EVALUATION OF FORAGING BEHAVIOR, DISPERSAL, AND PREDATION ON ESA-LISTED SALMONIDS BY CASPIAN TERNS DISPLACED FROM MANAGED COLONIES IN THE COLUMBIA PLATEAU REGION

2016 Final Annual Report

Submitted To: Grant County Public Utility District
& Priest Rapids Coordinating Committee

Submitted By: U.S. Geological Survey, Oregon State University,
& Real Time Research, Inc.

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

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Final Annual Report submitted: March 31, 2017

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EXECUTIVE SUMMARY

The primary objective of this study in 2016 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 associated with 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 salmonid 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 McNary Reservoir) to sites outside the Columbia River basin. During 2014-2016, the Corps and the U.S. Bureau of Reclamation (BOR) implemented the IAPMP by installing a variety of "passive nest dissuasion" materials prior to the nesting seasons 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 [*Larus 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 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 2016, some Caspian terns displayed persistent fidelity to the Potholes 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 2016 was largely limited to areas near the shoreline where passive nest dissuasion had not been installed. A total of six Caspian tern eggs were found on Goose Island in 2016; all six were either depredated by gulls or collected by researchers under permit. In comparison, 43 Caspian tern eggs were discovered on Goose Island and surrounding islets in 2015. For the second year in a row, 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 effective in greatly reducing (2015) or eliminating (2016) successful nesting attempts (i.e. fledged young) by Caspian terns on Goose Island.

As was the case in 2015, passive and active nest dissuasion techniques were successful in preventing all nesting and roosting by both Caspian terns and gulls on Crescent Island in 2016. One factor that likely contributed to the absence of nesting Caspian terns, and the lower site fidelity by terns at Crescent Island as compared to Goose Island, was the types of passive dissuasion used on the Crescent Island (i.e. fencing, rope, flagging, and native vegetation planted prior to the 2016 breeding season), which virtually eliminated all the open habitat that terns prefer for nesting on the island. Another factor was the successful dissuasion of all gulls from nesting on Crescent Island in both 2015 and 2016; 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) during 2015-2016. Similarly, Caspian terns displaced from Crescent Island could relocate to an alternative colony site on the mid-Columbia River, the Blalock Islands (70 river kilometers downriver from Crescent Island), where small numbers of Caspian terns have nested over the last decade.

The total estimated breeding population of Caspian terns in the Columbia Plateau region during 2016 was 675 breeding pairs at five separate colonies, four extant colonies (i.e. the Blalock Islands in John Day Reservoir [483 breeding pairs], Twinning Island in Banks Lake [6 pairs], Harper Island in Sprague Lake [3 pairs], an unnamed island in Lenore Lake [39 pairs]) and one incipient colony on an unnamed island in northeastern Portholes Reservoir (144 pairs). This represented a 23% decline in the total number of Caspian terns nesting in the Columbia Plateau region in 2016 compared to the pre-management average of 873 breeding pairs during 2005-2013, and was the smallest regional population size observed since Caspian tern monitoring began in 2005. These results suggest that although nest dissuasion actions implemented on Goose and Crescent islands in 2016 were highly effective in eliminating nesting at these two colonies, formerly the two largest Caspian tern colonies in the region where a total of 733 breeding pairs nested in 2013, it did not result in a commensurate decline in the regional population of nesting Caspian terns. This was due to the recent large increase in the size of the tern colony at the Blalock Islands, as well as the incipient colony that formed in northeastern Potholes Reservoir; the growth of these colonies was mostly attributable to terns that formerly nested at Goose and Crescent islands.

Juvenile salmonids made up 43.7% of the diet of Caspian terns nesting on the Blalock Islands in 2016; this is substantially lower than the comparable figure from 2015 (66.2%) and in comparison to previous years when terns nested at Crescent Island. The lower than expected proportion of salmonids in the diet of Blalock Islands Caspian terns may have been due to the unusually early outmigration timing for many salmonid populations in 2016. A large proportion of the salmonids in the diet of Caspian terns nesting at the Blalock Islands were steelhead (24%), which was lower than in 2015 (34%), but comparable to the highest values observed in the diet of terns nesting at Crescent Island in previous years. We estimated that Caspian terns nesting on the Blalock Islands consumed ca. 420,000 juvenile salmonids in 2016 (95% c.i. = 230,000 – 610,000), including ca. 140,000 steelhead (95% c.i. = 73,000 – 210,000).

After three years of implementation of the IAPMP, satellite-tracking of tagged Caspian terns has continued to indicate 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 or nearby if nesting fails, (3) engage in long distance dispersal to a more favorable colony site, or (4) wander nomadically across the Columbia Plateau region or a much larger area. Terns tagged at Potholes Reservoir have generally stayed nearby and searched for alternative nesting habitat, moved to nearby colonies (i.e. northeastern Potholes Reservoir in 2016) and returned to Goose Island when those colonies failed, or have wandered nomadically, often across large portions of Washington, Oregon, and California. Terns tagged at Crescent Island have primarily moved to a nearby colony located at the Blalock Islands in John Day Reservoir or exhibited long distance dispersal to the Columbia River estuary. In 2016, however, we saw late season movements back to McNary Reservoir to roost overnight at Badger Island, just upstream of Crescent Island. Also in 2016, very few tagged terns visited USACE-constructed islands in southern Oregon and northeastern California, and none demonstrated sustained visits suggestive of possible nesting attempts, possibly due to a lag effect in the recovery of forage fish following long-term drought in the area. We also saw tagged terns using the San Francisco Bay area in 2016, but did not observe any sustained associations with the restored colonies at the USACE-constructed tern islands at Don Edwards National Wildlife Refuge in the San Francisco Bay area.

Several measures of foraging activity within the Priest Rapids Project by satellite-tagged Caspian terns suggested that incremental reductions in predation on juvenile salmonids are resulting from management actions under the IAPMP: (1) The proportion of tagged Caspian terns that used the river reaches above Richland, WA, during the smolt outmigration was lower than during the previous two years; (2) 50% or less of active terns tagged at Potholes Reservoir and < 5% of those tagged at Crescent Island were detected in the Priest Rapids Project or the Hanford Reach in 2016; and (3) the Priest Rapids Reservoir continued to be used by a subset of the tagged terns, but only the Hanford Reach was identified as a core day use area during 2016. These results suggest that many displaced terns have continued to shift their foraging away from the Priest Rapids Project, but the non-breeding terns that remained on the Columbia Plateau region still constituted a significant presence in the Project during 2016.

Satellite telemetry remained a useful tool for documenting the response of Caspian terns to management at colonies in the Columbia Plateau region in 2016, helping to identify patterns of breeding dispersal, the distribution of core foraging areas, and previously unknown locations where nesting attempts occurred in 2016, or may occur in the future. Data from satellite-tagged terns documented the continued presence, movements, and distribution of non-breeding terns within the Columbia Plateau region. These data would not otherwise have been available as ground monitoring and aerial surveys are insufficient to detect and track displaced terns not associated with a breeding colony. Tracking satellite-tagged terns continued to facilitate the detection of loafing and roosting sites where smolt PIT tag recovery efforts could be concentrated, and for documenting that non-breeding individuals were still contributing to mortality of juvenile salmonids in the study area.

Caspian terns are a long-lived species, and results from the third year of the tagging study suggest that the terns displaced from Goose Island and Crescent Island display behavioral inertia. As such, reductions to the impacts of tern predation on smolt survival in the Priest Rapids Project and throughout the Columbia Plateau region are likely to proceed in gradual, incremental steps. Vigilance will be required to prevent further formation of incipient colonies and a pool of non-breeding terns is likely to remain on the Columbia Plateau region for some time following reductions in breeding habitat through management actions.

Resightings of Caspian terns that were previously color-banded indicated that some terns continued to exhibit site fidelity to the Potholes Reservoir area, while the Blalock Islands experienced a large influx of terns from the Crescent Island colony during 2015-2016. Evaluation of inter-regional movements in 2016 revealed that a high number of Caspian terns moved to the Columbia Plateau region from the Corps-constructed tern islands in southern Oregon and northeastern California (SONEC); the latter region experienced lingering effects of severe drought in 2016.

Predation rates (percentage of available tagged fish that were consumed) by Caspian terns nesting at colonies in the Columbia Plateau region were used to evaluate the efficacy of tern management initiatives to increase smolt survival in the region. Recoveries of tagged smolts on bird colonies were also used to estimate consumption rates by other piscivorous colonial waterbirds (e.g., California gulls, ring-billed gulls, and American white pelicans). Like results during 2014-2015, predation rates in 2016 indicated that management efforts to reduce the size of the Goose Island and Crescent Island Caspian tern colonies were successful in eliminating or nearly eliminating predation by terns from these two colonies, with estimated Caspian tern predation rates of less than 0.2% for all ESA-listed salmonid populations evaluated, per colony, in 2016. Predation rates at these two colonies in 2016 were significantly lower than predation rates observed during 2007-2013, prior to tern management. For example, predation rates by Goose Island terns on ESA-listed Upper Columbia River steelhead averaged 15.7% (95% CI = 14.1 – 18.9%) during 2007-2013 and predation rates by Crescent Island terns on ESA-listed Snake River steelhead averaged 3.9% (95% CI = 3.5 – 4.6%) during 2007-2014.

Despite the dramatic reduction in predation rates on smolts due to the virtual absence of Caspian terns nesting on Goose and Crescent islands, increases in predation rates were observed for Caspian terns nesting at some unmanaged sites, like results reported in 2015. This was particularly true for Caspian terns nesting at the Blalock Islands (John Day Reservoir) and in northeastern Potholes Reservoir. Predation rates were higher on steelhead populations compared to salmon populations, with an estimated 3.9% (95% CI = 2.9 – 5.7%) of Snake River steelhead consumed by Blalock Islands terns and 4.1% (95% CI = 2.9 – 6.3%) of Upper Columbia River steelhead consumed by terns nesting in northeastern Potholes Reservoir in 2016. Predation rates by Blalock Islands terns were also elevated on Snake River sockeye salmon, with an estimated 2.3% (95% CI = 1.2 – 4.1%) of available fish consumed in 2016. These predation rates exceeded the IAPMP target goal of < 2% per ESA-listed salmonid population, per colony. Predation rates by Caspian terns nesting at two other unmanaged colonies in the Columbia Plateau region (Twinning Island in Banks Lake and Lenore Lake) during 2016 were < 1.0% per ESA-listed salmonid population, per colony.

Estimates of consumption rates of juvenile salmonids by gulls nesting at certain colonies in the Columbia Plateau region were substantial in 2016. Consumption rates for gulls nesting on Miller Rocks (The Dalles Reservoir) were the highest of any bird colony evaluated as part this study, with consumption rates of 6.4% (95% CI = 2.9 – 12.8%), 6.7% (95% CI = 4.6 – 9.9%), and 10.1% (95% CI = 7.0 – 15.2%) for Snake River sockeye salmon, Snake River steelhead, and Upper Columbia River steelhead, respectively, in 2016. Consumption rates by gulls nesting on Anvil Island in the Blalock Islands (John Day Reservoir), Badger Island (McNary Reservoir), and Island 20 (middle Columbia River) were also highest on steelhead populations (generally > 3.0% per steelhead DPSs evaluated). Like results from Caspian terns, consumption rates of salmon populations by gulls were generally < 1.0% per salmonid population, except for Snake River sockeye. Gull consumption rates of Snake River sockeye salmon were higher than for other salmon ESUs (e.g., Snake River spring/summer Chinook salmon), and higher in 2016 when compared with predation rates observed in previous years. Further research is needed to better understand the mechanisms that influence fish susceptibility to consumption by gulls, specifically whether gulls are disproportionately consuming weak or compromised smolts, especially near dams. Regardless of the reasons, smolt consumption rates associated with certain gull colonies were comparable to or higher than those associated with Caspian tern colonies, and have continued to be some of the highest consumption rates associated with any piscivorous waterbird colony in the Columbia Plateau region since multi-predator species studies were initiated in 2007.

Minimum estimates of predation by American white pelicans nesting at the Badger Island colony were low (< 1.0% per ESA-listed salmonid population), indicating that pelicans nesting at this colony posed little risk to large aggregates of PIT-tagged smolts migrating through the mainstem Columbia River. Additional research is needed, however, to quantify PIT tag deposition probabilities in white pelicans and to evaluate impacts on specific stocks or groups of fish, which may be warranted.

An analysis of spatially- and temporally-explicit steelhead consumption rates by piscivorous colonial waterbirds within the Priest Rapids Project, data derived from acoustic-tagged smolts, estimated that 1.8% (95% CI = 0.9 – 3.3%) and 2.0% (95% CI = 1.0 – 3.9%) of steelhead were consumed by Caspian terns within the Wanapum and Priest Rapids developments, respectively. Predation rates in 2016 were like those is 2014 and 2015, but significantly lower than those observed prior to implementation of the IAPMP (4.0 – 10.1% per development, depending on year). Reductions in the number of Caspian terns nesting within foraging distance of the Project is likely a key contributing factor to recent improvements in steelhead survival in the middle Columbia River. Improvements in survival within the middle Columbia River, however, were offset by increased predation rates by some gull colonies and Caspian tern colonies nesting further downstream. An investigation of cumulative predation rates (predation from all bird colonies combined on smolts traveling between Rock Island and Bonneville dams) estimated that 30.1% (95% CI = 26.5 – 38.5%) of steelhead were depredated by colonial waterbirds in 2016. Results suggest that management efforts aimed at decreasing colonial waterbird predation must be implemented at a larger, system-wide scale to achieve management goals in the future.

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 identified as having the highest per capita (per bird) predation rates on juvenile salmonids, especially steelhead, a salmonid species known to be particularly susceptible to avian 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, WA. 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, WA, 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 populations from the Upper Columbia River 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.

Recoveries of passive integrated transponder (PIT) tags on bird colonies have been used to estimate predation rates (percentage of available tagged fish consumed by birds) and to compare the relative susceptibility of juvenile salmonids to predators in the Columbia River basin (Collis et al. 2001; Ryan et al. 2003; Antolos et al. 2005; Evans et al. 2012; Hostetter et al. 2015; Evans et al. 2016a). PIT tag data from bird colonies can also be used to compare smolt losses prior to and following avian predation management actions, data critical for evaluating the efficacy of management actions to reduce avian predation rates on ESA-listed salmonids (Evans et al. 2016b; BRNW 2016b).

Survival standards for juvenile salmonids established under the 2004 Biological Opinion for the Priest Rapids Project (Wanapum and Priest Rapids dams and associated reservoirs; hereafter the Project) require at least 86% survival through the Project (NMFS 2004). To evaluate whether these standards were met, Public Utility District No. 2 of Grant County, WA (GPUD) conducted salmonid survival studies within the Project during 2008-2010 and again during 2014-2016. Survival studies utilized double-tagged (acoustic tag plus PIT tag) smolts to track fish behavior and survival (Timko et al. 2011; Skalski et al. 2016), and to estimate mortality due to colonial waterbird predation (Evans et al. 2013; Evans et al. 2016a; BRNW 2016b). Results indicated that survival standards for steelhead were not always met and that survival varied significantly by development (one reservoir and dam) and year. Comparisons between total steelhead mortality (1-survival) and mortality caused by Caspian tern predation indicated that between 27% and 85% (depending on year) of all sources of steelhead mortality in the Project were attributable to predation by Caspian terns (Evans et al. 2013; Evans et al. 2016a; BRNW 2016b). Results also indicated that predation on steelhead by other colonial waterbirds (e.g., California gulls) was also substantial but that predation by these others species largely occurred downstream of the Project (Evans et al. 2016a; BRNW 2016b). In contrast to steelhead, survival data from yearling Chinook salmon and sockeye salmon indicated that survival standards were met in all years and reaches evaluated (Skalski et al. 2016), and that Caspian tern predation was a relatively minor source of mortality for salmon within the Project (Evans et al. 2016a; BRNW 2016b).

Resource management agencies (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 in Potholes Reservoir and Crescent Island in McNary Reservoir on the mid-Columbia River. Proposed management initiatives are focused on reducing Caspian tern predation on Columbia River 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 (USFWS 2005, 2006) 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 2016 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 2016 (BRNW 2017; Collis et al. 2016; USACE, unpubl. data). This study is a continuation of work funded by the PRCC during 2013-2015 (BRNW 2014a; BRNW 2015a; BRNW 2016b), with the aim of investigating the outcome of management initiatives implemented at the Caspian tern colonies on Goose and Crescent islands in 2016. 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 composition 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 2016 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 near 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 (this study), (2) in the Columbia River estuary, and (3) outside the Columbia River basin (related studies).

MANAGEMENT ACTIONS

In 2016, the Corps and BOR continued implementation of the IAPMP to reduce predation by Caspian terns on ESA-listed populations of salmonids from the Columbia River basin (USACE 2014). The primary objective of management in the third year of implementation was to reduce the numbers of Caspian terns breeding at colonies on Goose Island in Potholes Reservoir and on Crescent Island in McNary Reservoir to less than 40 breeding pairs each. To accomplish this task, the availability of suitable Caspian tern nesting habitat was nearly eliminated on both islands by installing a variety of “passive nest dissuasion” materials prior to the 2016 nesting season, materials that were designed to preclude tern nesting on both islands. In addition, on Crescent Island willows had been planted over extensive areas to preclude tern nesting over the long-term. Ultimately, 4.3 acres, or more than 85% of the upland area of Goose Island and the nearby islets, were covered with passive nest dissuasion materials consisting of stakes, rope, and flagging. On Crescent Island, about 2.4 acres of potential Caspian tern nesting habitat were covered with passive nest dissuasion materials consisting of fence rows of privacy fabric, as well as stakes, rope, flagging, and woody debris; any remaining open areas on Crescent Island had been planted with willows prior to the 2016 nesting season. On both islands, passive dissuasion was placed over all the area where Caspian terns have previously nested, as well as all areas of open, sparsely vegetated habitat that might be used by ground-nesting Caspian terns or gulls. An effort was also made to prevent nesting by the two species of gulls (California gulls and ring-billed gulls) that nest abundantly on both islands, 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 to try to dissuade both Caspian terns and gulls from nesting anywhere on either island.

As was the case in 2014-2015 (BRNW 2014b; BRNW 2015a; Collis et al. 2015; BRNW 2016b), 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 stipulated in the permits issued for these actions. 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. Therefore, 6 Caspian tern eggs were laid and discovered on Goose Island in 2016, compared to 43 tern eggs laid and discovered the previous year. These eggs were either depredated by gulls or collected under permit soon after laying, which prevented any successful breeding attempts (i.e. fledged young) by Caspian terns on Goose Island in 2016.

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 2016. This result may be explained by differences in the types of passive nest dissuasion materials used at the two islands and the proximity of suitable alternative nesting habitat for both terns and gulls near Crescent Island as compared to Goose Island. See Collis et al. (2016) for additional details regarding the implementation of the IAPMP in 2016.

DISPERSAL, FORAGING, & COLONY CONNECTIVITY

Satellite Telemetry

Efforts to assist with the evaluation of management to displace Caspian terns from colonies in the Columbia Plateau region using satellite telemetry began in 2014. During the first year of this study, we captured Caspian terns at Goose Island (Potholes Reservoir) at the beginning of the breeding season and fitted them with solar-powered satellite telemetry tags. 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), and our satellite telemetry research efforts were expanded in 2015. We continued to follow those terns with actively transmitting tags that were captured at Goose Island in 2014, and 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. Results from the 2015 telemetry study suggested a further incremental shift in foraging activity away from the Priest Rapids Project by Caspian terns (BRNW 2016b). Our efforts to monitor tern dispersal, foraging site use, and colony connectivity using satellite telemetry were continued again through the 2016 breeding season. However, due to the long lifespan of the satellite tags, there was no need to capture additional terns to deploy satellite tags as we could continue tracking a significant proportion of the terns that we satellite-tagged in 2014 and 2015. Our objectives during the third year of the study were similar to those during the previous two years, specifically to (1) describe the responses of terns to the loss of nesting habitat at Goose Island during the third year of management at that site, (2) describe the responses of terns to the loss of nesting habitat at Crescent Island during the second 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 during the preceding years, 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 third year of the study, satellite telemetry data continued to be used to evaluate dispersal patterns of Caspian terns displaced by management actions associated with the IAPMP, and to identify areas where terns continued to forage on juvenile salmonids in the Columbia Plateau region.

Methods: Platform Transmitting Terminal (PTT) 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). Satellite tags used in this study were manufactured by Microwave Telemetry, Inc. (Columbia, MD). Tags were 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 of the Caspian terns tagged (body mass of tagged terns ranged from 590 g to 720 g).

Tagging – No additional terns were tagged in 2016; however, 17 of the 29 satellite tags deployed in 2014, 24 of the 28 tags deployed at Crescent Island in 2015, and 14 of the 18 satellite tags deployed at Potholes Reservoir in 2015 were still attached and transmitting data at the beginning of the 2016 breeding season.

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 like 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. The Columbia Plateau region (*Map 1*).
2. Foraging areas of terns nesting at Goose Island in the past, prior to tern management activities (*Map 2*).
3. 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)

To represent foraging areas of terns nesting at Goose Island in the past, we used results from a GPS-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 https://nhd.usgs.gov) from The Dalles Dam (rkm 309) upstream to Rock Island Dam (rkm 729) on the Columbia River and from the Columbia River confluence to Lower Granite Dam (rkm 177) on the Snake River. 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 1*). This extent captures all the areas of the upper Columbia River 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, Lenore 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; FPC 2016). 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 and the PRCC (Priest Rapids Coordinating Committee), we calculated the proportion of daytime locations that fell within the Priest Rapids Reservoir (i.e. the primary focal area of interest in 2016), 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, 2015, and 2016.

To investigate potential differences in use of areas upstream of Richland, WA, between 2014, 2015, and 2016, we compared the behavior of terns satellite-tagged at Potholes Reservoir in 2014 during the smolt outmigration during each of those years. Potential differences in proportional use measures pre-management (GPS tagged terns in 2013) and post-management (satellite tagged terns in 2016) and between satellite-tagged terns in 2015 and 2016 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 Wanapum Reservoir during the 2014-2016 smolt outmigration periods. Second, we calculated the 50% utilization distribution within the Columbia Plateau region during the peak of the 2014-2016 smolt outmigration periods to examine changes in the core daytime use areas of terns tagged at Potholes Reservoir in 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 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 northeastern and central California (*Map 3*). It was not possible to exhaustively identify and confirm nesting status at all 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 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 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 km of any other colonies during those same 9 nights. In addition to the 10-km buffer, we also used a 2-km buffer to examine colony associations within Potholes Reservoir due to the proximity of the managed Goose Island colony site and the incipient Caspian tern colony that developed in northeastern Potholes Reservoir in 2016. These definitions of colony association were again consistent with limited visual observations at active colony sites that were regularly monitored in 2016 (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 55 satellite-tagged Caspian terns during the 2016 breeding season (01 April – 31 July). Of the tags still actively transmitting location data at the start of the 2016 breeding season, 17 were deployed on Caspian terns at Potholes Reservoir in 2014 (61% of originally deployed tags), 14 were deployed on Caspian terns at Potholes Reservoir in 2015 (78% of originally deployed tags), and 24 were deployed on Caspian terns at Crescent Island in 2015 (86% of originally deployed tags; *Table 1*). Of these 55 individuals, 51 migrated north from Mexico to the Columbia Plateau region prior to the 2016 breeding season, and four individuals remained in Mexico throughout the breeding season. Of the 51 tagged terns that returned north, 28 were male, 22 were female, and one was of unknown sex. Of the 55 satellite-tagged terns tracked during the 2016 breeding season, 16 tags ceased to transmit data sometime during the April-July breeding season (*Table 1*).

In 2016, the tracking of satellite-tagged Caspian terns was again able to direct monitoring crews to high use areas in need of on-the-ground site visits, which led to the early discovery of an active colony on a low-lying sand island located in northeastern Potholes Reservoir a little over 2 km from Goose Island (*Figure 1*). A few terns were observed loafing at the location during an aerial survey conducted on 26 April, but sustained use by satellite-tagged terns following the aerial survey resulted in a follow-up visit by boat on 07 May. At that time, the monitoring crew discovered a small Caspian tern colony with seven active nests. This colony later grew to around 80 active nests before the site was abandoned on 05 June, following a disturbance by at least one American mink (*Neovison vison*).

Foraging Activity (Priest Rapids Project) – For terns tagged at Potholes Reservoir in 2014, the proportion of birds using areas upstream of Richland, WA (*Table 2*), was reduced in 2016, as compared to 2014 and 2015: 36%, 35%, and 19% of active terns in this group were observed to visit the Hanford Reach in 2014, 2015, and 2016, respectively; 50%, 43%, and 31% were observed to visit Priest Rapids Reservoir, respectively; and 39%, 43%, and 13% were observed to visit Wanapum Reservoir, respectively. The foraging use of areas upstream of Richland, WA, in 2016 was reduced from levels observed in 2015 for all tagging groups (BRNW 2016b). In 2016, only a few birds tagged at Crescent Island were observed to have visited the Hanford Reach (4%) and no birds from this group were observed to visit Priest Rapids or Wanapum reservoirs (0%). A larger proportion of birds tagged at Potholes Reservoir used these reaches, however; 19% and 50% of terns tagged in 2014 and 2015, respectively, were observed to visit the Hanford Reach; 31% and 21% were observed to visit Priest Rapids Reservoir, respectively; and 13% and 14% were observed to visit Wanapum Reservoir, respectively. These proportions for terns tagged at Potholes Reservoir in 2014, Potholes Reservoir in 2015, and Crescent Island in 2015 are shown in *Table 3*. The proportion of terns satellite-tagged at Potholes Reservoir that were in the Hanford Reach/Priest Rapids Project area during the 2016 steelhead smolt outmigration varied by week, but was greatest during the peak of the steelhead outmigration for terns using the Priest Rapids Reservoir and Hanford Reach; whereas the highest use of the Wanapum Reservoir did not occur until the tail end of the 2016 steelhead outmigration (*Figure 2*).

Although a limited number of terns tagged at Crescent Island were observed upstream of Richland, WA, and between a third and half of the terns tagged at Potholes Reservoir were tracked to the Hanford Reach and the Priest Rapids Project during the smolt outmigration in 2014-2016, 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 2015 and 2016, a relatively small and similar (P = 0.22; Wilcoxon Rank Sum Test) proportion of all daytime locations of tagged Caspian terns were within the Priest Rapids Reservoir (mean proportions were 9% and 5% in 2015 and 2016, respectively; *Table 4*). This was also true for the combined Hanford Reach, Priest Rapids Reservoir, and Wanapum Reservoir; $\overline{x}$ = 19% in 2015 and $\overline{x}$ = 16% in 2016 (P = 0.59; Wilcoxon Rank Sum Test). However, on days when tagged terns were detected visiting a river reach of interest, most their daytime locations were within that area in 2015; whereas that proportion of time was much reduced in 2016. We found that the proportion of daytime locations at Priest Rapids Reservoir, when birds were present on a given day, was statistically higher in 2015 ($\overline{x}$ = 80%) than during the peak of the smolt outmigration in 2016 ($\overline{x}$ = 42% P < 0.001; Wilcoxon Rank Sum Test). This was also the case for the three combined reaches in 2015 ($\overline{x}$ = 76%) and in 2016 ($\overline{x}$ = 54%, P < 0.001; 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 2016 ($\overline{x}$ = 5%) were like those seen prior to management in 2013 ($\overline{x}$ = 5%, P = 0.5; Wilcoxon Rank Sum Tests). The average proportion of daytime locations at the three combined river reaches was also similar in 2016 ($\overline{x}$ = 16%) to the level observed pre-management at Goose Island in 2013 ($\overline{x}$ = 13%, P = 0.15; Wilcoxon Rank Sum Test). During 2016, on days when terns were tracked to these areas, a higher proportion of their daytime locations were at Priest Rapids Reservoir ($\overline{x}$ = 42%, P = 0.009; Wilcoxon Rank Sum Tests) and the combined Hanford Reach, Priest Rapids Reservoir, and Wanapum Reservoir ($\overline{x}$ = 54%, P < 001; Wilcoxon Rank Sum Tests) than for tagged terns in 2013 ($\overline{x}$ = 17% for the Priest Rapids Reservoir and $\overline{x}$ = 28% for all three reaches combined). For the third year in a row, a smaller percentage of the tagged individuals used the Hanford Reach and Priest Rapids Project as compared to 2013 (GPS telemetry study; see BRNW 2014a), but the proportion of daytime locations was similar on average for the first time since management began at Goose Island. The amount of time spent at the river on days when present, however, remained greater in 2016 than was recorded in 2013, but lower than during the 2014 and 2015 peak smolt outmigration time periods.

Our KDE analysis suggests that during the 2016 smolt outmigration period, tagged terns were active across the Columbia Plateau region, with core daytime use areas located at Potholes Reservoir, the Blalock Islands in John Day Reservoir, near the former Caspian tern colony at Crescent Island in McNary Reservoir, and the White Bluffs area along the Hanford Reach of the Columbia River (*Map 4*). In 2015 and 2014, however, core use areas were comprised of some of the locations listed above, but also included Banks Lake, Sprague Lake, and a more concentrated use of the Priest Rapids Reservoir (BRNW 2016b). Our KDE analysis further 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 then became more concentrated in the Priest Rapids Reservoir compared to the other two reaches in 2015 and 2016 for those terns tagged in 2014 at Goose Island (*Map 5*).

Identification of PIT tag scanning locations – In-season satellite tracking data and analysis of tern foraging hotspots at river reaches within the FCRPS identified multiple locations to scan for smolt PIT tags, including Cabin Island just upstream of Priest Rapids Dam and Mud Island near the town of Desert Aire (*Map 1*), plus multiple sand and gravel bars within the Hanford Reach regularly used by terns for loafing.

Overnight roosts – In 2016, the core overnight roosting sites (i.e. 50% utilization distribution; *Map 6*) of satellite-tagged terns that were tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir during the peak of the smolt outmigration was located at Goose Island in Potholes Reservoir. The 90% utilization distribution also included the Blalock Islands in the John Day Reservoir. These distributions were much reduced from that observed during the 2015 smolt outmigration period, when sites such as Twinning Island in Banks Lake, Harper Island in Sprague Lake, and Badger and Foundation islands upstream of Crescent Island saw more activity as overnight roosting sites by this group of tagged terns (BRNW 2016b).

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 used by terns nesting at Goose Island prior to management (*Map 2*) varied week to week during the breeding season. However, during the period of peak smolt outmigration in 2016, 69% of the terns tagged at Potholes Reservoir in 2014 with actively transmitting tags reported locations somewhere in the Columbia Plateau region, and 63% were detected within the foraging area defined by the 2013 GPS tag study at Goose Island. During that same time, 79% of the terns tagged at Potholes Reservoir in 2015 reported locations in the Columbia Plateau region and 64% were detected in the pre-management Goose Island foraging area. Of the terns tagged at Crescent Island, 61% were in the Columbia Plateau region during the peak smolt outmigration, but only 17% 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 in the Columbia Plateau region and detected in the pre-management Goose Island foraging area are shown in *Table 5*.

Foraging Activity (FRCPS River Reaches) – Of all the foraging areas within the FCRPS, John Day Reservoir was used during the peak smolt outmigration in 2016 by the largest percentage of terns tagged at Potholes Reservoir in 2014 (63%), which increased from 52% during the comparable period in 2015 (*Table 6*). The percentage of these terns that were detected at McNary Reservoir increased in 2016 (25%) compared to 2015 (17%), but use of the Snake River reach between Lower Monumental Dam and Lower Granite Dam was similar (13% in 2016 versus 17% in 2015). The John Day Reservoir also had the greatest proportional use by terns tagged at Crescent Island in 2015, with 61% of those terns detected somewhere within that reach during the peak smolt outmigration. During that same period, 52% of Crescent Island tagged terns were detected within McNary Reservoir, 13% within Ice Harbor Reservoir on the Snake River, but none of the tagged terns from this group reported locations 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 a similar extent as they did those river reaches above Richland during the peak smolt outmigration. Of the terns tagged at Potholes Reservoir in 2015, 57% were detected at John Day Reservoir, 21% at McNary Reservoir, and 21% on the Snake River between Lower Monumental and Lower Granite dams (*Table 7*).

