losses occurred, when they occurred, and the apparent cause of smolt mortality (colonial waterbird predation or unaccounted for mortality). Finally, data from JSATS steelhead studies in 2015 were compared and contrasted with avian consumption rates derived from similar studies conducted in 2014 (Evans et al. *in press*) and during 2008-2010 (Evans et al. 2013).

Methods: The methods of Evans et al. (*in press*) were used to estimate total smolt mortality (1 – survival) and mortality associated with consumption by piscivorous waterbirds nesting at colonies within foraging distance of the middle Columbia River in 2015. In brief, recoveries of PIT tags from double-tagged fish (acoustic and PIT tags; hereafter "tagged fish") on bird colonies, coupled with last known detections of live fish passing in-river hydrophone arrays, were used to estimate the impact of avian predators on smolt survival during out-migration through the middle Columbia River.

Study area – We investigated predation on tagged juvenile steelhead and sockeye within a 184-km stretch of the middle Columbia River in 2015 (*Figure 13*). In 2015, study fish were detected passing nine acoustic detection arrays (hydrophones placed in lines perpendicular to the shore; McMichael et al. 2010) that spanned from Wanapum Dam to an array located upstream from the confluence of the Snake and Columbia rivers. Five of these nine acoustic arrays (*Figure 13*) were used to estimate survival of tagged smolts in each section of the 184-km study stretch of the middle Columbia River, following Skalski et al. (2016).

Fish capture, tagging, and release – Detailed methods regarding the collection, tagging, and release of smolts used in this study are presented in Skalski et al. (2016). In brief, steelhead and sockeye salmon smolts were captured at Wanapum and Priest Rapids dams by dip-netting smolts from the wheel gate slots at each dam. Fish were examined to ensure they met the size requirement (15–89 g, or fish between 105 mm and 228 mm fork length) and the condition criteria (no signs of disease, ≤ 20% descaling, no open wounds, hemorrhaging, or deformities) for acoustic tagging (Timko et al. 2011). Fish suitable for tagging were anesthetized, implanted with an acoustic tag (*Lotek,* Model L-AMT 1.421) and a PIT tag (*Biomark*, Model HPT12), and held in a recovery tank for 18 to 24 hrs. Following the recovery period, fish were transported by truck and subsequently released by helicopter at designated release sites in the tailraces of Rock Island Dam (Rkm 729), Wanapum Dam (Rkm 670), and Priest Rapids Dam (Rkm 639; *Map 1*). Tagged steelhead smolts were released daily during 4–30 May, and tagged sockeye salmon smolts daily during 7–29 May.

Recovery of tags on bird colonies – Acoustic tags are not detectable using electronic sensors on bird colonies; consequently, PIT tags deposited on bird colonies were used to measure predation rates on the double-tagged fish used in this study. PIT tag recovery methods were the same as those described in *Section 4.1*, with the same colony-specific measures of detection and deposition probabilities applied (*Table 15* and *Table 16*).

Spatially- and temporally-explicit predation rate calculations – We employed a Bayesian analytical approach as an extension of the Cormack-Jolly-Seber (CJS) model, a mark-recapture estimation technique (Burnham et al. 1987). We estimated survival, detection, and recovery of each fish throughout the study area using a single model. We refer to the areas between consecutive or adjacent acoustic arrays as segments. We use indicator variables to represent each fish's interrogation and recovery history. Here we summarize the methods used to simultaneously model survival, interrogation, and recovery (see *Appendix A* for additional details).

We let Z_{ij} be an indicator variable representing the survival of fish *i* through segment *j.* We let ω_{rwj} be the probability of survival by a tagged fish from release location *r* through the j^{th} segment in week *w.* We let $\boldsymbol{D}_{ij}$ = [D_{ij1}, D_{ij2}, … , $D_{ijother}$] be an (*C*+1) x 1 indicator vector representing the cause of mortality for a fish which does not survive through segment *j*. Each element D_{ijc} indicates whether fish *i* was depredated by a bird from colony *c* of the *C* known colonies within segment *j*. $D_{ijother}$ represents the mortality of a fish from any other cause in segment *j*. We further let $\boldsymbol{\theta}_{rwj}$ = [$\theta_{rwj1,}$ θ_{rwj2}, … $\theta_{rwjother}$] where θ_{rwjc} is the probability of predation by a bird from colony *c* in the j^{th} segment associated with the r^{th} release of tagged smolts in week *w* and $\theta_{rwjother}$ represents the probability of mortality by any other cause with respect to the same release, week, and segment. Therefore,

$$[Z_{ij}, \boldsymbol{D}_{ij}] \sim \text{Multinomial}(Z_{i(j-1)}, [\omega_{\mathrm{rwj}}, \boldsymbol{\theta}_{rwj}]).$$

We let Y_{ij} be the indicator variable of whether fish *i* is detected at the downstream interrogation array associated with segment j^{th}. We let δ_{rwj} be the probability a surviving fish from the r^{th} release in week *w* is detected at this array. Therefore,

$$Y_{ij} \sim \text{Bernoulli}(\delta_{rwj} * Z_{i(j-1)}).$$

We let R_{ic} be the vector indicating whether the tag associated with fish *i* was recovered on colony *c*. As noted by Hostetter et al. (2015), not all smolt tags ingested by birds are subsequently deposited on their nesting colony. Furthermore, not all tags deposited by birds on their nesting colony are later detected by researchers after the nesting season (Evans et al. 2012). We let ϕ_c represent the probability that a tag consumed by a bird from colony *c* is deposited on the colony. We let ψ_{cw} represent the probability that a tag deposited on colony *c* in week *w* is detected at the end of the nesting season. Therefore,

$$R_{ic} \sim \text{Bernoulli}(\phi_c * \psi_{cw} * \textstyle\sum_j D_{ijc}).$$

PIT tags were intentionally sown on each colony to independently measure detection efficiency at each bird colony (see *Section 4.1*; *Table 15*). We let f_{cw} represent the number of PIT tags found of the n_{cw} intentionally sown on colony *c* in week *w*. We let ψ_{cw} represent the probability that a tag deposited on colony *c* in week *w* is detected. Therefore,

$$f_{ic} \sim \text{Binomial}(n_{cw},\ \psi_{cw}).$$

Each ψ_{cw} is assumed to be a logistic function of week:

$$\psi_{cw} = \beta_{0c} +\ \beta_{1c} * (w - m_c),$$

where m_c represents the median week of the breeding season at colony *c*.

The indicator variables detailed above were aggregated to estimate avian predation in five spatial aggregations of consecutive segments: (1) Wanapum Development (729–669 Rkm), (2) Priest Rapids Development (670–639 Rkm), (3) from the Priest Rapids release location to Vernita Bridge (639–625 Rkm), (4) Vernita Bridge to White Bluffs (625–593 Rkm), and (5) White Bluffs to the first Hanford array (593–545 Rkm; *Figure 13*)

Following the methods of Skalski et al. (2016), mortality and mortality due to bird predation within the two Priest Rapids Project developments were estimated using a paired release-recapture design (see *Appendix A* for additional details). The estimates associated with the Wanapum Development were inferred from smolt releases in the tailraces of Rock Island and Wanapum dams. The estimates associated with the Priest Rapids Development were inferred from smolt releases in the tailraces of Wanapum and Priest Rapids dams. Due to concerns raised by “delayed acclimation of steelhead smolts” (see Skalski et al. 2016), the estimates for segments (3) and (4) were inferred from only the Rock Island and Wanapum releases. All smolt releases were used in calculating avian predation in segment (5).

We let r_{RIS}, r_{WAN}, and r_{PR} refer to the set of smolts released in the tailraces at Rock Island, Wanapum, and Priest Rapids dams, respectively. We let $\boldsymbol{J}_k$ represent the set of segments in the kth spatial aggregation of segments and $r_k$represent the release(s) associated with avian predation estimates in $\boldsymbol{J}_k$. We let $D_{i\boldsymbol{J}_k c}$ indicate the death of fish *i* within $\boldsymbol{J}_k$. There is some complexity involved in the calculations of $D_{i\boldsymbol{J}_k c}$ for $\boldsymbol{J}_1$, $\boldsymbol{J}_2$, and $\boldsymbol{J}_3$, as each of these commence or terminate between consecutive interrogation arrays (see *Appendix A*).

We define $\hat{P}_{\boldsymbol{J}_k,c}$ to be the predation rate by birds from colony *c* in $\boldsymbol{J}_k$. Therefore,

$$\hat{P}_{\boldsymbol{J}_k,c} = \sum_{i \in \boldsymbol{r}_k} D_{i\boldsymbol{J}_k c} \Big/ \sum_{i \in \boldsymbol{r}_k} Z_{i\, J_{k,0}}$$

where $J_{k,0}$ is the array marking the upstream boundary of $\boldsymbol{J}_k$.

Similarly, we let $\widehat{M}_{\boldsymbol{J}_k}$ represent the probability of mortality in $\boldsymbol{J}_k$ by any cause other than predation by birds from the *C* colonies under consideration. Therefore,

$$\widehat{M}_{\boldsymbol{J}_k} = \sum_{i \in \boldsymbol{R}_k} D_{i\boldsymbol{J}_k other} \Big/ \sum_{i \in \boldsymbol{R}_k} Z_{i\, J_{k,0}}.$$

Imperfect rates of deposition and detection lead to positive estimates of predation rate for all segments in which birds from a particular colony were assumed to forage. We estimated positive rates of predation even when no direct evidence existed (i.e. when none of the tags whose detection history ended in a given segment were recovered on the colony of interest). Therefore, the estimated total predation rate by all piscivorous colonial waterbirds from all colonies in a segment was directly related to the number of colonies assumed to forage there. It follows, then, that we must be cautious in our assumptions about which bird colonies provided foragers in each segment. We assumed that birds from each colony foraged along a continuous, uninterrupted range of the river. The limits of this range were set equal to the first and last segments in which at least one tag's detection ended and the tag was subsequently found on the colony (i.e. confirmation of predation by birds from that colony).

Colony-specific foraging hotspots (areas of concentrated foraging) were investigated based on the percentage of available tagged smolts consumed within each river segment, per colony. To account for differences in the relative size (length) of each river segment evaluated, colony-specific predation rates were presented as predation probabilities per river kilometer. Results represent approximate foraging locations on tagged smolts because the actual foraging path of each bird was not known and the exact location of predation events between any two adjacent acoustic arrays within a segment was not known.

Non-informative priors were specified for most model parameters. Specifically, we let $[\omega_{\mathrm{rwj}}, \vec{\boldsymbol{\theta}}_{rwj}]$ ~ Dirichlet $(\vec{\mathbf{1}})$ where $\vec{\mathbf{1}}$ is an appropriately vector of ones. This implies that each element of $[\omega_{\mathrm{rwj}}, \vec{\boldsymbol{\theta}}_{rwj}]$ ~ Uniform(0,1) ∀ *r,w,j*. Uniform(0,1) prior distributions were also specified for β_{0c}, β_{1c}, and δ_{rwj}∀ *c,r,w,j*. For ψ_{cw} to be identifiable, informative Beta (α, β) priors were specified for each bird species and colony (Hostetter et al. 2015). The shape parameters for these prior distributions was assumed to be α = 16.20 and β = 6.55 for tern colonies and α = 33.71 and β = 183.61 for gull colonies (Hostetter et al. 2015).

All modelling was performed in STAN, accessed via R version 3.1.2 (RDCT 2014) using RStan (SDT 2016). We ran three parallel chains for 10,000 iterations each after a burn-in of 5,000 iterations. Chains were thinned by 10 to reduce autocorrelation of successive Markov chain Monte Carlo samples, resulting in 1,000 saved iterations. Chain convergence was tested using the Gelman-Rubin statistic ($\hat{R}$; Gelman et al. 2004). We report results as posterior medians along with the 2.5 and 97.5 percentiles, which are referred to as 95% Credible Intervals (95% CI).

The same list of assumptions associated with estimates of predation rates based on smolts that were only PIT-tagged (see *Section 4.1*) apply to double-tagged (acoustic- and PIT-tagged) fish, with three additional assumptions:

A1. Release and interrogation histories of tagged fish were complete and accurate.

A2. Acoustic tags were functional during the study period.

A3. Mortality due to handling and tagging is included in the "other" mortality probability designation.

Data proofing was done by researchers that conducted the JSATS component of the study, we assume protocols to censor irregular entries were followed and that the appropriate group of fish were included in JSATS analyses (A1). To confirm A2, tests were conducted on a random sample of tags to confirm tag life and functionality was as specified by the tag manufacturer (33 days; Skalski et al. 2016). Mortality after release that was potentially associated with handling and tagging likely occurred in 2015 (Skalski et al. 2016), which necessitates assumption A3. A significant number of losses due to handling and tagging would result in an overstatement of availability and consequently bias estimates of predation probabilities down.

<u>Results and Discussion:</u> Complete descriptions of smolt capture, tagging (acoustic and PIT), and releases from JSATS studies on the middle Columbia River in 2015 are summarized in Skalski et al. (2016). In brief, analyses of bird predation were based on fish releases in the middle Columbia River from three different release locations (Rkms 639, 669, and 729), totaling 1,672 steelhead and 1,677 sockeye salmon (*Table 20*), with roughly equal numbers released at each site, each week. Tagged steelhead ranged in size from 128 to 228 mm fork length (mean = 184 mm); tagged sockeye salmon ranged from 105 to 184 mm fork length (mean = 118 mm; Skalski et al. 2016).

Recovery of tags on bird colonies – PIT tags from 28 double-tagged fish (26 steelhead and 2 sockeye salmon) that were consumed within the study area were recovered on bird colonies in 2015 (*Table 20*). Many more double-tagged fish were consumed by birds in 2015 (n = 95 steelhead; n = 19 sockeye salmon), but these fish were consumed outside of the study area and were thus not included in spatially-explicit predation analyses within the middle Columbia River.

Detection and deposition estimates of PIT tags used to estimate spatially-explicit predation rates are presented in *Table 15* and *Table 16*, the same data used to calculate predation rate estimates reported in *Section 4.1*. No detection efficiency or deposition rate estimates, however, were available for birds nesting at two small, mixed-species colonies in Hanford Reach (ca. Rkm 601), so predation rates by birds nesting on these islands are minimum estimates of smolt losses. Furthermore, as noted above, tags recovered on avian loafing sites were excluded from estimates of colonial waterbird predation rates. This was done because some fraction of the tags recovered at loafing sites were presumably tags consumed by nesting birds (i.e. tags that were deposited off-colony and are thus incorporated in deposition corrected predation rate estimates) and because the particular species of avian predator (i.e. tern, cormorant, gull, or other) at these loafing sites could not be determined for each recovered tag. A relatively large number and proportion of steelhead tags (6 or 23% of all tags) depredated by birds within the middle Columbia River were found at the Mud Island (n = 3) and Marsh Unit 1 (n = 3) loafing sties. If these fish were consumed by non-breeding birds the estimated total avian consumption of tagged steelhead and sockeye salmon presented here is biased low to an unknown degree (see *Section 4.1* for a more detailed discussion).

Spatially- and temporally-explicitly predation rates – Estimated predation rates by piscivorous colonial waterbirds varied by river segment, fish species (steelhead, sockeye salmon) and bird colony, with predation rates ranging from < 0.1% to 2.7%, per river segment (*Figures 13*). Within the same river segment, avian predation rates were consistently higher on steelhead (range = 0.2–2.7%, per segment) compared with sockeye salmon (< 0.1–1.2%, per segment). This result is similar to relative differences in predation rates observed between steelhead (range = 0.4–1.8%, per segment) and yearling Chinook salmon (range = 0.2–0.8%, per segment) in the same section of the middle Columbia River during 2014 (Evans et al. *in press*). The smaller average size of tagged sockeye salmon (mean = 118 mm fork length) and yearling Chinook salmon (mean = 140 mm fork length; Skalski et al. 2015) compared with steelhead (mean = 184 mm fork length) may be related to higher predation rates on steelhead relative to these salmon species. Hostetter et al. (2012) and BRNW (2013) observed that smaller smolts were less susceptible to Caspian tern predation, both within and between salmonid species.

Of the five river segments within the middle Columbia River that were evaluated, colonial waterbird predation rates were the highest on steelhead in Wanapum Development (2.7%; 95 CI = 1.7–4.4%) and Priest Rapids Development (2.3%; 95% CI = 1.9–4.8%) relative to the three river segments evaluated below Priest Rapids Dam in the Hanford Reach (range = 0.2–1.6%, depending on the segment; *Figure 13*). Consumption of sockeye salmon smolts by birds was minimal compared with consumption of steelhead, with just 1.2% (95% CI = 0.5–2.3%) and 0.7% (95% CI = 0.1–1.6%) of sockeye consumed by breeding birds within the Wanapum and Priest Rapids developments, respectively (*Figure 13*). Predation rates within the Priest Rapids Project (reservoirs and dams combined) were estimated at 3.7% (95% CI = 1.7– 6.2%) and 1.9% (95% CI = 1.1–3.5%) for steelhead and sockeye, respectively. Total or reach-specific predation rates – predation from all breeding birds on smolts traveling through the entire study area – were estimated at 6.7% (95% CI = 5.1–9.1%) and 2.9% (95% CI = 1.9–4.3%) for steelhead and sockeye salmon, respectively.

An investigation of temporal trends indicates that fluctuations in avian predation rates were consistent with fluctuations in total mortality of juvenile steelhead, with increases in weekly total mortality commensurate with weekly bird predation rates (*Figure 14*). Trends were less obvious for sockeye salmon, presumably due to lower estimated total mortality of sockeye smolts (*Figure 14*). There was no obvious trend or relationship between the week when tagged smolts were released and probability of predation by colonial waterbirds. Evans et al (2013) observed that late migrating smolts in the middle Columbia River were more susceptible to bird predation than early migrants. Predation rates observed in the current study, however, were significantly lower than those observed by Evans et al. (2013) during 2008-2010 (range = 4.0–10.0%, per segment), data collected prior to the management of Caspian terns nesting on Goose Island in Potholes Reservoir.

Of the individual bird colonies evaluated, predation rates on steelhead were greatest for Caspian terns nesting on Twinning Island in Banks Lake, with terns consuming fish in all five river segments evaluated in 2015 (*Figure 15*). Despite their proximity to Priest Rapids Dam, there was no evidence that gulls nesting on Island 20 or cormorants and herons nesting at the two small colonies on islands at ca. Rkm 601 in Hanford Reach were commuting upstream to forage on smolts within the Wanapum or Priest Rapids developments (*Figure* 15). The numbers of tagged juvenile steelhead that were available to birds below Rock Island Dam (n = 399) and Wanapum Dam (n = 1,148) were small, however, and on-colony deposition probabilities were low for gulls or non-existent for birds nesting on the island in Hanford Reach, so these results should be interpreted cautiously.

Results demonstrate that piscivorous colonial waterbirds, particularly Caspian terns, were consuming fish upwards of 100 km from their presumed nesting sites. For example, smolts last detected alive at Rkm 625 were recovered on the Twinning Island tern colony in Banks Lake, nearly 100 km away. These results are not surprising given the foraging ranges of GPS-tagged and satellite-tagged Caspian terns (see *Section 2.1* for details), and demonstrate that Caspian terns are capable of commuting long distances to consume juvenile salmonids. In the present study, however, some fraction of smolt PIT tags deposited by birds on-colony may have been from non-breeders or from birds that visited the colony while prospecting for a nest site (BRNW 2015a; see also *Section 2*). Consequently, it is more challenging to use recoveries of fish tags on bird colonies as a measure of foraging behavior in nesting adults compared to studies where nesting adult birds are tagged to track their movements from the colony to foraging areas.

The amount of total smolt mortality (1 – survival) explained by colonial waterbird predation varied by spatial scale. For juvenile steelhead, predation by colonial waterbirds accounted for 19% and 27% of all steelhead losses (total mortality) in Wanapum and Priest Rapids developments, respectively, during 2015. The percentage of total steelhead mortality explained by colonial waterbird predation was similar to that observed for sockeye salmon (20% and 24% in the Wanapum and Priest Rapids developments, respectively), although estimates of total mortality for sockeye salmon were significantly lower than those for steelhead (*Figure 13*).

Survival standards for juvenile steelhead in the middle Columbia River (≥ 93% survival per development) were not achieved in the Priest Rapids Development during 2008 - 2010, nor in the Wanapum Development in 2010 (Timko et al. 2011). Evans et al. (2013) estimated between 4.0–10.0% (depending on the development and year) of available juvenile steelhead in the Wanapum and Priest Rapids developments were annually consumed by Caspian terns during this three-year period. In 2014, the first year of Caspian tern management at the Goose Island colony, survival standards for juvenile steelhead in both developments were met for the first time (Skalski et al. 2015), with Caspian tern predation rates estimated at just 1.1% and 1.8% in Wanapum and Priest Rapids developments, respectively (Evans et al. *in press*). In 2015, survival standards for steelhead were again met in the Priest Rapids Development, but fell short in Wanapum Development. These recent reductions in smolt mortality in the Priest Rapids Project are likely related to management efforts aimed at reducing the size of the Goose Island Caspian tern colony. For example, management efforts were able to reduce the size of the Goose Island Caspian tern colony to an average of 99 breeding pairs during 2014-2015 (assumes 39 nesting attempts in 2015), down from an average of 400 breeding pairs during 2008-2010. Recent increases in predation rates on steelhead by Caspian terns nesting at the Twinning Island colony, however, partially off-set benefits achieved by a major reduction in the size of the Goose Island tern colony during this period.