Colony Use and Association – As in the previous year, some of the satellite-tagged terns were not detected at the Priest Rapids Project during the 2016 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 7 – 8*. The 90% utilization distribution shows that both groups of satellite-tagged terns used the network of active and historical colony sites within the Pacific Northwest, and were not restricted to the Columbia Plateau region in 2016. The greatest use of tagged terns remained near colony sites in the Columbia Plateau region, however, particularly for those tagged terns that were detected at the Priest Rapids Project. Outside of the Columbia Plateau Region, the amount of time spent at the network of islands constructed by the US Army

Corps of Engineers (USACE) in southern Oregon and northeastern California by satellite-tagged terns was much reduced from the level observed in 2015 (BRNW 2016b), possibly due to a reduction in forage fish availability associated with continued drought affecting that area, such that it was not captured within the 90% utilization distribution. There was, however, more activity during 2016 in the San Francisco Bay area near the mouth of the Sacramento River, but that did not translate into any significant increase of activity around the USACE-constructed islands at Don Edwards National Wildlife Refuge (DENWR).

During the peak of the smolt outmigration period in 2016, terns tagged at Goose Island in 2014 or 2015 were detected at least once near Goose Island (6% and 29% of individuals tagged in 2014 and 2015, respectively), at the new tern colony in northeastern Potholes Reservoir (56% and 57% of tagged individuals, respectively), at Harper Island in Sprague Lake (13% and 7% of tagged individuals, respectively), at a unnamed island in Lenore Lake previously used in 2015 (0% and 14% of tagged individuals, respectively), and at the Blalock Islands in John Day Reservoir (56% and 50% of tagged individuals, respectively). Outside of the Columbia Plateau region, terns tagged at Goose Island in 2014 or 2015 were detected at least once near tern colonies in southern Oregon and northeastern California (13% and 7%, respectively), at colonies in the Salish Sea region of coastal Washington and British Columbia (6% and 7%, respectively), and near colony sites in the Columbia River estuary (19% and 7%, respectively) and near the USACE-constructed islands at DENWR in coastal California (0% and 7%, respectively; *Table 8*).

For terns tagged at Crescent Island in 2015, 61% were detected at the Blalock Islands in John Day Reservoir, 22% were detected near the Finley Islands in McNary Reservoir, 13% near the new tern colony in northeastern Potholes Reservoir, and 9% near Twinning Island on Banks Lake. Outside of the Columbia Plateau region, 17% of terns tagged at Crescent Island in 2015 were detected in the Columbia River estuary, and 4% were detected near tern colonies in the Salish Sea region of coastal Washington and British Columbia (*Table 8*). Regular monitoring at the Blalock Islands confirmed the presence of 15 of the 28 terns tagged at Crescent Island in 2015 during the 2016 breeding season, of which two were observed after their tags had stopped transmitting location data. Only three terns tagged at Crescent Island were visually confirmed to be breeding at the Blalock Islands in 2016, suggesting that those terns that formerly nested at the Crescent Island colony and attempted to nest at the Blalock Islands in 2016 may have been less successful nesting there as compared to the terns that attempted nesting there in 2015 (BRNW 2016b).

The 2016 breeding season marked the third year of tern management at the Goose Island colony, and the first year since management began when no successful nesting occurred at or adjacent to that site. During the first year of tern management at the Goose Island colony in 2014, a Caspian tern nesting colony formed on a small rocky islet neighbouring Goose Island; whereas in 2015 active and passive dissuasion efforts resulted in only two pairs of Caspian terns successfully nesting on Goose Island (BRNW 2015b). Concurrent with the increased success of nest dissuasion efforts between those two years, a smaller proportion of terns tagged at Potholes Reservoir demonstrated an association with Goose Island throughout the 2015 breeding season as compared to 2014 (BRNW 2016b). In 2016, the proportion of the terns tagged at Potholes Reservoir that maintained an association with Potholes Reservoir was further reduced (*Figure 3*), as many tagged individuals were associated with the new northeastern Potholes Reservoir colony until it failed in early June 2016 (*Figure 4*). Following the failure of the northeastern Potholes Reservoir colony, the satellite-tagged terns that had been associated with that colony temporarily dispersed, but most returned and used Goose Island as an overnight roost later in June (*Figure 4*). A small proportion of terns tagged at Potholes Reservoir were again associated with the colony at the Blalock Islands during the early part of the 2016 breeding season, but to a much lesser extent than in 2015. Like last year, a few tagged terns were regularly associated with the colonies at Sprague Lake and Lenore Lake. Outside of the Columbia Plateau region, a Caspian tern colony again formed on the rooftop at the former Kimberly Clark warehouse in Everett, Washington, and expanded to some nearby barges in 2016 and several of the terns satellite-tagged at Potholes Reservoir in 2014 and 2015 were associated with this site during the 2016 breeding season.

For the terns tagged at Crescent Island in 2015, the Blalock Islands provided the greatest attraction during the first part of the 2016 breeding season; over half of these terns were associated with the large colony at the Blalocks Islands during May (*Figure 5*). Beginning in mid-June, however, associations of satellite-tagged terns with the Blalock Islands declined and Badger Island in McNary Reservoir (2.5 km upstream of Crescent Island) began attracting the greatest number of satellite-tagged terns. Badger Island was used just as an overnight roost, however; no tern nesting occurred at the site in 2016. One tern tagged at Crescent Island was associated with the new colony in northeastern Potholes Reservoir until early June and Goose Island throughout July. Two individuals were associated with the small colony in Banks Lake; one throughout May and the other in June. Several terns tagged at Crescent Island in 2015 also displayed sustained associations with colonies in coastal Washington (Grays Harbor) and British Columbia (Frasier River Delta), as well as the Columbia River estuary colonies in Oregon (East Sand Island and Rice Island). Several the tagged terns in 2016 did not display a sustained association with any colony or were associated with multiple colonies during the breeding season, suggesting either no nesting attempt or very brief attempts.

Conclusions: Satellite telemetry remained a useful tool for documenting the response of Caspian terns to management at colonies in the Columbia Plateau region in 2016. Because passive and active dissuasion prevented Caspian terns from successfully nesting on Crescent and Goose islands, the sample of satellite-tagged terns continued to help identify patterns of breeding dispersal, including dispersal to previously unknown locations where nesting attempts occurred in 2016, or may occur in the future. Observations of tern movements and space use continued to be collected and reported in near real-time, which allowed for informed dialogue amongst regional resource managers. Data from satellite-tagged terns documented the continued presence, movements, and distribution of non-breeding terns within the Columbia Plateau region. These data would not otherwise have been available, as ground monitoring and aerial surveys are insufficient to detect and track displaced terns not associated with a breeding colony. Tracking satellite-tagged terns continued to facilitate the detection of loafing and 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 lower than during the previous two years; (2) 50% or less of terns tagged at Potholes Reservoir and < 5% of those tagged at Crescent Island were detected in the Priest Rapids Project or the Hanford Reach in 2016; (3) Priest Rapids Reservoir continued to be used by a subset of the tagged terns, but only the Hanford Reach was identified as a core day use area during 2016; (4) there was evidence that those satellite-tagged terns that were detected at the Priest Rapids Project and the Hanford Reach in 2016 were spending a similar amount of time there as did terns nesting at Potholes Reservoir during 2013 and less time than in 2014 and 2015; and (5) on days when satellite-tagged terns were detected in the Priest Rapids Project and the Hanford Reach in 2016, they again spent a larger proportion of the day on the river when compared to 2013, but less time than in 2014 and 2015. These results suggest that many displaced terns have continued to shift their foraging away from the Priest Rapids Project, but the non-breeding terns that remained on the Columbia Plateau region still constituted a significant presence at the Project during 2016.

Colony associations – Analysis of sustained associations with known Caspian tern colonies indicated that most satellite-tagged terns that attempted to nest in 2016 did so at locations within the Columbia Plateau region, primarily at the northeastern Potholes Reservoir and Blalock Island colonies, but also in small numbers at the Banks Lake, Lenore Lake, and Sprague Lake colonies. Several tagged terns were also associated with the East Sand Island colony in the Columbia River estuary, and there was a much higher number of tagged terns associated with the colony located at the Kimberly Clark warehouse site in Everett, Washington, than in previous years. In 2016, there was a late season increase in the number of terns satellite tagged at Crescent Island that were associated with Badger Island, just upstream of Crescent Island in McNary Reservoir. Although no Caspian terns were observed nesting at Badger Island in 2016, the island was used by nesting Caspian terns in 2011-2012 (BRNW 2012; BRNW 2013) and currently supports the only American white pelican (*Pelecanus erythrorhynchos*) breeding colony in Washington, as well as a large breeding colony of California gulls (*Larus californicus*); both species of these species could provide social attraction to prospecting Caspian terns in the future. Similar to the 2015 nesting season, a large fraction of tagged terns (a quarter to a third) apparently did not make any sustained effort or failed to breed during the 2016 nesting season.

Facilitation of PIT tag recovery – In 2016, the successful implementation of Caspian tern nest dissuasion at Goose and Crescent islands as part of the IAPMP continued to reduce our ability to measure smolt predation rates by terns in the Columbia Plateau region without a secondary methodology to track displaced terns (i.e. locations where non-breeding terns might deposit smolt PIT tags are less predictable). However, we were again 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 due to the long lifespan of the solar-powered satellite tags deployed in 2014 and 2015. Results from PIT tag recovery efforts at sites identified by satellite-tagged terns are described *below*.

General – After three years of implementation of the IAPMP, satellite tracking of tagged Caspian terns has continued to indicate several broad categories of response to management: (1) stay, search and compete for nest sites in much reduced nesting habitat at managed sites; (2) move to a nearby colony and attempt to nest there, returning to the colony of origin or nearby 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 have generally stayed nearby and searched for habitat, moved to nearby colonies (i.e. northeastern Potholes Reservoir, Lenore Lake, and Sprague Lake) and returned to Goose Island when those colonies failed, or wandered nomadically, often across large portions of Washington, Oregon, and California. Although, in 2016, we saw more long distance dispersal to the Salish Sea area of Washington by this group of tagged birds. In the previous year, terns tagged at Crescent Island primarily moved to a nearby colony located at the Blalock Islands in John Day Reservoir or exhibited long-distance dispersal to the Columbia River estuary. In 2016, we again saw some tagged individuals dispersing to colonies in the Columbia River estuary and the Blalock Islands to nest. In 2016, however, when breeding failures occurred at the Blalock Islands colony, we saw tagged terns moving back to McNary Reservoir to roost overnight at Badger Island, just upstream of Crescent Island. In 2016, very few tagged terns visited USACE-constructed islands in southern Oregon and northeastern California and none demonstrated sustained visits suggestive of possible nesting attempts, possibly due to the paucity of forage fish from a long-term drought in the area. We also saw tagged terns using the San Francisco Bay area in 2016, but did not observe any sustained associations with the restored colonies at the USACE-constructed tern islands at DENWR in the San Francisco Bay area.

Caspian terns are a long-lived species, and results from the third year of the tagging study suggest that a behavioral inertia may exist amongst the terns displaced from Goose Island and Crescent Island through the implementation of the IAPMP. As such, reductions in the predation rates by Caspian terns on smolts in the Priest Rapids Project and the Columbia Plateau region are likely to proceed in gradual, incremental steps. Vigilance will be required to prevent further formation of incipient colonies; however, a pool of non-breeding terns is likely to remain on the Columbia Plateau region for some time following reductions in breeding habitat by management actions.

Color Band Resightings

In 2016, 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).

Methods: On an annual basis, beginning in 2005, 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 (BRNW 2015a). In 2016, these previously-banded Caspian terns were resighted at various colony and roost sites in the Columbia Plateau region using binoculars and spotting scopes. This compliment of bands allowed us to individually identify each banded tern from a distance, such that the banding location (colony) and banding year are known. Band resighting was conducted up to 7 days/week at Goose Island and surrounding islets (Potholes Reservoir), up to 5 days/week at the Blalock Islands, and less often at smaller breeding colonies and roosting sites in the Columbia Plateau region during the 2016 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 2016 to evaluate movements of Caspian terns to and from the Columbia Plateau region.

Summaries of band resighting data collected at breeding colonies and loafing sites in the Columbia Plateau region during the 2016 field season are presented in this report, along with information on where those individuals were originally banded. These summaries represent dispersal or site fidelity across years, between the time when those terns were banded and when they were observed again in 2016. This report also includes summaries of banded Caspian terns observed at two sites (the Potholes Reservoir area and the Blalock Islands) in 2015, where relatively large numbers of terns were observed in the Columbia Plateau region, and locations where those terns were resighted in 2016. The summaries provide information on inter-annual dispersal from, or fidelity to, those two sites.

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 2005-2016. Movement probabilities were estimated between three regions: (1) the Columbia Plateau (including the Blalock Islands, Goose Island, and smaller colonies and loafing sites), (2) the Columbia River estuary (including East Sand Island, Rice Island, and other loafing sites), and (3) Corps-constructed alternative colony sites (all the Corps-constructed tern islands in southern Oregon and northeastern California [SONEC] region). *A priori* models were constructed to evaluate effects of transitions from one region to another and effects of year on movement probabilities. In addition, the following variables were included as covariates to evaluate effects on movement probabilities: (1) number of breeding pairs at source and receiving regions, (2) nesting success (average number of young raised per breeding pair), (3) distance between regions, (4) management implementation (dissuasion: yes or no), and (5) drought (yes or no). 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 sample sizes (AICc) was used to select the best model (Burnham and Anderson 2002) for estimating inter-regional movements. Based on movement probabilities between 2015 and 2016 from the best model, plus the numbers of Caspian terns present at each colony in 2015, numbers of terns that moved between regions from 2015 to 2016 were estimated.

Results and Discussion: A total of 153 previously color-banded Caspian terns were resighted at Potholes Reservoir, including on Goose Island and nearby islets, in 2016 (*Table 9*). The island in northeastern Potholes Reservoir where a new colony formed in 2016 is within 10 km of Goose Island, and 58 of the 153 color-banded Caspian terns that were resighted at Potholes Reservoir this year were seen at both Goose Island and at the new colony in northeastern Potholes Reservoir. Of the 153 Caspian terns that were resighted in Potholes Reservoir in 2016, 86% were previously banded at Goose Island, 9% were banded at Crescent Island, and 1% were banded each at East Sand Island (Columbia River estuary), the Port of Bellingham (Puget Sound), Malheur Lake (Malheur National Wildlife Refuge), and Brooks Island (San Francisco Bay; see *Map 9*).

A total of 510 previously color-banded Caspian terns were resighted at the active Caspian tern breeding colony and nearby loafing sites in the Blalock Islands during 2016 (see *Map 9*; *Table 10*). The loafing site that was near the town of Irrigon, Oregon, is within 10 km of the Blalock Islands, and 15 of 510 color-banded Caspian terns were resighted both at the Blalock Islands and this loafing site. Of the 510 banded Caspian terns resighted near the Blalock Islands during 2016, 58% were previously banded at Crescent Island, 36% were banded at Goose Island, 2% were banded each at Sheepy Lake (Lower Klamath National Wildlife Refuge, California), East Sand Island, and Malheur Lake, and 1% were banded at Crump Lake (Warner Valley, Oregon; see *Map 9*).

A total of 25 previously color-banded Caspian terns were resighted at a small active colony on Lenore Lake. Of these, 64% were previously banded at Goose Island, 28% were banded at Crescent Island, and 4% were banded each at East Sand Island and Malheur Lake. Only one previously color-banded Caspian tern (banded at Crescent Island) was resighted at a small colony on Twinning Island in Banks Lake in 2016 (see *Map 9*).

In McNary Reservoir and the Hanford Reach on the Columbia River, a total of 11 previously color-banded Caspian terns were resighted at non-breeding sites. Two Caspian terns (one banded at Goose Island and the other at Crescent Island) were resighted in the Hanford Reach, two Caspian terns (one banded at Goose Island and the other at Crescent Island) were resighted at the mouth of Snake River, and six Caspian terns (four banded at Crescent Island, one at Goose Island, and one at East Sand Island) were resighted at the mouth of Walla Walla River. One Caspian tern banded at Goose Island was resighted both at the mouth of the Snake River and at the Walla Walla River delta. At Ice Harbor Dam, eight banded Caspian terns were resighted; all had been previously banded at Crescent Island. Near Desert Aire on Priest Rapids Reservoir, 10 banded Caspian terns were resighted: seven had been banded at Goose Island, two were banded at Crescent Island, and one was banded at Malheur Lake. On Cabin Island near Priest Rapids Dam, eight banded Caspian terns were resighted: seven had been banded at Goose Island and one was banded at Sheepy Lake. Two Caspian terns banded at Goose Island were resighted both at Desert Aire and on Cabin Island (see *Map 9*).

Of a total of 222 color-banded Caspian terns seen in the Potholes Reservoir area during 2015, 167 were resighted again in 2016, either in Potholes Reservoir or elsewhere, some of which were resighted at multiple locations in 2016. Of a total of 239 resighting records of these 167 banded individuals during 2016, 45% were resighted in the Potholes Reservoir area, 39% were resighted at the Blalock Islands/Irrigon area, 6% were resighted each at Lenore Lake and Priest Rapids Reservoir, 2% were resighted at an active colony in Puget Sound at Everett, Washington, 1% were resighted at East Sand Island, and < 1% were resighted each in the Hanford Reach and at Ice Harbor Dam (see *Map 9*; *Table 11*).

Of a total of 515 banded Caspian terns seen in the Blalock Islands during 2015, 405 were resighted again in 2016, either in the Blalock Islands (including a loafing site in Irrigon) or elsewhere; some of these banded individuals were resighted at multiple locations in 2016. Of a total of 482 resighting records for these 405 terns during 2016, 76% were resighted in the Blalock Islands/Irrigon, 12% were resighted at Potholes Reservoir, 4% were resighted at East Sand Island, 2% were resighted each at Lenore Lake and Everett, 1% were resighted each at Priest Rapids Reservoir, McNary Reservoir, and Ice Harbor Dam, and < 1% were resighted at Tongue Point Pier in the Columbia River estuary (see *Map 9*; *Table 12*).

In summary, these results suggest that Caspian terns generally exhibited strong site fidelity to the Potholes Reservoir area, despite the third year of efforts to dissuade Caspian terns from nesting at Goose Island. The Blalock Islands experienced a large influx of nesting Caspian terns from colonies on both Crescent Island and Goose Island in 2015, but predominantly from Crescent Island. Many of the terns that immigrated to the Blalock Islands in 2015 returned to the Blalock Islands in 2016. Although most Caspian terns dissuaded from Goose and Crescent islands apparently remained in the Columbia Plateau region, some Caspian terns also dispersed to breeding or non-breeding sites along the coasts of Washington and Oregon. These results offer some insight into potential locations where Caspian terns from the Columbia Plateau region would recruit back into the breeding population, if further management to reduce the numbers of Caspian terns nesting in the Columbia Plateau region occurs in the future.

Out of 34 *a priori* models constructed in 2016, there were four competitive models within two ΔAICc units. Drought, management, and the number of breeding pairs (all in the source region) were each included in all or most of the competing models as having effects on movement probabilities. However, only the effect of drought was significant based on an evaluation of the 95% confidence limits for the coefficients. Movement probabilities were estimated from the best model, which included an interaction term between transition (from one region to another) and the number of breeding pairs, as well as additive terms for “drought” and “management” as affecting movements.

Movement probabilities from the Columbia Plateau region to the Columbia River estuary for Caspian terns banded as adults ranged from 1.5% to 3.4% per year during 2006-2016, with the highest probabilities observed in 2015 and 2016. This translates into an estimated movement of a total of 52 Caspian terns from the Columbia Plateau region to the Columbia River estuary in 2016 (*Table 13*). The movement probability in the opposite direction was lower (1.5%) in 2016.

Because of the large size of the source colony at East Sand Island, however, 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) was 137 individuals, and the direction of net movement was from the Columbia River estuary to the Columbia Plateau region in 2016. Although this number is small, it would partially off-set benefits to salmonids of tern management in the estuary. This is 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 (e.g., anchovy, smelt, surfperch) dominate the diet.

Based on the best model selected to estimate inter-regional movements (see *above*), movement probabilities from colonies on the Corps-constructed islands in the SONEC region to the Columbia Plateau region ranged from 3% to 18% during 2009-2015, with the highest movement probability in 2015. The movement probability from the SONEC colony sites to the Columbia Plateau region remained high (18%) in 2016 (*Table 13*), despite continued management actions to prevent terns from nesting at Crescent and Goose islands. The estimated number of adult Caspian terns that moved from the Corps-constructed colony sites in SONEC to the Columbia Plateau region in 2016 was 375 individuals. Insufficient data collection at the SONEC Corps-constructed islands in 2016 made accurate estimation of movement rate from the Columbia Plateau region to the SONEC region impossible; thus, net movement between the two regions is unknown. The drought in the SONEC region 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). Another year with high movement rates away from the Corps-constructed islands in the SONEC region in 2016 was presumably due to continued drought in the region. Consecutive seasons (2015 and 2016) of high movement probabilities from the Corps-constructed colony sites to the Columbia Plateau region might have been partly due to available nesting habitat at the Blalock Islands in John Day Reservoir and the strong fidelity by terns to Potholes Reservoir.

SYSTEM & COLONY-LEVEL MONITORING

The geographic scope of the IAPMP includes the 10 “at-risk” sites identified in the IAPMP and three 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 13 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 a small unnamed island in Lenore Lake (*Map 1*). 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), Solstice Island (north Potholes Reservoir), and Goose Island in Banks Lake (Adkins et al. 2014; *Map 1*). Other prospective colony sites that 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 include Island 20 and Island 18 in the Richland Islands complex on the Columbia River (*Map 1*).

Periodic monitoring was conducted at these prospective colony sites, as well as at newly identified sites, to help evaluate the consequences of management actions implemented on Goose and Crescent islands in 2016. We assessed whether reductions in colony size associated with the nest dissuasion actions at Goose and Crescent islands were off-set by commensurate increases in Caspian tern colony size at prospective and other new sites within the Columbia Plateau region, where Caspian terns may continue to consume significant numbers of ESA-listed salmonid smolts.

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 extant 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 2016 was completed with cost-sharing from the USACE and BOR.

Methods: Three aerial surveys were conducted during the 2016 nesting season from a fixed-wing aircraft (Cessna 205; Gold Aero Flying Service) to determine the distribution of Caspian terns (both nesting and loafing) 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 off the Columbia and lower Snake rivers that are within tern foraging range (~90 km) of the Federal Columbia River Power System (FCRPS) and the Priest Rapids Project (*Map 10*). The objective of aerial surveys was to identify all active Caspian tern nesting colonies and large roost sites within the Columbia Plateau region. The three aerial surveys of the region, each lasting two days, were conducted on the following schedule: (1) on 26-27 April, early in the incubation period, to check for the presence of newly formed colonies; (2) on 16-17 May, late in the incubation period, to determine numbers of breeding pairs, colony area, and habitat types occupied by nesting Caspian terns, as well as identify late-forming colonies; and (3) on 27-28 June, during the peak 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 known 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.

Geo-referenced, high-resolution, vertical aerial photography (2-cm cell size at ground level) was taken by Geoterra (Portland, OR) at Goose and Crescent islands, as well as at alternative colony sites where aerial surveys or field visits indicated that 30 or more breeding pairs of Caspian terns were nesting. The vertical aerial photography survey was flown on 20 May and the alternative colony sites that were photographed included the Blalock Islands complex (Anvil, Long, Middle, Southern, Sand, Rock, and Straight Six islands) in the Columbia River (*Map 1*). The geo-referenced images were analyzed to determine nesting distribution, colony size (number of active nests), and colony area (m^2) used by Caspian terns. Finally, these data were used to estimate nest density (number of active nests/m^2) of Caspian terns at each site.

The frequency of ground- 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 the number of Caspian terns present and the type of bird activity observed at the site. Sizable Caspian tern colonies (> 30 breeding pairs) were visited more often (weekly) to determine Caspian tern use of each island (i.e. roosting or nesting), seasonal colony/island attendance, nesting chronology, peak colony size, and the outcome of any nesting attempts (i.e. nesting success). Smaller colonies (< 30 breeding pairs) were visited less frequently (monthly) to determine nesting status, change in colony size, peak colony size, and nesting success, if applicable. If Caspian tern nesting occurred at a site, we estimated the number of breeding pairs and colony productivity (average number of young raised to fledging per breeding pair) using previously described methods (Collis et al. 2016). Aerial and land-based surveys of prospective and new Caspian tern colony sites were conducted with cost-sharing from the USACE and BOR.

Results and Discussion: Caspian terns were confirmed present at 33 different sites during aerial surveys conducted in the Columbia Plateau region during the 2016 nesting season (see *Map 10*). Most sites (n = 28) were loafing sites, with no signs of nesting activity, and most of those (n = 19) were located on the Columbia River. At all but five sites where Caspian terns were observed 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 28 sites.

System-wide action effectiveness monitoring confirmed that Caspian terns attempted to nest at four historical colony sites and one new site in 2016. The historical sites included the Blalock Islands on the Columbia River, Twinning Island in Banks Lake, Harper Island in Sprague Lake, and an unnamed island in Lenore Lake. In 2016, an incipient Caspian tern colony became established on a small, low-lying island in northeastern Potholes Reservoir. As was the case in 2015, the largest Caspian tern colony in the Columbia Plateau region was on the Blalock Islands, representing 72% of the total number of breeding pairs in the region in 2016 (see *below* for further details on each site).

Blalock Islands – The Blalock Islands are located on the Columbia River above John Day Dam near the town of Irrigon, OR, and are managed by the U.S. Fish and Wildlife Service as part of Umatilla National Wildlife Refuge (*Map 1*). 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 (Adkins et al. 2014), a low-lying gravel and cobble island. 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), each experiencing 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 Reservoir during the incubation period that, along with high winds, inundated nesting areas (Adkins et al. 2014).

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. In the weeks that followed Caspian tern nests were confirmed on Long Island (26 April) and Southern Island (30 April). 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 in 2015. 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 attempted to nest on the three small Blalock Islands, a ca. 11-fold increase in colony size as compared to the average colony size during 2005-2014 (*Figure 6*). We estimated that 247 young Caspian terns fledged from the Blalock Islands in 2015 or an average productivity of 0.37 young raised per breeding pair (Collis et al. 2015; BRNW 2016b). 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.

In 2016, Caspian terns were first seen in the Blalock Islands on 23 March, when 14 and 2 loafing adults were observed on Sand Island and Long Island, respectively. The first evidence of nesting by Caspian terns at the Blalock Islands during 2016 was observed in mid-April when 22 attended Caspian tern nests and ca. 230 adults were counted on Long and Middle islands. The first tern eggs were confirmed in nests on Long and Middle islands on 19 April. In the weeks that followed Caspian terns were confirmed nesting in small numbers on three additional islands in the Blalock Islands complex (i.e. Southern Island, Rock Island, and Sand Island). As many as ca. 1,200 adult Caspian terns were counted at the Blalock Islands on 7 May. Using aerial photography and ground counts during the peak of breeding, a total of 483 pairs of Caspian terns were estimated to have attempted to nest on islands in the Blalock Islands complex, with most nesting on Long and Middle islands. This represents a decrease in colony size at the Blalock Islands complex compared to 2015 (677 breeding pairs) and a ca. 8-fold increase in colony size as compared to the average colony size prior to management at Crescent Island (2005-2014; 58 breeding pairs; *Figure 6*). We estimated that 207 young Caspian terns fledged from the Blalock Islands in 2016, or an average productivity of 0.43 young raised per breeding pair, the highest Caspian tern nesting success ever observed at the Blalock Islands (Collis et al. 2016). As in previous years, inundation of tern nests due to high reservoir levels coupled with high winds was a factor limiting colony size and nesting success at the Blalock Islands in 2016.

Twinning Island – At the southern end of Banks Lake, near Coulee City, WA, two basalt islands with thin topsoil provide nesting habitat for colonial waterbirds (*Map 1*). These two sites, Twinning Island and Goose 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 nesting 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 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 (Adkins et al. 2014). 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 (Adkins et al. 2014).

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. Based on counts of oblique aerial photos, a total of 64 breeding pairs of Caspian terns attempted to nest on Twinning Island in 2015, like the estimated colony size in 2014 (67 breeding pairs; *Figure 7*; Collis et al. 2015, BRNW 2016a). 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 failed by 10 June (Collis et al. 2015; BRNW 2016a). The primary cause of Caspian tern colony failure in 2015 was thought to be a combination of avian and mammalian nest predation.

In 2016, Caspian terns were first seen on Twinning Island in early May, when 10 adult terns and three attended tern nests were counted. Based on counts of oblique aerial photos, a total of 6 breeding pairs of Caspian terns attempted to nest on Twinning Island in 2016, lower than the estimated colony size in 2015 (64 breeding pairs; Collis et al. 2016; *Figure 7*). In 2016, egg-laying by terns on Twinning Island was not confirmed prior to the colony being abandoned by nesting terns in late May. The primary cause of Caspian tern colony failure at Twinning Island is thought to be a combination of nest predation (avian and mammalian) and human disturbance.

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 (*Map 1*). 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 pair in 2014 (BRNW 2014b). The island has also been home to a large California and ring-billed gull colony, as well as a double-crested cormorant colony (BRNW 2014b). 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 2014b).

In 2015, Caspian terns were first seen on Harper Island on 16 May, when three attended nests were confirmed to be active. A total of 10 breeding pairs of Caspian terns apparently attempted to nest on Harper Island in 2015, like the estimated colony size in 2014 (8 breeding pairs; Collis et al. 2015; BRNW 2016a; *Figure 8*). In 2015, egg-laying was not 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 is not known.

In 2016, Caspian terns were first seen on Harper Island on mid-May, when four adult terns and one attended tern nest were counted. A total of three breeding pairs of Caspian terns apparently attempted to nest on Harper Island in 2016, lower than the estimated colony size in 2015 (10 breeding pairs; Collis et al. 2016; *Figure 8*). In 2016, egg-laying was not confirmed at the Harper Island Caspian tern colony prior to colony abandonment, which was confirmed in early June; as was the case in previous years, the cause(s) of colony failure in 2016 is not known.

Lenore Lake – In 2014, a Caspian tern breeding colony was discovered on a small unnamed island on Lenore Lake (just north of Soap Lake, WA; *Map 1*), 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. In 2015, 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.

In 2016, Caspian terns were first seen on the unnamed island in Lenore Lake in mid-April, when two adult terns were counted. Caspian terns were first observed breeding at Lenore Lake in early May, when 22 adult terns and one attended tern nest were counted. A total of 39 breeding pairs of Caspian terns attempted to nest at the colony in 2016, higher than the estimated colony size in 2015 (16 breeding pairs; Collis et al. 2016; *Figure 9*). We estimated that 23 young Caspian terns fledged from the small island in Lenore Lake in 2016, or a productivity of 0.59 young raised per breeding pair, while only 6 Caspian terns fledged from the colony the previous year.

Northeastern Potholes Reservoir – In 2016, an incipient Caspian tern breeding colony was discovered on a small low-lying island in northeastern Potholes Reservoir (*Map 1*). During low water this island becomes land-bridged, providing access to the site by mammalian predators. Terns were first observed at this site in mid-April, when three loafing terns were counted. Caspian terns were first observed breeding at the site in early May, when 53 adult terns and 7 attended tern nests were counted. A total of 144 breeding pairs of Caspian terns attempted to nest at the colony in 2016. Both egg-laying and hatching (tern chicks) were confirmed at the site prior to the colony being abandoned by terns in early June, presumably due to predation and disturbance caused by a mink on the small island. This is the first documented nesting by terns in the northern end of Potholes Reservoir since 2004, when a small colony existed on Solstice Island (Adkins et al. 2014).

Columbia Plateau Region – In total, an estimated 675 breeding pairs of Caspian terns nested at five different breeding colonies in the Columbia Plateau region during 2016 (*Figure 10*). This represented a 23% decline in the total number of Caspian terns nesting in the Columbia Plateau region as compared to the pre-management average (2005-2013; 873 breeding pairs), and was the smallest regional tern population size observed since monitoring began in 2005 (*Figure 10*). These results suggest that although nest dissuasion actions implemented on Goose and Crescent islands in 2016 were highly effective in eliminating nesting at these two colonies, formerly the two largest Caspian tern colonies in the region where a total of 733 breeding pairs nested in 2013, it did not result in a commensurate decline in the regional population of nesting Caspian terns (*Figure 10-11*). This was due to the relatively large tern colony at the Blalock Islands and the incipient colony in northeastern Potholes Reservoir, whose growth was mostly attributed to terns that previously nested at Goose and Crescent islands relocating to nest at these two sites (see *above*).