In summary, avian predation rates on juvenile salmonids in the middle Columbia River during the 2015 out-migration varied by river segment, fish species, bird colony, and week, demonstrating that avian predation rates varied both spatially and temporally. Predation by piscivorous colonial waterbirds remained a significant source of mortality for steelhead smolts, although predation rates by Caspian terns have been greatly reduced since management actions were initiated at Goose Island colony in 2014. Of those double-tagged steelhead that were consumed by birds in 2015, Caspian terns nesting on Twinning Island in Banks Lake contributed the most to smolt mortality. In contrast to avian predation on steelhead smolts, avian predation on sockeye salmon smolts was generally low and survival was high, indicating birds posed little risk to sockeye smolts out-migrating through the middle Columbia River in 2015. Results from this study and from Evans et al. (*in press*) suggest that management of Caspian terns in the Columbia Plateau region has enhanced steelhead smolt survival within the middle Columbia River. Although this result is encouraging, other data suggest that this demonstrated increase in reach-specific survival of steelhead was largely, if not entirely, offset by decreased survival rates for steelhead smolts in reaches downstream of the study area (see *Section 4.1*).

4.3. Diet Composition and Smolt Consumption

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). An observation blind was set up offshore of Long and Middle island, which are within the Blalock Islands complex so that tern prey items could be identified with the aid of binoculars and spotting scopes. The target sample size was 100 bill load identifications per week. Bill load observations at the Blalock Islands tern colony were conducted 3-5 days per week from May to early August. Prey items were identified to the taxonomic level of family. We identified prey to species, where possible, and salmonids were identified as steelhead trout or 'other salmonids' (i.e. Chinook salmon, coho salmon, or sockeye salmon). Trout were distinguished from 'other salmonids' by the shape of the caudal fin, body shape, coloration and speckling patterns, shape of parr marks, or a combination of these characteristics (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.

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

Results and Discussion: Based on bill load identifications at the Blalock Islands Caspian tern colony during May-July, 67.3% of the prey items consumed by Caspian terns nesting on the Blalock Islands were juvenile salmonids in 2015 (n = 1,575 identified bill loads). This was similar to the proportion of the diet that was juvenile salmonids for Caspian terns nesting on Crescent Island during the 2000-2012 breeding seasons (66.2%; BRNW unpublished data). These data suggest that salmonids comprised a similar, if not greater, proportion of the diet for terns nesting at the Blalock Islands compared to Crescent Island. Notably, steelhead smolts made up a larger proportion of the salmonid prey items in the Caspian tern diet at the Blalock Islands (34% of all salmonids identified) compared to the diet at Crescent Island in previous years (10–23% during 2000-2012).

Each year, millions of juvenile salmonids are released from Columbia River Basin hatcheries, which provide Caspian terns nesting on the mid-Columbia River with a reliable and relatively consistent food supply, as compared to the food supply available to Caspian terns nesting at other inland colonies (e.g., in the Upper Klamath Basin).

Juvenile salmonids were by far the most prevalent prey type in the diet of Caspian terns nesting on Blalock Islands in 2015, followed by centrarchids (bass and sunfish, 25.4%) and cyprinids (carp and minnows, 3.1%). The proportion of juvenile salmonids in the diet of Caspian terns nesting on the Blalock Islands was highest in early May (83.6%), corresponding to the peak of the juvenile salmonid outmigration through the mid-Columbia River, and generally declined thereafter. Seasonal declines in the proportion of salmonids in the diet probably reflect changes in availability of hatchery-reared smolts near the Blalock Islands tern colony. Nevertheless, the proportion of salmonids in the diet of Blalock Islands Caspian terns was consistently higher throughout the breeding season compared to that of Caspian terns nesting on East Sand Island in the Columbia River estuary (BRNW 2015d).

We estimated that Caspian terns nesting on the Blalock Islands consumed ca. 550,000 juvenile salmonids in 2015 (95% CI = 310,000–800,000). This point estimate was higher than the estimated smolt consumption by Caspian terns nesting at Crescent Island in most years during 2000-2012, although point estimates in 2001 and 2002 both exceeded 600,000 smolts. Estimated consumption of steelhead smolts by Blalock Islands terns in 2015 was ca. 240,000 (95% CI = 130,000–350,000). This was a substantially higher point estimate than for Caspian terns nesting at Crescent Island during 2000-2012 (point estimates ranged from 50,000 to 160,000; *Figure 16*).

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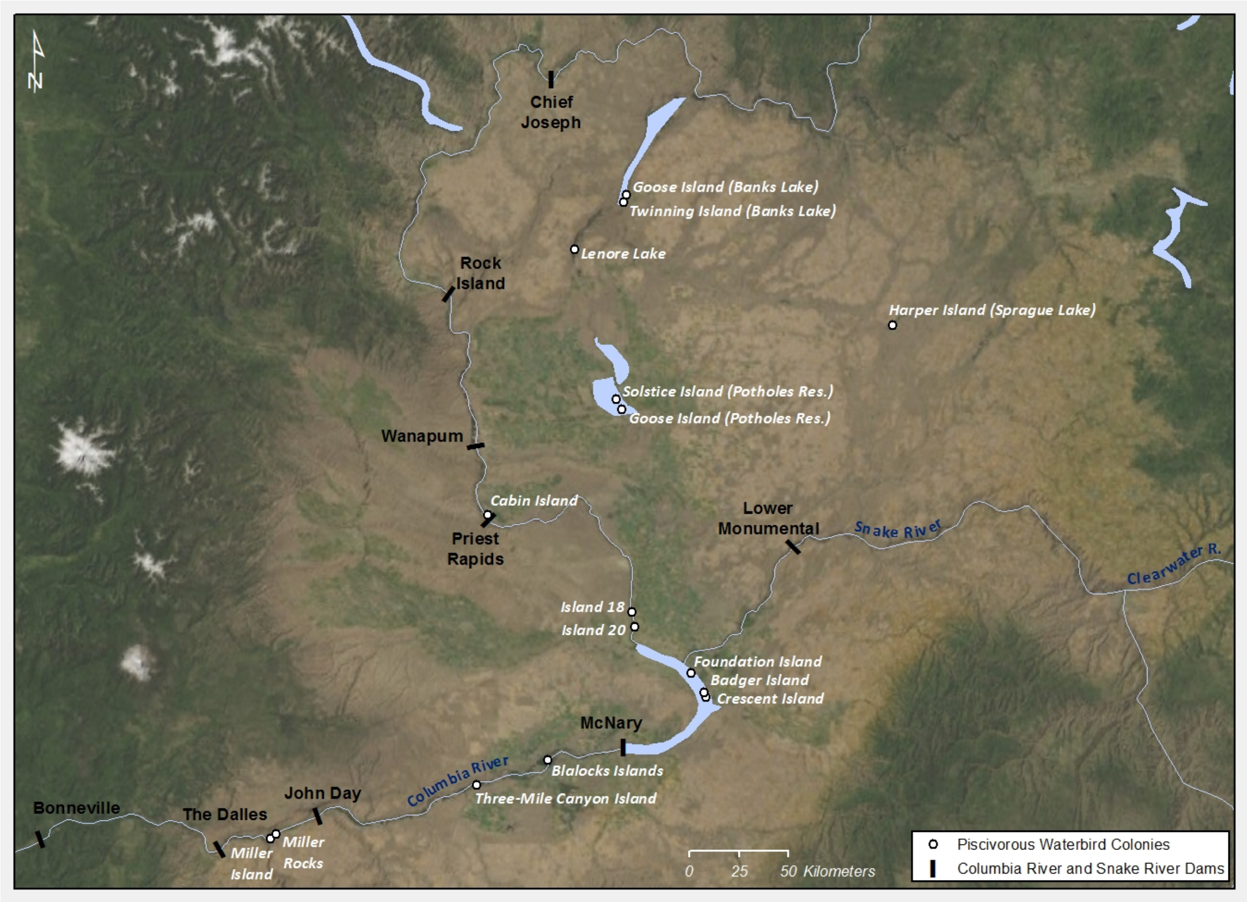
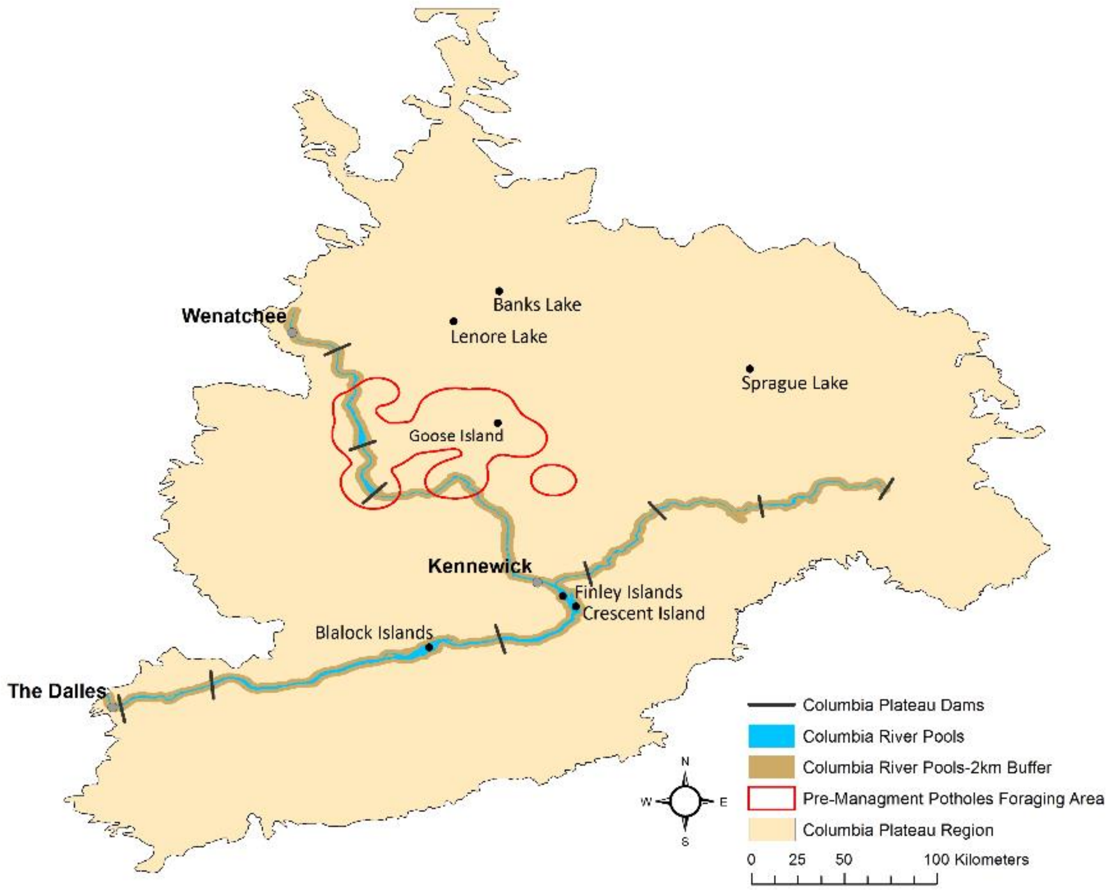
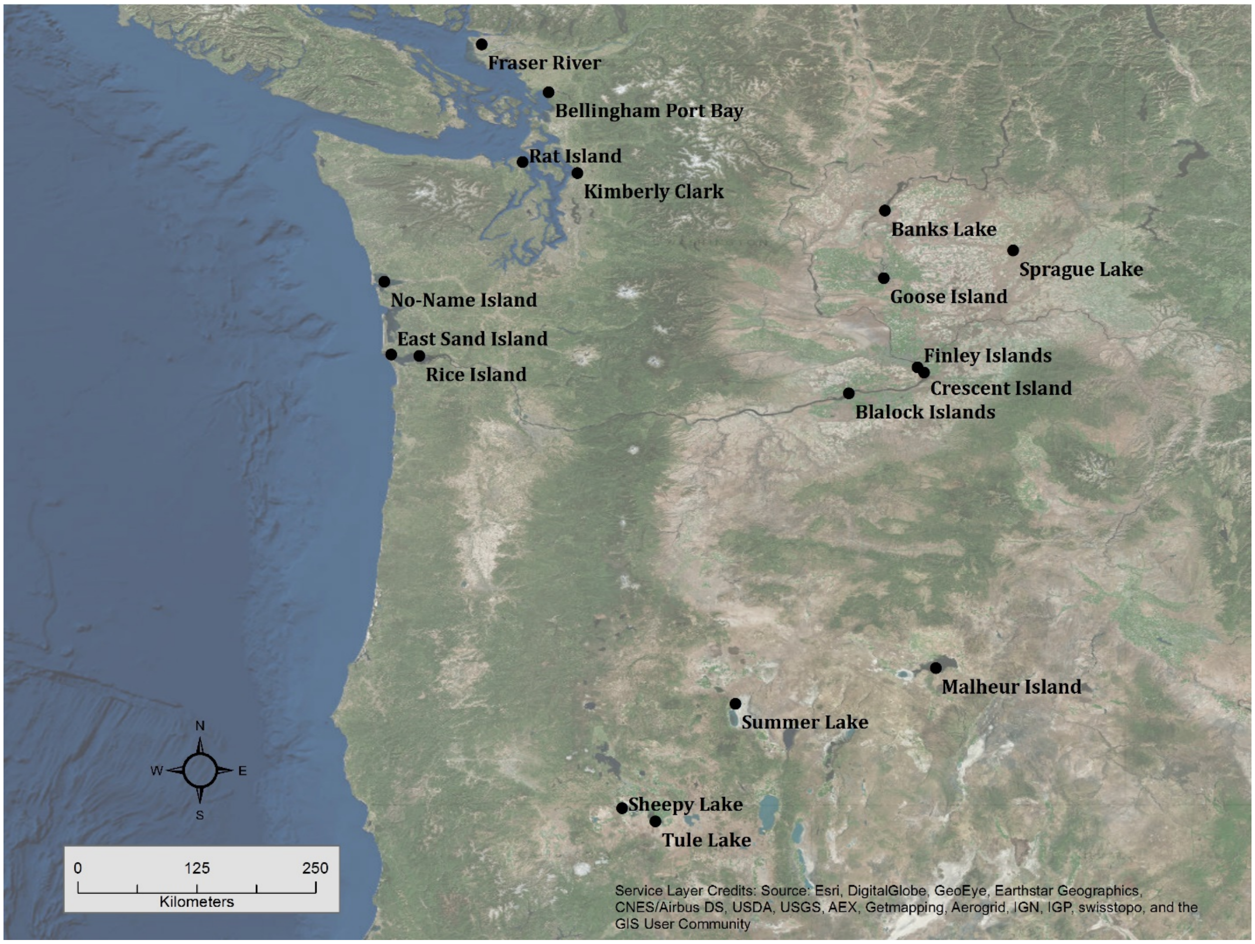


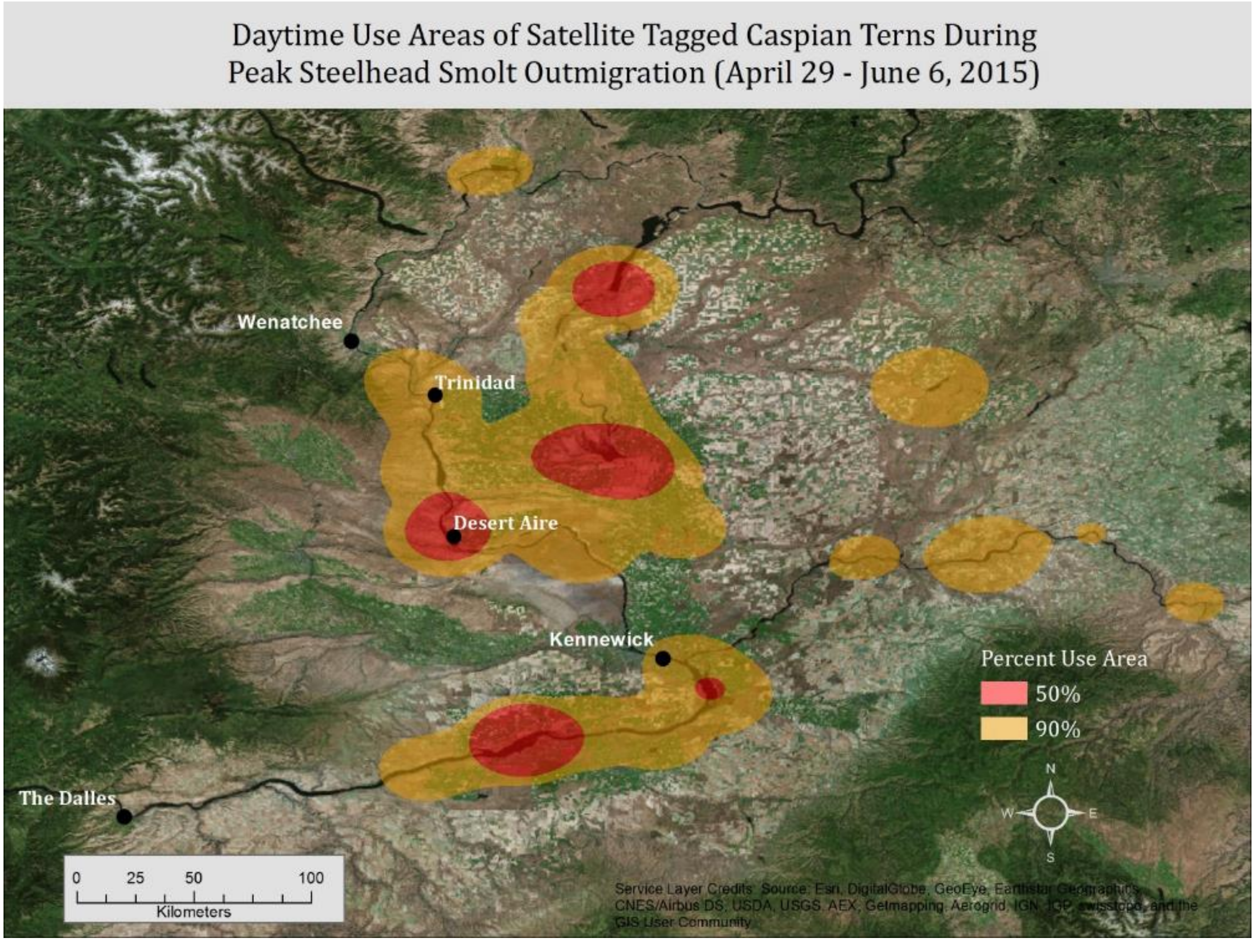
Map 1. Study area in the Columbia Plateau region in 2015.



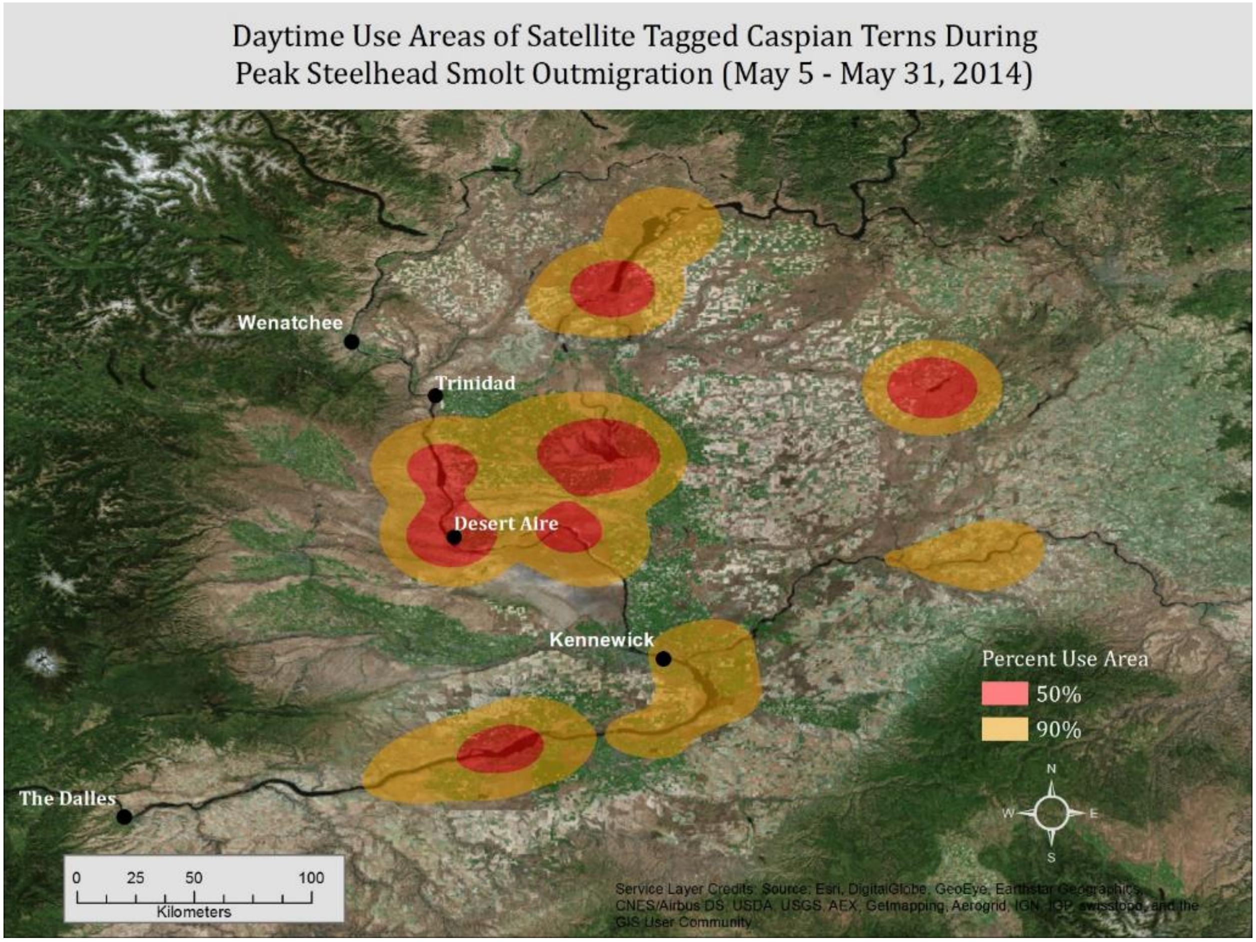
Map 2. Columbia Plateau region of eastern Washington State, and the pre-management foraging areas (red polygons) of Caspian terns nesting at Goose Island in Potholes Reservoir in 2013 (BRNW 2014a). The foraging area used is a 95% contour interval for a kernel density estimate based on GPS locations collected from nesting terns that were within 60 km of the colony but excluding locations within 500 m of the colony.



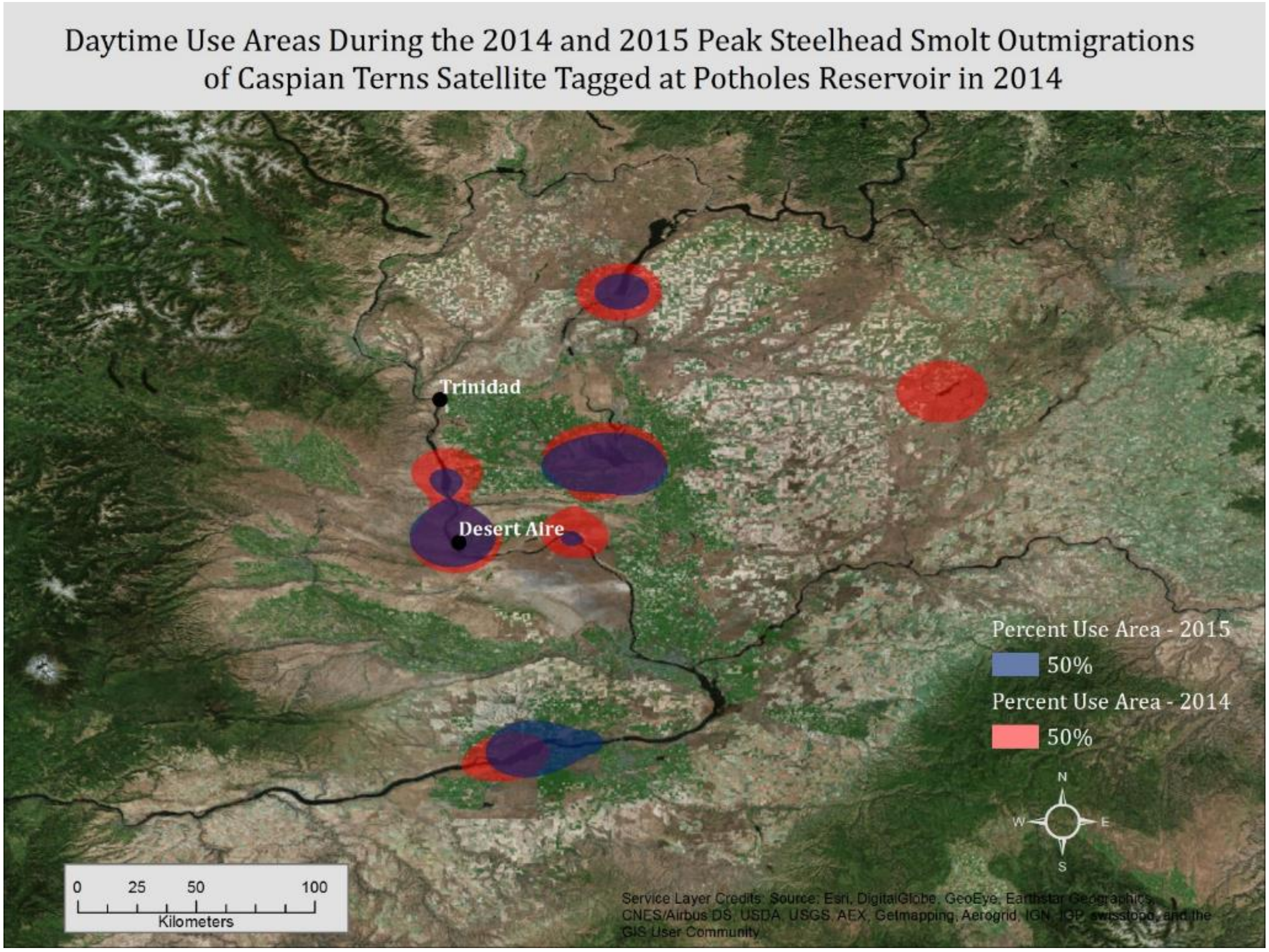
Map 3. Caspian tern colony sites in the Columbia Plateau region, western Washington, southern British Columbia, Oregon, and northern California evaluated for colony association by satellite tagged terns during the peak smolt outmigration period in 2015. Colony sites in the San Francisco Bay area were also considered for associated use by satellite-tagged terns, but were not visited and are not included on this map.



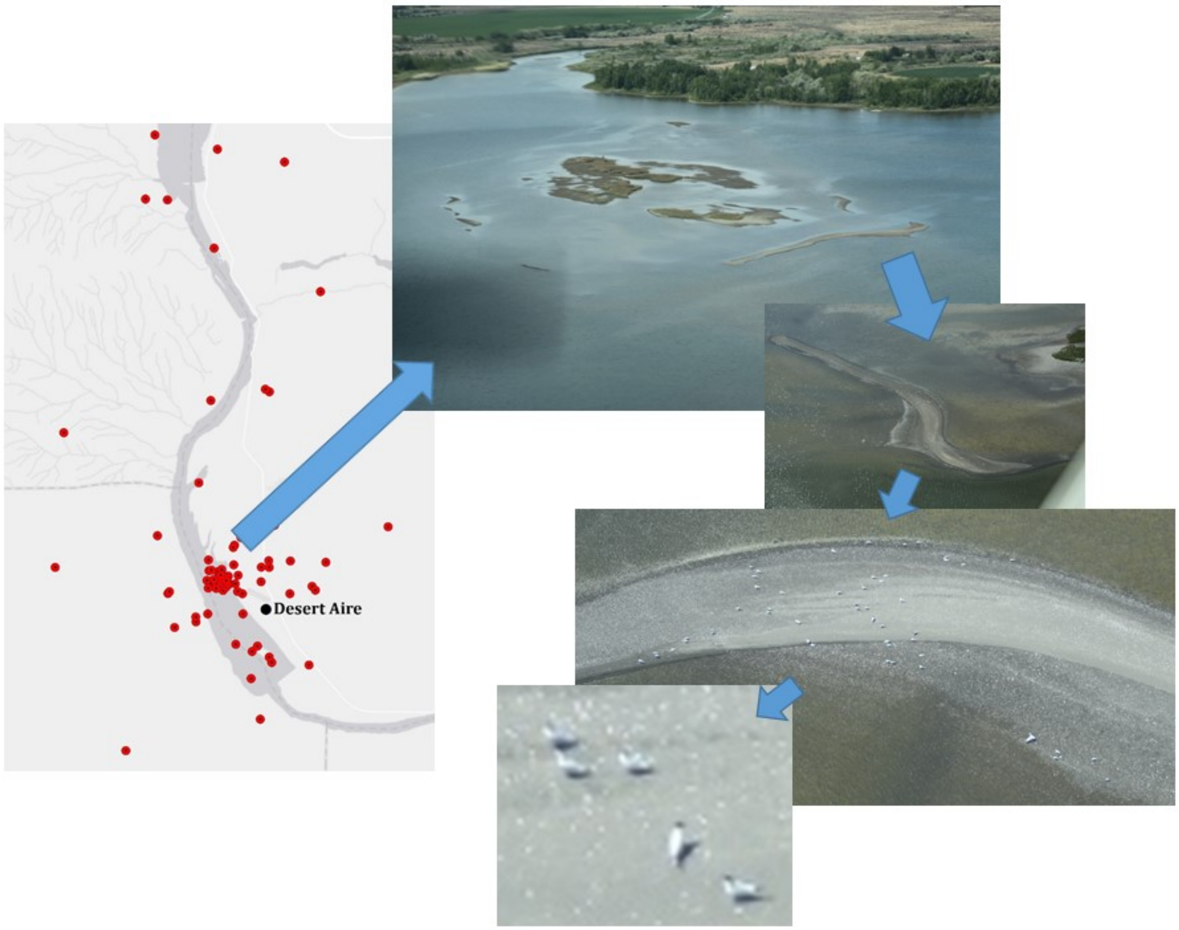
Map 4. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2015 (April 29 – June 6) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 and Crescent Island in 2015 that were tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir during that time period. Red indicates the area where the probability of finding an individual tagged tern is 50% and yellow encompasses the area where the probability is 90% (note: higher percentage areas also include the lower percentage areas contained within). Only the use distribution areas on the Columbia Plateau are shown here.



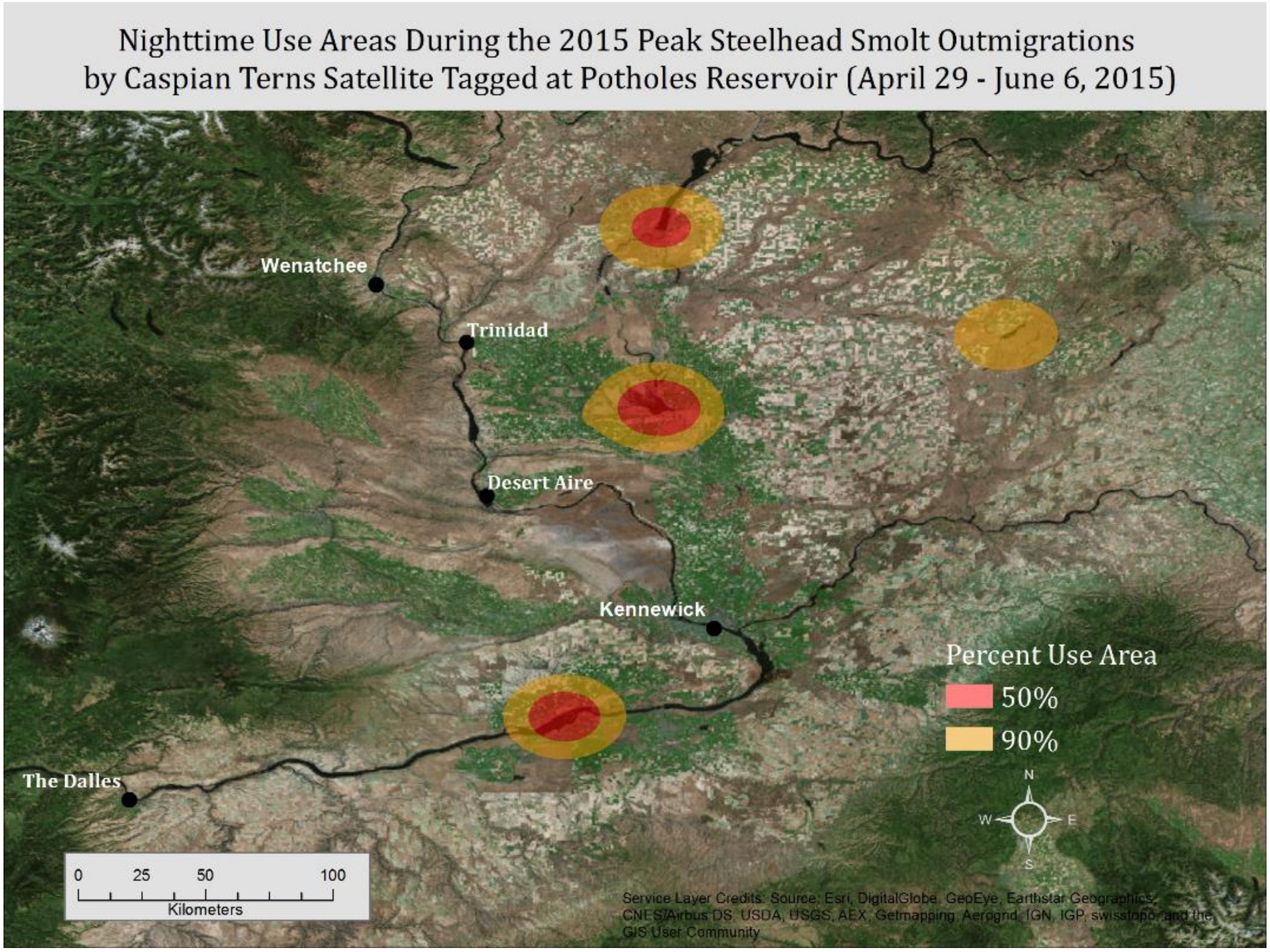
Map 5. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2014 (May 5 – May 31) for Caspian terns satellite tagged at Potholes Reservoir in 2014 that were tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir during that time period. Red indicates the area where the probability of finding an individual tagged tern is 50% and yellow encompasses the area where the probability is 90% (note: higher percentage areas also include the lower percentage areas contained within). Only the use distribution areas on the Columbia Plateau are shown here.



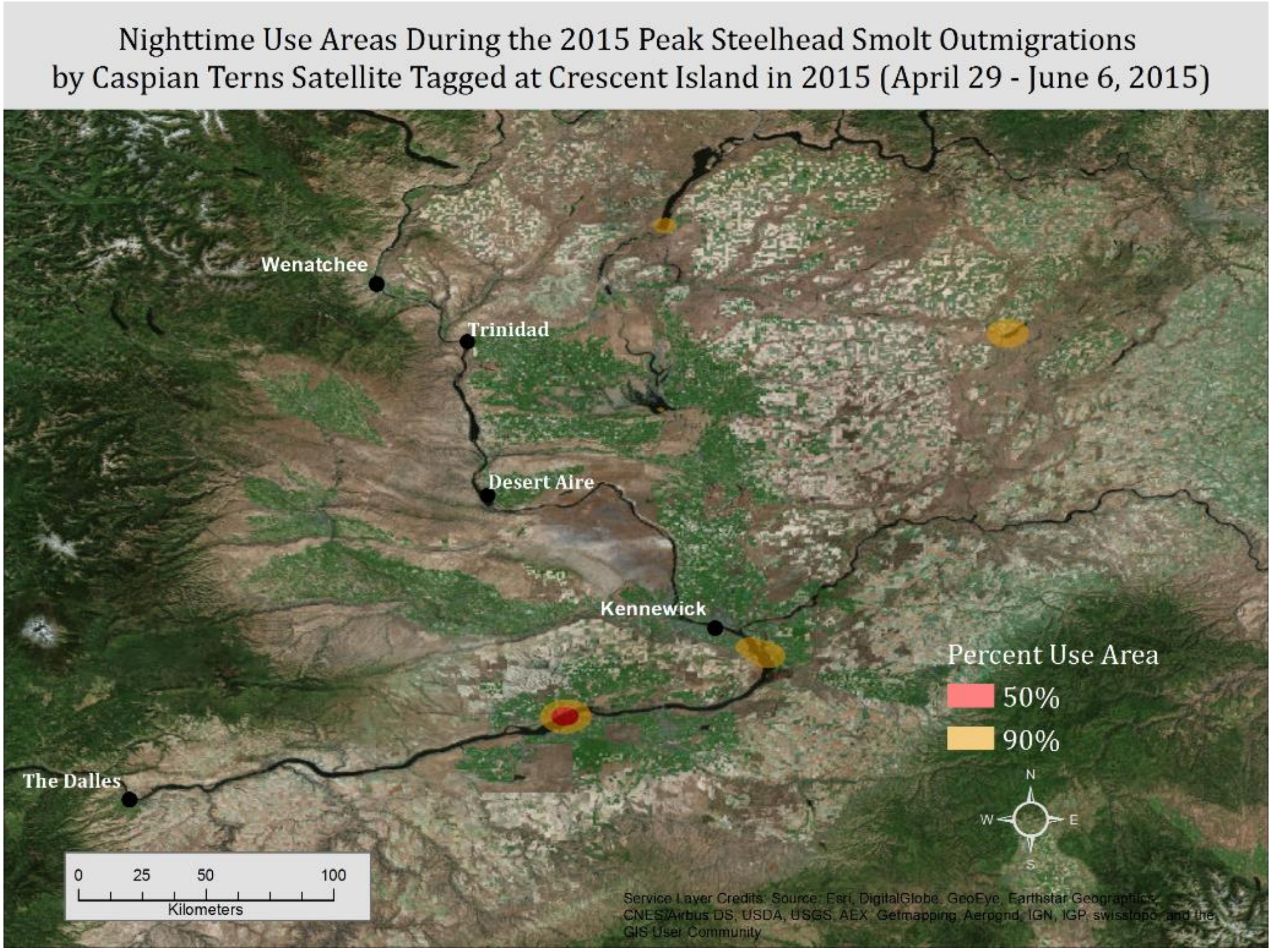
Map 6. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2014 (May 5 – May 31) and 2015 (April 29 – June 6) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 that were tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir during those time periods. Red indicates the area where the probability of finding an individual tagged tern is 50% in 2014. Blue indicates the area where the probability of finding an individual tagged tern is 50% in 2015. Purple indicates the overlap in 50% utilization distribution between the two years. Only locations within the Columbia Plateau were used.



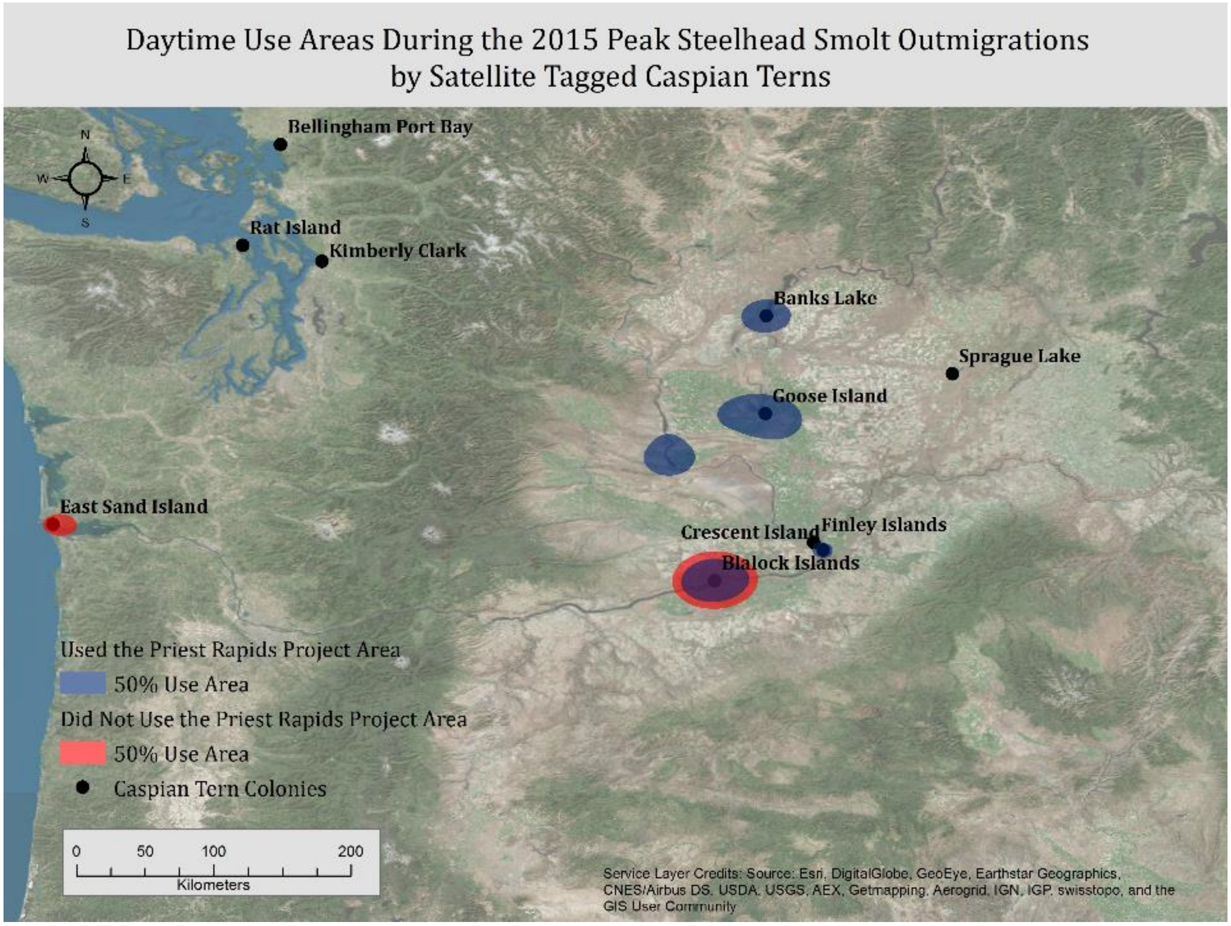
Map 7. Satellite telemetry locations during the week of 11-17 May indicated concentrated use by Caspian terns at an exposed sand bar in the Priest Rapids Reservoir, near the community of Desert Aire. At least 50 terns were seen loafing at the site during a visit by boat on 12 May. Photographs are from an aerial survey conducted on 15 May funded by the U.S. Army Corps of Engineers, Walla Walla District. This location was one of the sites identified from satellite telemetry data for post-breeding season scanning to detect PIT tags from salmonid smolts consumed and deposited by Caspian terns.