PREDATION ON JUVENILE SALMONIDS

Predation Rates Based on PIT Tag Recoveries

The goal of the IAPMP is to reduce predation rates on salmonid populations (distinct population segments [DPSs] or evolutionarily significant units [ESUs]; hereafter ESU/DPS) by Caspian terns to less than 2% per salmonid population, per colony (USACE 2014). The main objectives for collecting smolt PIT tag data as part of this study in 2016 were to (1) estimate colony-specific Caspian tern predation rates on ESA-listed salmonid ESUs/DPSs, (2) assess relative differences in these predation rates prior to and following Caspian tern management actions, and (3) to evaluate the consumption rates by other colonial waterbird species (California gulls, ring-billed gulls, and American white pelicans) of smolts in the region. Comparisons between current and previous predation rates were made in the context of management initiatives for terns nesting on Goose Island in Potholes Reservoir, WA, and Crescent Island in McNary Reservoir, WA. Predation rates at unmanaged Caspian tern colonies (USACE 2014), such as the colony on the Blalock Islands in John Day Reservoir, Twinning Island in Banks Lake, an unnamed island in Lenore Lake, and the colony in northeastern Potholes Reservoir, were also compared and contrasted prior to and following management activities. Finally, because Caspian terns are not the only fish-eating colonial waterbird that consume juvenile salmonids, estimates of predation rates by other piscivorous waterbirds at selected colonies – those previously identified as potentially posing a risk to smolt survival in the region (Evans et al. 2016a) – were also evaluated as part of this study in 2016.

Methods: Predation rates were derived using the number of PIT tags found on a given bird colony from the number available passing upstream dams, and then adjusting for the proportion of consumed tags that were deposited by birds on their nesting colony (referred to as “deposition probability”) and the proportion of the deposited tags subsequently detected by researchers following the nesting season (referred to as “detection probability”; see Hostetter et al. 2015 for additional details). Below is a detailed description of the key input parameters used to calculate predation rates as part of this study in 2016.

Availability of PIT-tagged smolts – The number of PIT-tagged smolts available to birds were based on the number interrogated (detected alive) passing Rock Island Dam (middle Columbia River), Lower Monumental Dam (lower Snake River), or McNary Dam (mainstem 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 (as designated by NOAA) based on the species, run-type, rearing-type, and origin of each PIT-tagged fish detected (see Evans et al. 2012 for additional details). Smolt availability to avian predators was limited to fish detected passing dams during 1 April to 31 July, which reflects the period of overlap in active smolt outmigration and the nesting season for piscivorous waterbirds in the region (Evans et al. 2012; Adkins et al. 2014).

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 on the Columbia River for Caspian terns nesting in Potholes Reservoir, WA (Evans et al. 2012; BRNW 2014a). In 2016, we continued efforts initiated in years past to capture, PIT-tag, and release ESA-listed steelhead and yearling Chinook salmon smolts into the tailrace of Rock Island Dam; this tagging is necessary to achieve a representative and sufficient number of tagged fish for estimation of survival and avian predation rates. A detailed description of sampling methods used to tag smolts at RIS is presented in Evans et al. (2012). 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 outmigration. Smolts were randomly selected for tagging (i.e. tagged regardless of 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 [mm], weight [g]), and external condition (disease, body injuries, descaling, and fin damage obtained via high resolution photography; see Hostetter et al. 2011 for details) of each fish was collected.

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

Detection and Deposition Probabilities – Not all smolt PIT tags ingested by birds are subsequently deposited on their nesting colony (Hostetter et al. 2015), nor are all the tags deposited by birds on their colony recovered by researchers following the nesting season (Evans et al. 2012). For instance, PIT tags implanted in depredated fish can be stolen by other avian predators (kleptoparasitized), damaged during digestion, or excreted off-colony (e.g., at loafing sites). Of those tags deposited intact on the colony (i.e. tags potentially detectable by researchers) some proportion can be blown off the colony during wind storms, washed away during rain storms or flood events, or otherwise damaged or lost during the nesting season (Evans et al. 2012). To quantify detection probabilities, PIT tags with known tag codes were intentionally sown (hereafter referred to as "control tags") on each colony to quantify detection efficiency based on the number of known sown tags recovered following the nesting season (see *Predation rate calculations* below for details). Studies to quantify PIT tag deposition rates were conducted during 2004-2013 for Caspian terns and California and ring-billed gulls. Results from these studies were then used to infer deposition rates at bird colonies in 2016 (see *Results and Discussion*). A more detailed description of the methods used to quantify detection and deposition probabilities is provided in Evans et al. (2012) and Hostetter et al. (2015).

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 minimum estimates of predation rates (see *Predation rate calculations*). There were also no deposition rate data available for tags deposited by birds at mixed-species colonies because the predator species (e.g., a Caspian tern versus a California gull) responsible for depositing individual tags could not be determined, so we also assumed a deposition probability of 1.0 for mixed-species colonies.

Predation rate calculations – The methods of Hostetter et al. (2015) were used to calculate ESU/DPS-specific predation rates. In brief, 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 colony was the product of the three rates described above, (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:

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

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 were 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.

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

The derived annual predation rate constitutes the estimated proportion of available PIT-tagged smolts consumed by birds nesting at a 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 smolts were interrogated passing an upstream dam in each year to avoid imprecise results that might arise from small sample sizes of available PIT-tagged smolts (Evans et al. 2012).

A detailed list of predation rate model assumptions and procedures used to evaluate the validity of those assumptions is provided in Evans et al. (2012) and Hostetter et al. (2015). Briefly, the model assumed that (A1) PIT tag interrogation data obtained at dams from PTAGIS were accurate (PTAGIS 2017), (A2) PIT-tagged fish passing dams were available to birds nesting downstream, (A3) predation, detection, and deposition were independent variables and in the case of detection and deposition, were accurately measured, and (A4) PIT-tagged fish were consumed in a relatively short (one week) period following detection/release at dams. All assumptions were validated to the extent possible, or possible violation of the assumption (e.g., predation within a week of detection/release) had little influence on predation rates (Evans et al. 2012; Hostetter et al. 2015).

Results and Discussion: Numbers of PIT-tagged smolts used in predation rate analyses varied by ESA-listed salmonid population and interrogation/release sites (Rock Island Dam, Lower Monumental Dam, McNary Dam). Like sample sizes in previous years (see BRNW 2013, BRNW 2015a, BRNW 2015b, BRNW 2016b), numbers of PIT-tagged smolts originating from the Snake River were generally greater than those originating from the Upper Columbia River. For all ESUs/DPSs and interrogation/release sites, numbers of available PIT-tagged fish exceeded the 500-minimum needed to generate reliable predation rate estimates from data collected in 2016.

A total of 6,766 steelhead smolts (4,969 hatchery, 1,797 wild) and 5,338 yearling Chinook salmon smolts (4,742 hatchery, 596 wild) were captured, PIT-tagged, and released at Rock Island Dam (RIS) as part of this study. Only 489 previously PIT-tagged steelhead and 272 previously PIT-tagged Chinook salmon were recaptured at the RIS trap, indicating that in the absence of our tagging project, adequate numbers of fish would not have been available for analyses of avian predation rates in 2016. All the steelhead smolts PIT-tagged at RIS as part this study were ESA-listed Upper Columbia River steelhead. Not all 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 1,789 of the yearling Chinook salmon smolts PIT-tagged at RIS were known ESA-listed spring-run Chinook salmon, while the remaining fish were a mixture of ESA-listed spring-run and non-listed summer-run Chinook salmon.

Steelhead and yearling Chinook salmon were tagged and released from 11 April to 11 June 2016. Fish were tagged in concert with, and in proportion to, the run-at-large (*Figure 12*), with sampling effort peaking in early May for both species. Run-timing for both species was early (left-shifted) in 2016 compared with years past, with the peak passage period occurring about a week earlier in 2016 (*Figure 13*). Length data collected in 2016 were like data collected in years past, with mean fork lengths of 195 mm (standard deviation [SD] = 27 mm) and 138 mm (SD = 16 mm) for steelhead and yearling Chinook salmon, respectively, in 2016. An evaluation of external smolt condition indicated steelhead arrived at RIS in better condition in 2016 compared with years past (*Figure 14*). In 2016, about 10% of steelhead had moderate-to-severe external signs of body injuries, fin 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 anomalies in steelhead, observed in 9% of study fish in 2016. By comparison, over 25% of sampled steelhead were of compromised condition in 2015, the highest rate of anomalies observed since evaluations were first initiated in 2008 (*Figure 14*). Like condition data collected during 2013-2015, yearling Chinook salmon captured at RIS generally arrived in better condition than steelhead, with just 5% of yearling Chinook salmon in previous years (see BRNW 2013, BRNW 2015a, BRNW 2015b, BRNW 2016b).

A total of 11 breeding colonies and 4 loafing sites were scanned for smolt PIT tags following the 2016 nesting season (*Map 11*). From these locations, a total of 12,770 PIT tags from 2016 migration-year smolts (Chinook salmon, coho salmon, sockeye salmon, and steelhead combined) were recovered (*Table 14*). Most of tags were recovered from breeding colonies (n = 11,792 or 92% of all recovered tags), while 8% were recovered at loafing sites, some of which were immediately adjacent to breeding sites (*Table 14*; *Map 11*). Of the breeding colony sites evaluated, the largest numbers of smolt PIT tags were found on the Blalock Islands Caspian tern colony (n = 4,228), followed by the Miller Rocks gull colony (n = 2,720), and the Badger Island mixed gull and American white pelican colony (n = 1,962 from all nesting habitat scanned on Badger Island; *Table 14*). Of the loafing sites evaluated, most PIT tags were found on the Blalock Islands at several sites near the active Caspian tern colony (n = 868), followed by sites in the Hanford Reach (n = 75). Relatively few tags (n = 16) were found on Mud Island just upstream of Priest Rapids Dam in 2016, which was inundated by high water events several times during smolt outmigration period. In 2015, however, Mud Island remained dry throughout much of the smolt outmigration period and larger numbers of smolt PIT tags (n = 147) were recovered (BRNW 2016b). Each of the loafing sites evaluated was routinely visited by satellite-tagged Caspian terns (see *above*), but other piscivorous waterbird species (e.g., California gulls, American white pelicans, and double-crested cormorants) may have also used these sites during the 2016 smolt outmigration period.

A total of 4,836 PIT tags from 2016 migration year smolts were recovered on four unmanaged Caspian tern colonies (i.e. Blalock Islands, northeastern Potholes Reservoir, Lenore Lake, and Twinning Island) following the nesting season, representing 41% of all smolt PIT tags recovered from bird breeding colonies in 2016 (*Table 14*). We did not attempt to recover PIT tags from the managed Caspian tern colonies (i.e. Goose Island and Crescent Island) in 2016 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 adult terns and tern eggs observed at each site and estimated per capita (per bird) predation rates (see *below* for further explanation).

A total of 6,958 smolt PIT tags were recovered from other piscivorous waterbird colonies after the 2016 nesting season, including five gull colonies, one American white pelican colony, and two mixed-species colonies (*Table 14*). Of these other colonies, the majority of smolt PIT tags (n = 5,028 or 72%) were recovered from the five gull colonies (*Table 14*).

Caspian tern predation rates at managed colonies – Active and passive dissuasion was successful at preventing Caspian terns from forming a colony on Goose Island in Potholes Reservoir in 2016 (see *above; see* also Collis et al. 2016). Despite the lack of sustained Caspian tern nesting attempts on Goose Island in 2016, small numbers of adult terns were observed roosting on Goose Island during the breeding season and a few individuals laid eggs in areas outside of the former colony area (e.g., along the shoreline). On average, 6 adults (equivalent to 3 breeding pairs) were observed on Goose Island each week throughout the smolt outmigration period and five adults (equivalent to 5 pairs) laid eggs. A similar situation was observed at Goose Island in 2015, whereby an average of 28 adults were counted weekly during the smolt outmigration period and 39 eggs were laid in areas outside of the former colony area.

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 2016, we used information on the number of adult terns observed on Goose Island (3-5 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 2016 (see Collis et al. 2016 for additional details). Using this approach, we predicted that < 0.2% of Upper Columbia River steelhead and < 0.1% of Upper Columbia River spring Chinook salmon – the two ESA-listed ESUs/DPSs most susceptible to Goose Island tern predation – were consumed by terns in 2016 (*Table 15*). By comparison, the average pre-management predation rate by Caspian terns nesting on Goose Island was 15.7% (95% CI = 14.1–18.9%) and 2.5% (95% CI = 1.7–3.6%) for Upper Columbia River steelhead and Upper Columbia River spring Chinook salmon, respectively, during 2007-2013 (*Table 15*). Predicted smolt predation rates in 2016 were far below the IAPMP target goal of less than 2.0% per salmonid population, per colony. In 2014, following the first year of tern management on Goose Island, steelhead predation rates were estimated at 2.9% (95% CI = 1.9–5.1%), with 156 breeding pairs persisting throughout the nesting season. In 2015, when the equivalent of 14-39 nesting pairs were present, steelhead predation rates were predicted to be between 0.5–1.5% (depending on the measure of colony size). Collectively, results indicated that management efforts during 2014-2016 aimed at reducing the size of the Goose Island tern colony have resulted in significantly lower predation rates on ESA-listed salmonids, particularly on steelhead smolts.

Like in 2015, the Caspian tern colony at Crescent Island was eliminated in 2016, with no (zero) Caspian tern nests initiated and no Caspian tern adults observed, nesting or roosting, on Crescent Island during the smolt outmigration period. As such, PIT tag recovery was not conducted and the predation rates of Crescent Island terns on salmonid smolts were presumably non-existent (*Table 15*). 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 15*). 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 (*Table 15;* see also Collis et al. 2016).

Analyses of smolt predation rates at managed Caspian tern colonies in 2016 indicated that the IAPMP target goal of achieving predation rates of less than 2% per ESA-listed salmonid population, per colony, were met, with predation rates nearly or completely eliminated at both Goose and Crescent islands. Presumably, this marks the second time since the Crescent Island colony formed in the 1986 and the first time since the Goose Island colony formed in 2003 when no or very few salmonid smolts were consumed by the area's two historically largest nesting colonies.

Caspian tern predation rates at unmanaged colonies – Following the nesting season, a total of 4,228 PIT tags from 2016 migration year smolts were recovered on the Caspian tern colony on the Blalock Islands (*Map 11*), the largest number of tags recovered on any individual bird colony in 2016 (*Table 14*). Recoveries of control PIT tags sown on the Blalock Islands colony indicated that detection efficiency ranged from 51% to 89% for PIT tags deposited between 1 April and 31 July 2016 (*Table 16*). 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 17*).

Like estimates made in 2015, predation rates by Caspian terns nesting at the Blalock Islands were highest on steelhead populations, with estimated predation rates of 3.1% (95% CI = 2.3–4.6%) and 3.9% (95% CI = 2.9–5.7%) on Upper Columbia River steelhead and Snake River steelhead, respectively, in 2016 (*Table 18*). Predation rates on most salmon populations by Blalock Islands terns were significantly lower, ranging from 0.2% (Upper Columbia River spring Chinook salmon) to 0.6% (Snake River fall Chinook salmon; *Table 18*). The one exception was predation on Snake River sockeye salmon (2.3%), where rates were lower than those on steelhead DPSs, but differences between sockeye and steelhead were not statistically significant (*Table 18*). 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; Evans et al. 2016a). 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 reason for higher predation rates on Snake River sockeye salmon compared with other salmon ESUs in 2016 is unknown, and is unusual relative to years past when predation rates on sockeye salmon were like other salmon ESUs (*Table 15*). Interestingly, Snake River sockeye salmon were also more susceptible to predation by birds from colonies of several other species in 2016, including predation by gulls nesting on the Blalock Islands and gulls nesting on Miller Rocks Island (see *below*).

For the second consecutive year, predation rates by Caspian terns nesting on the Blalock Islands were significantly higher compared with those documented at the Blalock Islands prior to implementation of the IAPMP, with predation rates on steelhead DPSs in 2015, and to lesser extent in 2016, some of the highest recorded at any Caspian tern colony in the region since 2007 (*Table 15*). Significantly higher predation rates on smolts by terns nesting on the Blalock Islands during the post-management period were due to the colony's much larger size (677 breeding pairs in 2015 and 483 pairs in 2016) compared with the pre-management period (average of 58 breeding pairs during 2005-2014). Data from Caspian terns satellite-tagged at Goose and Crescent islands in 2014 and 2015 confirms connectivity between the 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 (see *above*).

Following the nesting season, 574 PIT tags from 2016 migration year smolts were recovered on the newly established Caspian tern colony in northeastern Potholes Reservoir (*Table 14*; *Map 11*). Recoveries of control PIT tags sown on the island to measure detection efficiency indicated that detection efficiency ranged from 66% to 77% for PIT tags deposited between 1 April and 30 June 2016 (*Table 16*). 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 17*). Estimated predation rates on most ESA-listed ESU/DPSs by terns nesting at the northeastern Potholes Reservoir colony in 2016 were < 0.2% per population, with the notable exception of predation rates on Upper Columbia River steelhead (4.1%; 95% CI = 2.9–6.3; *Table 15*). Although steelhead are known to be particularly susceptible to Caspian tern predation, predation rates were higher than those anticipated based on colony size (144 breeding pairs) and short duration of nesting activities (five weeks) at the northeastern Potholes Reservoir colony in 2016. For instance, a colony of 159 pairs that persisted throughout the breeding season on Goose Island in Potholes Reservoir in 2014 consumed an estimated 2.9% (95% CI = 1.9-5.1%) of Upper Columbia River steelhead (Collis et al. 2015). These results provide evidence that even a relatively small, short-lived colony of Caspian terns in Potholes Reservoir can have a significant impact on steelhead survival in the region. Adaptive management plans aimed at dissuading terns from nesting throughout all of Potholes Reservoir in 2017 will aim to eliminate or minimize predation rates on Upper Columbia River steelhead in the future.

An investigation of weekly predation rates on steelhead by terns nesting at the northeastern Potholes Reservoir colony indicated that predation rates were the lowest during the peak smolt passage period in early May and then significantly increased as the number of available steelhead in the river declined in late May (*Figure 15*). Predation rates during the latter portion of steelhead run were more than 14% of available fish in 2016 (*Figure 15*), a remarkably high weekly predation rate given the relatively small size of the northeastern Potholes Reservoir colony. Hostetter et al. (2012) and Evans et al. (2016a) observed similar temporal trends at other Caspian tern colonies in the region, whereby predation rates decreased as more fish became available. Hostetter et al. (2012) attributed this trend to predator swamping (Ims

1990), whereby the probability of an individual fish being consumed decreases as prey available increases.

Following the nesting season, only 16 PIT tags from 2016 migration year smolts were recovered on the Lenore Lake Caspian tern colony (*Table 14*; *Map 11*). Recoveries of control PIT tags sown on the Lenore Lake colony to measure detection efficiency indicated that detection efficiency was high when measured following the breeding season (80%; *Table 16*). However, no measure of detection efficiency during the smolt-outmigration was obtained because nesting cormorants were present on the island during the first visit to Lenore Lake in March, preventing researcher access to the colony to sow control tags. 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 17*). The paucity of smolt tags recovered on the Lenore Lake Caspian tern colony resulted in predation rate estimates of < 0.2% for all ESA-listed ESUs/DPSs evaluated in 2016 (*Table 15*). It is worth noting, however, that number of nesting terns (39 pairs in 2016, up from 16 pairs in 2015) and the number of smolt PIT tags (16 in 2016, up from 1 in 2015) have increased since the Lenore Lake colony formed in 2014. At current colony sizes and predation rates, however, impacts remain well below the goal of < 2% predation rate goal from the IAPMP (USACE 2014).

Like data from the Lenore Lake tern colony, just 18 PIT tags from 2016 migration year smolts were recovered on the Twinning Island Caspian tern colony following the nesting season (*Table 14*; *Map 11*). Recoveries of control PIT tags sown on Twinning Island to measure detection efficiency indicated that detection efficiency ranged from 54% to 92% for PIT tags deposited between 1 April and 31 July 2016 (*Table 16*). 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 17*). As reflected by the paucity of smolt PIT tags recovered following the nesting season, predation rates by terns nesting on Twinning Island in Banks Lake were estimated to be < 0.2% for all ESA-listed ESUs/DPSs evaluated in 2016 (*Table 15*). By comparison, predation rates on Upper Columbia River steelhead by terns nesting on Twinning Island were estimated at 2.6% (95% CI = 1.8–3.9%) in 2015 (*Table 15*). The significant decrease in predation rates by Twinning Island Caspian terns in 2016 is related to changes in colony size, whereby very few terns attempted to nest on Twinning Island in 2016 (6 breeding pairs) compared with 2015 (64 pairs; see *above*).

Reductions in the numbers of Caspian terns nesting at Twinning Island, and associated predation rates by terns from the colony, maybe related to the incipient tern colony that formed in northeastern Potholes Reservoir in 2016, whereby higher fidelity to Potholes Reservoir compared with Banks Lake resulted in a smaller Twinning Island nesting colony in 2016. Future plans to actively dissuade terns from nesting throughout Potholes Reservoir could, however, make the Banks Lake colony more attractive as a nesting site in 2017. For instance, the number of terns attempting to nest on Twinning Island increased in 2015 following successful tern management activities throughout Potholes Reservoir during that year, including terns that were initially satellite-tagged at Goose Island and relocated to nest on Twinning Island (see *above*). The productivity of terns nesting at Twinning Island, however, has generally been low (few or no young raised each year), 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 in years when a relatively large colony was established (Collis et al. 2016).

In summary, predation rates on ESA-listed salmonid populations by Caspian terns nesting at unmanaged colony sites in the Columbia Plateau region exceeded the 2% IAPMP predation rate target for terns nesting at the Blalock Islands (Upper Columbia River steelhead, Snake River steelhead, and Snake River sockeye) and at the unnamed island in northeastern Potholes Reservoir (Upper Columbia River steelhead only) in 2016. Predation rates at all other unmanaged colony sites were well below the 2% target. At the Blalock Islands, increases in predation rates were commensurate with increases in the size of the tern colony, with the colony size increasing from an average of 59 breeding pairs during 2007-2014 to 677 and 483 breeding pairs in 2015 and 2016, respectively. Results indicate that predation rates by Caspian terns nesting on the Blalock Islands and the northeastern Potholes Reservoir island during the post-management period were comparable to those of Caspian terns nesting on Crescent Island or Goose Island during the pre-management period for some, but not all, of the salmonid populations evaluated. Consequently, increased predation rates by Caspian terns nesting at unmanged colonies in 2016 likely offset some of the survival benefits achieved by the elimination of Caspian tern nesting on Crescent and Goose islands. The population that has benefited the most from Caspian tern management since implementation of the IAPMP is Upper Columbia River steelhead, where predation rates by all Caspian tern colonies combined in the Columbia Plateau region ranged from about 15–25% prior to management actions and 6–12% following management actions. Much of the benefit – as measured by decreased predation rates and increased smolt survival – has occurred between Rock Island and McNary dams (see *Table 15*; also see Evans et al. 2016a, Payton et al. 2016).

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* (BRNW 2016b). Based on the large numbers fish consumed in good condition by nesting gulls in free-flowing sections of the middle Columbia River and in open reservoirs within the middle and mainstem Columbia River – colonies without Caspian terns nesting nearby – smolt consumption by gulls may be largely of healthy or uncompromised fish. However, research to address this critical uncertainty is currently lacking for gulls in the published literature (Evans et al. 2016a).

A total of 2,720 PIT tags from 2016 migration year smolts were recovered on the Miller Rocks gull colony following the nesting season (*Table 14*; *Map 11*), the second largest number of tags recovered from scanned sites in 2016. Detection efficiency ranged from 80% – 84% for tags deposited between 1 April and 31 July (*Table 16*). 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 17*).

After adjustments for PIT detection and deposition probabilities were applied, smolt consumption rates by gulls nesting on Miller Rocks were the highest of any piscivorous waterbird colony evaluated as part of this study in 2016 (*Table 18* and *Table 19*). Of those ESUs/DPSs evaluated, the highest recorded consumption rates by gulls nesting at Miller Rocks were 10.1% (95% CI = 7.0–15.2%) for Upper Columbia River steelhead, 6.7% (95% CI = 4.6–9.9%) for Snake River steelhead, and 6.4% (95% CI = 2.9–12.8%) for Snake River sockeye salmon (*Table 18*). Like results from other tern and gull colonies, impacts to Snake River sockeye relative to other salmon ESUs were surprisingly high in 2016 and comparable to those of steelhead DPSs. Of the six ESA-listed ESUs/DPSs evaluated, only predation rates on Snake River spring-summer Chinook salmon (1.2%) and Snake River fall Chinook salmon (1.0%) were below the 2% IAPMP predation rate target in 2016.

An investigation of weekly predation rates on steelhead smolts separated by rear-type (hatchery, wild) indicated that hatchery and wild fish were equally susceptible to gull predation (*Figure 16*). Overall (all weeks combined), hatchery fish were consumed at a slightly higher rate than their wild counterparts, but differences were not statistically significant (*Figure 16*). Unlike weekly predation rates observed at Caspian tern colonies, where predation rates decrease as the number of available smolts increases (Hostetter et al. 2012; Evans et al. 2016a), gulls consumed a similar proportion of available steelhead smolts throughout the entire outmigration period (*Figure 16*). This finding suggests that the gull colony on Miller Rocks was not “swamped” by larger numbers (a greater density) of steelhead smolts in the river.

Consumption rates of smolts by gulls nesting on Miller Rocks in 2015 and 2016 were some of the highest observed for any piscivorous waterbird colony in the Columbia Plateau region since studies of multiple avian predators were first initiated in 2007 (Evans et al. 2012; BRNW 2014a; Evans et al. 2016a). 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) indicated that PIT tag deposition rates were 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. Finally, high smolt consumption rates by gulls nesting at some colonies are associated with the large size of the 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). In 2016, an estimated 3,733 adult gulls were counted on the Miller Rocks gull colony. In 2015, when ESU/DPS-specific predation rates by gulls nesting on Miller Rocks were 1–3% higher per salmonid population than those observed in 2016, an estimated 4,433 gulls nested on Miller Rocks (BRNW 2016b).

Data have indicated that smolt consumption rates by gulls nesting at Miller Rocks are consistently higher compared to other gull colonies in the region (Evans et al. 2016a; BRNW 2016b; this study), despite the smaller average size of the Miller Rocks colony compared with other gull colonies (BRNW 2014a). Miller Rocks is in close proximity to John Day and The Dalles dams (18 Rkm and 23 Rkm, respectively), and Evans et al. (2016a) 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 good-condition smolts from open reservoirs and free-flowing sections of the river as well (Evans et al. 2016a).

Since at least 2012, there have been two separate gull colonies present within the Blalock Islands complex in John Day Reservoir, one on Anvil Island (Rkm 440) and one on Straight Six Island (Rkm 439). A total of 1,033 and 68 PIT tags from 2016 migration year smolts were recovered on Anvil and Straight Six islands, respectively (*Table 14*). Detection efficiency ranged from 90% to 88% on Anvil Island and from 78 to 98% on Straight Six Island (*Table 16*). 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 17*).

Like results from 2015, of the two gull colonies in the Blalock Islands complex, smolt consumption rates were significantly higher for gulls nesting on Anvil Island as compared to gulls nesting on Straight Six Island, with the highest rates observed on Upper Columbia River steelhead (5.4%; 95% CI = 3.6–8.3%) and Snake River steelhead (3.3%; 95% CI = 2.0–5.0%). By comparison, consumption rates by gulls nesting on Straight Six Island were < 1.0% for all salmonid populations evaluated in 2016 (*Table 18*). Of the salmon populations evaluated, consumption rates were highest on Snake River sockeye salmon, with an estimated 3.1% (95% CI = 1.0–7.4%) consumed by gulls nesting on Anvil Island (*Table 19*). BRNW (2016b) hypothesized that higher smolt consumption by gulls nesting on Anvil Island compared to gulls on Straight Six Island was due to (1) differences in colony size (5,804 adult gulls counted on Anvil Island; 937 adult gulls counted on Straight Six island in 2016) 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 as compared to those dominated by ring-billed gulls. This difference in smolt consumption rates between the 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 with ring-billed gulls.

A total of 492 PIT tags from 2016 migration year smolts were recovered on a portion of the nesting habitat on Badger Island that was used exclusively by nesting gulls (*Table 14*; *Map 11*). Control tags sown on the island after the nesting season indicated a detection efficiency of 60% (*Table 16*). The earlier arrival of American white pelicans on Badger Island prevented the sowing of control tags on the island by researchers prior to the smolt outmigration period in 2016. 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 17*).

Smolt consumption rates by gulls nesting on Badger Island were highly variable, ranged from < 0.1% on Snake River fall Chinook salmon to a high of 3.8% (95% CI = 2.1–6.8%) for Upper Columbia River steelhead (*Table 19*). Like gulls nesting on Miller Rocks, consumption rates were higher for steelhead populations compared with salmon populations, except for consumption rates on Snake River sockeye salmon, which were comparable to those on steelhead (*Table 18 and Table 19*) in 2016. Consumption rates for gulls nesting at Badger Island in 2016 were likely underestimated because (1) no measure of pre-season detection efficiency was possible and pre-season detection efficiency is almost always lower than post-season detection efficiency (*Table 16*) and (2) because > 60% of the gull colony overlapped spatially with breeding American white pelicans, precluding the correction of deposition probabilities (see *Methods*). As such, predation rate estimates reported herein are derived from a subset of smolt PIT tags known to have been deposited by gulls on the colony. The Badger Island gull colony, which consisted of 4,126 adults in 2016, formed for the first time in 2015. Although there is no proof of where the gulls that nested on Badger Island originated, it is likely that most, if not all, had previously nested on Crescent Island, as dissuasion activities associated with the IAPMP eliminated the gull colony on Crescent Island in 2015, the same year the gull colony formed on Badger Island (Collis et al. 2015; see *above*).

A total of 718 PIT tags from 2016 migration year smolts were recovered on the Island 20 gull colony (*Table 14*; *Map 11*). Recoveries of control PIT tags sown on the Island indicated that detection efficiency ranged from 72% to 83% for PIT tags deposited between 1 April and 31 July 2015 (*Table 16*). 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 17*).

Consumption rates of salmonid smolts by gulls nesting on Island 20 were < 1.0% for most ESUs/DSPs evaluated in 2016, with the notable exception of predation on Upper Columbia River steelhead, where an estimated 5.7% (95% CI = 3.7–8.9%) of available fish were consumed (*Table 19*). Most consumed Upper Columbia River steelhead by gulls nesting on Island 20 were hatchery fish, with predation rates nearly 4 times greater on hatchery fish compared with wild fish in 2016 (*Figure 16*). Temporal trends in predation rates by gulls nesting on Island 20 were like those for gulls nesting on Miller Rocks, whereby a similar proportion of available smolts were consumed throughout the 2016 steelhead outmigration period (*Figure 16*). These results provide evidence from another large gull colony that gulls were not swamped by increasing numbers of steelhead smolts during the peak of the run.

In 2015, consumption rates by Island 20 gulls for both Upper Columbia River steelhead (7.9%; 95% CI = 5.3-12.0%) and Snake River steelhead (3.6%; 95% CI = 1.7–6.9%) were significantly higher than those observed in 2016 (*Table 19*). Reductions in predation rates by gulls nesting on Island 20 in 2016 compared with 2015 are likely associated with a reduction in colony size (16,558 adults counted in 2015, compared with 14,316 adults counted in 2016) and perhaps also changes in river conditions. For instance, in 2015, several measures of the river environment during the outmigration period suggested 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 and 2016 (FPC 2017). In addition, daily outflow rates at McNary Dam were consistently lower in 2015 compared with other years (DART 2016). In a study exploring biotic and abiotic factors that influence steelhead smolt survival in the region, Payton et al. (2016) observed an association between avian predation rates and water transit times within the middle Columbia River, whereby predation rates decreased as water transit times decreased (i.e. a faster river environment).