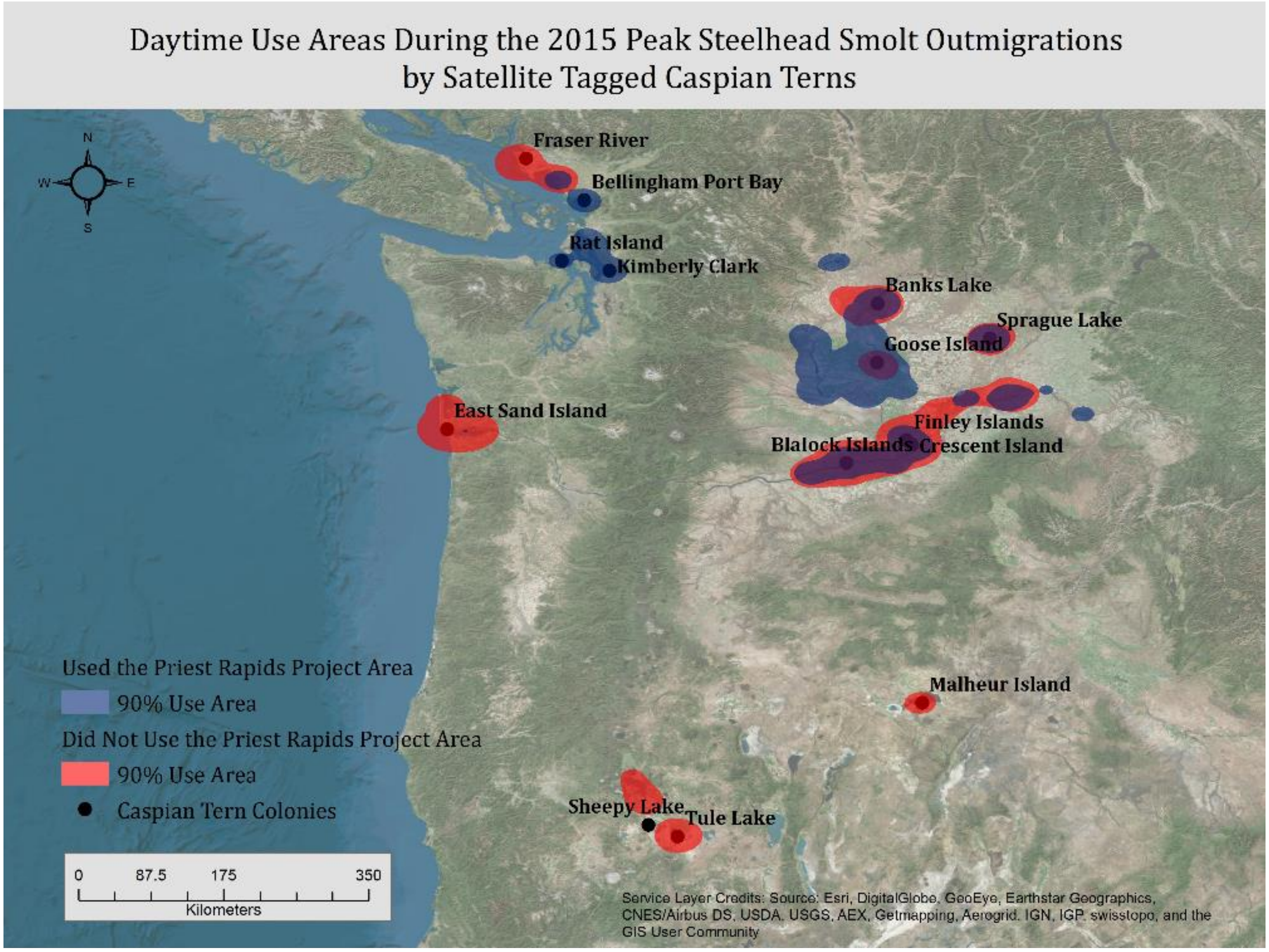
Map 8. Nighttime utilization distribution analysis during the peak of steelhead smolt outmigration in 2015 (April 29 – June 6) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015. Red indicates the area where the probability of finding an individual tagged tern is 50% and yellow encompasses the area where the probability is 90% (note: higher percentage areas also include the lower percentage areas contained within). Only locations within the Columbia Plateau were used.



Map 9. Nighttime utilization distribution analysis during the peak of steelhead smolt outmigration in 2015 (April 29 – June 6) for Caspian terns satellite-tagged at Crescent Island in 2015. Red indicates the area where the probability of finding an individual tagged tern is 50% and yellow encompasses the area where the probability is 90% (note: higher percentage areas also include the lower percentage areas contained within). Only locations within the Columbia Plateau were used.

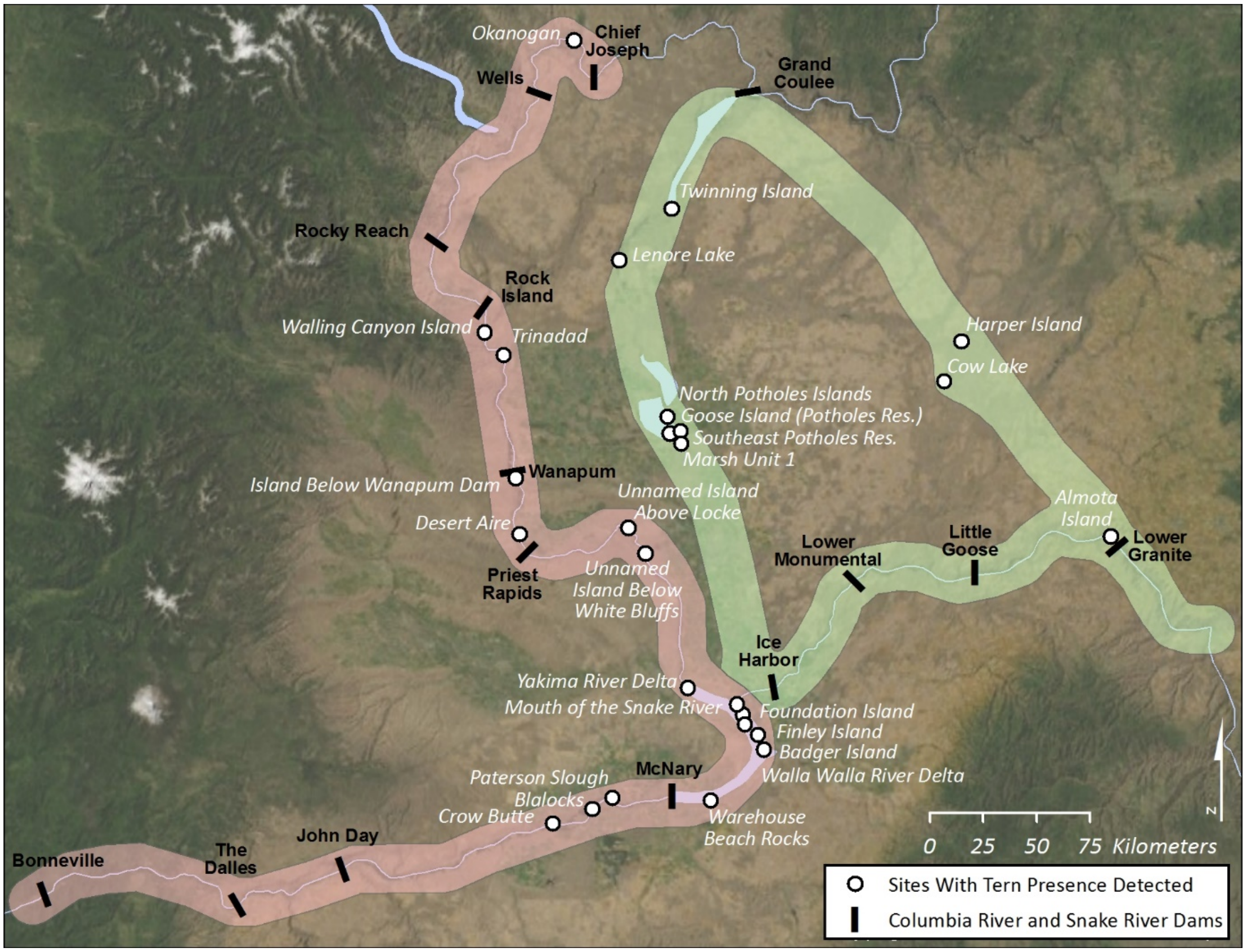


Map 10. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2015 (April 29 – June 6) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 and at Crescent Island in 2015. Red indicates the area where there was a 50% probability of finding an individual tagged tern that did not report any locations from within the Priest Rapids Project area during the time period. Blue indicates the area where there was a 50% probability of finding an individual tagged tern that had at least one location within the Priest Rapids Project area during the time period. Purple indicates the overlap in 50% utilization distribution between the two groups.

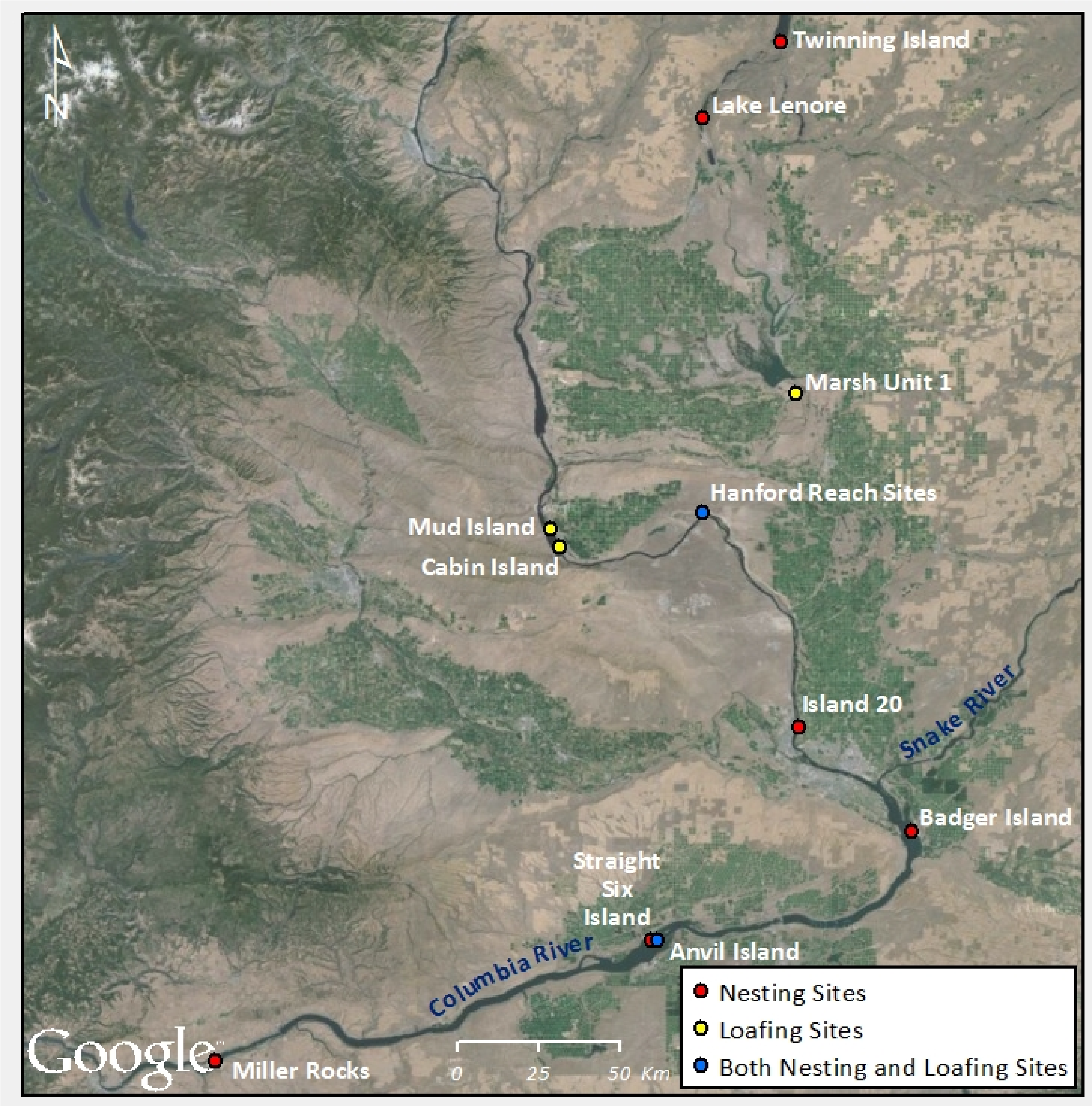


Map 11. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2015 (April 29 – June 6) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 and at Crescent Island in 2015. Red indicates the area where there was a 90% probability of finding an individual tagged tern that did not report any locations from within the Priest Rapids Project area during the time period. Blue indicates the area where there was a 90% probability of finding an individual tagged tern that had at least one location within the Priest Rapids Project area during the time period. Purple indicates the overlap in 90% utilization distribution between the two groups.

Map 12. Locations where Caspian terns were either color-banded (2005-2014) or subsequently resighted in 2015 following banding.



Map 13. Aerial survey flight paths along the Columbia and Snake rivers and at off-river locations within the Columbia Plateau region, including sites where Caspian terns were observed loafing and nesting in 2015.



Map 14. Locations of bird nesting and loafting sites scanned for smolt PIT tags in 2015.

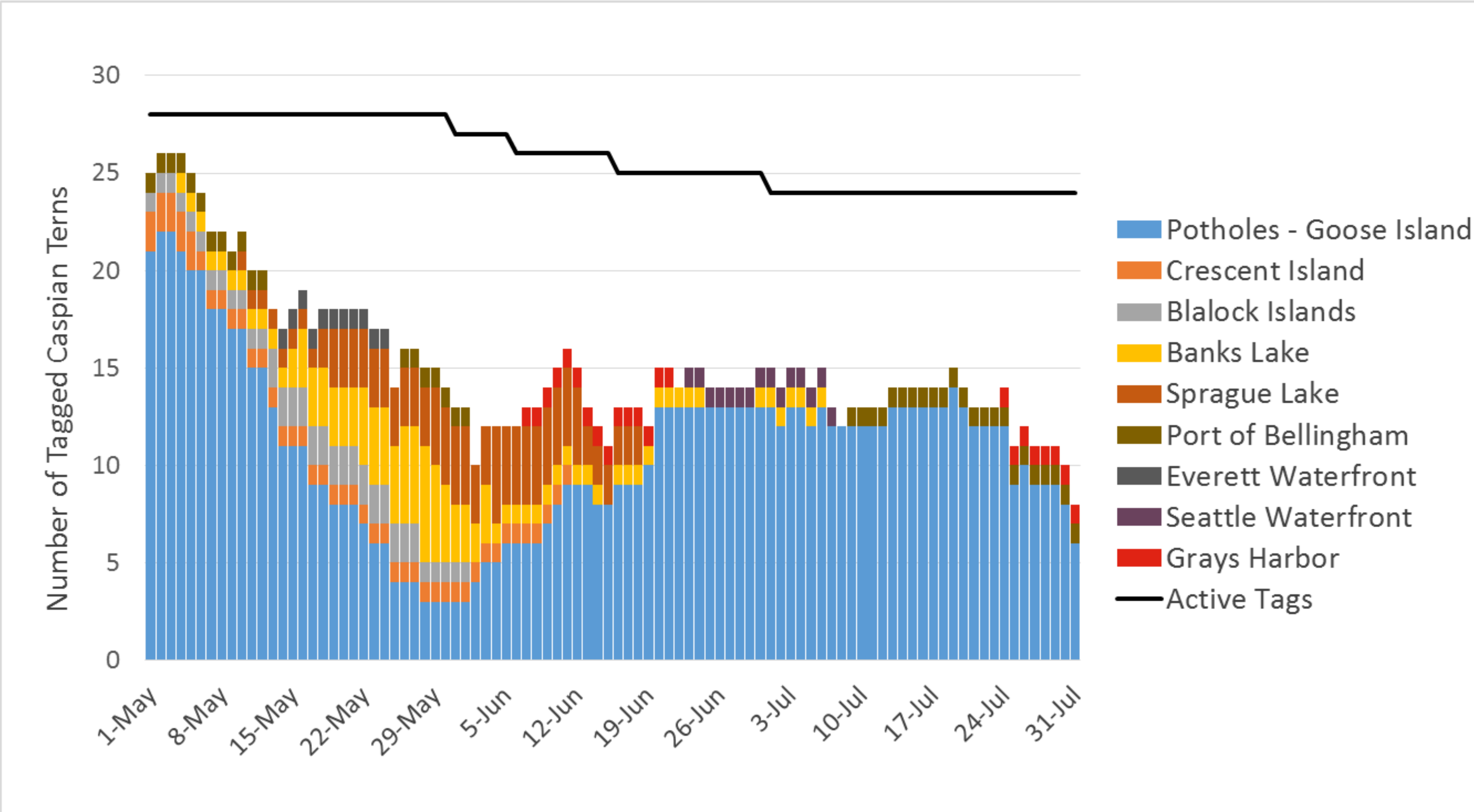


Figure 1. Colony associations of satellite-tagged Caspian terns during 1 May – 31 July 2014. A tagged individual was considered to be associated with a specific colony on a particular day of the season if it had been positively located at that colony on at least 3 of the previous 9 nights and had not been located at any other colonies during those 9 nights.

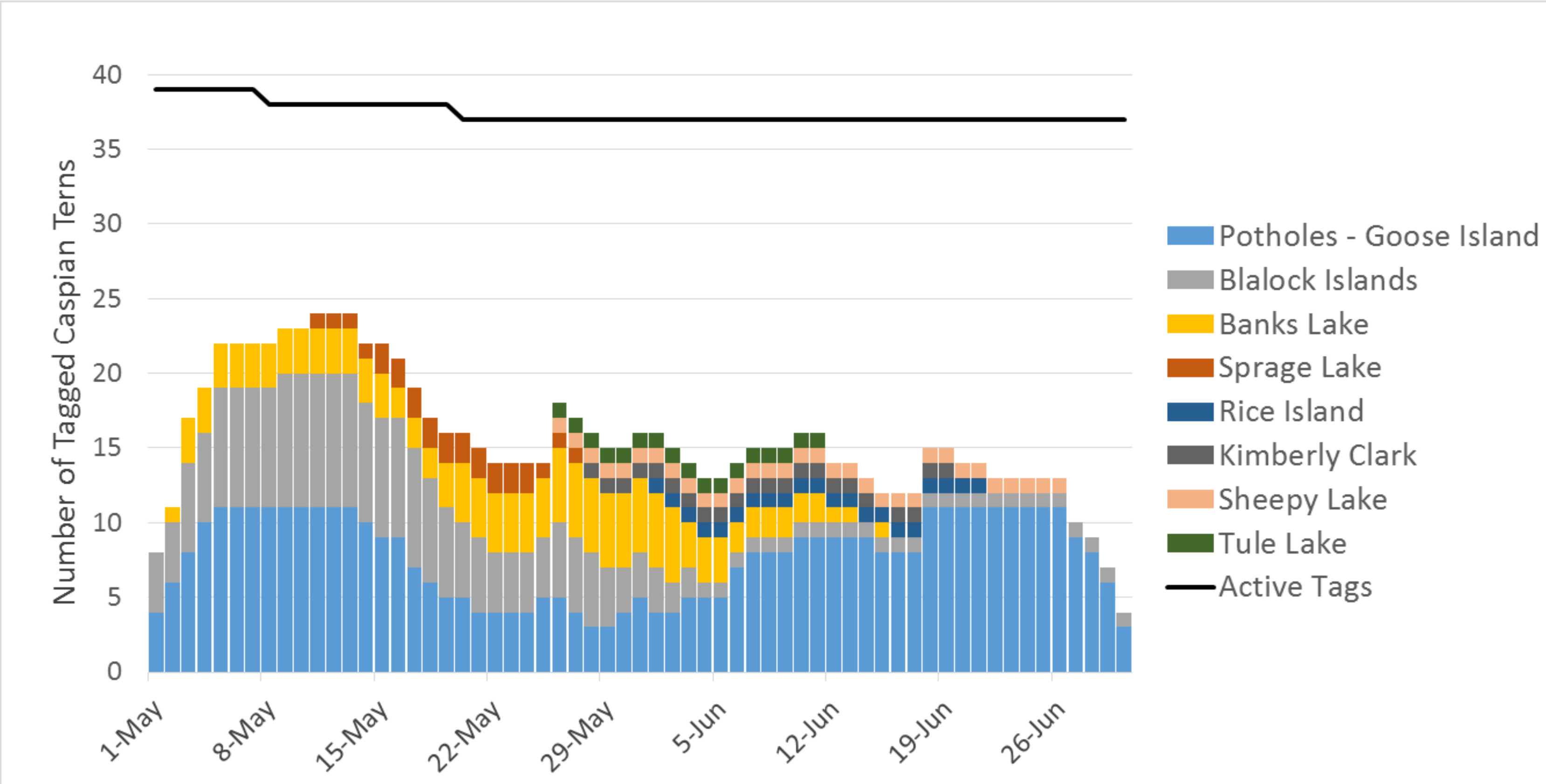


Figure 2. Colony associations of Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 during 29 April – 30 June 2015. A tagged individual was considered to be associated with a specific colony on a particular day of the season if it had been consistently located at that colony across 9 nights and had not been located at any other colonies during those 9 nights.

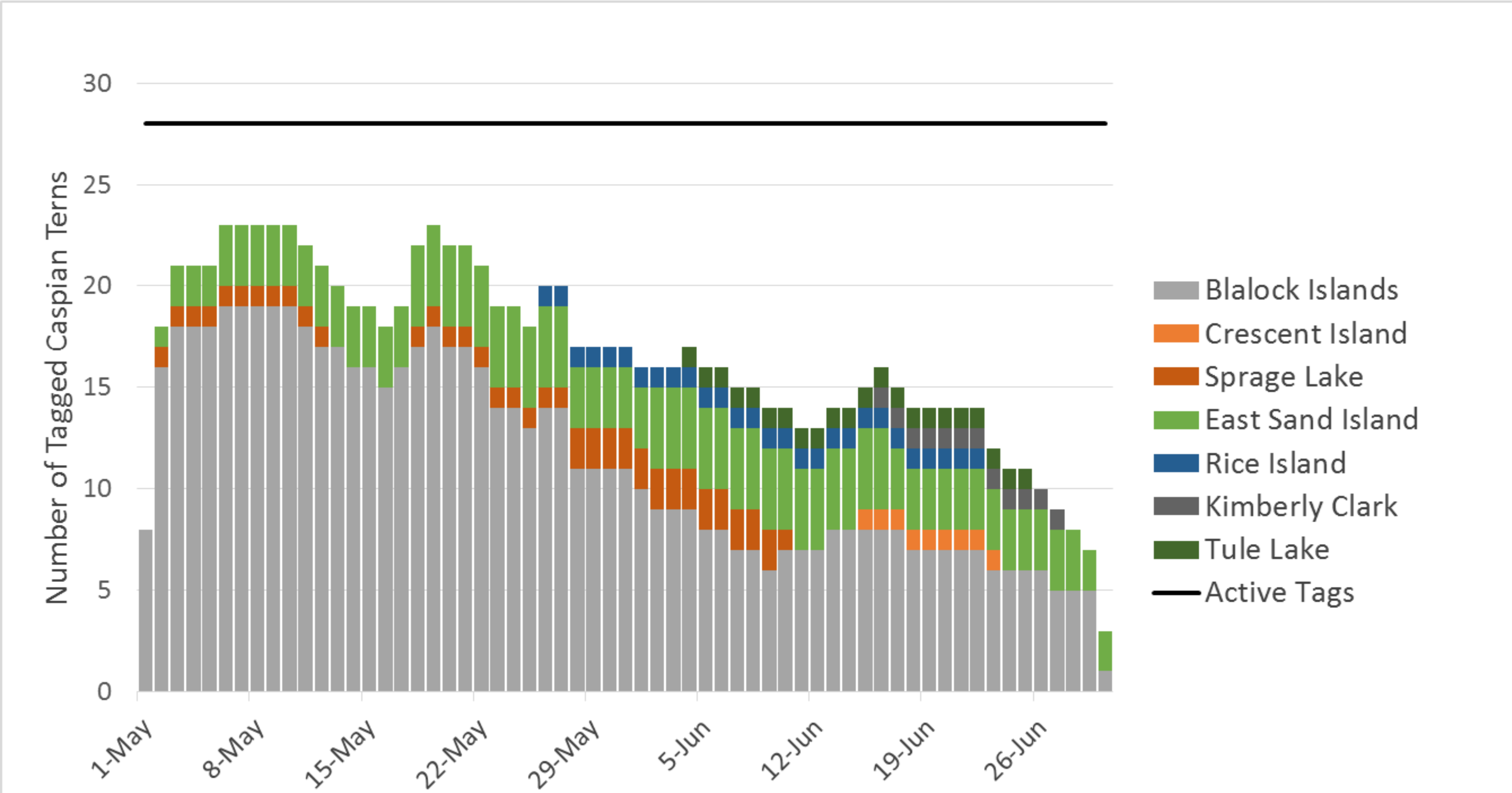


Figure 3. Colony associations of Caspian terns satellite-tagged at Crescent Island in 2015 during 29 April – 30 June 2015. A tagged individual was considered to be associated with a specific colony on a particular day of the season if it had been consistently located at that colony across 9 nights and had not been located at any other colonies during those 9 nights.

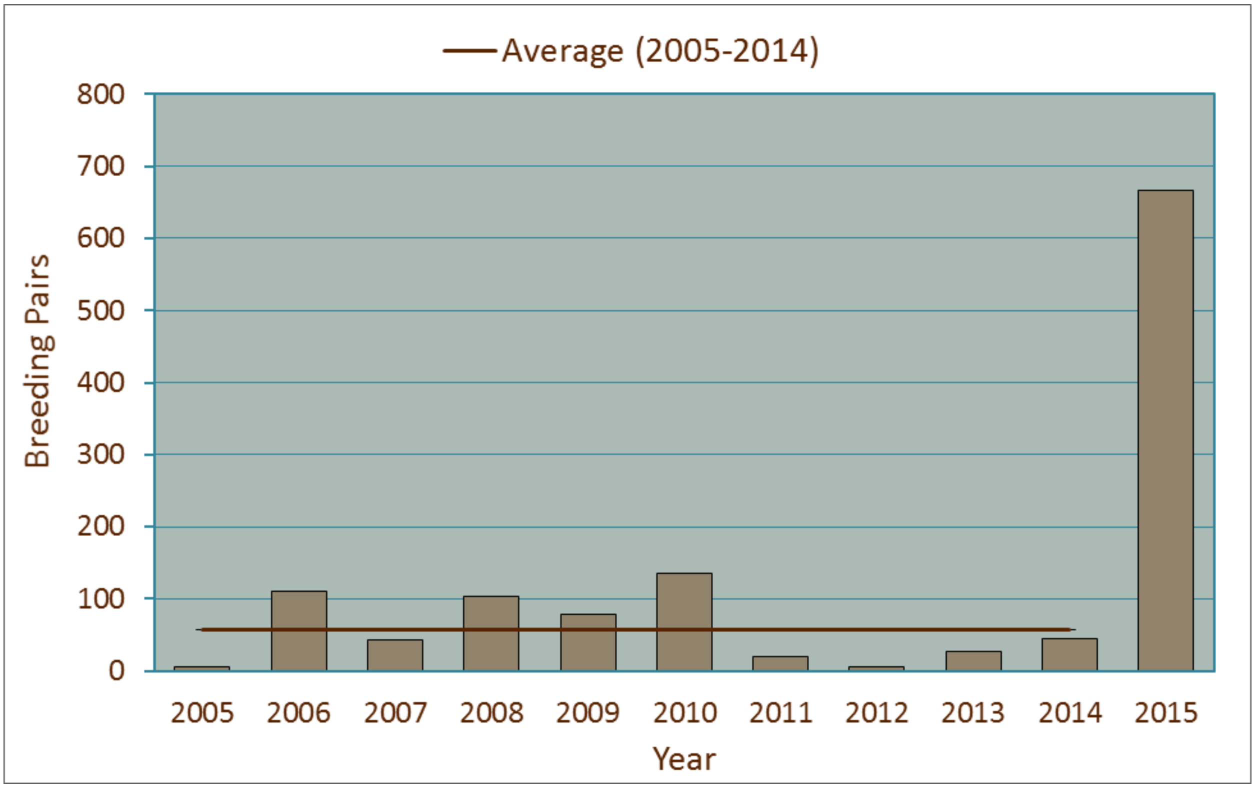


Figure 4. Size of the Caspian tern breeding colony (number of breeding pairs) at the Blalock Islands, John Day Reservoir, mid-Columbia River during 2005-2015.

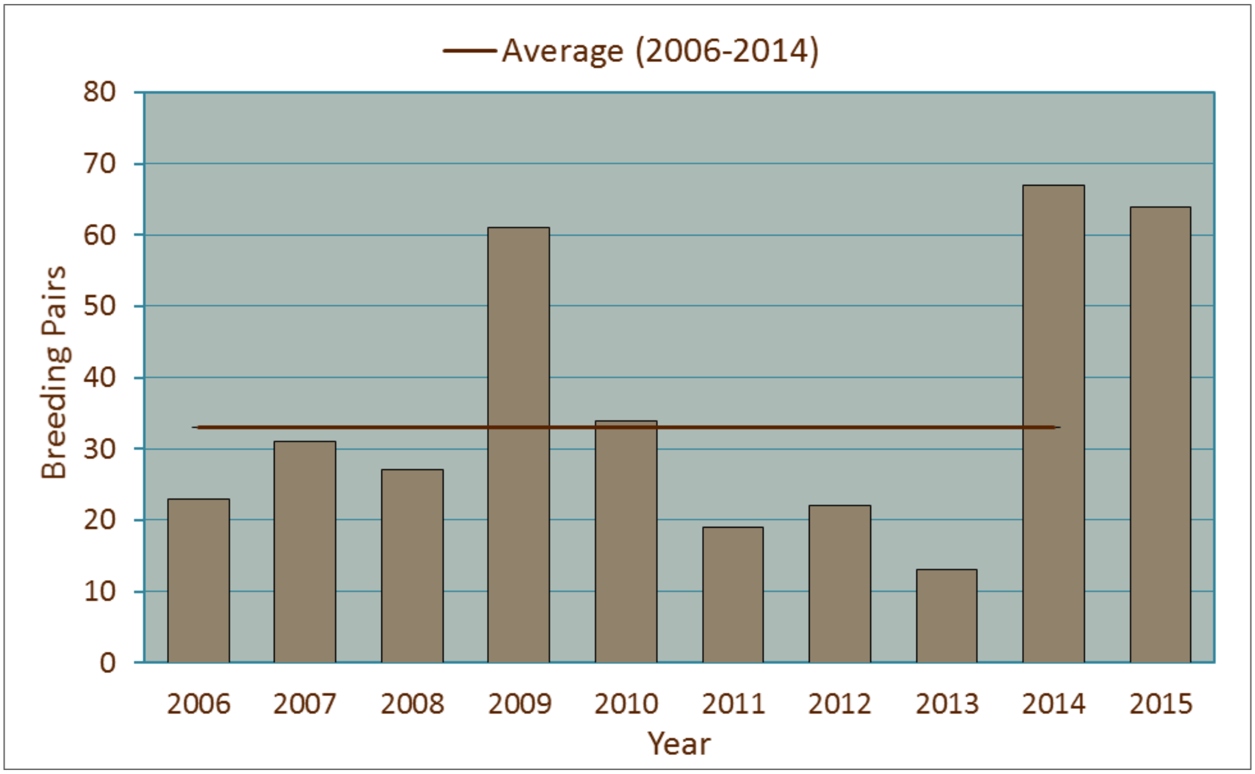


Figure 5. Size of the Caspian tern breeding colony (number of breeding pairs) at Twinning Island in Banks Lake during 2006-2015. In 2005, Caspian terns nested on two islands in Banks Lake (Twinning and Goose islands), and colony size was estimated to be less than 10 breeding pairs at each site.

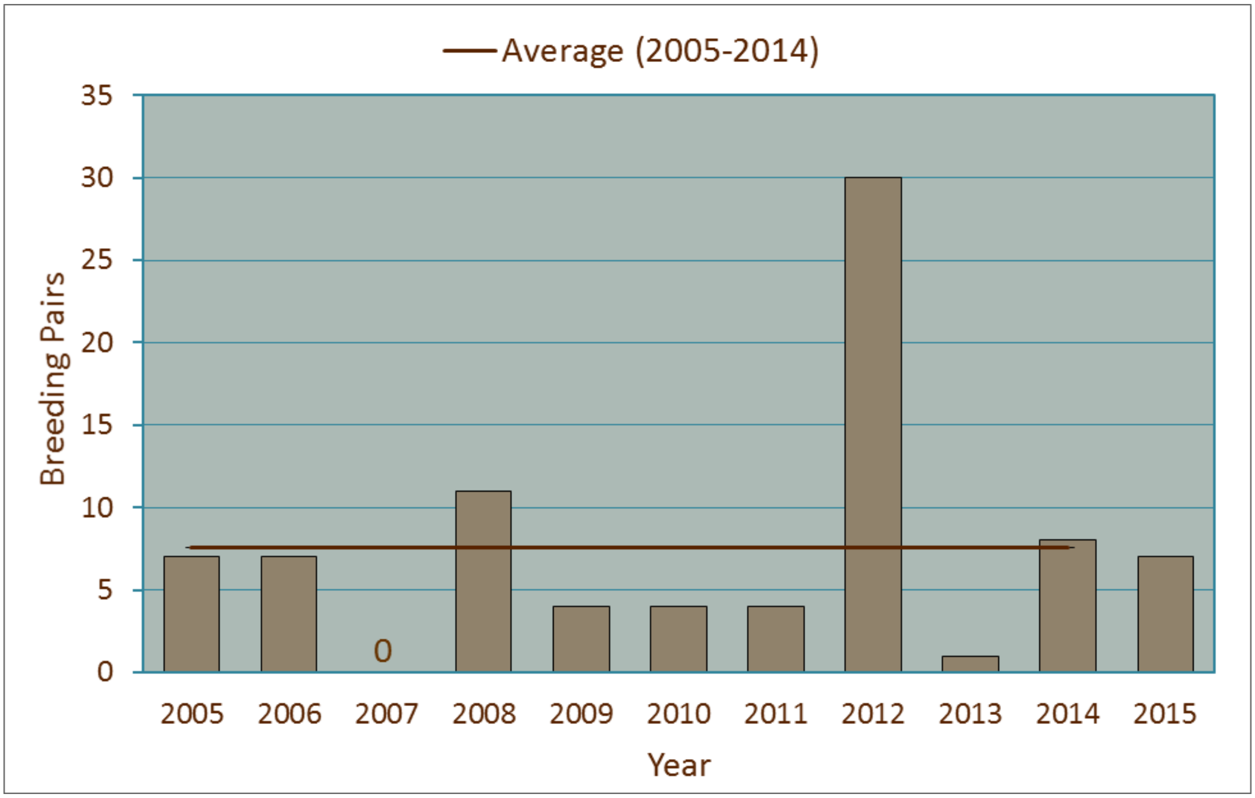


Figure 6. Size of the Caspian tern breeding colony (number of breeding pairs) at Harper Island in Sprague Lake during 2005-2015. Caspian terns did not attempt to nest on Harper Island in 2007.

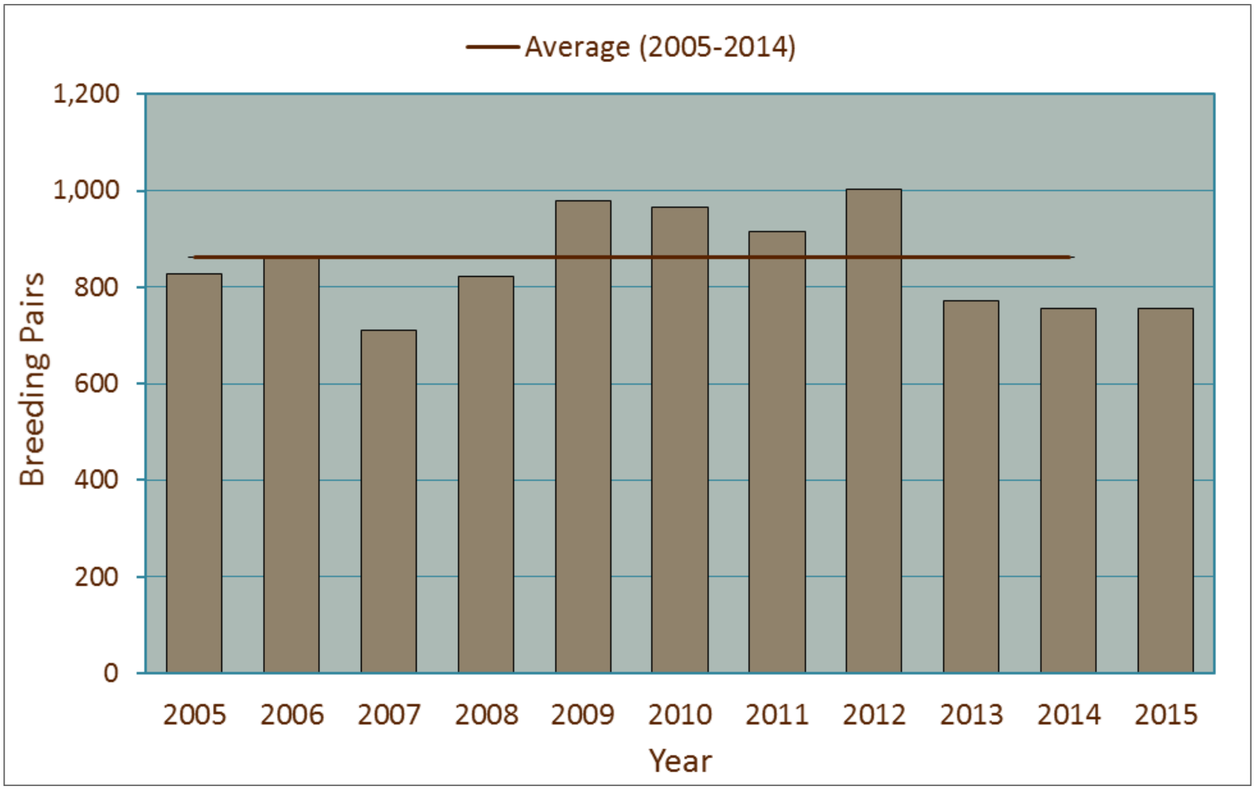


Figure 7. Total numbers of Caspian tern breeding pairs nesting at all known colonies in the Columbia Plateau region during 2005-2015.