In summary, for the second consecutive year, consumption rates by gulls from some breeding colonies (e.g., Miller Rocks, Blalock Islands, and Island 20) were similar or greater than the highest predation rates observed at Caspian tern colonies (e.g., Blalock Islands) in the Columbia Plateau region during 2016. Results from this study and those of Hostetter et al. (2015) and Evans et al. (2016a) suggest that some, but not all, of the gull colonies in the Columbia Plateau region may pose a significant risk to smolt survival in the Columbia River. Based on the large number and percentage of available smolts consumed by gull colonies, additional studies aimed at quantifying what fraction of gull smolt consumption is on dead or compromised fish and what factors (river flows, proximity to dams, availability of alternative prey, and others) influence smolt susceptibility to gull predation, seem warranted.

American white pelican predation rates – A total of 458 PIT tags from 2016 migration year smolts were recovered on a portion of Badger Island where exclusively American white pelicans nested (*Table 14*). Control tags sown on the island after the nesting season indicated a detection efficiency of 58% (*Table 16*). 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 American white pelicans during the 2016 nesting season. Additionally, predation rate estimates represent minimums because > 60% of the pelican colony overlapped spatially with breeding gulls (see also Badger Island gull predation rates *above*). As such, predation rate estimates reported herein are derived from a subset of PIT tags deposited by nesting white pelicans on Badger Island.

Minimum smolt predation rate estimates for Badger Island pelicans were < 0.3% for all ESA-listed salmonid ESUs/DPSs evaluated (*Table 19*). Minimum predation rate estimates in 2016 were very like those recorded in years past, with white pelican predation rates generally less than 0.5% of available tagged fish in most years (Evans et al. 2012; BRNW 2013; BRNW 2016a). A more detailed discussion of Badger Island American white pelican predation on tagged smolts can be found in Evans et al. (2012) and BRNW (2016b). In brief, it is important to note that estimates of white pelican predation rates 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 smolt PIT tags recovered on the Badger Island, however, would not dramatically change estimates of predation rates, as predation rates would still be < 1.0% for all salmonid populations evaluated. There is some evidence, however, that predation rates by white pelicans on smolts originating for other river systems and at other locations (e.g., near Prosser Dam on the Yakima River), particularly subyearling Chinook salmon, may differ than those of smolts originating from the upper Columbia and Snake rivers. For example, during 2010-2014 minimum predation rates (those corrected for detection but not deposition probabilities) on Yakima River subyearling 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). Additional research on smolt predation rates by Badger Island white pelicans should include studies of deposition rates and 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).

Finally, in addition to PIT tags from juvenile 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 2016 were recovered on the Badger Island pelican colony after the nesting season. PIT tags were from adult sockeye salmon (n = 11), adult steelhead (n = 13), and adult Chinook salmon (n = 1 jack salmon) tagged at the Bonneville Dam and Priest Rapids Dam fishways during upstream migration or as post-spawn steelhead (kelts) returning to the ocean. Adult salmonids ranging in size from 425 mm fork length (sockeye salmon tagged at the Priest Rapids Dam fishway) to 675 mm fork length (steelhead tagged in Asotin Creek, a Snake River tributary) were consumed by Badger Island pelicans.

Mixed-species predation rates – A small mixed-species colony of gulls (< 50 adults counted) and double-crested cormorants (< 70 adults counted) occupied the same small island in Lenore Lake where Caspian terns nested in 2016 (*Map 11*). Due to infrequent surveys at this site and the proximity of the three species of piscivorous waterbirds nesting and loafing on the island, we could not assign each scanned tag to a species of avian predator. However, only 19 PIT tags from a 2016 migration year smolt were recovered on the mixed-use nesting area following the breeding season (*Table 14*). No data on deposition rates are available for this mixed-species colony, so predation rates represent minimum estimates of smolt losses. Based on the paucity of smolt tags recovered, minimum predation rates were < 0.2% for all ESUs/DPSs evaluated in 2016.

The nesting by gulls on Badger Island in 2016 (see *above*) resulted in a section of the island where > 60% of both the American white pelicans and gulls nested near one another, forming a mixed-species colony area where PIT tags recovered by researchers after the nesting season could not be assigned to a species of predator. A total of 1,470 PIT tags from 2016 migration year smolts were recovered on the mixed-species area following the nesting season (*Table 14*), the 3rd largest number of PIT tags recovered from a breeding site in 2016. Control tags sown on the island after the nesting season indicated a detection efficiency of 58% (*Table 16*). No data on deposition rates are available for this mixed-species colony, so predation rates represent minimum estimates of smolt losses. Minimum predation rate estimates ranged from < 0.1% of Snake River spring-summer Chinook salmon to 0.5% (95% CI = 0.1-1.6) of Snake River sockeye salmon (*Table 19*). Based on low deposition probabilities for gulls (*Table 17*) and the large numbers of smolt PIT tags recovered, actual or best predation rate estimates (those corrected for both detection and deposition probabilities) are likely much higher. Assuming that American white pelican deposition rates are comparable to those reported in Teuscher et al. (2015) at 30%, actual predation rates by birds nesting at the Badger Island mixed-species colony would be roughly 5 to 7 times higher than those reported herein.

Minimum predation rates by the mixed-species colony on Badger Island in 2016 were like minimum predation rate estimates in 2015, when minimum estimates ranged from < 0.1% to 0.4% of each available salmonid population consumed (BRNW 2016b). Similar caveats regarding the actual predation rates on juvenile salmonids by birds nesting at Badger Island also existed in 2015.

Cumulative avian consumption rates – The representative tagging of juvenile steelhead and yearling Chinook salmon that occurred at Rock Island Dam (RIS), 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 predation rates as part of this study. Results may provide valuable insight regarding the overall magnitude of colonial waterbird predation on juvenile salmonids outmigrating through the middle Columbia River 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 (see also BRNW 2016b), 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 (*Table 18*). This approach standardizes fish availability for all evaluated bird colonies within the Columbia Plateau region, resulting in a cumulative measure of avian consumption rates on steelhead and yearling Chinook salmon during outmigration from Rock Island Dam to Bonneville Dam, for those bird colonies included in this study. Because 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 for the entire smolt outmigration period through the impounded section of the Columbia River.

Results indicated that cumulative avian consumption rates were consistently and significantly higher on steelhead released into the tailrace of RIS compared with yearling Chinook salmon (*Table 20*). This finding is consistent with differences in the relative susceptibility of steelhead versus salmon to avian predation observed in other salmonid populations (e.g., Snake River steelhead versus Snake River spring/summer Chinook salmon; *Table 18* and *Table 19*). A discussion of factors that influence the greater susceptibility of steelhead to avian predation compared with salmon is provided above (see also Evans et al. 2016a and BRNW 2016b).

In 2016, cumulative avian consumption rates indicated that 31.9% (95% CI = 26.5–38.4%) and 8.0% (95% CI = 5.6–11.4%) of RIS released PIT-tagged steelhead and yearling Chinook salmon, respectively, were consumed by piscivorous waterbirds nesting at colonies evaluated in this study (*Table 20*). For both salmonid species and for the second consecutive year (2015, 2016), most the consumption by birds was based at breeding colonies located downstream of McNary Dam (Rkm 470). For steelhead, most the avian consumption was attributable to gulls nesting on Miller Rocks (7.7% of released fish), Caspian terns nesting on the Blalock Islands (3.7% of released fish), and gulls nesting at the Blalock Islands (5.0% of released fish; *Table 20*). For yearling Chinook salmon, the clear majority of consumption by birds was attributable to gulls nesting on Miller Rocks (5.3% of released fish; *Table 20*). Conversely, consumption rates of yearling Chinook salmon by birds from all other colonies, including the colonies of Caspian terns and gulls on the Blalock Islands, were < 1.0% (*Table 20*). These estimates do not account for other sources of mortality (piscine predation, dams, disease, or other sources) that occurred during outmigration from Rock Island Dam to the vicinity of each bird colony, suggesting that consumption by birds from11 colonies evaluated herein were a substantial source of smolt mortality, possibly the single greatest source of mortality for steelhead, during outmigration from RIS to Bonneville Dam in 2016. Evans et al. (2016a) also documented that avian consumption of steelhead, and to lesser extent yearling Chinook salmon, was substantial compared with other documented sources of smolt losses during outmigration. For example, avian consumption estimates reported herein were 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 2016 were lower than those observed in 2015 (40.1% and 9.4% for steelhead and yearling Chinook, respectively; Collis et al. 2016), but like those observed in other years (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 ranged between 21% and 35% during 2008-2013. During this period, predation rates by Caspian terns nesting on Goose Island in Potholes Reservoir were the highest of all evaluated colonies (11–22%, depending on the year), a colony where smolt predation rates were dramatically reduced in 2014-2016 as part of the IAPMP. The primary reason for increased cumulative avian consumption rates of steelhead in recent years was increased consumption by gulls nesting at Miller Rocks (particularly in 2015, when predation rates on RIS released steelhead were 11.6%) and Caspian terns and gulls nesting at the Blalock Islands, colonies that account for most steelhead consumption by piscivorous waterbirds breeding in the Columbia Plateau region. Despite the finding of high cumulative avian consumption rates of steelhead smolts in 2015 and 2016, 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, reductions due to implementation of the IAPMP.

Finally, cumulative avian consumption rates presented herein are minimums because the consumption by non-breeding birds and non-colonial or semi-colonial piscivorous waterbirds, such as common mergansers (*Mergus merganser*), great blue herons (*Ardea herodias)*, and others, were not investigated as part of this study or many other studies (e.g., Evans et al. 2012; Evans et al. 2016a). While non-colonial or semi-colonial waterbird species are known to consume juvenile salmonids in the Columbia River basin, their consumption 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 and Crescent islands that remained in the region but did not nest, is unknown and could account for a measurable level of losses for outmigrating smolts in the middle and mainstem Columbia River.

JSATS Analysis

Spatially explicit measures of avian consumption rates are essential for evaluating the efficacy of Caspian tern management to increase smolt survival in the middle Columbia River (Evans et al. 2016a; BRNW 2016b). Reductions in the numbers of Caspian terns nesting on Goose and Crescent islands 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 *above*). To address this critical question and to document where (spatially) and when (temporally) within the Priest Rapids Project steelhead were depredated by Caspian terns or consumed by other piscivorous colonial waterbird species (e.g., California gulls), we collaborated with researchers at Blue Leaf Environmental, Inc. that were conducting acoustic telemetry survival studies in 2016. Because acoustic-tagged (AT) fish were also PIT-tagged (i.e. double tagged), we were able to estimate the location within the river where tagged steelhead were consumed by birds based on last know locations of live fish passing telemetry arrays prior to consumption by birds.

The objectives of this analysis in 2016 were like those in 2015: (1) calculate avian consumption rates of acoustic-tagged (AT) smolts 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. Survival and avian consumption rate results from AT steelhead studies in 2016 were then compared with data derived from similar studies conducted in 2014 (Evans et al. 2016a) and in 2015 (BRNW 2016b). Collectively, results were used to identify where steelhead smolt losses occurred, when they occurred, and the apparent cause of mortality (colonial waterbird predation or unaccounted for mortality).

Methods: The methods of Evans et al. (2016a) 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 Priest Rapids Project in 2016. In brief, recoveries of PIT tags from double-tagged fish (acoustic tag and PIT tag; hereafter "tagged fish") on bird colonies, coupled with last known detections of live fish passing in-river telemetry arrays, were used to estimate the impact of avian predators on steelhead smolt survival.

Study area – We investigated predation on tagged juvenile steelhead within a 202 Rkm section of the middle Columbia River in 2016 (*Figure 17*). Study fish were detected passing nine telemetry arrays, arrays that spanned from the Wanapum Reservoir to an array located upstream from the confluence of the Snake and Columbia rivers (*Figure 17*). Six of these nine arrays were used to jointly estimate survival and avian predation of tagged steelhead within the study area. Additionally, PIT tag arrays at four downstream sites were also incorporated in the analysis: McNary Dam (MCN, Rkm 470), John Day Dam (JDA, Rkm 348), Bonneville Dam (BON Rkm 234), and a pair-trawl net detection system in the Columbia River estuary (EST, Rkm 75). Detections at these sites were used to infer survival to the last telemetry array at Rkm 527 (see *Spatially and temporally explicit consumption rate calculations* for details).

Fish capture, tagging, and release – Detailed methods regarding the collection, tagging, and release of tagged smolts used in this study are presented in Skalski et al. (2017). In brief, 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) 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), PIT-tagged (*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) and Priest Rapids Dam (Rkm 639; *Map 11*). Tagged steelhead smolts were released daily during 1–25 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 consumption rates of the double-tagged fish used in this study. PIT tag recovery methods were the same as those described above, with the same colony-specific measures of detection and deposition probabilities applied (*Table 16* and *Table 17*).

Spatially and temporally explicit consumption 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 (detections at arrays) and recovery (detection on a bird colony) history. Here we summarize the methods used to simultaneously model survival, interrogation, and recovery:

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,

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

Estimation of the probabilities of interrogation at each acoustic array was complicated by higher than expected rates of tag failure for certain batches of acoustic tags in 2016. Skalski et al. (2017) found evidence of poor tag performance in certain lots of tags and grouped them accordingly into two “batches”; each batch was associated with rates of normal tag failure and a higher than average tag failure rate. The likelihood-based approach, in conjunction with the use of detections at downstream PIT tag arrays, allowed us to directly model the probable incidence of tag failure versus fish mortality.

We let Y_{ij} be the indicator variable of whether fish *i* is detected at the interrogation array defining the downstream boundary of segment *j*th. We let δ_{rwj} be the probability that a surviving fish from the *r*th release in week *w* is detected at this array. Due to the possible failure of acoustic telemetry tags, we further include a variable, X_{ij}, to indicate whether fish *i* is still detectable at array *j*. Note that since PIT tags are assumed to never fail, X_{ij}=1 for all PIT tag arrays (i.e. when j > 6). We let κ_{bj} be the probability that a tag from batch *b* fails within segment *j*. Thus,

$$X_{ij} \sim \begin{cases} \text{Bernoulli } \left(X_{i(j-1)} * \left(1-\kappa_{bj}\right)\right) & \text{for j} \leq 6 \\ \text{Bernoulli } (1) & \text{for j} > 6 \end{cases}$$

$$Y_{ij} \sim \text{Bernoulli } (\delta_{rwj} * Z_{ij} * X_{ij}),$$

and

$$\kappa_{bj} \sim \text{Beta } (a_{bj}, d_{bj}),$$

where a_{bj} and d_{bj} were specified based on a preliminary analysis of travel times and test tag failure rates (see *Appendix A).*

We let R_{ic} be the vector indicating whether the tag associated with fish *i* was recovered on colony *c*. As noted by Evans et al. (2012) and Hostetter et al. (2015), not all smolt tags ingested by birds are subsequently deposited on their nesting colony and not all tags deposited by birds on their nesting colony are subsequently detected by researchers after the breeding season. 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 *above*; *Table 16*). 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 combined to estimate avian consumption in six spatial aggregations of consecutive segments: (1) Wanapum Development (729–669 Rkm), (2) Priest Rapids Development (669–639 Rkm), (3) from the Priest Rapids release location to Vernita Bridge (639–625 Rkm), (4) Vernita Bridge to White Bluffs (625–595 Rkm), (5) White Bluffs to Hanford (595–545 Rkm), and (6) Hanford to Pasco (545—527 Rkm; *Figure 17*).

We let r_{RIS} and r_{PR} refer to the set of smolts released in the tailraces at Rock Island and Priest Rapids dams, respectively. We let $\boldsymbol{J}_k$ represent the set of segments in the k[th] spatial aggregation of segments and r_k represent the release(s) associated with avian consumption estimates in $\boldsymbol{J}_k$. We let $D_{i\boldsymbol{J}_k c}$ indicate the death of fish *i* within $\boldsymbol{J}_k$. We define $\hat{P}_{\boldsymbol{J}_k,c}$ to be the consumption 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 consumption by birds from the *C* colonies under consideration. Therefore,

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

Avian consumption and total mortality rates are associated with double-tagged steelhead released below Rock Island Dam. No correction is employed for the “paired-release” methods used for survival estimates by Skalski et al. (2016) due to the incongruous nature of avian predation throughout the study area, as well as the general assumption that a negligible amount of consumption by Caspian terns takes place in the proximity of dams (Evans et al. 2016a).

Imperfect rates of deposition and detection lead to positive estimates of consumption rates for all segments in which birds from a colony were assumed to forage. We estimated positive rates of consumption even when no direct evidence existed (i.e. when none of the tags whose detection history ended in each segment were recovered on the bird colony of interest). Therefore, the estimated total consumption rate by all piscivorous colonial waterbirds from all colonies in a segment was directly related to the number of bird colonies whose members were assumed to forage there. It follows, then, that we must be cautious in our assumptions about which bird colonies contributed foragers in each segment. We assumed that most birds from each colony foraged along a continuous, uninterrupted reach of the river. The limits of this reach 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 consumption by birds from that colony). The one notable exception to this assumption is the Caspian tern colony in the Blalock Islands complex. Several tags last detected in the Priest Rapids Reservoir were later found on this colony. From evidence associated with satellite-tagged birds (see *above*), we assume this is evidence of these fish being consumed from within this area, rather than these tags failing and being consumed further downstream.

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 consumptionn rates were presented as consumption 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 consumption events between any two adjacent acoustic arrays within a segment was not known (see also Evans et al. 2016a).

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) $\forall$ *r,w,j*. Uniform (0,1) prior distributions were also specified for β_{0c}, β_{1c}, and $\delta_{rwj} \forall$ *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 were 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 (A1-A4) associated with consumption rate estimates derived from smolts that were PIT-tagged only (see *above*) apply to double-tagged (acoustic- and PIT-tagged) fish, with three additional assumptions: (A5) release and interrogation histories of tagged fish at acoustic arrays were complete and accurate, (A6) acoustic tags were functional during the study period (see *Appendix A*), and (A7) mortality due to handling and tagging is included in the "other" mortality probability designation.

Data proofing was done by researchers at Blue Leaf Environmental, Inc. (BLE) that conducted the AT component of the study and protocols to censor irregular entries and compile the appropriate group of fish were followed (A5). To confirm A6, tests were conducted by BLE on a random sample of tags to confirm that tag life and functionality were as specified by the tag manufacturer (33 days). As noted above and in Skalski et al. (2017), tag failure rates were assumed to be higher than expected and adjustments were needed to correct survival estimates in 2016 (see Skalski et al. 2017 and *Appendix A* for details). Mortality after release that was potentially associated with handling and tagging likely occurred in 2016, as was the case in previous years (Skalski et al. 2016), which necessitates assumption A7. A significant number of losses due to handling and tagging would result in an overstatement of availability and consequently bias estimates of avian consumption probabilities down.

Results and Discussion: Complete descriptions of smolt capture, tagging (acoustic tag and PIT tag), and releases from telemetry studies in the Priest Rapids Project in 2016 are summarized in Skalski et al. (2017). Analyses of colonial waterbird consumption rates were based on steelhead releases at two different release locations (Rkm 669 and 729), totaling 1,762 steelhead (*Table 21*), with roughly two thirds released at the upriver site (n = 1,204), for each of four weeks. Tagged steelhead ranged in size from 130 to 229 mm fork length (mean = 190 mm; Skalski et al. 2017).

Recovery of tags on bird colonies – PIT tags from 57 double-tagged steelhead were likely consumed by birds within the study area in 2016 (*Table 21*). An additional 97 double-tagged steelhead were consumed by birds outside of the study area (i.e. downstream from the last telemetry array located near the confluence of the Snake and Columbia rivers).

Detection and deposition rate estimates for PIT tags used to estimate spatially and temporally explicit consumption rates are presented in *Table 16* and *Table 17,* the same data used to calculate consumption rate estimates reported above. As noted above, tags recovered on avian loafing sites were excluded from estimates of colonial waterbird consumption 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 consumption rate estimates) and because the species of avian predator (i.e. tern, gull, pelican, or other) at these loafing sites could not be determined for each recovered tag.

Spatially and temporally explicitly consumption rates – Estimated consumption rates by piscivorous colonial waterbirds varied by river segment and bird colony, with steelhead consumption rates ranging from < 0.1% to 2.0%, per river segment (*Figure 18*). Of the six river segments evaluated, avian consumption rates were the highest on steelhead in the Wanapum Development (1.8%; 95% CI = 0.9–3.3%) and Priest Rapids Development (2.0%; 95% CI = 1.0–3.9%), relative to the four river segments below Priest Rapids Dam in the Hanford Reach (range = 0.1–1.1%, depending on the segment; *Figure 18*). Consumption rates within the Priest Rapids Project (reservoirs and dams combined) were estimated at 3.7% (95% CI = 2.3– 5.8%) in 2016. Total or reach-specific consumption rates – consumption by all breeding birds on smolts traveling through the 202 Rkm study area – were estimated at 6.7% (95% CI = 4.5–10.3%) in 2016.

Of the individual bird colonies evaluated, consumption rates on steelhead within the Priest Rapids Project were greatest for Caspian terns nesting on the unnamed island in northeastern Potholes Reservoir, with terns consuming an estimated 1.2% (95% CI = 0.5–2.5%) and 1.7% (95% CI = 0.7–3.2%) of available fish in the Wanapum and Priest Rapids developments, respectively, in 2016. The remaining avian consumption within the Project was from the small tern colony on Lenore Lake and terns nesting on the Blalock Islands, where terns consumed an estimated 0.4% (95% CI = 0.1–1.3%) and 0.3% (95% CI = 0.1–0.8%) of available tagged fish within the Wanapum and Priest Rapids developments, respectively. Despite their proximity to Priest Rapids Dam, there was no evidence that gulls nesting on Island 20 were commuting upstream to forage on smolts within the Wanapum or Priest Rapids developments (*Figure 18*). It should be noted, however, that consumption rates by gulls differed depending on the release location for steelhead within the study area, with tagged steelhead released into the tailrace of Priest Rapids Dam more susceptible to gull predation than fish released into the tailrace of Rock Island Dam in 2016 (*Table 21*). The numbers of double-tagged steelhead available to birds were small, however, and on-colony deposition probabilities were low for gulls (*Table 17*), so relative differences in gull consumption by release group should be interpreted cautiously. None-the-less, the larger number and percentage of steelhead released at Priest Rapids Dam that were recovered on the Island 20 gull colony suggests that consumption rates were higher than those represented by steelhead released at Rock Island Dam that survived to the foraging range of Island 20 gulls in 2016.

Like data collected in 2015, spatially explicit consumption estimates demonstrated 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 upstream of Wanapum Dam were recovered on the Blalock Islands Caspian tern colony in John Day Reservoir. These results are not surprising given the foraging ranges of GPS-tagged and satellite-tagged Caspian terns documented as part of this study (see *above* for details), and demonstrate that Caspian terns can commute long distances to consume juvenile salmonids

(Maranto et al. 2010). 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 *above*). Consequently, it is more challenging to use recoveries of fish tags on bird colonies as a measure of the foraging behavior of nesting adults, as compared to studies where nesting adult birds are tagged to track their movements from the colony to foraging areas. It is also important to note that consumption rates for Caspian terns and other piscivorous colonial waterbirds presented here likely represent minimum estimates of total smolt mortality caused by birds because an unknown number of adult birds, especially Caspian terns dissuaded from nesting at Goose and Crescent islands, may have remained in the area as non-breeders or failed-breeders but continued to consume juvenile salmonids during the 2016 smolt outmigration period. Mortality to steelhead due to predation from these non- or failed-breeders is included in our estimate of total smolt mortality (1-survival), but not our estimate of mortality due to avian consumption (see *Methods* and Evans et al. 2016a).

The proportion of total steelhead mortality explained by colonial waterbird consumption varied by spatial scale, with colonial waterbirds accounting for 17% and 14% of all steelhead losses in Wanapum and Priest Rapids developments, respectively, in 2016. An investigation of temporal trends indicates that weekly fluctuations in avian consumption rates were consistent with weekly fluctuations in total mortality rates, with increases in weekly total mortality commensurate with increases in weekly avian consumption rates in 2016 (*Figure 19*). In a multi-year synthesis of spatially and temporally explicit consumption rates, Evans et al. (2016a) observed a similar trend and concluded that within season variation in total mortality of steelhead and yearling Chinook salmon was largely explained by variation in avian consumption rates. Regression analyses from this study revealed strong and statistically significant relationships between total mortality and mortality associated with consumption by birds (R^2 = 0.95 and 0.62, $P < 0.01$, for steelhead and yearling Chinook salmon, respectively).

Survival standards for juvenile steelhead (≥ 93% survival per development, > 86% survival for the entire Project) were not achieved during 2008 – 2010 (Skalski et al. 2016). Evans et al. (2013) estimated that between 4.0% and 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 that three-year period. Starting in 2014, the first year of Caspian tern management at the Goose Island colony, survival standards for juvenile steelhead within the Project 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. 2016a). In 2015, survival standards for steelhead were again met at the Project level, although development standards fell short in the Wanapum Development. Estimates of Caspian tern predation rates in 2015 were 2.7% and 2.3% for Wanapum and Priest Rapids developments, respectively (BRNW 2016b). Survival estimates from 2016 are currently pending, but preliminary results indicate standards were met at the Project level (Skalski et al. 2017). Caspian tern predation rate estimates in 2016 were once again relatively low (1.8% and 2.0% for Wanapum and Priest Rapids developments, respectively) compared to those during 2008-2010. Reductions in steelhead mortality in the Project during 2014-2016 are likely related to management efforts aimed at reducing the size of the Goose Island Caspian tern colony. For example, management efforts could reduce the size of the Goose Island Caspian tern colony to an average of 67 breeding pairs during 2014-2016 (includes the 39 and 3 nesting attempts in 2015 and 2016, respectively), 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 in 2015 (see BRNW 2016b) and the northeastern Potholes Reservoir colony in 2016, however, partially off-set benefits achieved by the large reduction in the size of the Goose Island tern colony during this period. As noted above, an unknown number of non-breeding or failed-breeding Caspian terns were also likely present in the region during the post-management period, birds that presumably consumed juvenile steelhead within the Project (see *above*).

In summary, avian predation rates remained a significant source of steelhead mortality, although predation rates by Caspian terns have been greatly reduced since management actions were initiated at the Goose Island colony in 2014. Caspian terns nesting at the unnamed island in northeastern Potholes Reservoir contributed the most to steelhead mortality within the Project in 2016. Results from this study and from Evans et al. (2016a) and BRNW (2016b) 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 offset by decreased survival rates for steelhead smolts in reaches downstream, particularly consumption by gulls from certain colonies and predation by the large Caspian tern colony on the Blalock Islands. Results suggest that adaptive management to reduce the size of some currently unmanaged Caspian tern colonies and to address gull predation, particularly at the Miller Rocks colony, are warranted if the goals of the IAPMP are ultimately to be achieved.

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 islands, 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, 43.7% of the prey items consumed by Caspian terns nesting on the Blalock Islands were juvenile salmonids in 2016 (n = 1,314 identified bill loads). This was lower than the average 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), and lower than the proportion observed at the Blalock Islands in 2015 (67.3%). Steelhead smolts again made up a large proportion of the salmonid prey items in the Caspian tern diet at the Blalock Islands in 2016 (24% of all salmonids identified). This proportion was smaller than at the Blalock Islands in 2015 (34% of all salmonids identified), but high compared to the tern diet at Crescent Island in previous years (10–23% during 2000-2012).

Juvenile salmonids (43.7%) and centrarchids (bass and sunfish, 42.7%) were by far the most prevalent prey types in the diet of Caspian terns nesting on the Blalock Islands in 2016. All other prey types (percids [perch], ictalurids [catfish], cyprinids [carp and minnows], petromyzontids [lamprey], and others) made up less than 5% of the diet each. The proportion of juvenile salmonids in the diet of Caspian terns nesting on the Blalock Islands was highest in late April and early May (76.8%), 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, with seasonal declines more rapid in 2016 due to an earlier outmigration timing than most years.

We estimated that Caspian terns nesting on the Blalock Islands consumed ca. 420,000 juvenile salmonids in 2016 (95% c.i. = 230,000 – 610,000). This point estimate was lower than for Caspian terns at the Blalock Islands in 2015 (310,000 – 800,000), but there was substantial overlap in 95% confidence intervals. The 2016 estimate was within the range of estimated smolt consumption by Caspian terns nesting at Crescent Island during 2000-2012 (point estimates ranged from 330,000 to 680,000 smolts). Estimated consumption of steelhead smolts by Blalock Islands terns in 2016 was ca. 140,000 (95% c.i. = 73,000 – 210,000), compared to 240,000 (95% c.i. = 130,000 – 350,000) in 2015. In 2016, estimated steelhead consumption fell to within the range observed for Caspian terns nesting at Crescent Island during 2000-2012 (point estimates ranged from 50,000 to 160,000; *Figure 20*).