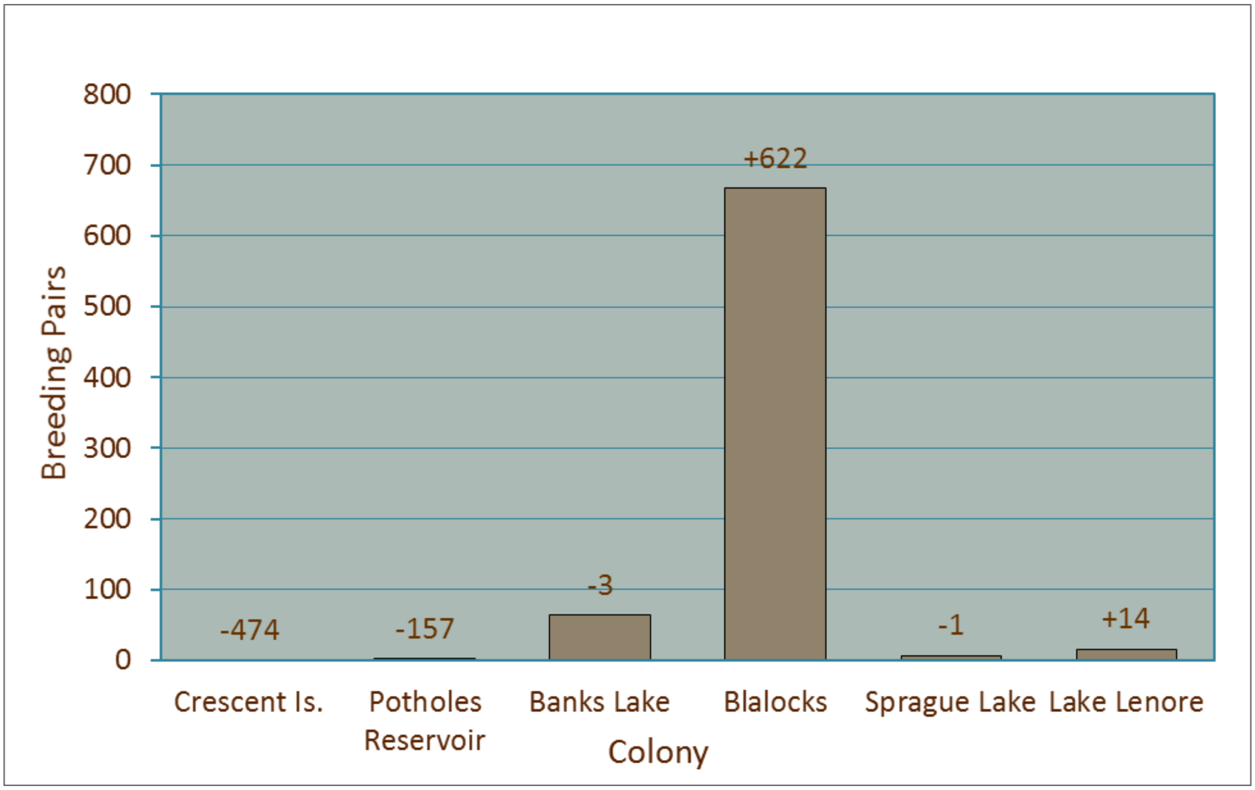


Figure 8. Sizes of Caspian tern breeding colonies (numbers of breeding pairs) in the Columbia Plateau region during the 2015 breeding season. Numbers over each bar indicate the change in colony size in 2015 compared to the previous year.

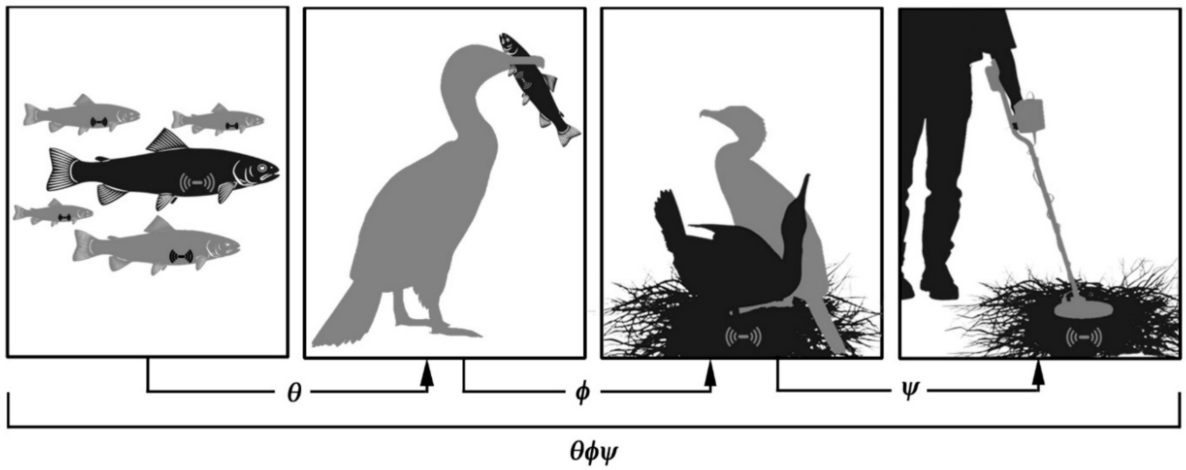
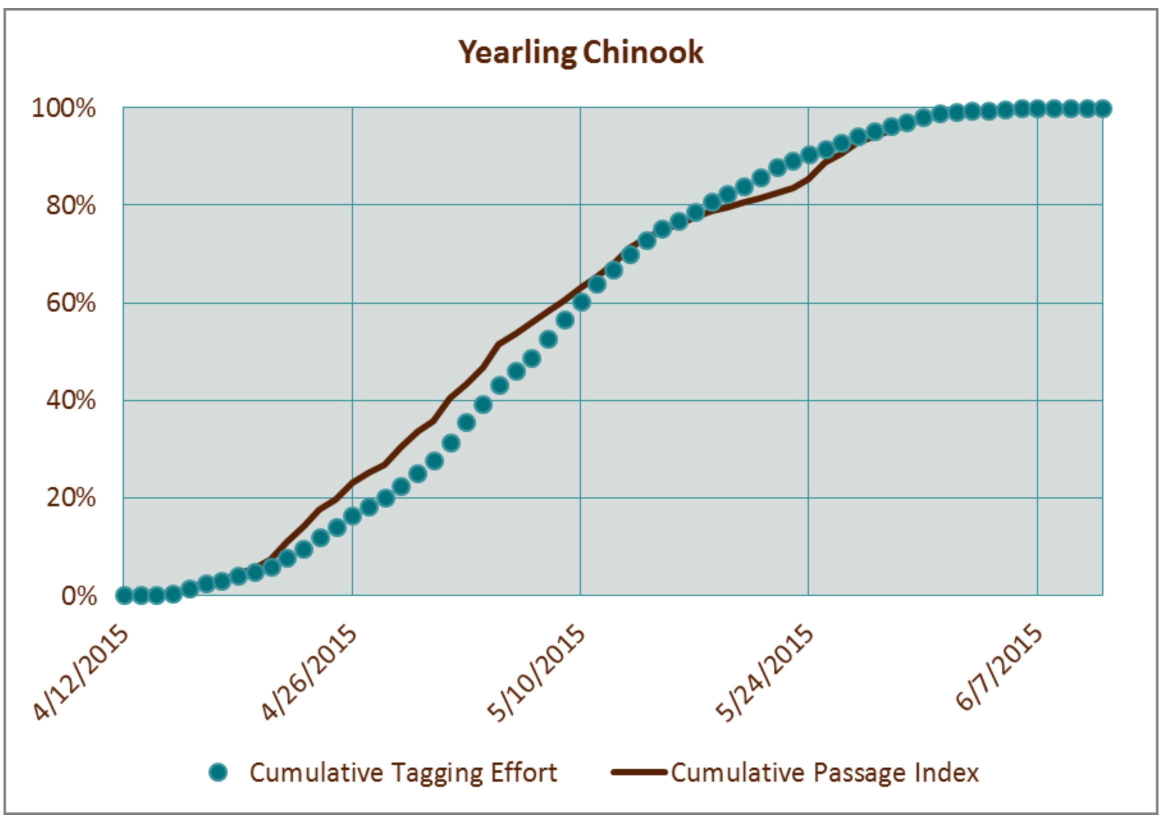


Figure 9. Conceptual model of the tag-recovery process in studies of avian predation. The probability of recovering an implanted fish tag on a bird colony is the product of three probabilities: a tagged fish was consumed (predation rate, θ), a consumed tag was deposited on the nesting colony (deposition rate, ϕ), and a deposited tag was detected by researchers (detection efficiency, ψ). Diagram from Hostetter et al. (2015).



Yearling Chinook
100%
80%
60%
40%
20%
0%
4/12/2015
4/26/2015
5/10/2015
5/24/2015
6/7/2015
Cumulative Tagging Effort
Cumulative Passage Index

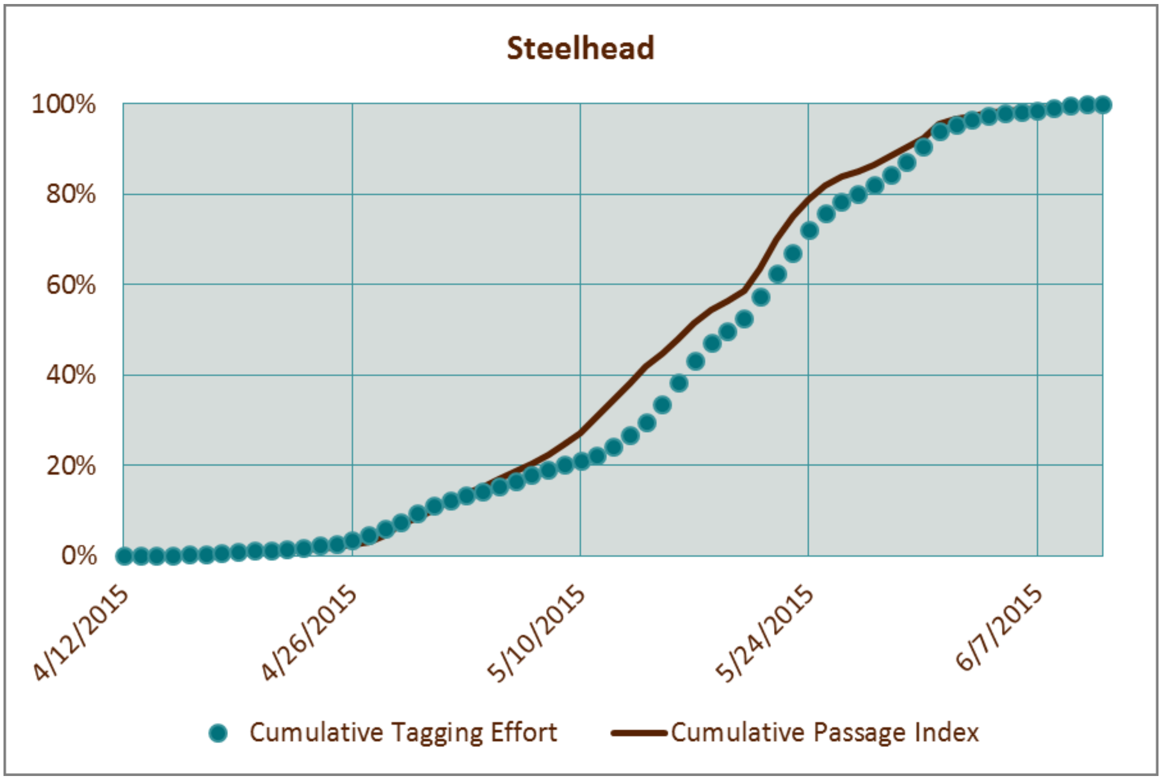


Figure 10. Proportion by sampling date of all steelhead and yearling Chinook salmon PIT-tagged at the Rock Island Dam fish trap by researchers relative to the passage index. Passage index data were obtained from Columbia River DART (2016).

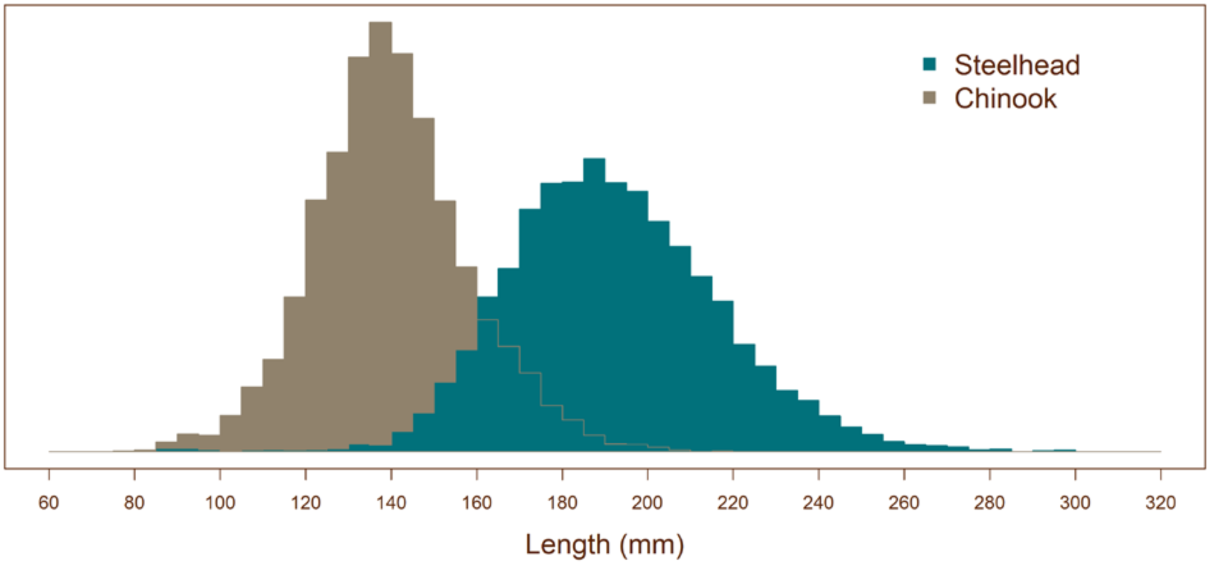


Figure 11. Distributions of fork lengths for juvenile steelhead and yearling Chinook salmon PIT-tagged at Rock Island Dam during 2015.

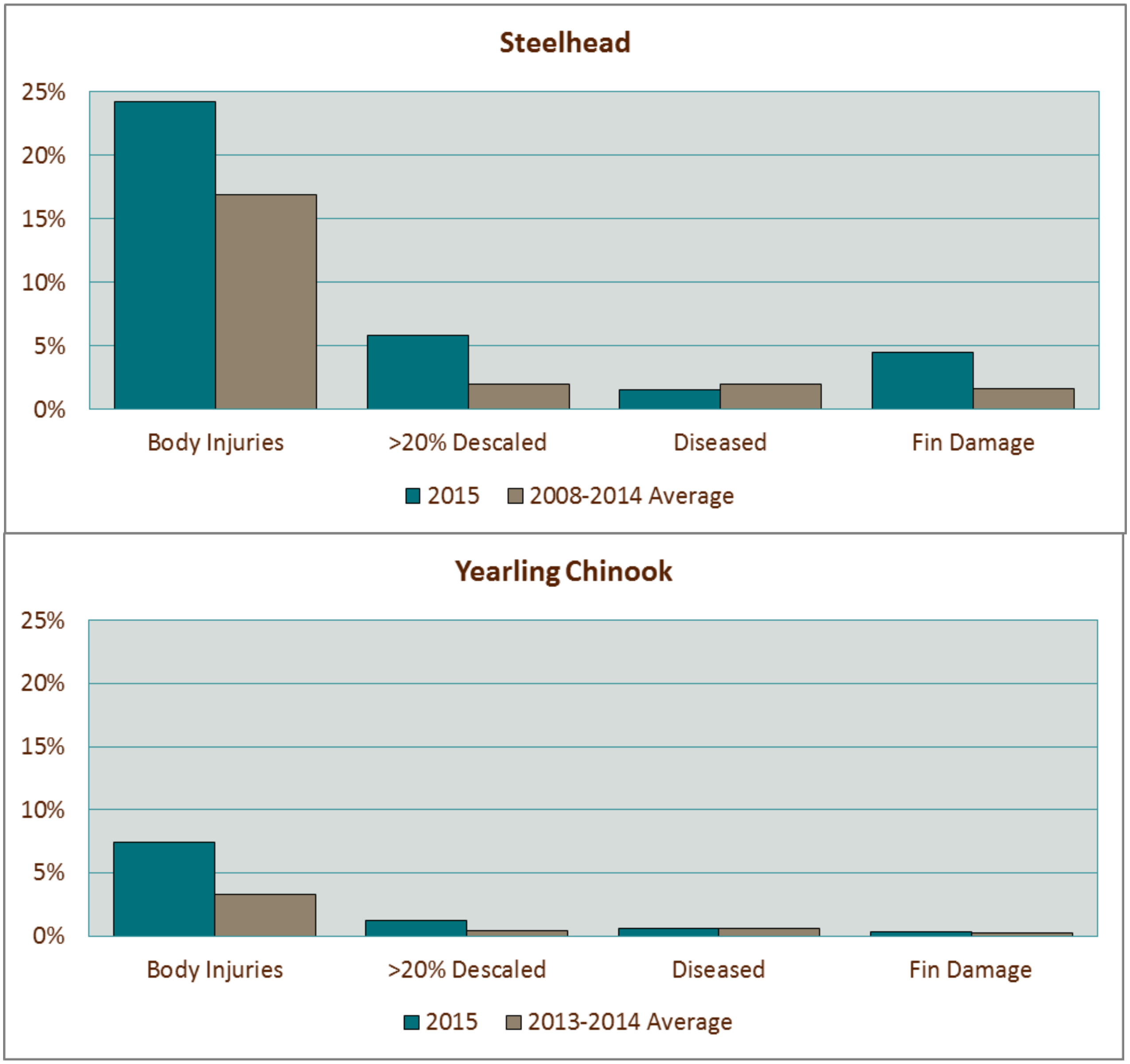


Figure 12. Proportion of juvenile steelhead and yearling Chinook salmon PIT-tagged at Rock Island Dam with external body injuries, descaling, fin damage, and disease during 2008-2015.

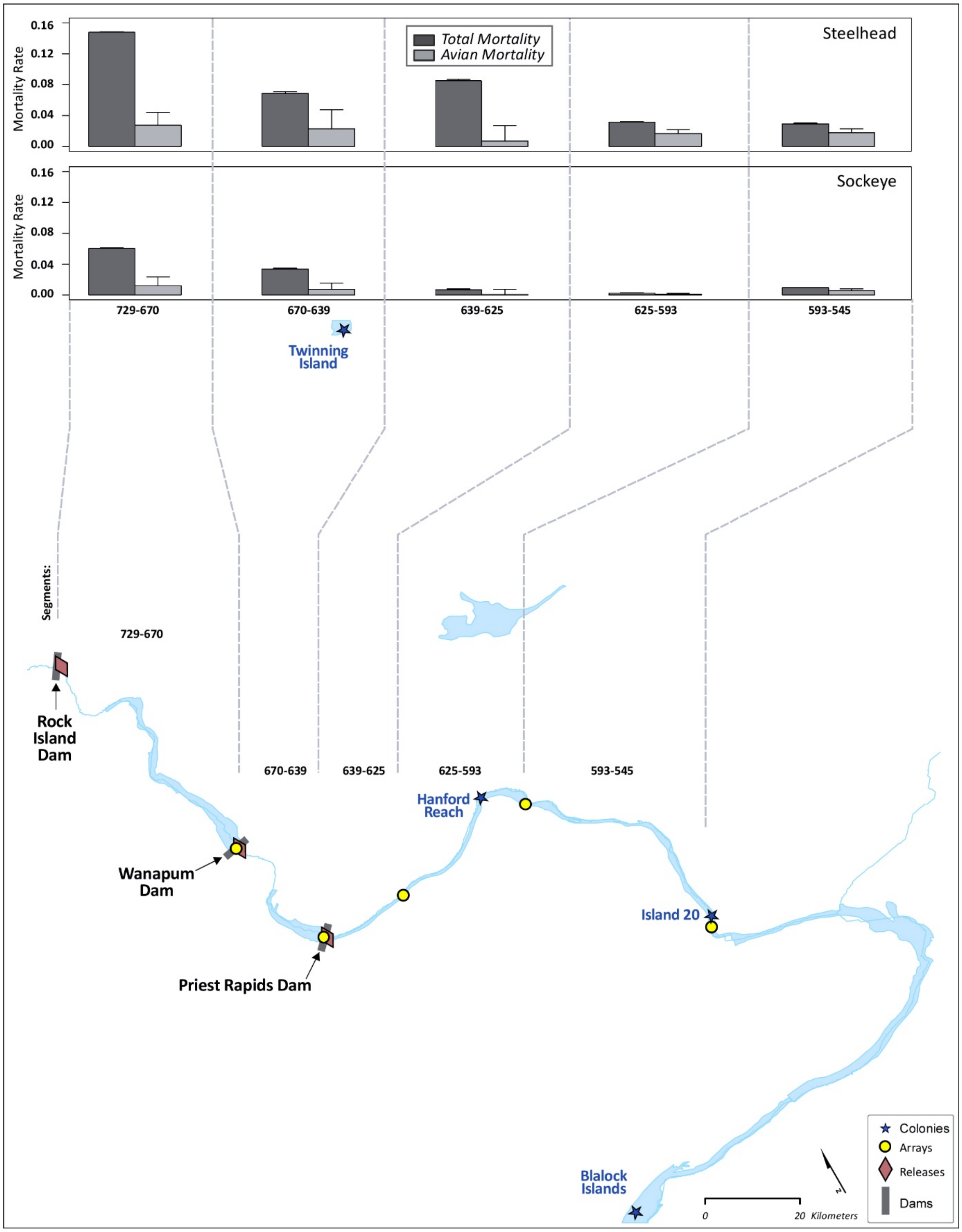


Figure 13. Estimated total mortality and mortality associated with consumption by piscivorous colonial waterbirds for tagged steelhead and sockeye salmon smolts in a section of the middle Columbia River during the 2015 outmigration. Locations of smolt release sites (red diamonds),

acoustic arrays (yellow dots), bird colony sites (blue stars), and hydroelectric dams (grey bars) are shown (see also Appendix A).

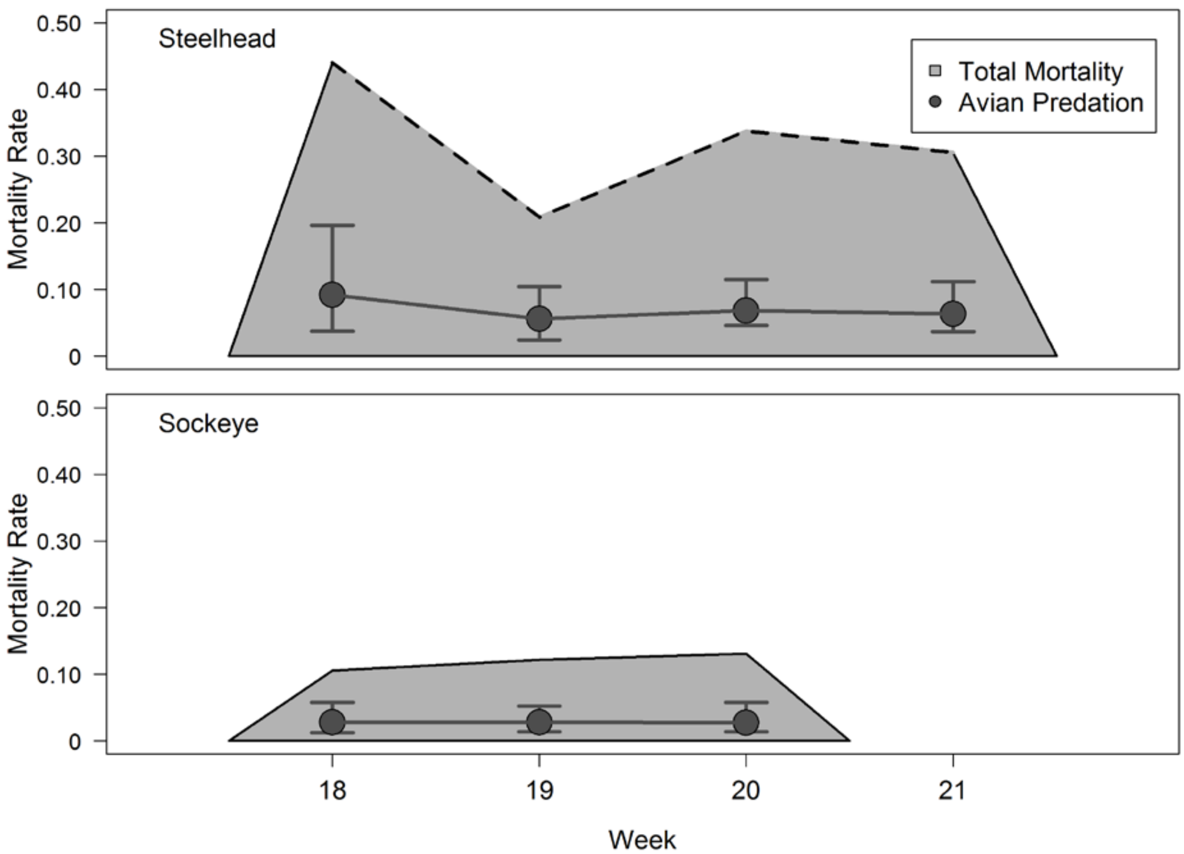


Figure 14. Weekly reach-specific avian predation rates (percentage of tagged fish consumed) and total mortality of tagged juvenile steelhead and sockeye salmon released into the middle Columbia River at river kilometer 729 in 2015. Release weeks are based on the Julian calendar, with week 18 starting on 26 April 2015.

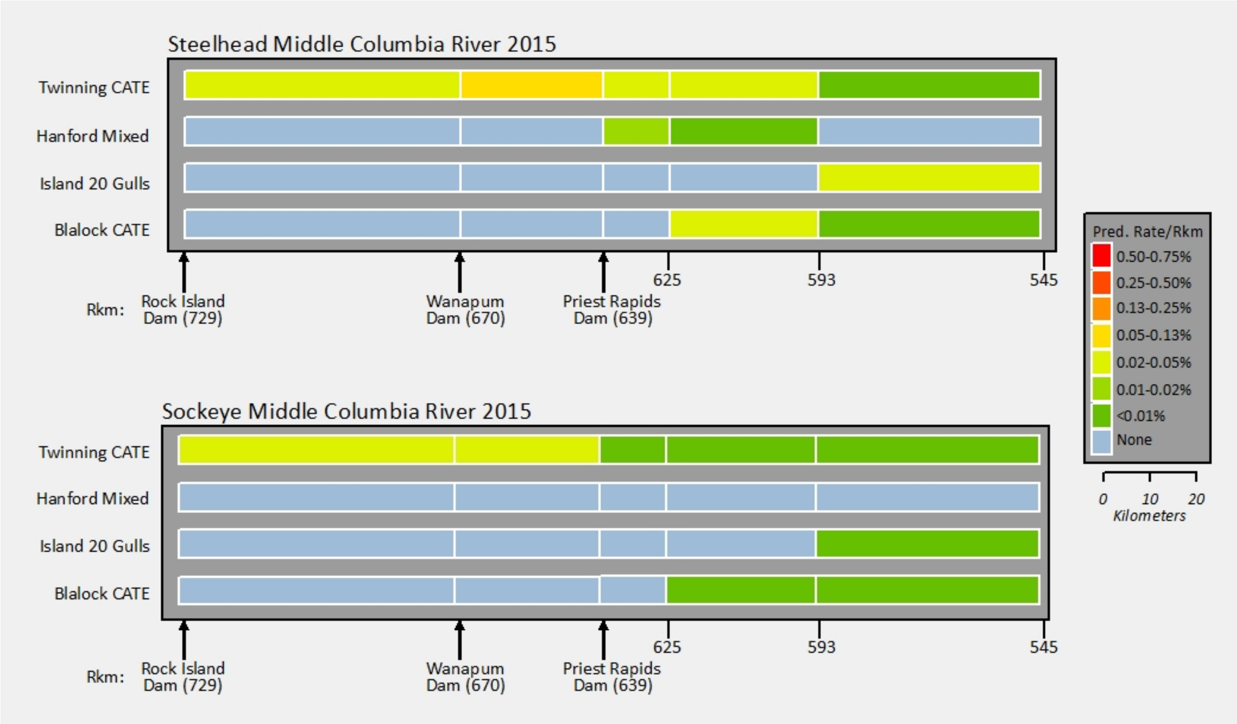


Figure 15. Bird colony-specific locations of predation on tagged juvenile steelhead and sockeye salmon in sections of the middle Columbia River in 2015. Results are depicted as predation rates per river kilometer. Species of piscivorous colonial waterbirds evaluated include Caspian terns (CATE), California and ring-billed gulls (Gulls), and double-crested cormorants and great blue herons at a mixed-species colony site (Mixed).

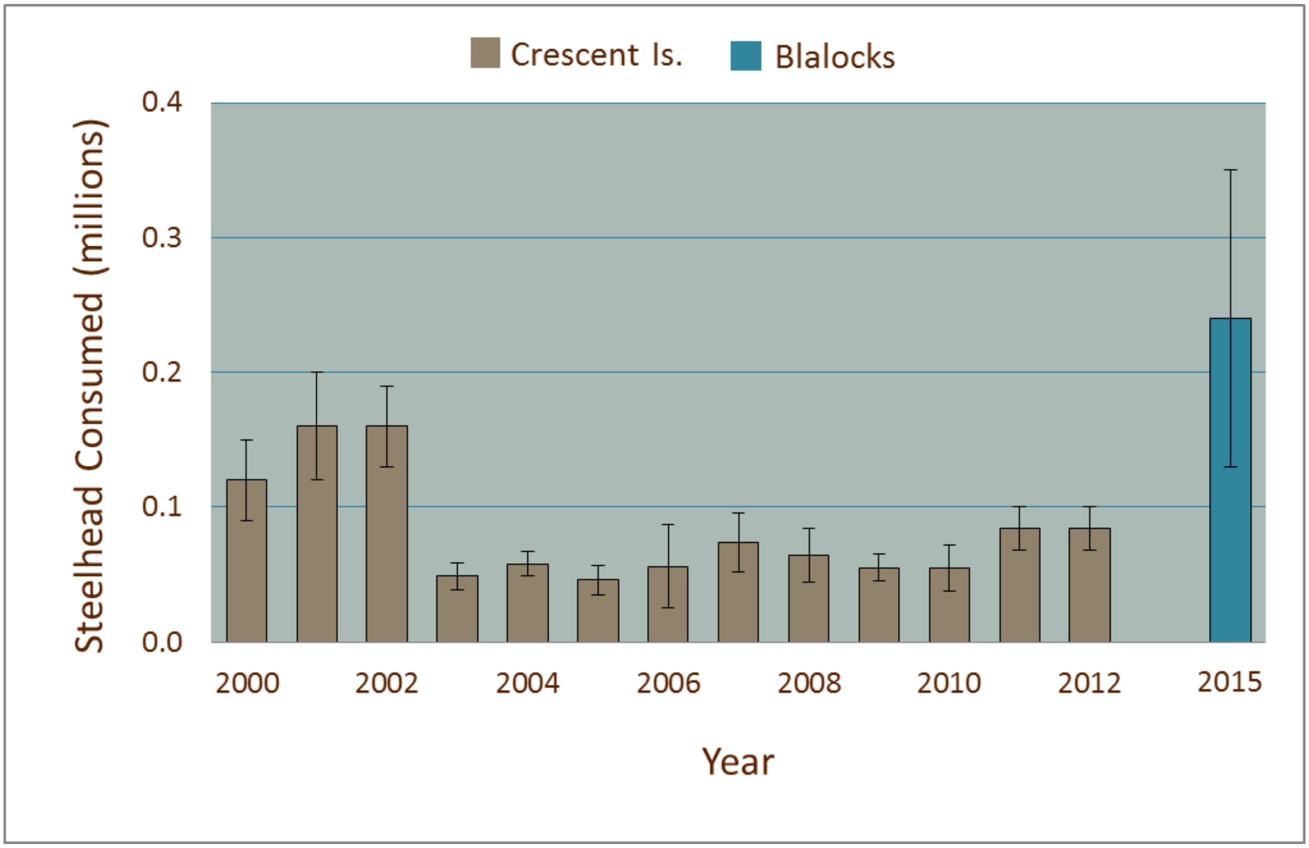


Figure 16. Estimated total annual consumption of juvenile steelhead by Caspian terns nesting on Crescent Island (200-2012) and the Blalock Islands (2015) in the mid-Columbia River. Estimates are based on fish identified in tern bill-loads on-colony and bioenergetics calculations. Error bars represent 95% confidence intervals for the number of smolts consumed.

Table 1. Comparison of visits to Columbia River reservoirs upstream of Richland, WA, during the peak steelhead smolt outmigration in 2014 and 2015 by Caspian terns tagged at Goose Island, Potholes Reservoir in April 2014. Values are the percentages of active tagged birds that visited each pool at least once during the time period.

Peak Outmigration Period	Year	Hanford Reach	Priest Rapids Reervoir	Wanapum Reservoir	Number of Active Tags
May 5 – May 31	2014	36%	50%	39%	28
April 28 – June 6	2015	35%	43%	43%	23

Table 2. Use of Columbia River reservoirs upstream of Richland, WA, by tagged Caspian terns during the 2015 peak steelhead smolt outmigration, 29 April – 6 June. Values are the percentages of active tagged birds that visited each reservoir at least once during the time period, by tagging group. Blank cells indicate that no tagged terns were detected in these locations during the outmigration period.

Peak Outmigration Period	Tagged Group	Hanford Reach	Priest Rapids Reservoir	Wanapum Reservoir	Number of Active Tags
April 28 - June 6, 2015	Potholes Reservoir 2014	35%	43%	43%	23
	Potholes Reservoir 2015	56%	50%	44%	18
	Crescent Island 2015	7%	4%		28

Table 3. Comparison of daytime river use by tagged Caspian terns at Upper Columbia River reservoirs during the peak of steelhead smolt outmigration in 2013, 2014, and 2015, for terns that were tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir. Values are the average proportion of daily GPS tag (2013) or satellite tag (2014 and 2015) locations recorded at (1) Priest Rapids Reservoir and (2) the Hanford Reach, Priest Rapids Reservoir, and Wanupum Reservoir combined. Proportions were calculated for the complete smolt outmigration time period ("Complete Time Period") and for days when individual terns were detected in each region of interest ("On Days with River Use"). The first measure indicates relative use of these locations across all days of the outmigration. The second measure indicates the pattern of visitation within days when visits occurred (i.e. short, isolated visits or extended and/or repeated visits across the day).

	Priest Rapids Reservoir		Hanford Reach, Priest Rapids Reservoir, and Wanupum Reservoir	
Year	Complete Time Period	On Days with River Use	Complete Time Period	On Days with River Use
2013 (n=21)	5%	17%	13%	28%
2014 (n=24)	10%	87%	25%	89%
2015 (n=37)	9%	80%	19%	76%

Table 4. Use of the Columbia Plateau region and the historical Goose Island Caspian tern foraging areas by satellite-tagged Caspian terns during the 2015 steelhead smolt outmigration 29 April - 6 June 2015. Values are the percentages of active tagged birds that visited each region at least once per week, by tagging group. The Columbia Plateau region is defined as indicated in Map 2. The historical Goose Island Caspian tern foraging area is taken from a study conducted on Caspian terns nesting on Goose Island in May 2013 (one year prior to the initiation of tern management there), using GPS telemetry tags to track foraging patterns (Map 2).

Peak Outmigration Period	Tagged Group	Columbia Plateau	Goose Island Foraging Area	Number of Active Tags
April 29 - June 6	Potholes Reservoir 2014	91%	87%	23
	Potholes Reservoir 2015	94%	83%	18
	Crescent Island 2015	89%	18%	28

Table 5. Comparison of visits to reservoirs on the Columbia and Snake rivers during the peak steelhead smolt outmigration in 2014 and 2015 by Caspian terns tagged at Goose Island, Potholes Reservoir in April 2014. Values are the percentages of active tagged birds that visited each pool at least once during the time period.

Peak Outmigration Period	Year	Bonneville to John Day	John Day Reservoir	McNary Reservoir	Ice Harbor Reservoir	Lower Monumental to Lower Granite	Number of Active Tags
May 5 – May 31	2014	4%	32%	29%	7%	18%	28
April 28 – June 6	2015	9%	52%	17%	9%	17%	23

Table 6. Use of reservoirs on the Columbia and Snake rivers by satellite-tagged Caspian terns during the 2015 peak steelhead smolt outmigration, 29 April – 6 June. Values are the percentages of active tagged birds that visited each reservoir at least once during the time period, by tagging group. Blank cells indicate that no tagged terns were detected in these locations during the outmigration period.

Peak Outmigration Period	Tagged Group	Bonneville to John Day	John Day Reservoir	McNary Reservoir	Ice Harbor Reservoir	Lower Monumental to Lower Granite	Number of Active Tags
April 28 - June 6, 2015	Potholes Reservoir 2014	9%	52%	17%	9%	17%	23
	Potholes Reservoir 2015		44%	22%		17%	18
	Crescent Island 2015		89%	50%	14%	18%	28

Table 7. Use of active, historical, or potential colony sites by tagged Caspian terns during the 2015 peak steelhead smolt outmigration, 29 April – 6 June. Values are the percentages of active tagged birds that visited each colony site at least once during the time period, by tagging group. Blank cells indicate that no tagged terns were detected in these locations during the steelhead outmigration period.

		On Plateau – Off River						On Plateau – On River			Off Plateau				
Peak Outmigration Period	Tagged Group	Goose Island	Columbia NWR	North Potholes	Banks Lake	Sprague Lake	Lenore Lake	Crescent Island	Finley Islands	Blalock Islands	Columbia Estuary	Interior OR/NE CA	Salish Sea & Alaska	Coastal California	Number of Active Tags
April 29 - June 6	Potholes Reservoir 2014	57%	43%	22%	43%	9%	9%		4%	43%	9%	22%	22%		23
	Potholes Reservoir 2015	72%	50%	11%	61%	22%	6%		6%	44%		11%	22%		18
	Crescent Island 2015	11%	7%		7%	11%	4%	11%	26%	86%	29%	4%	4%		28

Table 8. Numbers of banded Caspian terns resighted in the Potholes Reservoir area in 2015 and the colony locations where they were originally marked with uniquely engraved alphanumeric color bands during 2005-2014. The Potholes Reservoir area includes Goose Island, small islands in northern Potholes Reservoir, and a marsh unit in Columbia National Wildlife Refuge.

Colony where banded	Banded as adults	Banded as chicks	Total
Goose Island	119	72	191
Crescent Island	3	13	16
Sheepy Lake	0	4	4
East Sand Island	0	4	4
Port of Bellingham	0	2	2
Brooks Island	0	2	2
Crump Lake	0	2	2
Malheur Lake	0	1	1
Total	**122**	**100**	**222**

Table 9. Numbers of banded Caspian terns resighted at the Blalock Islands in 2015 and the colony locations where they were originally marked with uniquely engraved alphanumeric color bands during 2005-2014.

Colony where banded	Banded as adults	Banded as chicks	Total
Crescent Island	150	159	309
Goose Island	106	72	178
East Sand Island	1	11	12
Port of Bellingham	0	6	6
Sheepy Lake	0	6	6
Malheur Lake	0	3	3
Crump Lake	0	1	1
Total	**257**	**258**	**515**

Table 10. Numbers of banded Caspian terns seen at Crescent Island in 2014 and resighted in 2015 at breeding or non-breeding sites. Terns were banded in 2005-2014 with color bands engraved with unique alphanumeric codes. A total of 262 banded terns were seen at Crescent Island in 2014 and resighted in 2015 elsewhere; some of them were resighted at multiple locations in 2015.

Location resighted in 2015	Banded as adults	Banded as chicks	Total
Blalock Islands	153	84	237
Potholes Reservoir area*	25	6	31
East Sand Island	22	5	27
Malheur Lake	12	3	15
Twinning Island	8	2	10
Tule Lake	3	4	7
McNary Reservoir**	1	1	2
East Link Island (Summer Lake)	2	1	3
Lenore Lake	2	0	2
Rat Island (Salish Sea)	0	2	2
Total	**228**	**108**	**336**

* Potholes Reservoir area includes Goose Island, islands in northern Potholes Reservoir, and Marsh Unit 1 in the Columbia National Wildlife Refuge.

** McNary Reservoir includes Borgans Island, mouth of the Snake River, and Finley Islands.

Table 11. Numbers of banded Caspian terns seen at Goose Island in 2014 and resighted in 2015 at breeding or non-breeding sites. Terns were banded in 2005-2014 with color bands engraved with unique alphanumeric codes. A total of 224 banded terns were seen at Goose Island in 2014 and resighted in 2015 at Goose Island or elsewhere; some of them were resighted at multiple locations in 2015.

Location resighted in 2015	Banded as adults	Banded as chicks	Total
Potholes Reservoir area*	99	46	145
Blalock Islands	83	39	122
Twinning Island	27	9	36
Malheur Lake	16	2	18
East Sand Island	8	8	16
Tule Lake	7	8	15
Rat Island (Salish Sea)	2	5	7
Lenore Lake	3	2	5
Everett (Coastal Washington)	2	1	3
Desert Aire (Priest Rapids Reservoir)	2	0	2
Rice Island (Columbia River estuary)	0	1	1
Sheepy Lake	1	0	1
Total	**250**	**121**	**371**

* Potholes Reservoir area includes Goose Island, islands in northern Potholes Reservoir, and Marsh Unit 1 in Columbia National Wildlife Refuge.

Table 12. Inter-colony movement probabilities of Caspian terns between 2014 and 2015. Data used in movement probability estimates were from terns banded as adults during 2005-2014 and re-sighted during 2006-2015. The numbers of individuals that moved between 2014 and 2015 were estimated from movement probabilities between those years multiplied by estimated numbers of adult terns present at source regions in 2014.

Source colony	Receiving colony	Movement probabilities (%)	Estimated number of individuals that moved
Columbia River estuary	Columbia Plateau region	1.4	172
Columbia River estuary	Corps-constructed islands	<0.0001	Below detectable level
Columbia Plateau region	Columbia River estuary	4.4	67
Columbia Plateau region	Corps-constructed islands	0.7	11
Corps-constructed islands	Columbia River estuary	5.0	79
Corps-constructed islands	Columbia Plateau region	18.7	293

Table 13. Number of 2015 migration year PIT-tagged juvenile salmonids (Chinook salmon, coho salmon, sockeye salmon, and steelhead combined) recovered on bird colonies and bird loafing-roosting locations in the Columbia Plateau region in 2015. Piscivorous colonial waterbird species include Caspian terns (CATE), California and ring-billed gulls (Gulls), American white pelicans (AWPE), and double-crested cormorants (DCCO). Mixed colonies represent a combination of these species. Only breeding colonies where an appreciable number of tags were recovered were included in analyses of predation rates (see Methods).