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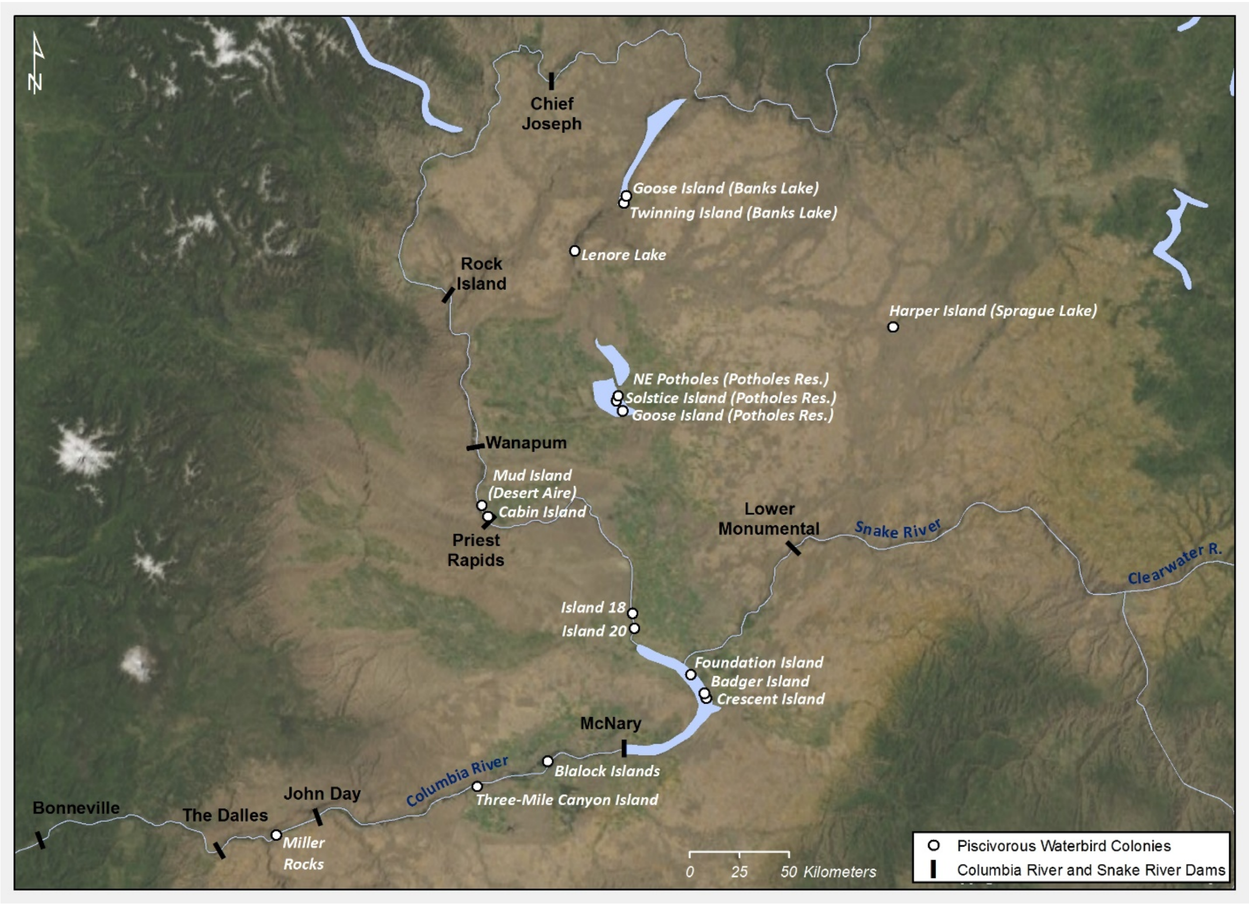
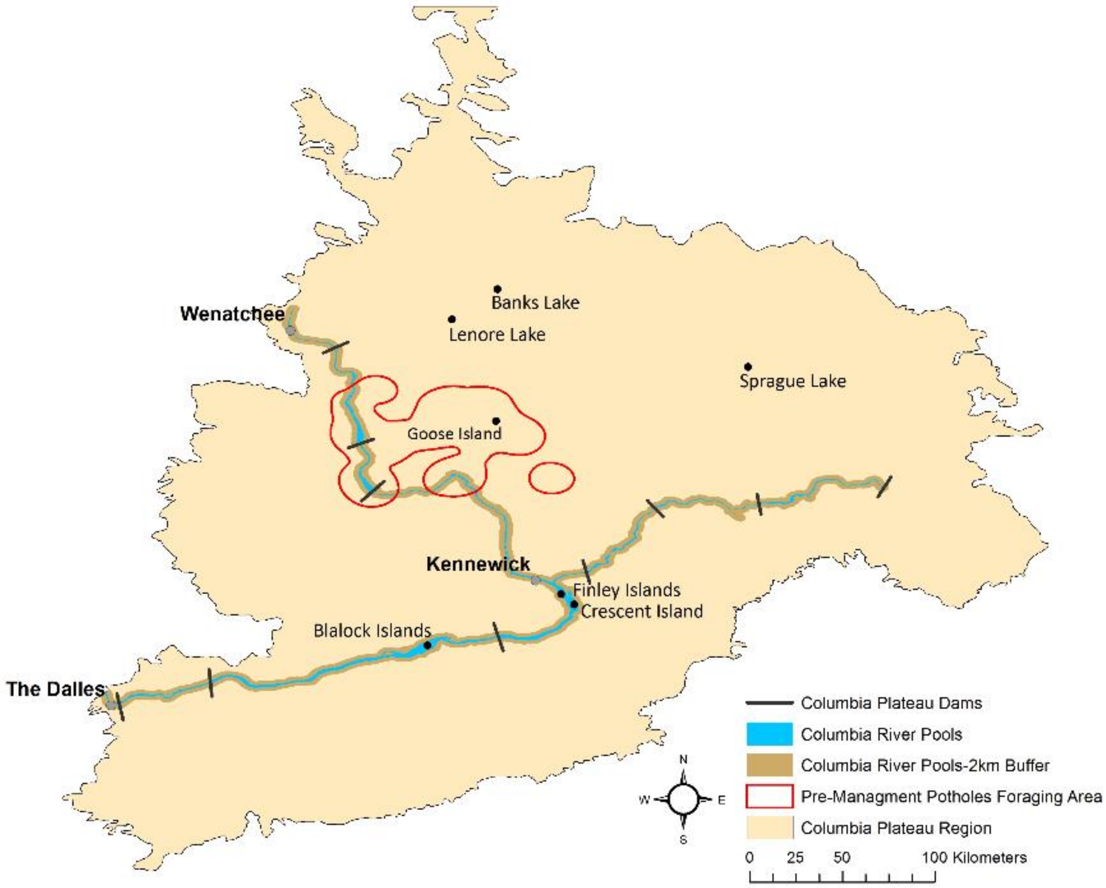
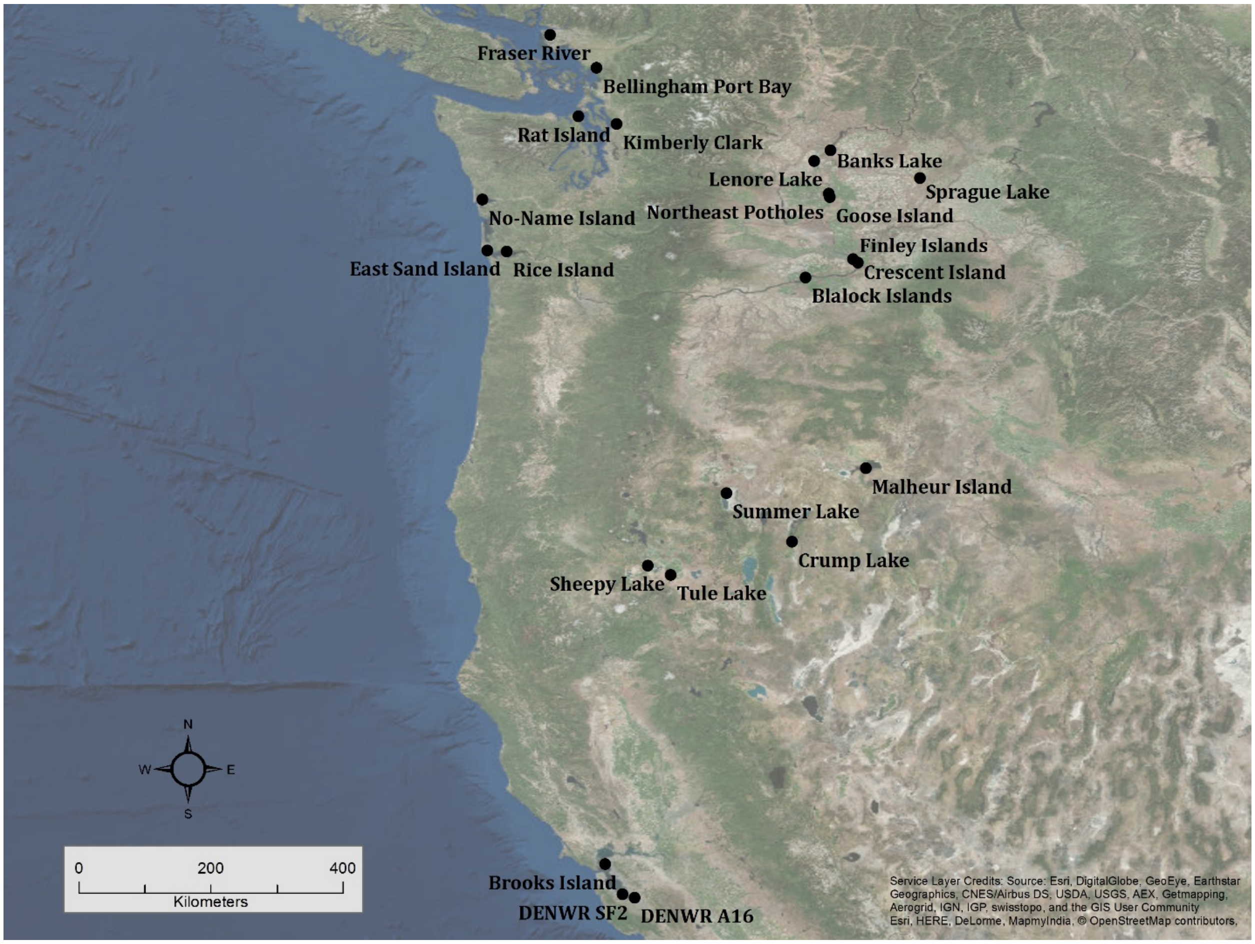
MAPS



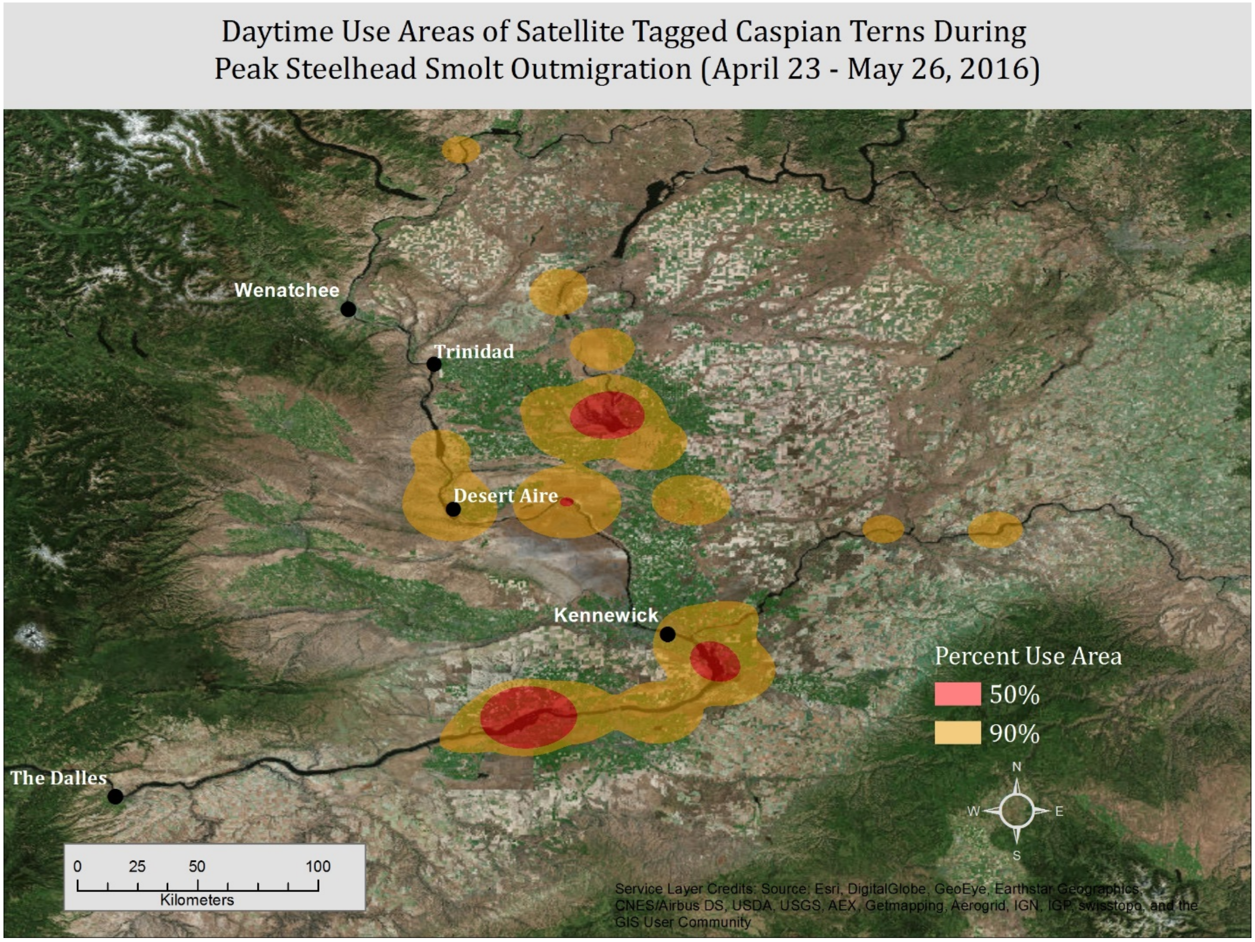
Map 1. Study area in the Columbia Plateau region in 2016.



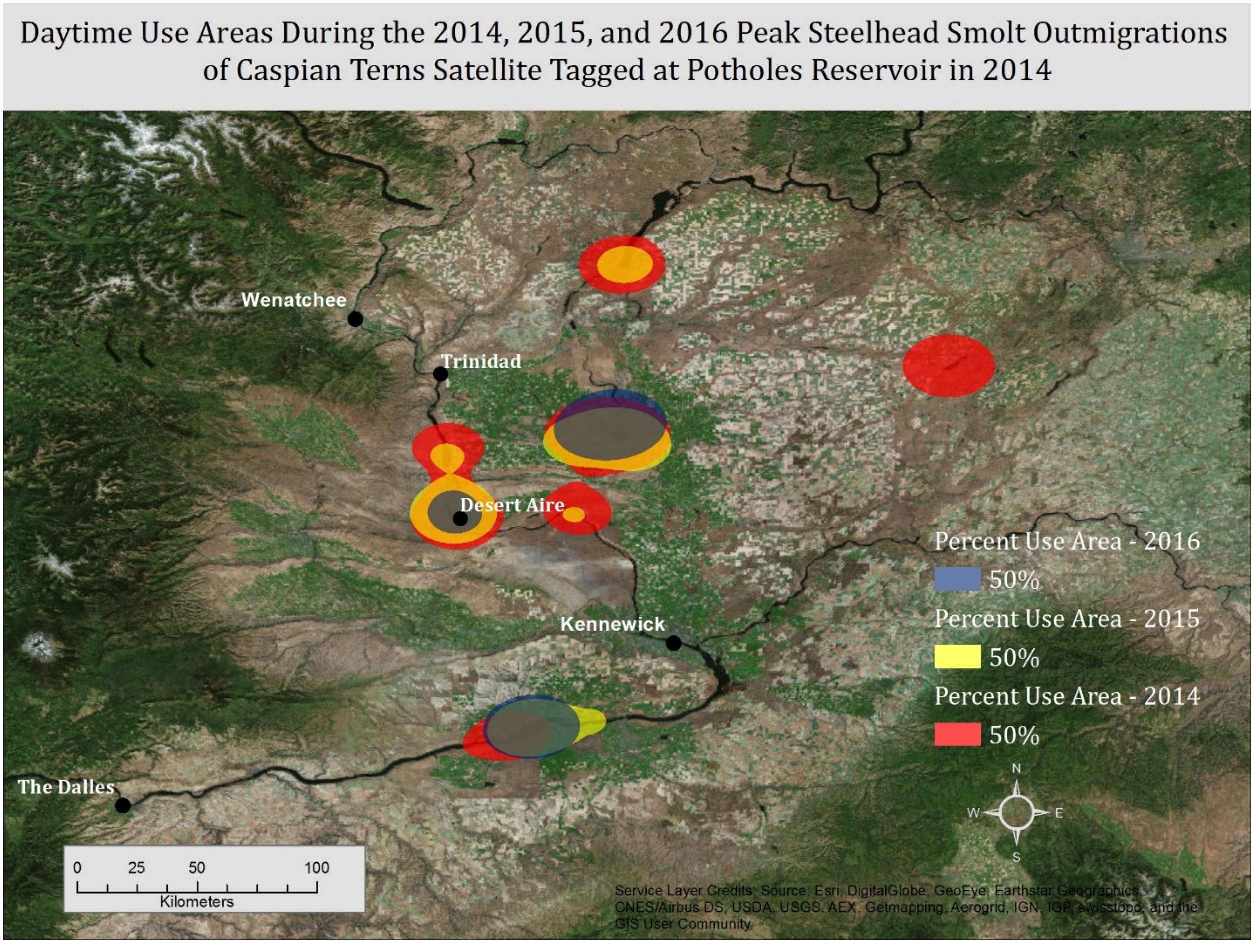
Map 2. Columbia Plateau region of eastern Washington State, and the pre-management foraging areas (red polygons) of Caspian terns nesting at Goose Island in Potholes Reservoir in 2013 (BRNW 2014a). The foraging area used is a 95% contour interval for a kernel density estimate based on GPS locations collected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



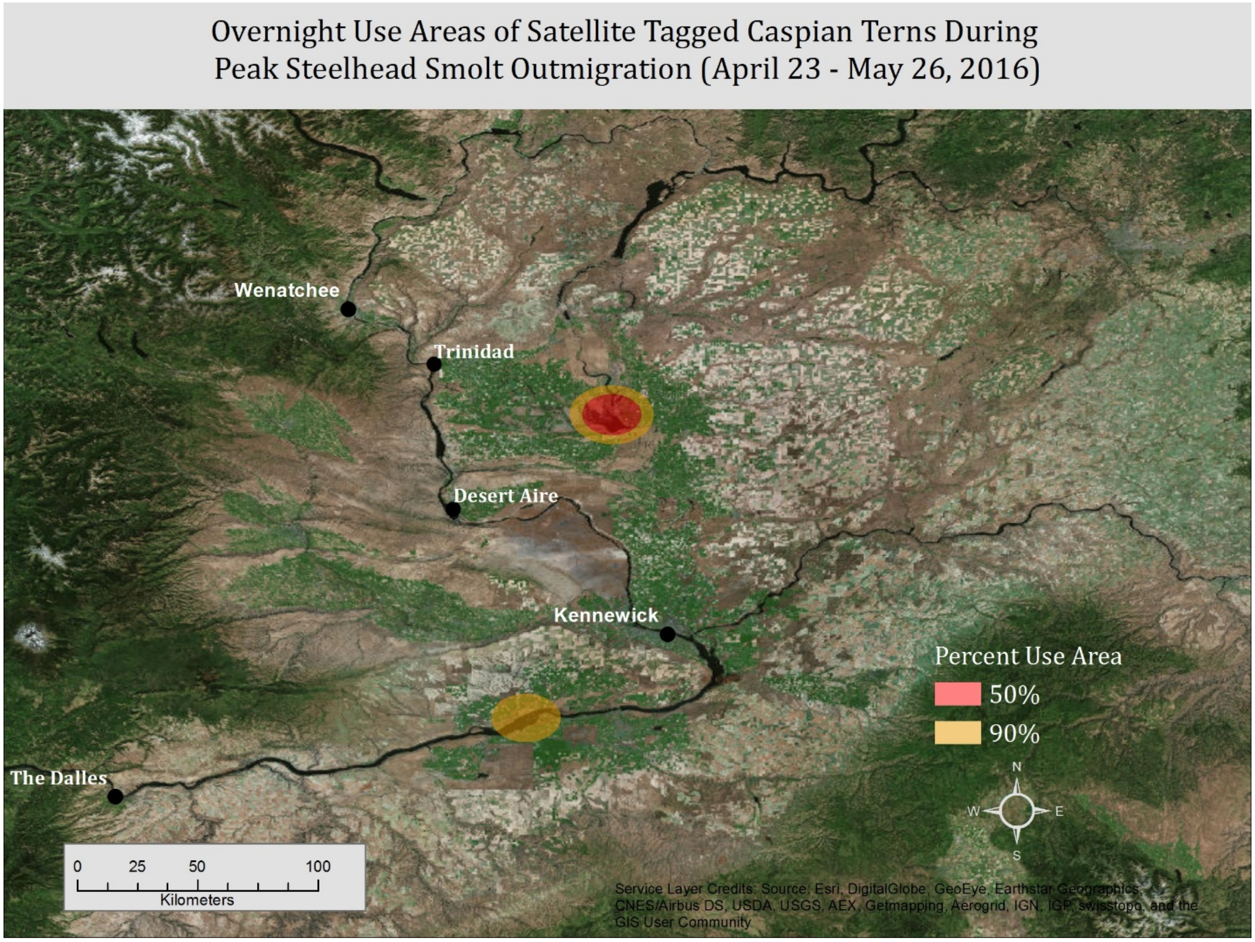
Map 3. Caspian tern colony sites in the Columbia Plateau region, western Washington, southern British Columbia, Oregon, and California evaluated for colony association by satellite-tagged terns during the peak smolt outmigration period in 2016.



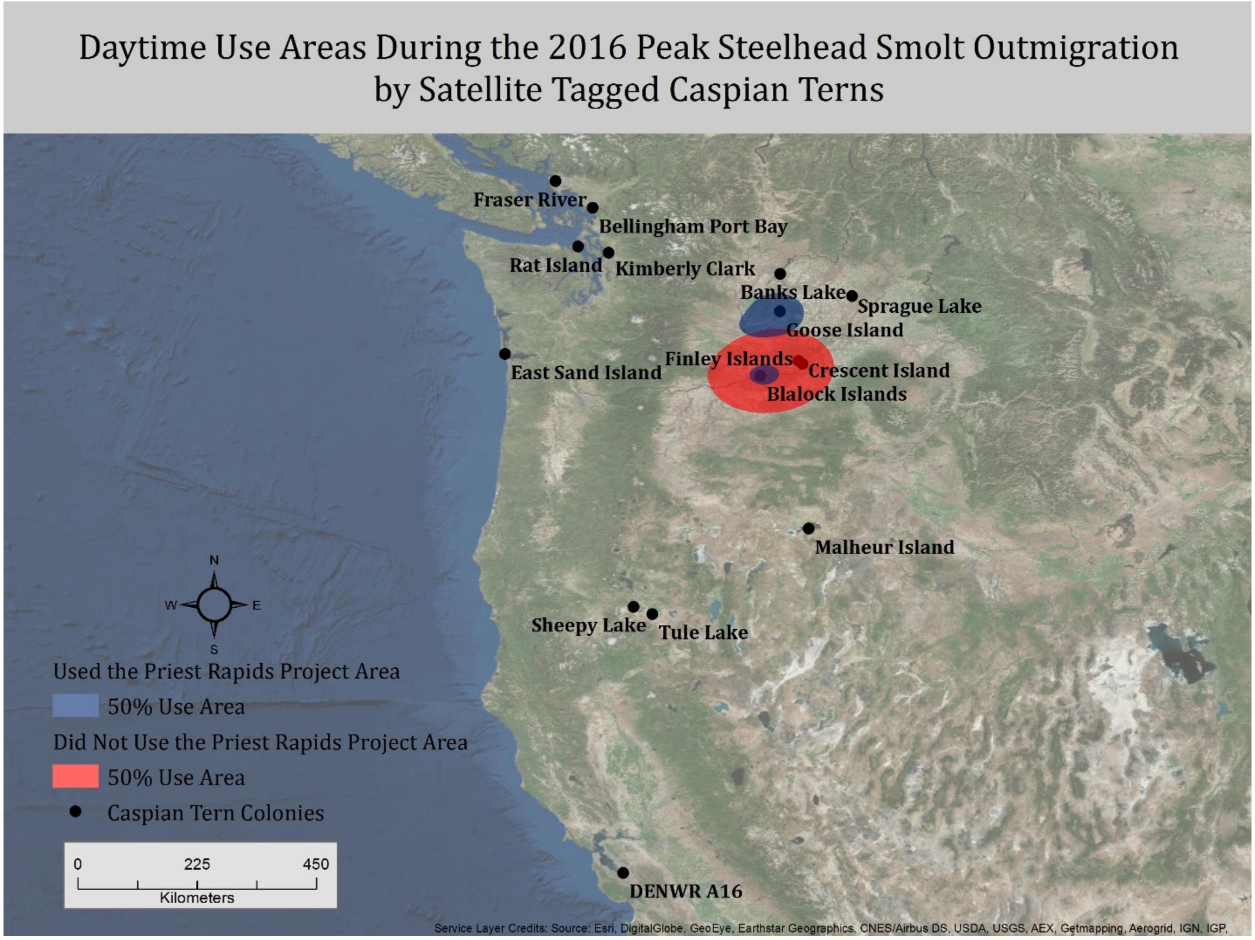
Map 4. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2016 (April 23 – May 26) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 and Crescent Island in 2015 that were tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum 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 in the Columbia Plateau region are shown here.



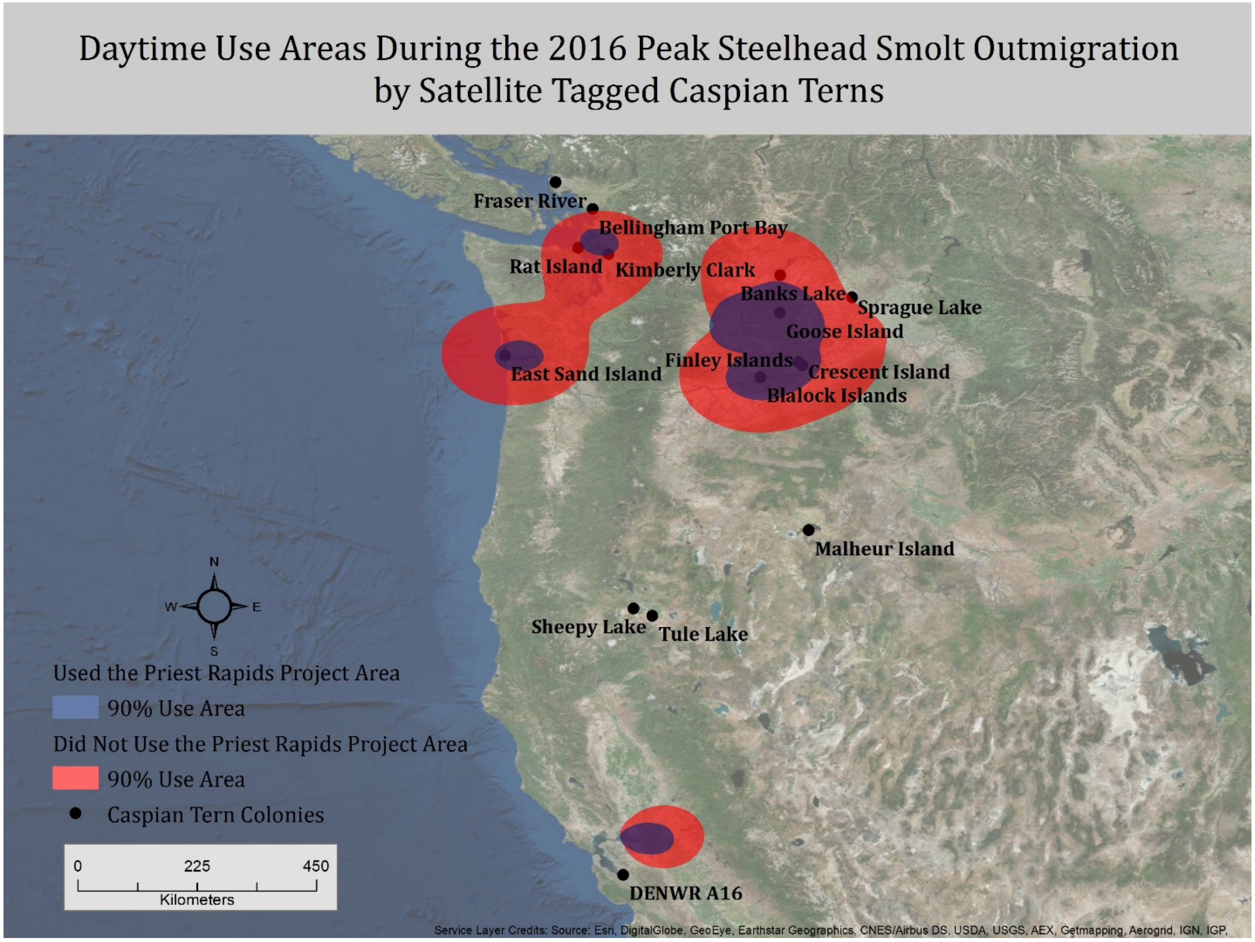
Map 5. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2014 (May 5 – May 31), 2015 (April 29 – June 6), and 2016 (April 23 – May 26) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 that were tracked to the Hanford Reach, Priest Rapids Reservoir, and/or Wanapum Reservoir during those time periods. Red/orange indicates the area where the probability of finding an individual tagged tern was 50% in 2014. Yellow/orange indicates the area where the probability of finding an individual tagged tern was 50% in 2015. Blue/purple indicates the area where the probability of finding an individual tagged tern was 50% in 2016. Grey indicates the overlap in 50% utilization distribution between the three years. Only locations within the Columbia Plateau region were used.



Map 6. Nighttime utilization distribution analysis during the peak of steelhead smolt outmigration in 2016 (April 23 – May 26) for satellite-tagged Caspian terns 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 was 50% and yellow encompasses the area where the probability was 90% (note: higher percentage areas also include the lower percentage areas contained within). Only locations within the Columbia Plateau region were used.

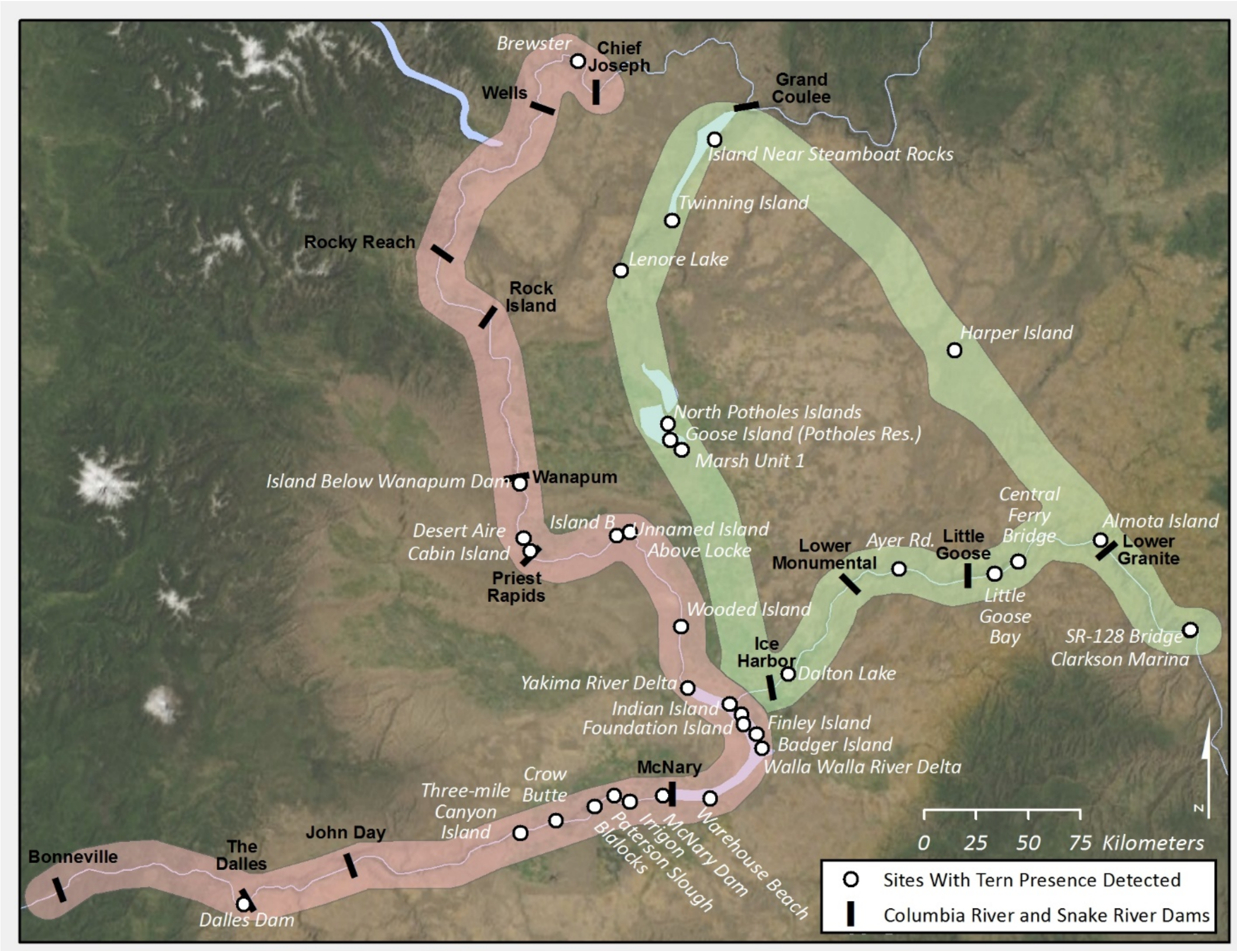


Map 7. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2016 (April 23 – May 26) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 and at Crescent Island in 2015. Red indicates the area where there was a 50% probability of finding an individual tagged tern that did not report any locations from within the Priest Rapids Project area during that 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 that time period. Purple indicates the overlap in 50% utilization distribution between the two groups.

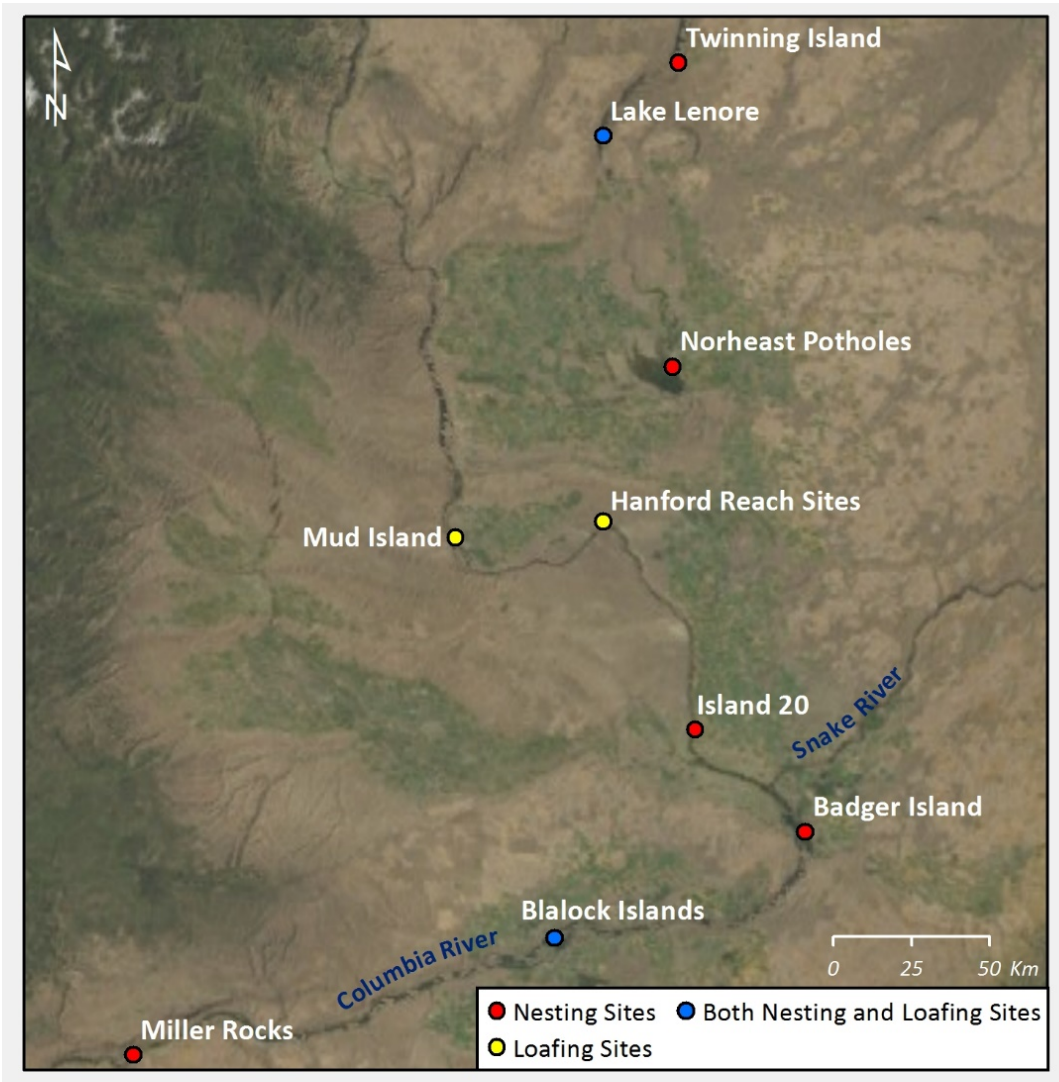


Map 8. Daytime utilization distribution analysis during the peak of steelhead smolt outmigration in 2016 (April 23 – May 26) for Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 and at Crescent Island in 2015. Red indicates the area where there was a 90% probability of finding an individual tagged tern that did not report any locations from within the Priest Rapids Project area during that 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 that time period. Purple indicates the overlap in 90% utilization distribution between the two groups.

Map 9. Locations where Caspian terns were either color-banded (2005-2015) or subsequently resighted in 2016 following banding.



Map 10. 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 or nesting in 2016.



Map 11. Locations of bird nesting and loafing sites scanned for smolt PIT tags in the Columbia Plateau region following the 2016 nesting season.

FIGURES

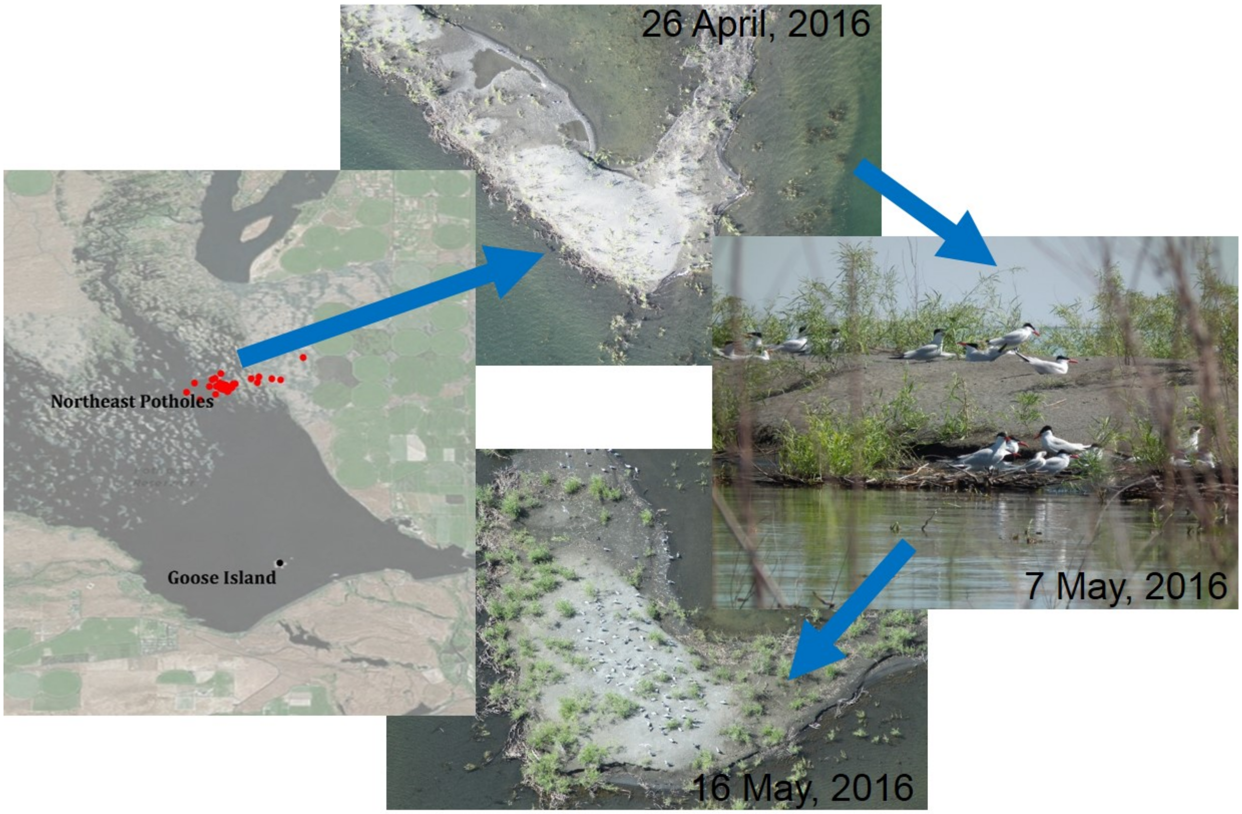


Figure 1. Satellite telemetry locations in northeastern Potholes Reservoir where a Caspian tern colony formed during the 2016 breeding season. A few loafing terns were observed during a late April aerial survey, but repeated detection of satellite-tagged terns at the site led to further investigation by boat, revealing the presence of an incipient breeding colony. The colony was well established and eggs had been laid by the time the next planned aerial survey was conducted on May 16, 2016. The colony later failed on June 5 due to what appeared to be disturbance by American mink (Neovison vison).

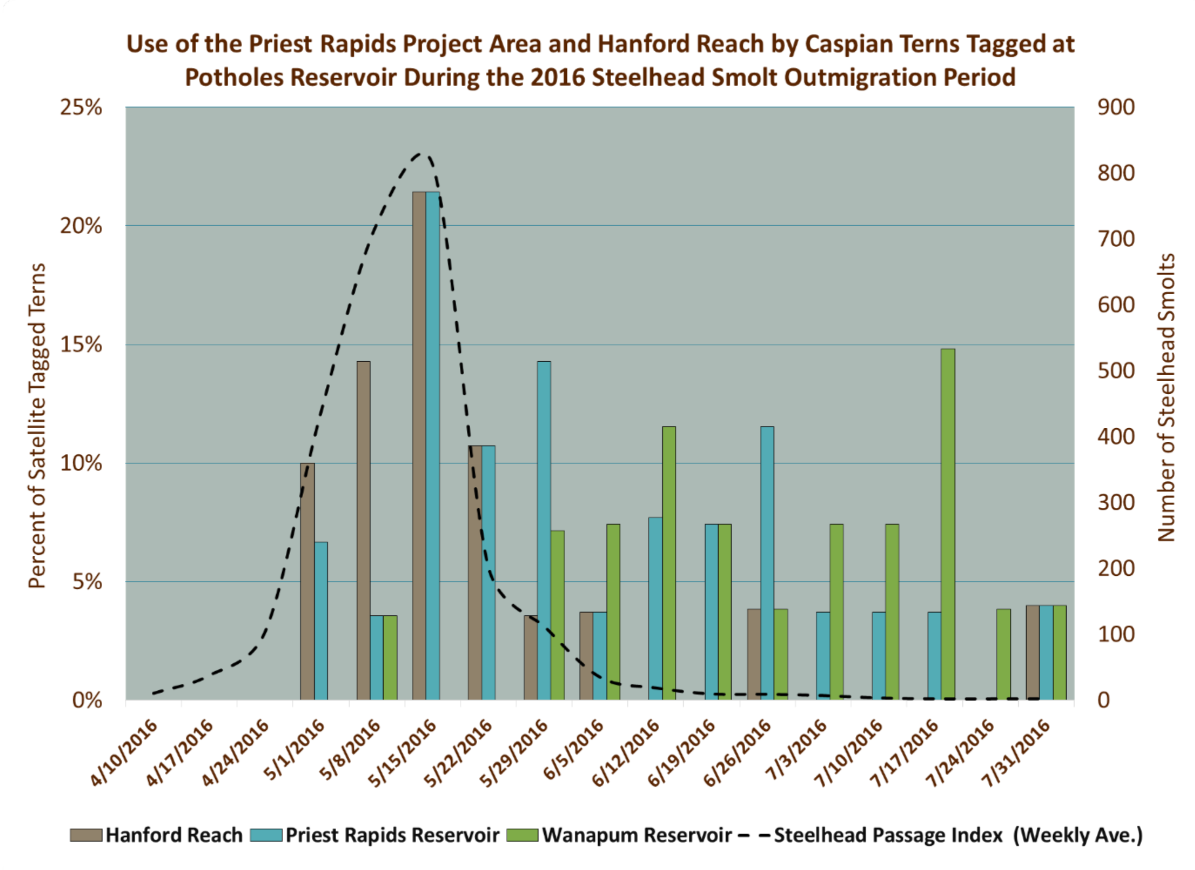


Figure 2. Percentage of Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 that were located at river reaches within the Priest Rapids Project Area and the Hanford Reach each week during the 2016 steelhead smolt outmigration period superimposed on the 2016 steelhead passage index at Rock Island Dam, WA (RIS). The 95% steelhead smolt passage index at RIS for the 2016 outmigration occurred between 23 April and 26 May (FPC 2016).

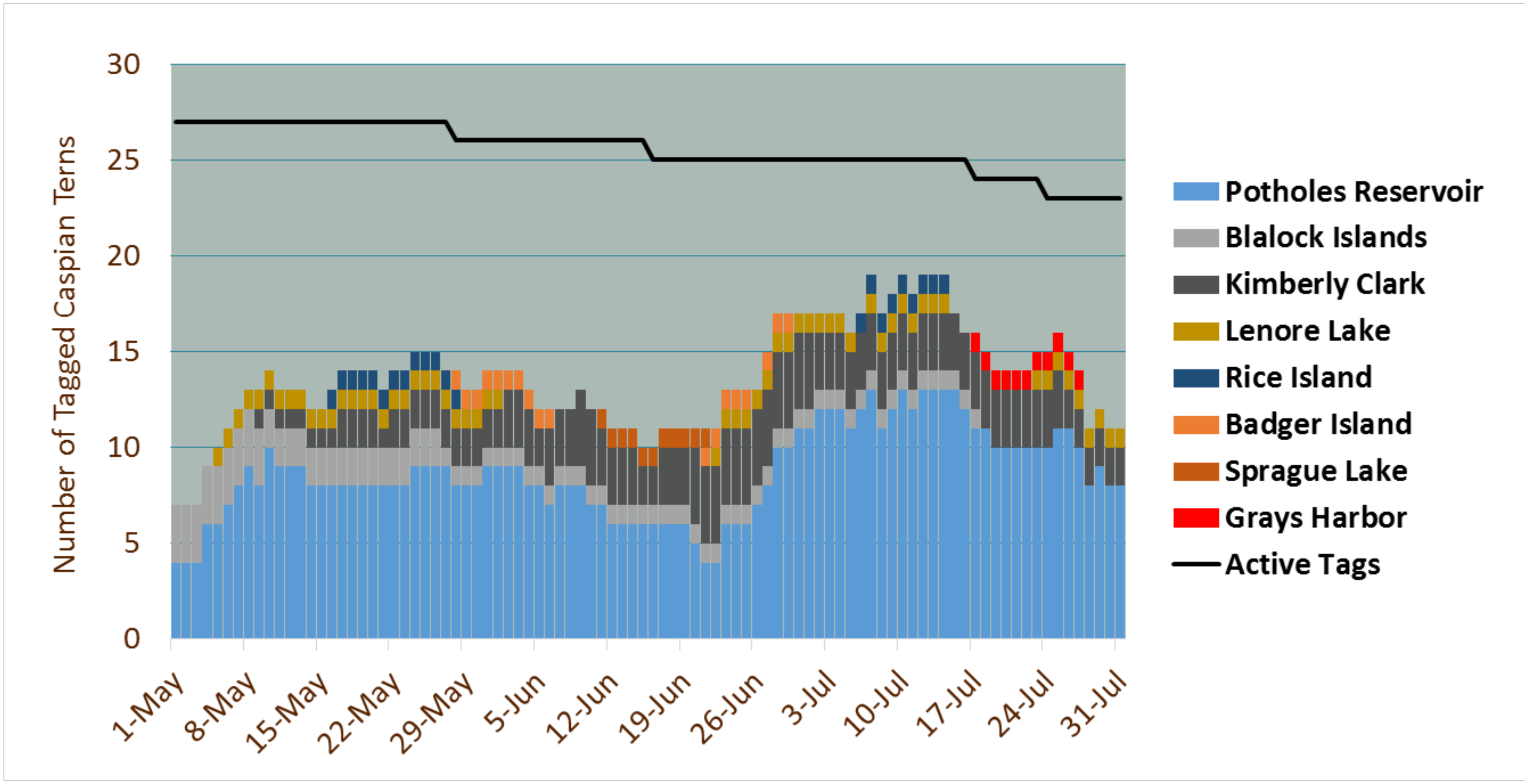


Figure 3. Colony associations of Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 during 01 May – 31 July 2016. A tagged individual was associated with a specific colony on a particular day of the season if it had been consistently located at that colony across nine nights and had not been located at any other colonies during those nine nights.

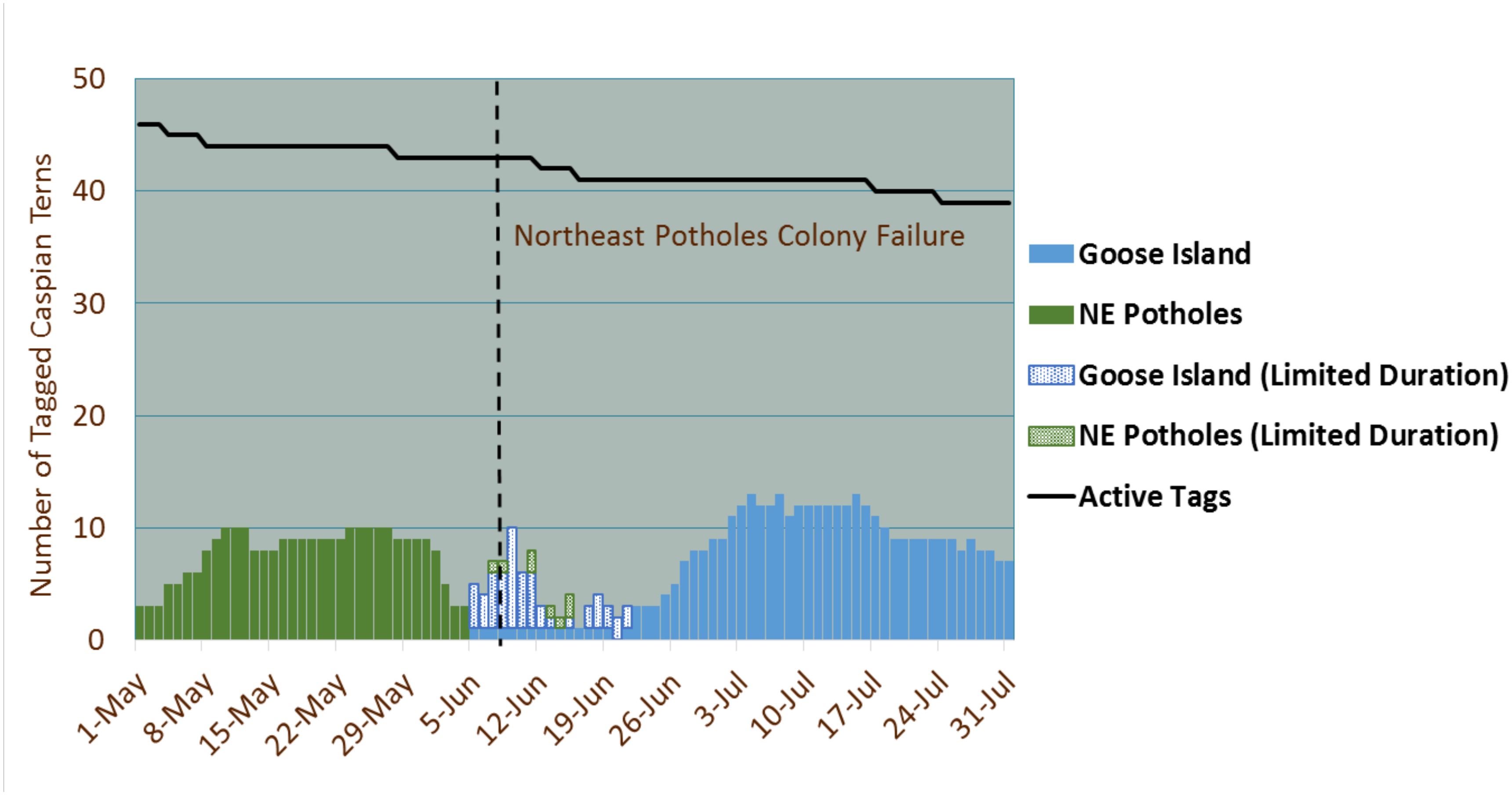


Figure 4. Colony associations of Caspian terns satellite-tagged at Potholes Reservoir in 2014 and 2015 during 01 May – 31 July 2016 at Potholes Reservoir. A tagged individual was associated with a specific colony on a particular day of the season if it had been consistently located at that colony across nine nights and had not been located at any other colonies during those nine nights. A limited duration association was considered for individuals that had multiple nights at a colony, but less than nine consecutive nighttime locations.

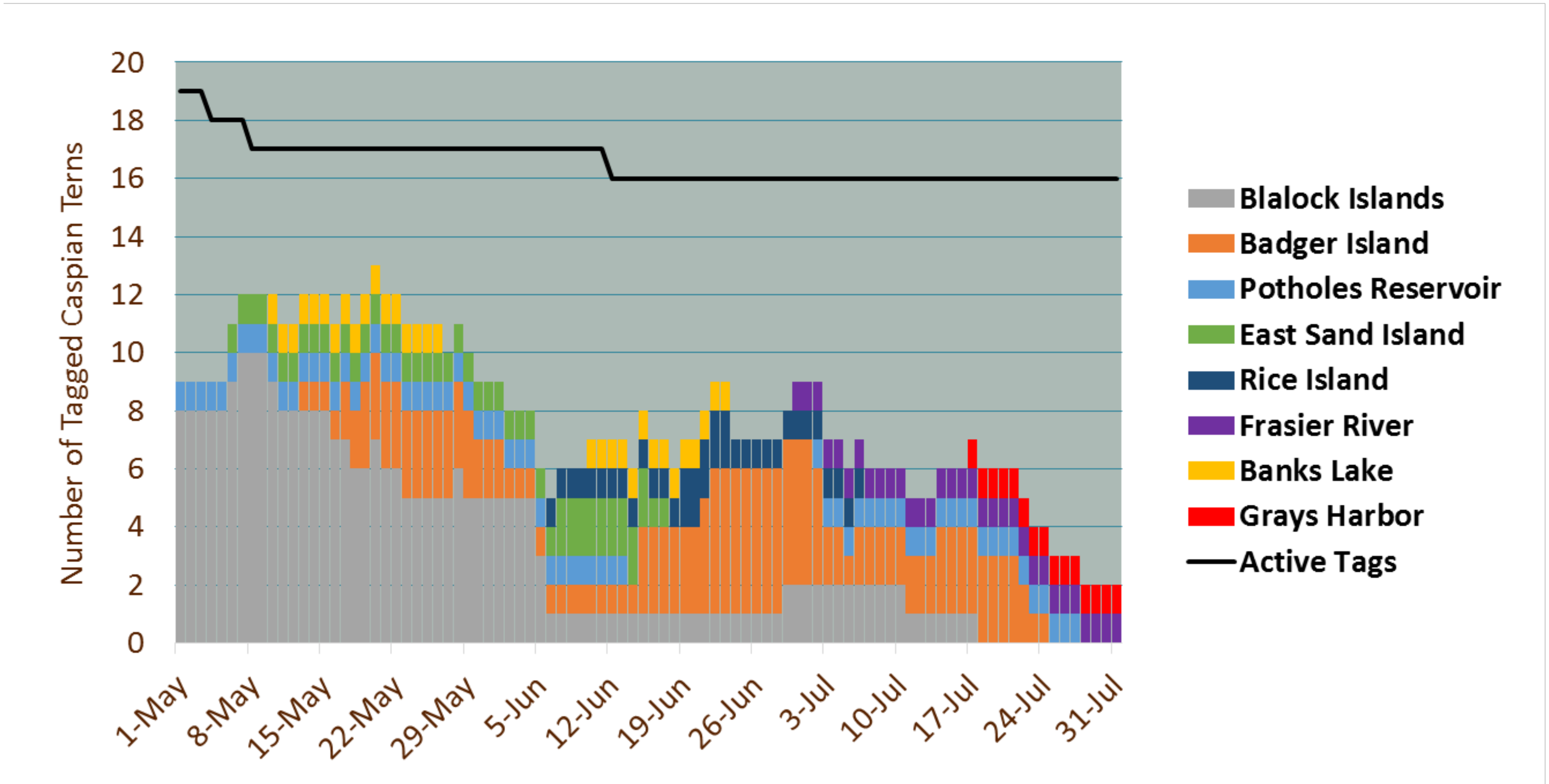


Figure 5. Colony associations of Caspian terns satellite-tagged at Crescent Island in 2015 during 01 May – 31 July 2016. A tagged individual was associated with a specific colony on a particular day of the season if it had been consistently located at that colony across nine nights and had not been located at any other colonies during those nine nights.

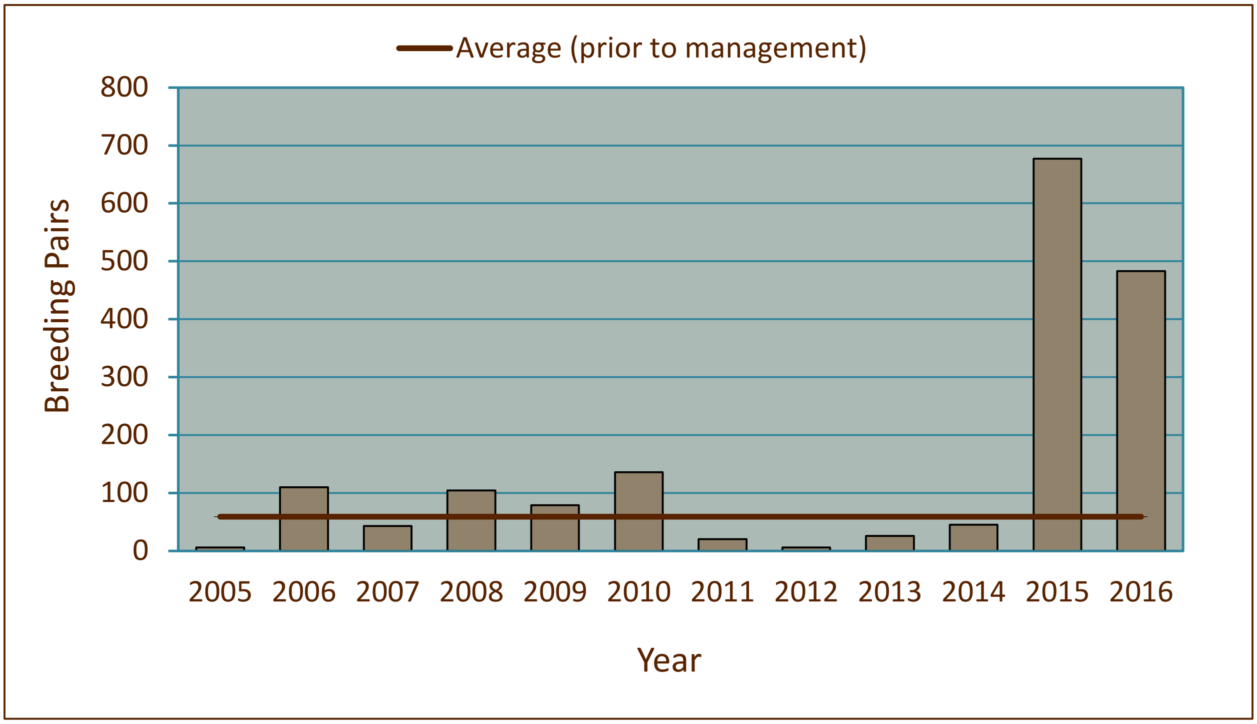


Figure 6. Size of the Caspian tern breeding colony (number of breeding pairs) at the Blalock Islands in the mid-Columbia River during 2005-2016, including the average number of breeding pairs of Caspian terns nesting at the Blalock Islands during the period prior to implementation of tern management in the Columbia Plateau region (2005-2013).

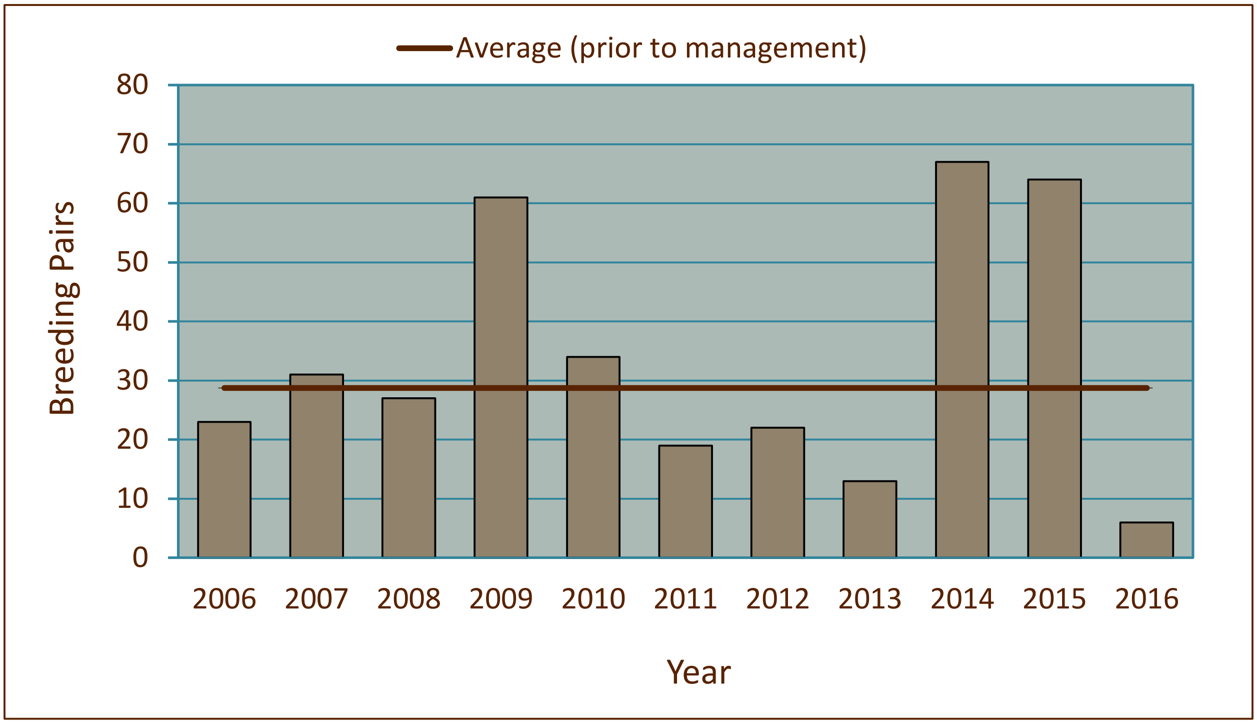


Figure 7. Size of the Caspian tern breeding colony (number of breeding pairs) at Twinning Island in Banks Lake during 2006-2016. In 2005, Caspian terns nested on two islands in Banks Lake (Twinning and Goose islands), and colony size was estimated to be less than 10 breeding pairs at each site. Presented in this figure is the average number of breeding pairs of Caspian terns nesting on Twinning Island during the period prior to tern management in the Columbia Plateau region (2006-2013).

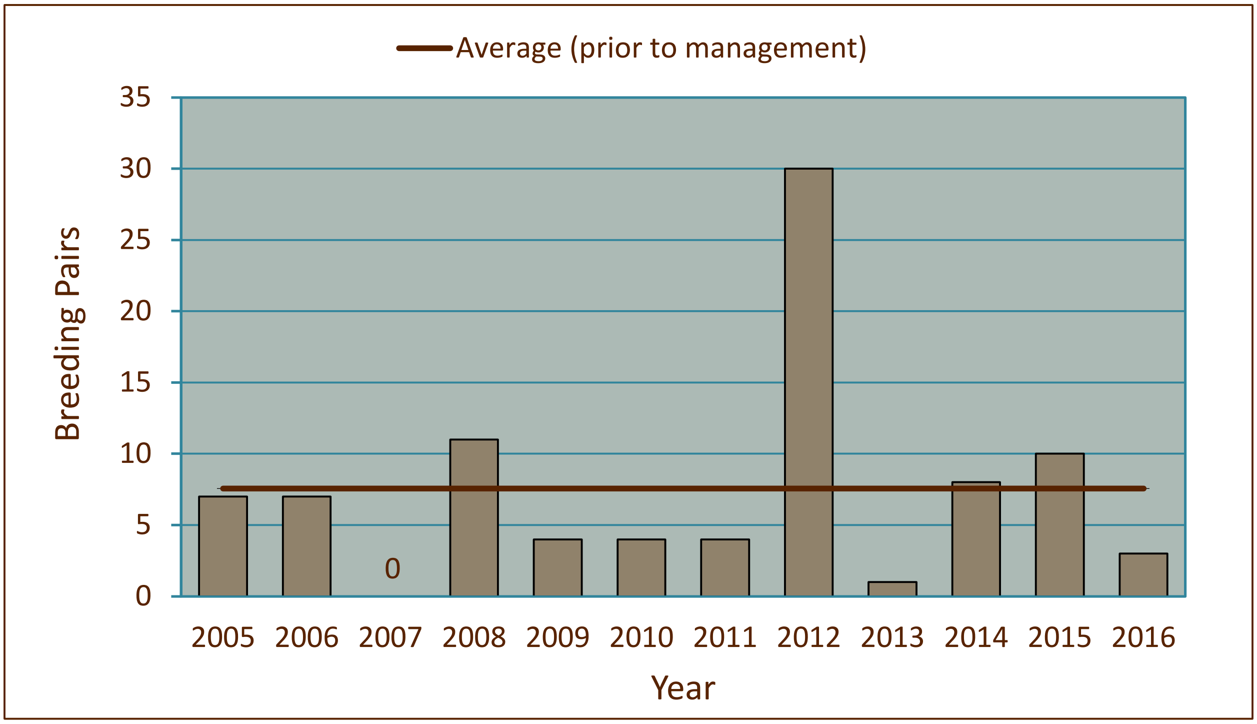


Figure 8. Size of the Caspian tern breeding colony (number of breeding pairs) at Harper Island in Sprague Lake during 2005-2016. Caspian terns did not attempt to nest on Harper Island in 2007. Included in this figure is the average number of breeding pairs of Caspian terns nesting on Harper Island during the period prior to tern managemention the Columbia Plateau region (2005-2013).