Location	Rkm	Bird Species	Area Use	No. Recovered
Twinning Island	Off-river (Banks Lake)	CATE	Breeding	604
Lenore Lake	Off-river (Lenore Lake)	Mixed	Breeding	1
Marsh Unit 1	Off-river (Columbia NWR)	Mixed	Loafing	107
Mud Island	645	Mixed	Loafing	147
Cabin Island	641	Mixed	Loafing	32
Hanford Reach	597-582	Mixed	Breeding	171
		Mixed	Loafing	42
Island 20	549	Gull	Breeding	1,164
Badger Island	512	Gull	Breeding	973
		AWPE	Breeding	987
		Mixed	Breeding	1,068
Blalock Islands	440-439	CATE	Breeding	7,294
		Gull [1]	Breeding	943
		Gull [2]	Breeding	64
		Mixed	Loafing	382
Miller Rocks	331	Gull	Breeding	3,851
Total				**17,830**

[1] Gulls nesting on Anvil Island within the Blalock Islands complex
[2] Gulls nesting on Straight Six Island within the Blalock Islands complex

Table 14. Average annual predation rates by Caspian terns nesting at colonies in the Columbia Plateau region on Snake River (SR) and Upper Columbia River (UCR) ESA-listed salmonid populations during 2007-2015. Management actions were implement on Goose Island in Potholes Reservoir in 2014 and 2015 and on Crescent Island in 2015. No management actions have been conducted at the Twinning Island or Blalock Islands Caspian tern colony sites, but these sites are identified as high-risk sites where terns dissuaded from Goose and Crescent islands may relocate as a result of management actions in the region. Predation rates were adjusted to account for tag loss due to on-colony detection efficiency and deposition rates. Estimates with 95% credible intervals from data collected in 2015 are provided in Tables 4 and 6. Estimates with 95% credible intervals from data collected during 2007-2014 are provided in BRNW (2015b).

	Goose Island Terns			Crescent Island terns		Twinning Island Terns		Blalock Islands Terns	
ESU/DPS	**2007-2013**	**2014**	**2015 [1]**	**2007-2014**	**2015 [1]**	**2009-2014**	**2015**	**2007-2014**	**2015**
SR Sockeye	0.1%	< 0.1%	< 0.1%	1.1%	< 0.1%	< 0.1%	< 0.1%	0.3%	1.3%
SR Spr/Sum Chinook	< 0.1%	< 0.1%	< 0.1%	0.7%	< 0.1%	< 0.1%	< 0.1%	0.1%	1.4%
UCR Spr Chinook	2.5%	0.6%	0.1%	0.5%	< 0.1%	< 0.1%	0.1%	< 0.1%	0.9%
SR Fall Chinook	< 0.1%	< 0.1%	< 0.1%	0.8%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.4%
SR Steelhead	< 0.1%	< 0.1%	< 0.1%	3.9%	< 0.1%	< 0.1%	< 0.1%	0.6%	8.0%
UCR Steelhead	15.7%	2.9%	1.5%	2.4%	< 0.1%	0.3%	2.6%	0.6%	8.2%

[1] Based on a predicted, per capita (per bird) predation rate estimates and not empirically-derived PIT tag recovery data from 2015 (see Methods)

Table 15. Range of detection efficiency estimates for PIT tags sown on bird colonies during the 2015 nesting season. Results were used to calculate estimates of the proportion of PIT tags deposited by birds on their nesting colony that were subsequently detected by researchers on the colony following the nesting season (see Figure 9). Sample sizes of the numbers of sown tags are provided. Piscivorous colonial waterbird species include Caspian terns (CATE), California and ring-billed gulls (Gulls), American white pelicans (AWPE), and mixed-species colonies (Mixed).

Location	Rkm	Bird Species	Sample Size	Detection Efficiency
Twinning Island	Off-river (Banks Lake)	CATE	100 (2)	58 – 87%
Island 20	549	Gull	100 (2)	78 – 89%
Badger Island	512	Gull	50 (1)	94%
		AWPE	50 (1)	66%
		Mixed	50 (1)	66%
Blalock Islands	440-439	CATE	100 (2)	53 – 91%
		Gull [1]	100 (2)	85 – 98%
		Gull [2]	100 (2)	72 – 98%
Miller Rocks	331	Gull	100 (2)	74 – 95%

[1] Gulls nesting on Anvil Island within the Blalock Islands complex
[2] Gulls nesting on Straight Six Island within the Blalock Islands complex

Table 16. Mean on-colony PIT tag deposition rate (DR [95% credible interval]) for nesting Caspian terns, California and ring-billed gulls, and American white pelicans. Results were used to calculate estimates of the proportion of PIT tags consumed by birds that were subsequently deposited on their nesting colony (see Figure 9). Sample sizes (n) of consumed PIT-tagged fish used to estimate deposition rate and the years when studies of deposition rates were conducted are provided. PIT-tagged fish were consumed during different periods of the day (morning, evening) and throughout the period of smolt out-migration in each study year (April to June; see Hostetter et al. [2015] for a detailed description of methods and results).

Species	Colony	Study Years	n	DR (95% CI)
Caspian terns	Twinning Is., Blalock Islands	2004-2006	456	71% (51 - 89%)
California and ring-billed gulls	Island 20, Badger Is., Blalock Islands, Miller Rocks	2012-2013	1,812	15% (11 – 21%)
American white pelicans	Badger Is.	NA (no deposition studies were conducted; DR of 100% assumed)		
Mixed	Hanford Reach, Badger Is.	NA (no deposition studies were conducted at mixed colonies; DR of 100% assumed)		

Table 17. Estimated predation rates (95% credible interval) on PIT-tagged salmonids by Caspian terns nesting at the Blalock Islands, gulls nesting at the Blalock Islands, and gulls nesting at Miller Rocks. Predation rates were adjusted to account for tag loss due to on-colony detection efficiency (see Table 15) and deposition rates (see Table 16). The number (n) of PIT-tagged smolts interrogated/released at McNary Dam are provided. Only salmonid populations (Snake River [SR], Upper Columbia River [UCR]) with > 500 PIT-tagged smolts available were evaluated.

ESU/DPS[1]	N	Blalock Is. Terns	Blalock Is. Gulls[1]	Blalock Is. Gulls[2]	Miller Rocks Gulls
SR Sockeye	1,712	1.3% (0.7-2.5)	1.1% (0.2-3.2)	0.2% (<0.1-1.6)	7.4% (4.1-13.1)
SR Spr/Sum Chinook	31,474	1.4% (1.1-2.2)	0.1% (<0.1-0.3)	0.1% (<0.1-0.2)	1.7% (1.1-2.6)
UCR Spr Chinook	4,921	0.9% (0.5-1.5)	0.5% (0.1-1.3)	0.1% (<0.1-0.5)	3.5% (2.1-6.0)
SR Fall Chinook	4,390	0.4% (0.2-0.8)	0.6% (0.2-1.5)	0.1% (<0.1-0.6)	2.6% (1.4-4.6)
SR Steelhead	6,824	8.0% (6.0-11.8)	2.4% (1.4-4.0)	0.2% (<0.1-0.6)	9.7% (6.6-14.6)
UCR Steelhead	2,056	8.2% (5.9-12.4)	6.1% (3.4-10.5)	0.6% (0.1-2.0)	13.2% (8.3-21.1)

[1] Gulls nesting on Anvil Island within the Blalock Islands complex
[2] Gulls nesting on Straight Six Island within the Blalock Islands complex

Table 18. Estimated predation rates (95% credible interval) on PIT-tagged salmonid populations by Caspian terns nesting at Twinning Island (Banks Lake), gulls nesting on Island 20, gulls nesting on Badger Island, American while pelicans nesting on Badger Island, and a mixed gull and pelican colony on Badger Island in 2015. Predation rates were adjusted to account for tag loss due to on-colony detection efficiency (see Table 15) and deposition rates (see Table 16), where adequate date existed. The number (n) of PIT-tagged smolts interrogated/released at Lower Monumental Dam or Rock Island Dam are provided. Only salmonid populations (Snake River [SR], Upper Columbia River [UCR]) with > 500 PIT-tagged smolts available were evaluated.

ESU/DPS	N	Twinning Is. Terns	Lenore Lk.[1] Mixed[2]	Hanford Reach[1] Mixed[2]	Island 20 Gulls	Badger Is. Gulls	Badger Is. Pelicans[2]	Badger Is. Mixed[2]
SR Sockeye	486	NA	NA	NA	NA	NA	NA	NA
SR Spr/Sum Chinook	4,471	<0.1%	<0.1%	<0.1%	0.5% (0.1-1.4)	0.1% (<0.1-0.5)	0.1% (<0.1-0.2)	0.1% (<0.1-0.2)
UCR Spr Chinook	766	0.1% (<0.1-0.9)	<0.1%	0.2% (<0.1-0.7)	0.6% (<0.1-3.7)	0.5% (<0.1-3.3)	0.1% (<0.1-0.7)	0.1% (<0.1-0.7)
SR Fall Chinook	1,393	<0.1%	<0.1%	<0.1%	0.3% (<0.1-2.1)	0.3% (<0.1-1.9)	<0.1%	0.1% (<0.1-0.4)
SR Steelhead	2,400	<0.1%	<0.1%	<0.1%	3.6% (1.7-6.9)	3.1% (1.5-6.0)	0.2% (0.1-0.6)	0.3% (0.1-0.7)
UCR Steelhead	7,222	2.6% (1.8-3.9)	<0.1%	0.1% (0.1-0.2)	7.9% (5.3-12.0)	4.1% (2.6-6.4)	0.1% (<0.1-0.2)	0.2% (0.1-0.3)

[1]No measure of detection efficiency available; predation rates are not adjusted for on-colony detection rates and should be considered minimums.

[2]Predation rates by American white pelicans and mixed-species colonies were not adjusted for deposition rates and should be considered minimum estimates.

Table 19. Cumulative estimated predation rates (95% credible interval) of PIT-tagged steelhead and yearling Chinook salmon released (n) into the tailrace of Rock Island Dam by piscivorous waterbirds nesting at 11 different colonies in the Columbia Plateau region in 2015. Predation rates were adjusted to account for tag loss due to on-colony PIT tag detection efficiency (see Table 15) and deposition rates (see Table 16). Predation rates were not adjusted for survival of fish to the vicinity of each downstream colony. Bird species included Caspian terns (CATE), ring-billed and California gulls (Gulls), American white pelican (AWPE), and mixed-species colonies (Mixed).

Location	Colony	RKM	Steelhead (n = 7,069)	Yearling Chinook (n = 5,763)
Twinning Island	CATE	Off-river	2.6% (1.9-4.0)	0.1% (<0.1-0.3)
Lenore Lake[1]	Mixed[2]	Off-river	<0.1%	<0.1%
Hanford Reach [1]	Mixed[2]	597-582	0.1% (0.1-0.2)	0.1% (<0.1-0.2)
Island 20	Gulls	545	7.7% (5.2-11.7)	0.4% (0.1-1.1)
Badger Island	AWPE[2]	512	0.1% (<0.1-0.3)	<0.1%
	Gulls		4.1% (2.6-6.4)	0.1% (<0.1-0.4)
	Mixed[2]		0.2% (0.1-0.3)	<0.1%
Blalock Islands (Anvil Is.)	CATE	441	7.4% (5.6-10.8)	1.1% (0.7-1.8)
	Gulls		4.2% (2.7-6.6)	0.6% (0.2-1.4)
Blalock Islands (Straight Six Is.)	Gulls	439	0.2% (<0.1-0.6)	0.2% (<0.1-0.8)
Miller Rocks	Gulls	331	11.6% (8.0-17.3)	6.2% (4.0-9.7)
Total			**40.1% (34.0-47.9)**	**9.4% (6.9-13.0)**

[1]No measure of detection efficiency available; predation rates are not adjusted for on-colony detection rates and should be considered minimums.
[2]Predation rates by American white pelicans and mixed-species colonies were not adjusted for deposition rates and should be considered minimum estimates.

Table 20. Numbers of double-tagged (acoustic and PIT) juvenile steelhead and sockeye salmon released (n) and subsequently consumed by birds within the middle Columbia River between Rkm 545 and 729 in 2015. The number of tags consumed were not adjusted for on-colony detection (see Table 15) and deposition rates (see Table 16) and thus represents minimum numbers of tagged fish consumed by birds. Only tags recovered on breeding colonies were used to estimate predation rates by colonial waterbirds (see Methods). Bird species included Caspian terns (CATE), ring-billed and California gulls (Gulls), American white pelican (AWPE), and mixed-species colonies (Mixed).

Location	Bird Species	Area Use	Steelhead (n=1,672)	Sockeye (n=1,677)
Twinning Island	CATE	Breeding	13	1
Lenore Lake	Mixed	Breeding	0	0
Marsh Unit 1	Mixed	Loafing	3	0
Mud Island	Mixed	Loafing	3	0
Cabin Island	Mixed	Loafing	0	0
Hanford Reach	Mixed	Breeding	3	0
	Mixed	Loafing	1	0
Island 20	Gull	Breeding	1	1
Badger Island	Gull	Breeding	0	0
	AWPE	Breeding	0	0
	Mixed	Breeding	0	0
Blalock Islands	CATE	Breeding	2	0
Total			**26**	**2**

APPENDIX A
Paired Release-Recapture Predation Model

Presented herein is a more detailed description of the JSATS configuration used by Skalski et al. (2016) to estimate smolt survival and how our model used this configuration to estimate avian predation within the middle Columbia River in 2015.

Hydrophone arrays used to interrogate releases of tagged fish as part of this study were located at river kilometers (Rkm) 670, 657, 625, 593, 545, and 542. Tagged steelhead and sockeye salmon were released into tailraces of Rock Island (RIS), Wanapum (WAN), and Priest Rapids (PR) dams. Total smolt mortality (1 – survival) and mortality due to colonial waterbird predation were calculated across five spatial aggregations of arrays and were defined as the: (1) Wanapum Development (RIS release – WAN release), (2) Priest Rapids Development (WAN release – PR release), (3) from the Priest Rapids release location to Vernita Bridge (PR release – A625), (4) Vernita Bridge to White Bluffs (A625 – A593), and (5) White Bluffs to the first Hanford array (A593 – A545; *Figure A1*).

The death of an individual fish *i* due to one of the *C* piscivorous bird colonies under consideration within the j^{th} segment of river is modelled by the indicator variable, D_{ijc}. Of the five spatial aggregations listed above, (1 – 3) all either commence or terminate between consecutive interrogation arrays. This requires us to partition D_{ijc} for several combination of *i,j,c* to estimate predation. Below is description of the post-hoc partitioning process:

Z_{ij} indicates whether fish *i* has survived to array *j*. D_{ijc} indicates whether fish *i* was depredated by piscivorous waterbirds from colony *c* within segment *j.* We let $\boldsymbol{J}_k$ represent the set of segments in the k^{th} spatial aggregation of segments.

We define $\hat{P}_{\boldsymbol{J}_k,c}$ to be the predation rate by colony *c* in $\boldsymbol{J}_k$. So

$$\hat{P}_{\boldsymbol{J}_k,c} = \sum_{i \in r_k} D_{i,\boldsymbol{J}_k,c} \Big/ \sum_{i \in \boldsymbol{R}_k} Z_{i,J_{k,0}}$$

where r_k represents the release(s) associated with this estimate and $J_{k,0}$ denotes the upstream, bounding array of $\boldsymbol{J}_k$.

$\hat{P}_{\boldsymbol{J}_1,c}$ therefore requires an estimate of $\sum_{i \in r_k} D_{i\boldsymbol{J}_k c}$ where $\boldsymbol{J}_1$= {RIS release – A670, A670 – WAN release}. It follows that $\sum_{i \in r_k} D_{i,\boldsymbol{J}_k,c} = \sum_{i \in r_{RIS}} \sum_{j \in \boldsymbol{J}_1} D_{i,j,c}$. However, since the Wanapum release is between two consecutive interrogation arrays, our model produces no estimates of $\sum_{i \in r_{RIS}} D_{i,(\text{A670}-\text{WANrelease}),c}$. Rather this value must be imputed.

If we first estimate $\sum_{i \in r_{RIS}} D_{i,(WANrelease-A657),c}$ we can use the identity

$$\sum_{i \in r_{RIS}} D_{i,(A670-WANrelease),c}$$

$$= \sum_{i \in \boldsymbol{r}_{RIS}} D_{i,(A670-A657),c} - \sum_{i \in r_{RIS}} D_{i,(WANrelease-A657),c}$$

to estimate $\sum_{i \in r_{RIS}} D_{i,(\mathrm{A670-WANrelease}),c}$.

We assume the average survival and predation rates from the Wanapum release to A657, to be equivalent between releases. This means

$$P_{(WANrelease-A657),\mathrm{c}} = \sum_{i \in \boldsymbol{r}_{RIS}} D_{i,(WANrelease-A657),c} \Big/ \sum_{i \in \boldsymbol{r}_{RIS}} Z_{i,WANrelease}$$
$$= \sum_{i \in r_{WAN}} D_{i,(WANrelease-A657),c} \Big/ \sum_{i \in r_{WAN}} Z_{i,WANrelease}$$

and

$$S_{(WANrelease-A657)} = \sum_{i \in \boldsymbol{r}_{RIS}} Z_{i,A657} \Big/ \sum_{i \in \boldsymbol{r}_{RIS}} Z_{i,WANrelease}$$
$$= \sum_{i \in r_{WAN}} Z_{i,A657} \Big/ \sum_{i \in \boldsymbol{r}_{WAN}} Z_{i,WANrelease} .$$

From this we can infer

$$\sum_{i \in r_{RIS}} Z_{i,WANrelease} = \sum_{i \in r_{RIS}} Z_{i,A670} * S_{(WANrelease-A657)}.$$

Therefore

$$\begin{aligned}
&\sum_{i \in r_{RIS}} D_{i,(A670-WANrelease),c} \\
&\quad = \sum_{i \in \boldsymbol{r}_{RIS}} D_{i,(A670-A657),c} - \sum_{i \in r_{RIS}} D_{i,(WANrelease-A657),c} \\
&\quad = \sum_{i \in r_{RIS}} D_{i,(A670-A657),c} - P_{(WANrelease-A657),\mathrm{c}} * \sum_{i \in r_{RIS}} Z_{i,WANrelease} \\
&\quad = \sum_{i \in r_{RIS}} D_{i,(A670-A657),c} - \\
&\qquad \sum_{i \in r_{RIS}} Z_{i,A670} * P_{(WANrelease-A657),\mathrm{c}} * \\
&\qquad \sum_{i \in \boldsymbol{r}_{RIS}} Z_{i,A657} \; / \; S_{(WANrelease-A657)} \; .
\end{aligned}$$

A similar process can be used for estimates of $P_{\boldsymbol{J}_2,c}$ and $P_{\boldsymbol{J}_3,c}$.

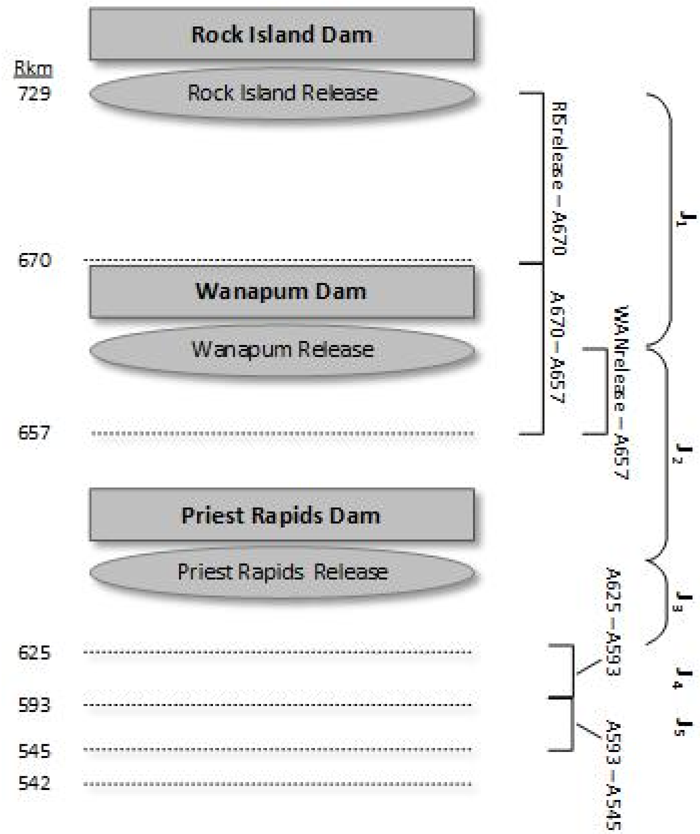


Figure A1. Schematic of the design used to estimate spatially-explicit total smolt mortality and mortality due to avian predation in the middle Columbia River in 2015. Paired-release configuration and aggregations adopted from Skalski et al. (2016).