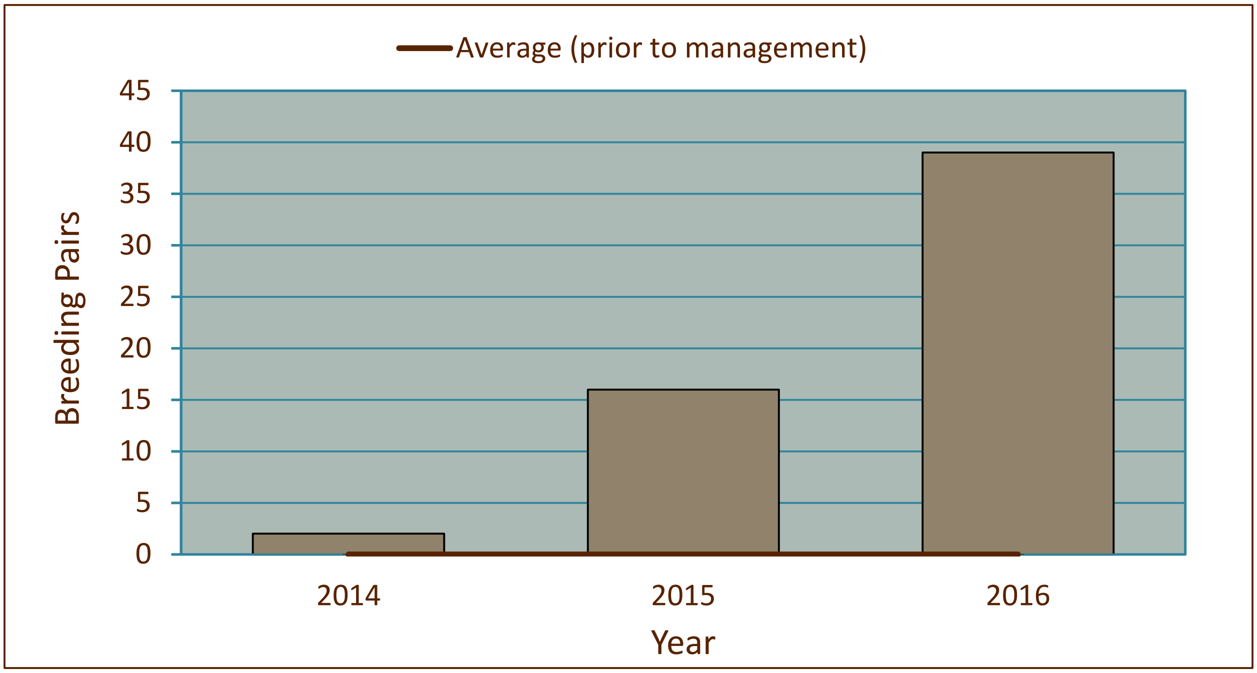


Figure 9. Size of the Caspian tern breeding colony (number of breeding pairs) at a small unnamed island in Lenore Lake during 2014-2016. Caspian terns did not nest at Lenore Lake prior to the implementation of tern management in the Columbia Plateau region (before 2014).

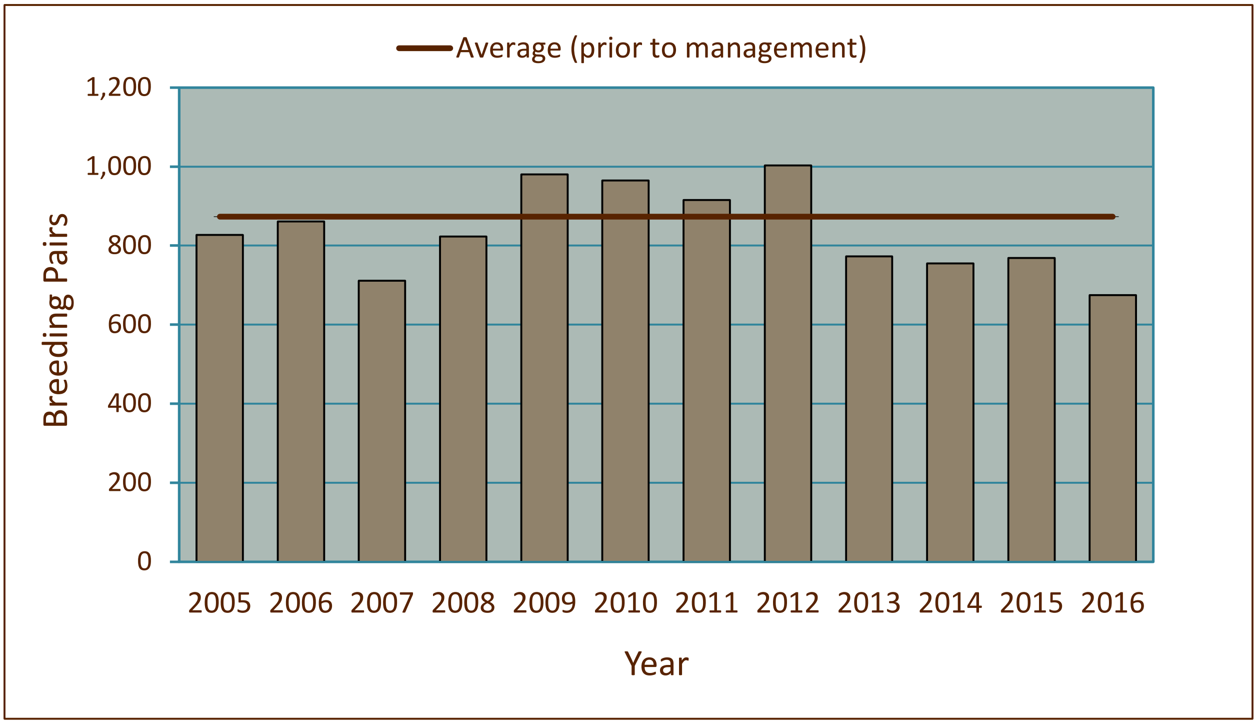


Figure 10. Total numbers of Caspian tern breeding pairs nesting at all known colonies in the Columbia Plateau region during 2005-2016, including the average number of breeding pairs of Caspian terns in the Columbia Plateau region prior to the implementation of tern management (2005-2013).

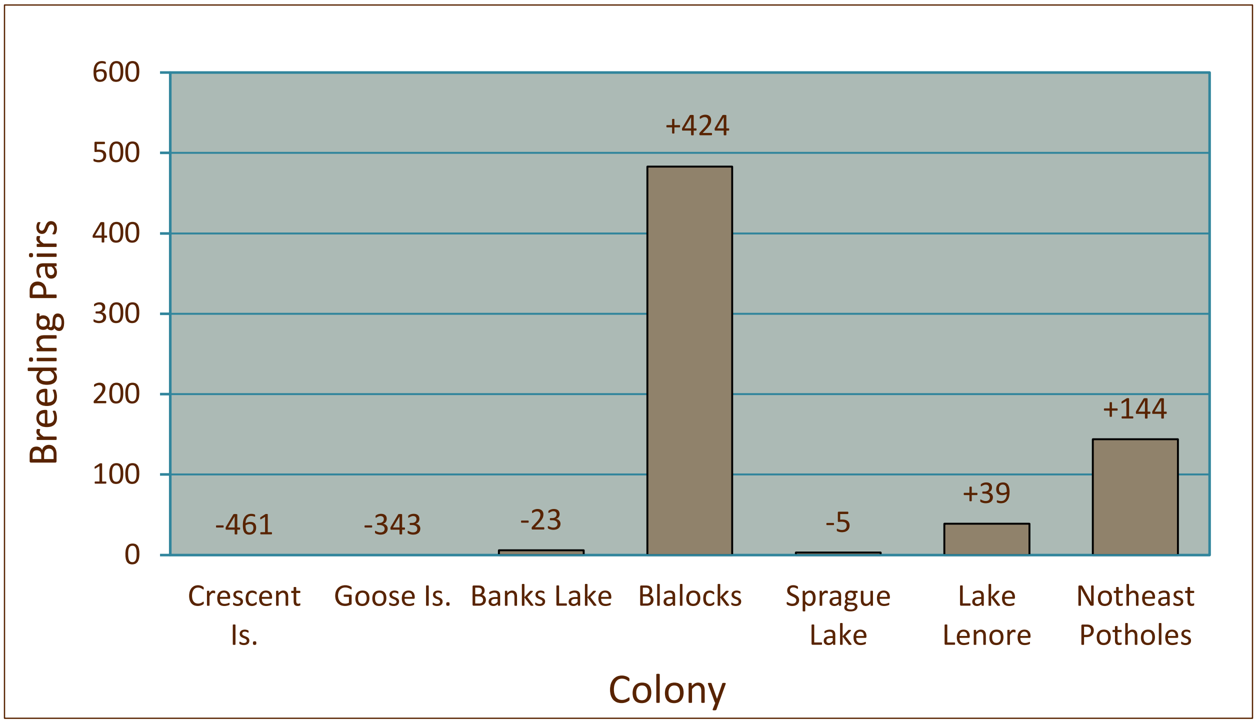


Figure 11. Sizes of Caspian tern breeding colonies (numbers of breeding pairs) in the Columbia Plateau region during the 2016 breeding season. Numbers over each bar indicate the change in colony size in 2016 compared to the pre-management management average (before 2014).

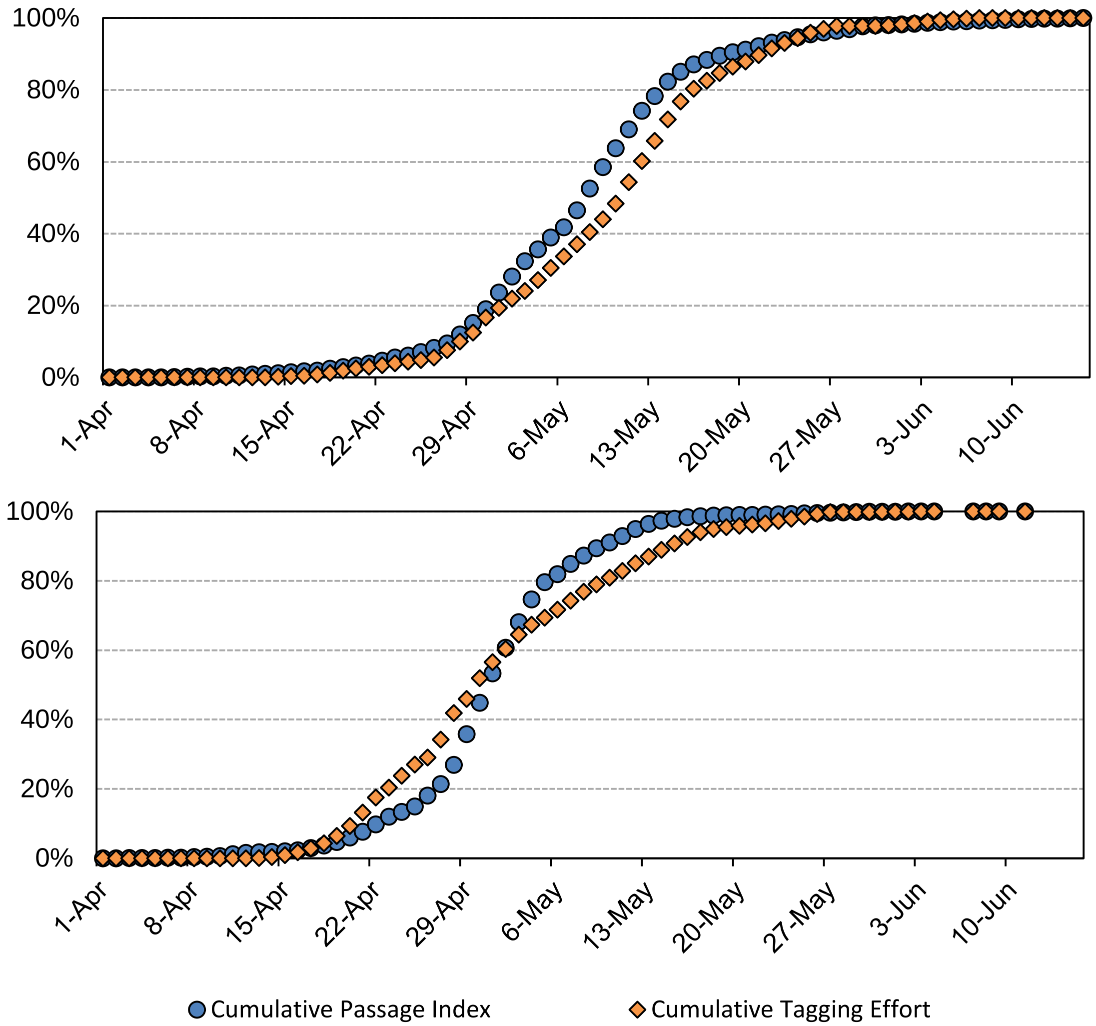


Figure 12. Proportion by sampling date of steelhead (top) and yearling Chinook salmon (bottom) PIT-tagged at the Rock Island Dam (RIS) fish trap relative to the respective RIS Passage Index. Passage index data were obtained from Columbia River DART (2016).

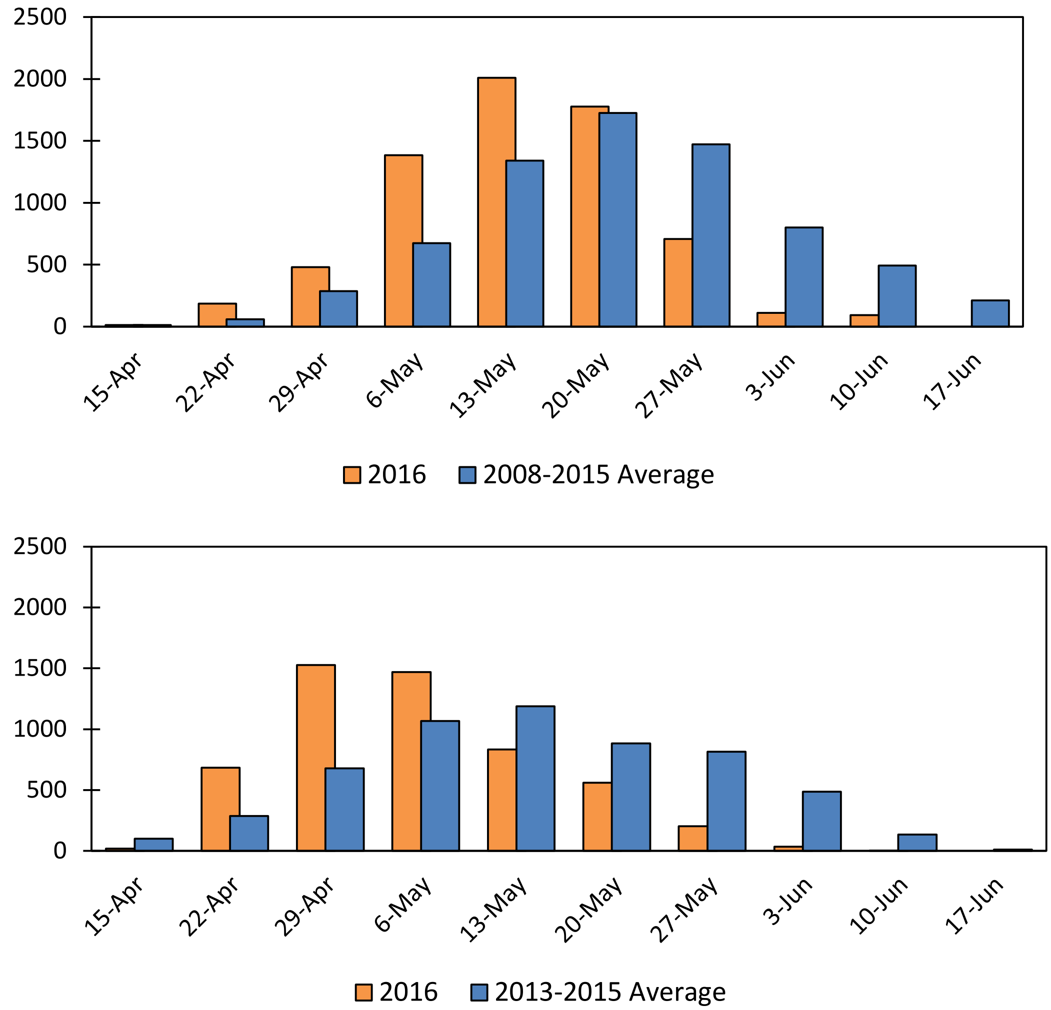


Figure 13. Numbers of PIT-tagged steelhead (top) and yearling Chinook salmon (bottom) released by week at Rock Island Dam during the 2016 outmigration compared to average weekly releases during 2008-2015.

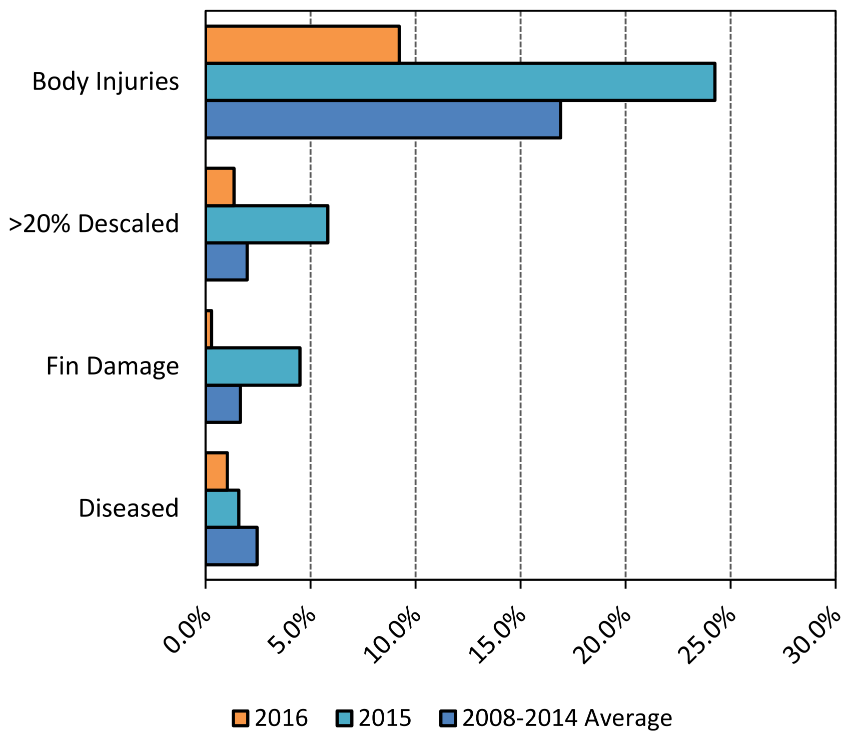


Figure 14. Proportion of PIT-tagged steelhead sampled at Rock Island Dam with external body injuries, extensive descaling, fin damage, and disease during the 2016 outmigration compared to 2015 and the average during 2008-2014.

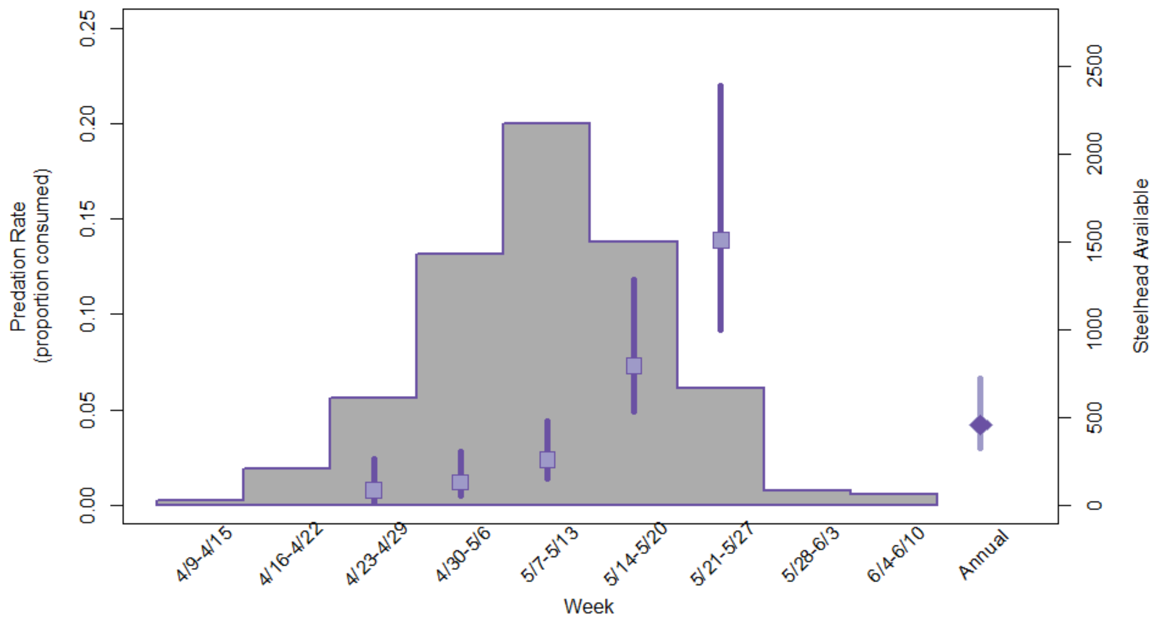


Figure 15. Estimated weekly and annual predation rates (vertical bars indicate 95% credible interval) on PIT-tagged steelhead released into the tailrace of Rock Island Dam by Caspian terns nesting on an unnamed island in northeastern Potholes Reservoir in 2016.

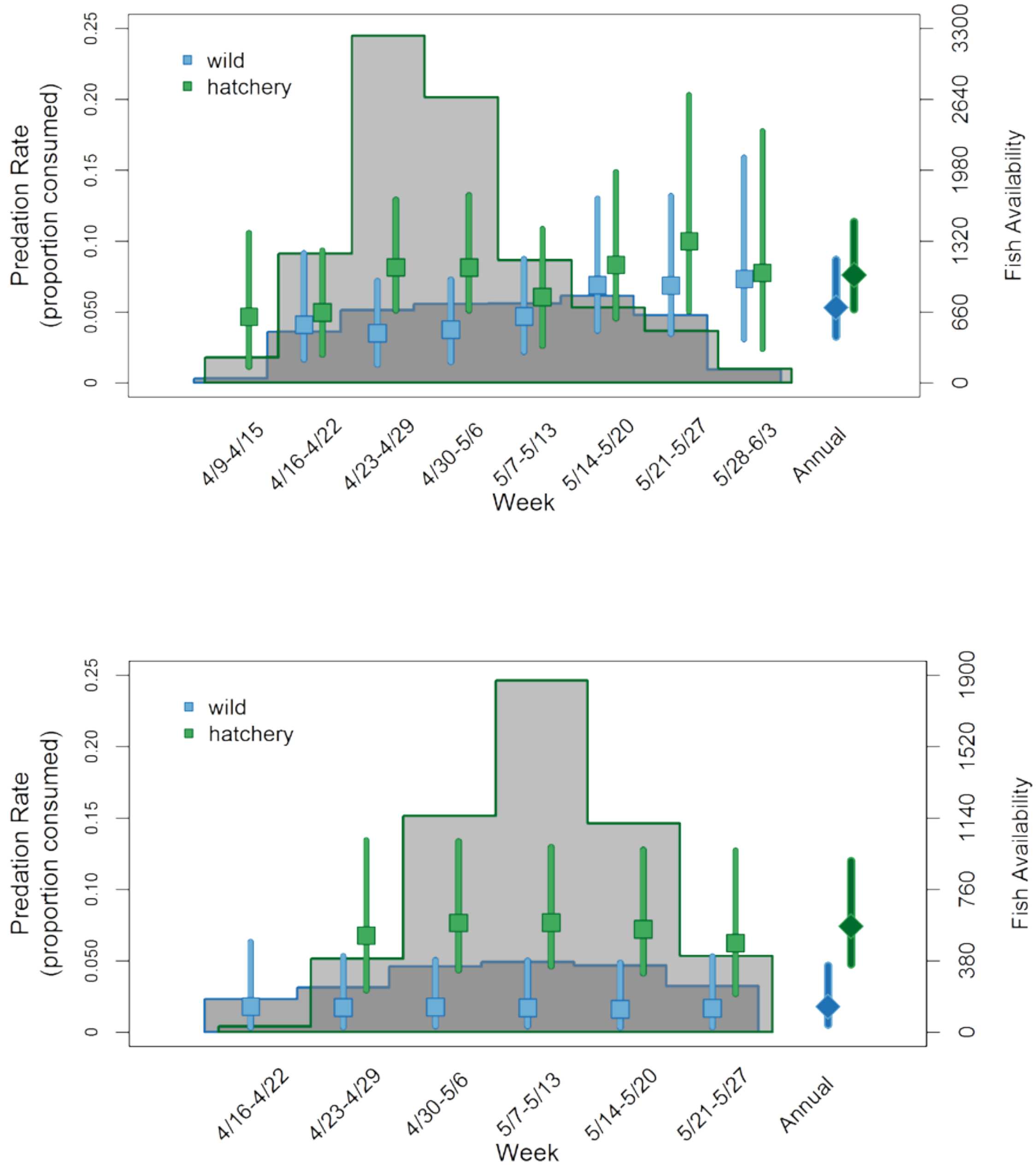


Figure 16. Estimated weekly and annual predation rates (vertical bars indicate 95% credible intervals) of wild and hatchery steelhead by California gulls nesting on Miller Rocks (top) and by California and ring-billed gulls nesting on Island 20 (bottom) in the middle Columbia River during the 2016 outmigration.

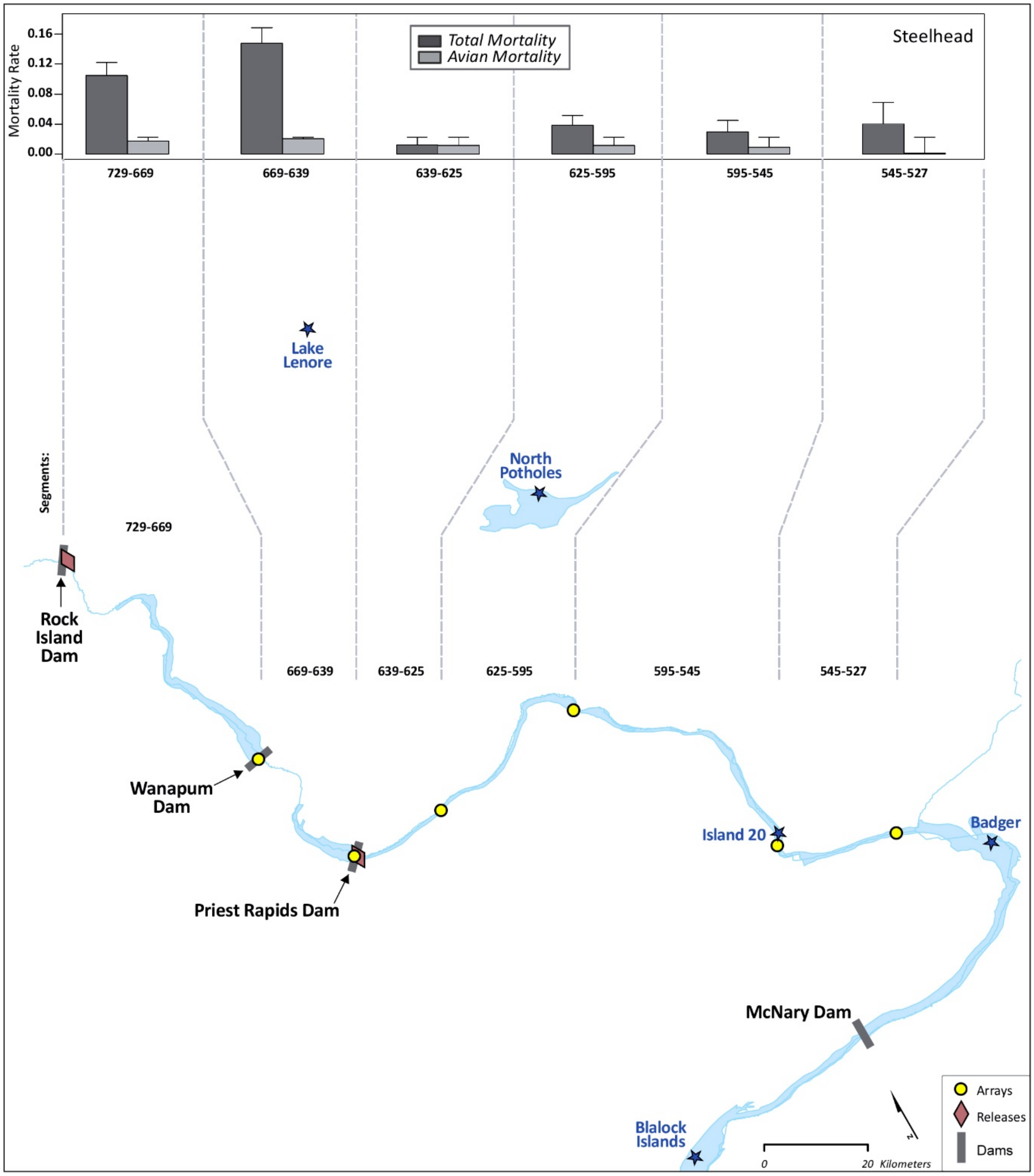


Figure 17. Estimated total mortality and mortality associated with consumption by piscivorous colonial waterbirds for double-tagged steelhead smolts in the middle Columbia River during the 2016 outmigration. Locations of smolt release sites (brown diamonds), acoustic arrays (yellow dots), bird colony sites (blue stars), and hydroelectric dams (grey bars) are shown.

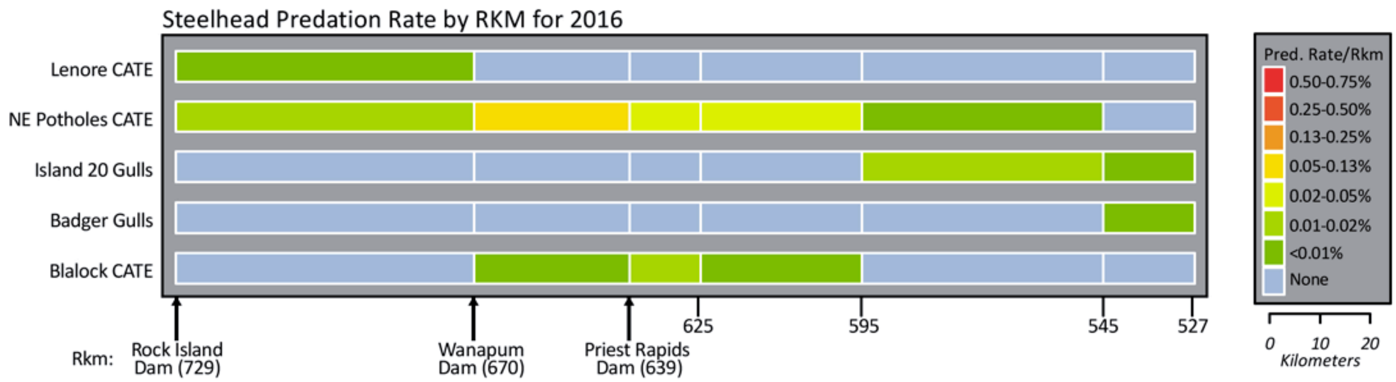


Figure 18. Colony-specific locations of consumption of double-tagged steelhead in sections of the middle Columbia River between river kilometer (Rkm) 527 and 729 in 2016. Results are depicted as consumption rates per river kilometer. Species of piscivorous colonial waterbirds evaluated include Caspian terns (CATE) and California and ring-billed gulls (Gulls).

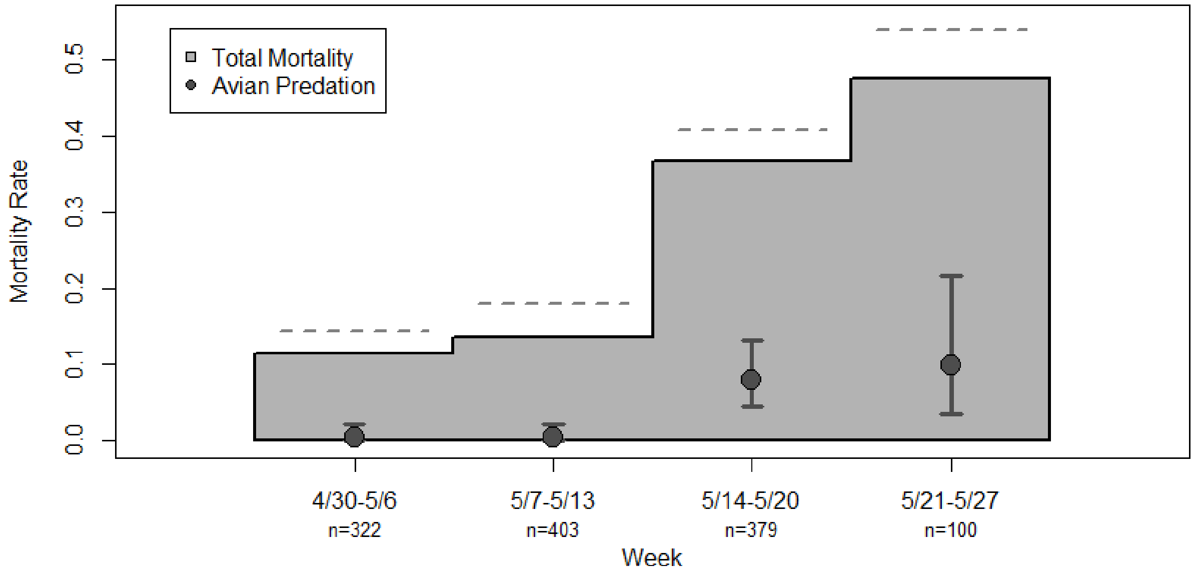


Figure 19. Weekly avian consumption rates (vertical bars indicate 95% credible intervals) and total mortality of double-tagged steelhead traveling through the middle Columbia River between river kilometer (Rkm) 729 and 527. Sample sizes (n) are based on releases of tagged steelhead into the tailrace of Rock Island Dam at Rkm 729.

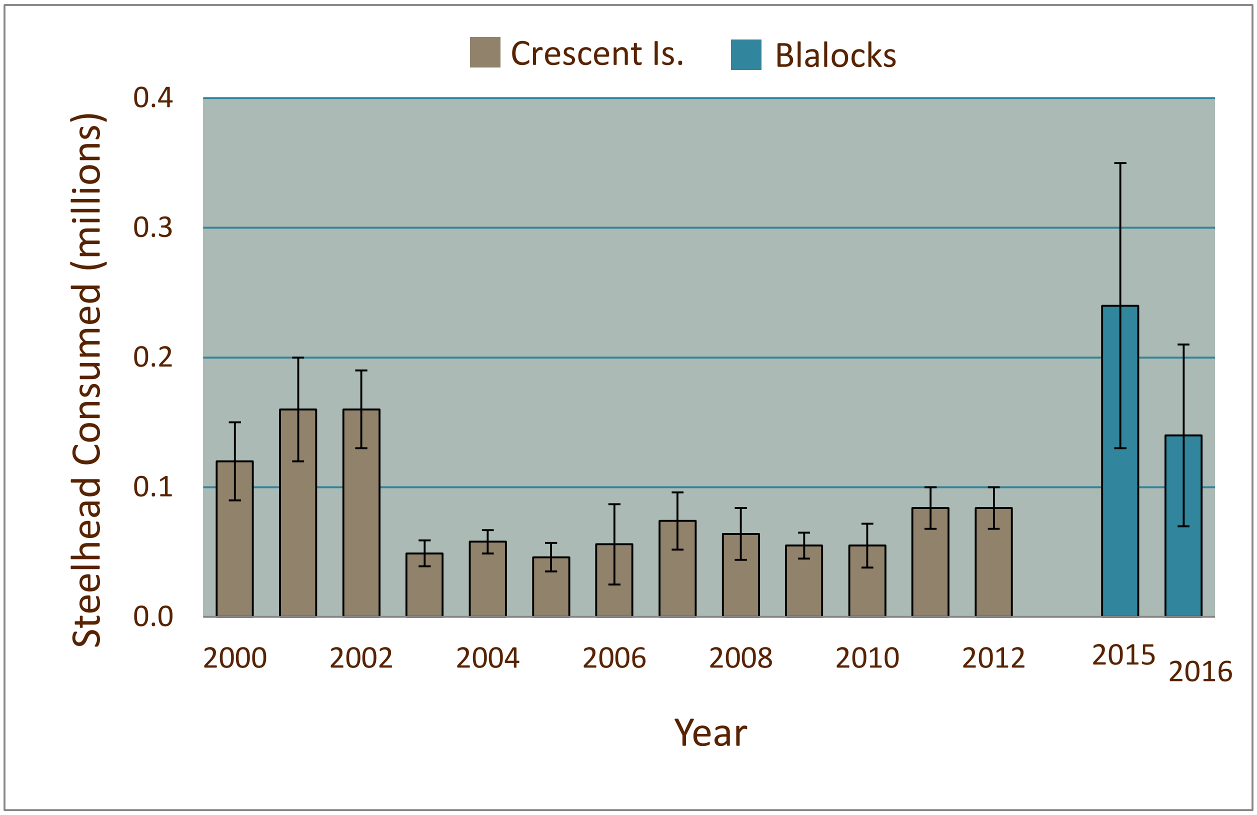


Figure 20. Estimated total annual consumption of juvenile steelhead by Caspian terns nesting on Crescent Island (2000-2012) and in the Blalock Islands (2015-2016) in the mid-Columbia River. Estimates are based on fish identified in tern bill-loads on-colony and bioenergetics calculations (see Methods). Error bars represent 95% confidence intervals for the number of smolts consumed.

TABLES

Table 1. Number of Caspian terns satellite-tagged at Potholes Reservoir in 2014 and Potholes Reservoir and Crescent Island in 2015 that were active throughout the 2016 breeding season (01 April – 31 July).

Deployment Date	Location	Number of Terns Tagged	Subset of Tags Active on 01 April 2016	Subset of Tags Active on 31 July 2016
April 2014	Potholes Reservoir	28	17	11
April 2015	Potholes Reservoir	18	14	12
April 2015	Crescent Island	28	24	16

Table 2. Comparison of visits to Columbia River reservoirs upstream of Richland, WA, during the peak steelhead smolt outmigration in 2014, 2015, and 2016 by Caspian terns satellite-tagged at Goose Island, Potholes Reservoir in April 2014. Values are the percentages of active tagged birds that visited each reservoir at least once during the time period.

Peak Outmigration Period	Year	Hanford Reach	Priest Rapids Reservoir	Wanapum Reservoir	Number of Active Tags
May 5 – May 31	2014	36%	50%	39%	28
April 28 – June 6	2015	35%	43%	43%	23
April 23 – May 26	2016	19%	31%	13%	16

Table 3. Use of Columbia River reservoirs upstream of Richland, WA, by satellite-tagged Caspian terns during the 2016 peak steelhead smolt outmigration, 23 April – 26 May. 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 23 - May 26, 2016	Potholes Reservoir 2014	19%	31%	13%	16
	Potholes Reservoir 2015	50%	21%	14%	14
	Crescent Island 2015	4%			23

Table 4. Comparison of daytime river use by tagged Caspian terns at Upper Columbia River reservoirs during the peak of steelhead smolt outmigration in 2013, 2014, 2015, and 2016 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, 2015, and 2016) locations recorded at (1) Priest Rapids Reservoir and (2) the Hanford Reach, Priest Rapids Reservoir, and Wanapum 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 Wanapum 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%
2016 (n=19)	5%	42%	16%	54%

Table 5. Use of the Columbia Plateau region and the historical Goose Island Caspian tern foraging areas by satellite-tagged Caspian terns during the 2016 steelhead smolt outmigration 23 April - 26 May 2016. 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 during 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 23 - May 26	Potholes Reservoir 2014	69%	63%	16
	Potholes Reservoir 2015	79%	64%	14
	Crescent Island 2015	61%	17%	23

Table 6. Comparison of visits to reservoirs on the Columbia and Snake rivers during the peak steelhead smolt outmigration in 2014, 2015, and 2016 by Caspian terns satellite-tagged at Goose Island, Potholes Reservoir in April 2014. Values are the percentages of active tagged birds that visited each reservoir at least once during the time period. Blank cells indicate that no tagged terns were detected in these locations during the outmigration 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
April 23 – May 26	2016		63%	25%		13%	16

Table 7. Use of reservoirs on the Columbia and Snake rivers by satellite-tagged Caspian terns during the 2016 peak steelhead smolt outmigration, 23 April – 26 May. 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 23 - May 26, 2016	Potholes Reservoir 2014		63%	25%		13%	16
	Potholes Reservoir 2015		57%	21%		21%	14
	Crescent Island 2015		61%	52%	13%		23

Table 8. Use of active, historical, or potential colony sites by tagged Caspian terns during the 2016 peak steelhead smolt outmigration, 23 April – 26 May. 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	Northeast 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 23 – May 26	Potholes Reservoir 2014	6%		56%		13%				56%	19%	13%	6%		16
	Potholes Reservoir 2015	29%		57%		7%	14%			50%	7%	7%	7%	7%	14
	Crescent Island 2015			13%	9%				22%	61%	17%		4%		23

Table 9. Numbers of banded Caspian terns resighted at Potholes Reservoir in 2016 and the colony locations where they were originally marked with unique alphanumeric color bands during 2005-2015. Potholes Reservoir includes Goose Island and nearby islets.

Colony where banded	Banded as adults	Banded as chicks	Total
Goose Island	75	57	132
Crescent Island	4	10	14
East Sand Island	0	2	2
Malheur Lake	0	2	2
Bellingham	0	2	2
Brooks Island	0	1	1
Total	**79**	**74**	**153**

Table 10. Numbers of banded Caspian terns resighted at the Blalock Islands in 2016 and the colony locations where they were originally marked with unique alphanumeric color bands during 2005-2015. The Blalock Islands includes a loafing site near Irrigon, Oregon.

Colony where banded	**Banded as adults**	**Banded as chicks**	Total
Crescent Island	126	170	296
Goose Island	103	81	184
Sheepy Lake	0	10	10
East Sand Island	0	9	9
Malheur Lake	0	8	8
Crump Lake	1	2	3
Total	**230**	**280**	**510**

Table 11. Numbers of banded Caspian terns seen in the Potholes Reservoir area in 2015 and resighted in 2016 at breeding or non-breeding sites. Terns were banded in 2005-2015 with color bands engraved with unique alphanumeric codes. A total of 167 banded terns were seen in the Potholes Reservoir area in 2015 and resighted again at Potholes Reservoir or elsewhere during the 2016 breeding season; some of these 167 banded terns were resighted at multiple locations in 2016.

Location resighted in 2016	Banded as adults	Banded as chicks	Total
Potholes Reservoir area[1]	63	45	108
Blalock Islands area[2]	64	29	93
Lenore Lake	12	3	15
Priest Rapids Reservoir[3]	8	6	14
Everett, Washington	2	3	5
East Sand Island, Columbia River estuary	1	1	2
Hanford Reach, Columbia River	1	0	1
Ice Harbor Dam, Snake River	0	1	1
Total	**151**	**88**	**239**

[1] Includes Goose Island and islands in northeastern Potholes Reservoir
[2] Includes the Blalock Islands and a loafing site near Irrigon, Oregon
[3] Includes Desert Aire and Cabin Island

Table 12. Numbers of banded Caspian terns seen at the Blalock Islands in 2015 and resighted in 2016 at breeding or non-breeding sites. Terns were banded in 2005-2015 with color bands engraved with unique alphanumeric codes. A total of 405 banded terns were seen at the Blalock Islands in 2015 and resighted again at the Blalock Islands or elsewhere during the 2016 breeding season; some of these 405 banded terns were resighted at multiple locations in 2016.

Location resighted in 2016	Banded as adults	Banded as chicks	Total
Blalock Islands area[1]	185	182	367
Potholes Reservoir area[2]	43	16	59
East Sand Island, Columbia River estuary	12	9	21
Lenore Lake	8	1	9
Everett, Washington	2	6	8
Priest Rapids Reservoir[3]	4	2	6
McNary Reservoir[4]	4	2	6
Ice Harbor Dam, Snake River	5	0	5
Tongue Point Pier, Columbia River estuary	1	0	1
Total	**264**	**218**	**482**

[1] Includes Goose Island and islands in northeastern Potholes Reservoir
[2] Includes the Blalock Islands and a loafing site near Irrigon, Oregon
[3] Includes Desert Aire and Cabin Island
[4] Includes Hanford Reach, mouth of the Snake River, and delta of the Walla Walla River

Table 13. Inter-colony movement probabilities of Caspian terns between 2015 and 2016. Data used in movement probability estimates were from terns banded as adults during 2005-2015 and re-sighted during 2006-2016. The numbers of individuals that moved between 2015 and 2016 were estimated from movement probabilities between those years multiplied by the estimated numbers of adult terns present at source regions in 2015.

Source colony	Receiving colony	Movement probabilities (%)	Estimated number of individuals that moved
Columbia Plateau region	Columbia River estuary	3.4	52
Columbia River estuary	Columbia Plateau region	1.5	189
Corps-constructed islands[1]	Columbia Plateau region	17.7	375
Corps-constructed islands[1]	Columbia River estuary	11.0	233

[1] Located in the southern Oregon/northeastern California (SONEC) region

Table 14. Number of 2016 migration year PIT-tagged juvenile salmonids (all species combined) recovered on bird colonies and loafing locations in the Columbia Plateau region following the 2016 breeding season. Piscivorous colonial waterbird species include Caspian terns (CATE), California and ring-billed gulls (Gulls), and American white pelicans (AWPE). Mixed colonies or loafing sites represent a combination of these species. Only breeding colonies where an appreciable number of tags were recovered were included in analyses of predation/consumption rates (see Methods). Numbers of recovered PIT tags shown here were not adjusted to account for tag loss due to on-colony detection efficiency (see Table 16) and deposition rates (see Table 17), and thus represent minimum numbers of consumed fish by birds.

Location	Rkm	Bird Species	Area Use	No. Recovered
Twinning Island	Off-river (Banks Lake)	CATE	Breeding	18
Lenore Lake	Off-river (Lenore Lake)	CATE	Breeding	16
		Mixed	Loafing/Breeding	19
Northeast Potholes	Off-river (Potholes Res.)	CATE	Breeding	574
Mud Island	645	Mixed	Loafing	16
Hanford Reach	597-582	Mixed	Loafing	75 [3]
Island 20	549	Gull	Breeding	718
Badger Island	512	Gull	Breeding	492
		AWPE	Breeding	458
		Mixed	Breeding	1,470
Blalock Islands	441-439	CATE	Breeding	4,228
		Gull [1]	Breeding	1,033
		Gull [2]	Breeding	65
		Mixed	Loafing	868 [4]
Miller Rocks	331	Gull	Breeding	2,720
Total				**12,770**

[1] Gulls nesting on Anvil Island within the Blalock Islands complex
[2] Gulls nesting on Straight Six Island within the Blalock Islands complex
[3] Recoveries from three discrete unnamed islands
[4] Recoveries from four discrete sites (i.e. Southern Island, Sand Island, Long/Middle islands, Rock Island)

Table 15. 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 2007-2016. Management actions were implemented on Goose Island in Potholes Reservoir during 2014-2016 and on Crescent Island during 2015-2016. No management actions have been conducted at the Twinning Island, Lenore Lake (established in 2015), northeastern Potholes Reservoir (NP; established in 2016), or the Blalock Islands Caspian tern colony sites. Estimates with 95% credible intervals from data collected in 2016 are provided in Tables 18 and 19. Estimates with 95% credible intervals from data collected during 2007-2015 are provided in BRNW (2016b).

	Managed Colony Sites							Unmanaged Colony Sites								
	Goose Island Terns				Crescent Island terns			Twinning Island Terns			Lenore Lake Terns		NP Terns	Blalock Islands Terns		
ESU/DPS	2007-2013	2014	2015 [1]	2016 [1]	2007-2014	2015 [1]	2016 [1]	2009-2014	2015	2016	2015	2016	2016	2007-2014	2015	2016
SR Sockeye	0.1%	< 0.1%	< 0.1%	< 0.1%	1.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.3%	1.3%	2.3%
SR Sp/Su Chinook	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.7%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.1%	1.4%	0.3%
UCR Spr Chinook	2.5%	0.6%	0.1%	< 0.1%	0.5%	< 0.1%	< 0.1%	< 0.1%	0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.9%	0.2%
SR Fall Chinook	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.8%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.4%	0.6%
SR Steelhead	< 0.1%	< 0.1%	< 0.1%	< 0.1%	3.9%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.6%	8.0%	3.9%
UCR Steelhead	15.7%	2.9%	1.5%	0.1%	2.4%	< 0.1%	< 0.1%	0.3%	2.6%	0.1%	< 0.1%	0.1%	4.1%	0.6%	8.2%	3.1%

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

Table 16. Range of detection efficiency estimates for PIT tags sown on bird colonies during the 2016 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. 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)	54 – 92%
Lenore Lake	Off-river	CATE	25 (1)	80%
Northeast Potholes	Off-river (Potholes Res.)	CATE	50 (2)	66 – 77%
Island 20	549	Gulls	100 (2)	72 – 83%
Badger Island	512	Gulls	50 (1)	60%
		AWPE	50 (1)	58%
		Mixed	50 (1)	58%
Blalock Islands	440-439	CATE	200 (2)	51 – 89%
		Gulls [1]	100 (2)	90 – 88%
		Gulls [2]	100 (2)	78 – 98%
Miller Rocks	331	Gulls	100 (2)	80 – 84%

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

Table 17. 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. 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 outmigration 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	Badger Is.	NA (no deposition studies were conducted at mixed colonies; DR of 100% assumed)		

Table 18. Estimated predation/consumption rates (95% credible interval) of PIT-tagged salmonids by Caspian terns nesting at the Blalock Islands, gulls nesting at the Blalock Islands, and gulls nesting at Miller Rocks in 2016. The numbers (n) of PIT-tagged smolts interrogated 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	1,095	2.3% (1.2-4.1)	3.1% (1.0-7.4)	0.3% (<0.1-2.2)	6.4% (2.9-12.8)
SR Spr/Sum Chinook	47,573	0.3% (0.2-0.5)	0.1% (<0.1-0.2)	< 0.1%	1.2% (0.8-1.9)
UCR Spr Chinook	11,320	0.2% (0.1-0.4)	0.1% (<0.1-0.3	< 0.1%	2.5% (1.6-4.0)
SR Fall Chinook	6,726	0.6% (0.4-1.1)	0.4% (0.1-1.0)	< 0.1%	1.0% (0.4-2.1)
SR Steelhead	14,332	3.9% (2.9-5.7)	3.3% (2.2-5.0)	0.2% (<0.1-0.4)	6.7% (4.6-9.9)
UCR Steelhead	7,414	3.1% (2.3-4.6)	5.4% (3.6-8.3)	0.8% (0.3-1.7)	10.1% (7.0-15.2)

[1] Gulls (predominately California gulls) nesting on Anvil Island within the Blalock Islands complex.
[2] Gulls (predominately ring-billed gulls) nesting on Straight Six Island within the Blalock Islands complex.

Table 19. Estimated predation/consumption rates (95% credible interval) on PIT-tagged salmonid populations by Caspian terns nesting at Twinning Island (Banks Lake), an unnamed island in Lenore Lake (Lenore Lake), an unnamed island in northeastern Potholes Reservoir (NPR), 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 during the 2016 outmigration. The numbers (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. Terns	NPR Terns	Island 20 Gulls	Badger Is. Gulls	Badger Is. Pelicans[1]	Badger Is. Mixed[1]
SR Sockeye	522	< 0.1%	< 0.1%	< 0.1%	0.9% (<0.1-5.8)	1.2% (<0.1-7.7)	0.2% (<0.1-1.0)	0.5% (0.1-1.6)
SR Sp/Su Chinook	38,633	< 0.1%	< 0.1%	< 0.1%	0.2% (0.1-0.4)	0.2% (0.1-0.4)	< 0.1%	< 0.1%
UCR Sp Chinook	1,956	< 0.1%	< 0.1%	0.1% (<0.1-0.3)	0.2% (<0.1-3.8)	0.9% (0.1-3.3)	< 0.1%	< 0.1%
SR Fall Chinook	5,461	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	< 0.1%	0.1% (<0.1-0.2)
SR Steelhead	20,729	< 0.1%	< 0.1%	< 0.1%	1.2% (0.7-2.0)	1.1% (0.6-1.9)	< 0.1%	0.2% (0.1-0.3)
UCR Steelhead	7,003	0.1% (0.1-0.2)	0.1% (0.1-0.2)	4.1% (2.9-6.3)	5.7% (3.7-8.9)	3.8% (2.1-6.8)	< 0.1%	0.1% (<0.1-0.2)

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

Table 20. Cumulative estimated predation/consumption rates (95% credible interval) of PIT-tagged steelhead released (n) into the tailrace of Rock Island Dam by piscivorous waterbirds nesting at 11 different colonies in the Columbia Plateau region during 2016. Predation/consumption 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 pelicans (AWPE), and mixed-species colonies (Mixed).

Location	Colony	RKM	Steelhead (n = 6,766)	Yearling Chinook (n = 5,338)
Twinning Island	CATE	Off-river	0.1% (0-0.3)	0.1% (0-0.2)
Lenore Lake	CATE	Off-river	0.1% (0-0.3)	<0.1%
North Potholes	CATE	Off-river	4.2% (3-6.6)	0.1% (0-0.4)
Island 20	Gulls		5.8% (3.7-9)	0.3% (0-1)
Badger Island	AWPE[1]		<0.1%	<0.1%
	Mixed[1]		<0.1%	<0.1%
	Gulls		3.8% (2.1-6.7)	0.3% (0-1.3)
Blalock Islands (Anvil Is.)	CATE		3.7% (2.7-5.5)	0.4% (0.2-0.8)
	Gulls		5.0% (3.3-7.8)	0.9% (0.4-2)
Blalock Islands (Straight Six)	Gulls		<0.1%	<0.1%
Miller Rocks	Gulls		7.7% (5.2-11.8)	5.3% (3.3-8.5)
Total			**31.9% (26.5-38.4)**	**8.0% (5.6-11.4)**

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

Table 21. Numbers of double-tagged (AT and PIT) steelhead released (n) into the tailrace of Rock Island Dam (RIS) and Priest Rapids Dam (PRD) that were subsequently consumed by birds within the middle Columbia River between river kilometer 527 and 729 during the 2016 outmigration. The number of tags consumed was not adjusted for on-colony detection or deposition probabilities, and thus represents minimum numbers of tagged fish consumed by birds. Only tags released at Rock Island Dam and subsequently recovered on breeding colonies were used to estimate predation/consumption rates by colonial waterbirds in the study area (see Methods). Bird species included Caspian terns (CATE), ring-billed and California gulls (Gulls), and American white pelicans (AWPE).

Location	Bird Species	Area Use	Steelhead Released (n) and Recovered on Bird Colonies	
			RIS (n=1,204)	PRD (n=558)
Twinning Island	CATE	Breeding	0	0
Lenore Lake	CATE	Breeding	3	0
North Potholes	CATE	Breeding	27	16
Island 20	Gulls	Breeding	1	4
Badger Island	Gulls, AWPE	Breeding	0	0
Blalock Islands (Anvil Is.)	CATE	Breeding	4	2
	Gulls	Breeding	0	0

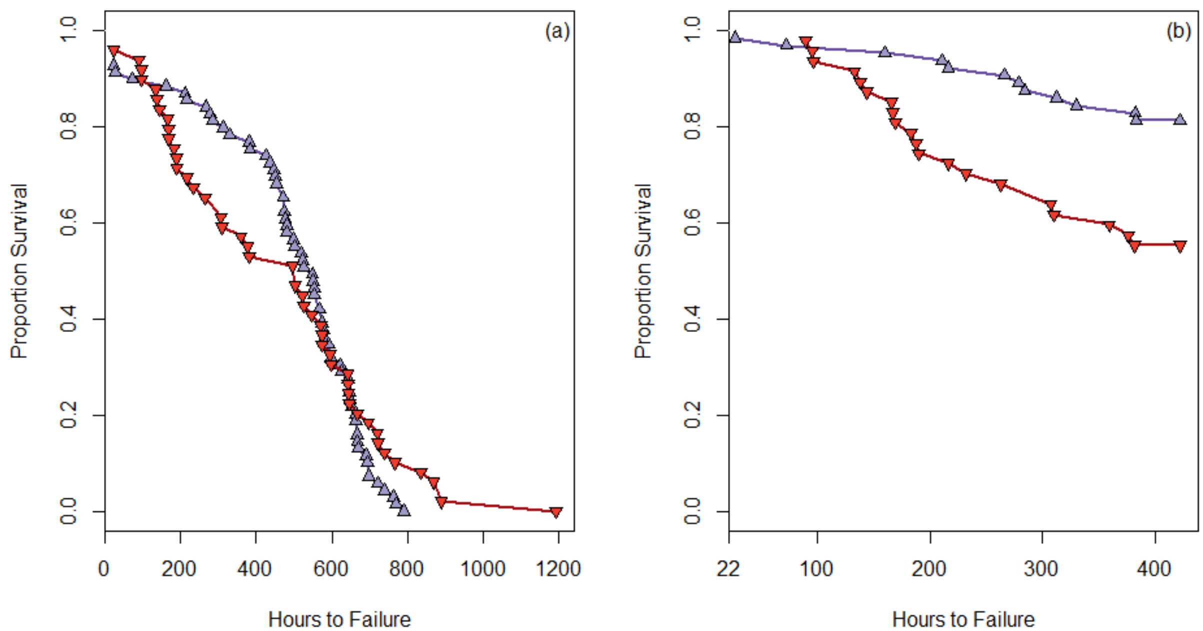
APPENDIX A: HIERARCHICAL BAYESIAN MODELING OF ACOUSTIC TAG FAILURE

The standard mortality-specific mark-recapture-recovery (MS-MRR) model assumes imperfect detection rates at each interrogation opportunity. It is further assumed that the probabilities of detection at these interrogation points are mutually independent. Incidences of tag failures, however, can violate this assumption. As originally noted by Skalski et al. (2017), excessive rates of tag failure in certain lots of acoustic tags were observed in the acoustic telemetry tags implanted in steelhead smolts out-migrating through the middle Columbia River in 2016. Thus, estimates of survival and predation would be biased without the explicit recognition of probable occurrences of tag failure in MS-MRR models. Theoretically, the estimation of acoustic tag failure rates could be done simultaneously with the other parameters in the MS-MRR model. In practice, however, such a model is computationally intractable. Here we use data from test tags, implanted tags in steelhead known to have survived outmigration through the study area, and travel time data collected from fish passing consecutive acoustic arrays to develop spatially-explicit estimates of the probability of tag failure. Presented here is a description of the derivation of prior distributions for tag failure probabilities, which were incorporated into an adaptation of the MS-MRR model.

We assume the failure of an acoustic tag is strictly dependent on time. Skalski et al. (2017) evaluated 118 randomly sampled test acoustic tags to assess tag life. Researchers partitioned all received tags into 26 “lots”. The failure rates among these lots were found to be exceptionally variable. In the judgment of Skalski et al. (2017), a dichotomous classification of the tags into two batch categories could sufficiently address the differences in tag failure among the lots without excessive loss of precision. These batch classifications were assigned based on whether the observed lot failure rate within 120 hours of activation was greater than or less than 12%. A list of lots with their associated batch type was provided to Real Time Research for incorporation into the estimates of spatially explicit avian predation rates. In contrast to the post-stratification approach of Skalski et al. (2017), the likelihood based methods of the MS-MRR framework allow for an alternative approach to incorporating this information into survival and avian predation/consumption estimates via the use of expected travel time between consecutive acoustic arrays to model spatially explicit tag failure probabilities.

As noted by Skalski et al. (2017), nonparametric Kaplan–Meier survival curves (Kaplan and Meier 1958) associated with the randomly assigned test tags suggest that tag life span is difficult to describe with standard parametric models (*Figure A1*). However, we find that an exponential failure rate model can adequately approximate tag loss over a narrower interval of considered tag-life. We first note that steelhead implanted with acoustic tags were all released at least 22 hours after activation. We also find that, based on observed travel times through the study area, at most a negligible number of acoustic-tagged steelhead took longer than 400 hours to exit the study area, through death or outmigration. Thus, the failure-time window of interest can be reduced to failures taking place between 22 and 400 hours post-tagging, truncating failure times prior to and censoring failure times subsequent. The Kaplan–Meier curves for this restricted time-interval of interest suggest exponential failure rate curves may provide an adequate fit for both batches of tags (*Figure A1*).

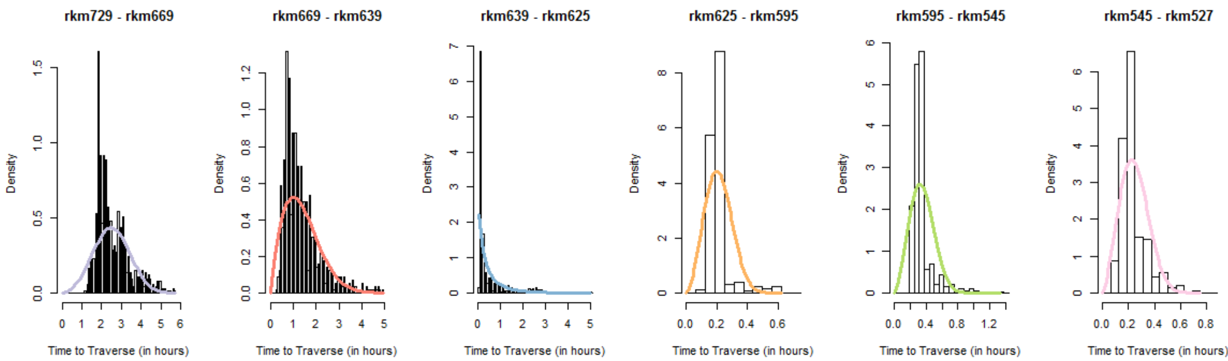
Figure A1. Kaplan—Meier tag-life curves for both batches of test tags plotted (a) over the full time-period of the study and (b) the truncated time interval window suggested for implementation in this analysis.



Furthermore, a large amount of additional information with respect to tag life is available via the incorporation of data from double-tagged (acoustic and PIT) fish that, due to subsequent detections at one or more downstream PIT tag detection arrays, were known to have survived migration through the entire study area. However, the data associated with implanted tags lacks exact measures of failure time for two reasons: (1) there are only records of the last detection of each acoustic tag and (2) there are positive probabilities of working tags passing acoustic arrays undetected. Thus, the inclusion of information from implanted acoustic tags necessitates the use of a hierarchical Bayesian model. The memoryless property of the exponential failure rate model implies that the probability of a tag failing between each array is dependent only on the time it takes to travel between arrays. Therefore, with data regarding travel time among the segments readily available, we can make probabilistic statements about the time of tag failure.

For each river segment in the study area, an empirical distribution of travel time was constructed using data from all acoustic-tagged steelhead detected at both bounding arrays of each segment. The observed travel times across each inter-array segment approximately follow a Weibull distribution (defined by parameters λ_j and K_j; *Figure A2*).

Figure A2. Histograms representing the empirical distributions of travel times observed by steelhead out-migrating through each river segment of the study area. The fitted Weibull distribution densities for each segment are overlaid.



We employ a state space to model probability of tag failure. As in the MS-MRR model, we let X_{ij} be an indicator variable of whether the tag from fish *i* is still active after segment *j* and Y_{ij} be an indicator variable of whether the tag is detected at the *j*th acoustic array. The model can then be written:

$$X_{ij} \sim \text{Bernoulli}\ (X_{i(j-1)} * (1-\kappa_{ij})),$$

$$Y_{ij} \sim \text{Bernoulli}\ (\delta_{rwj} * X_{ij})$$

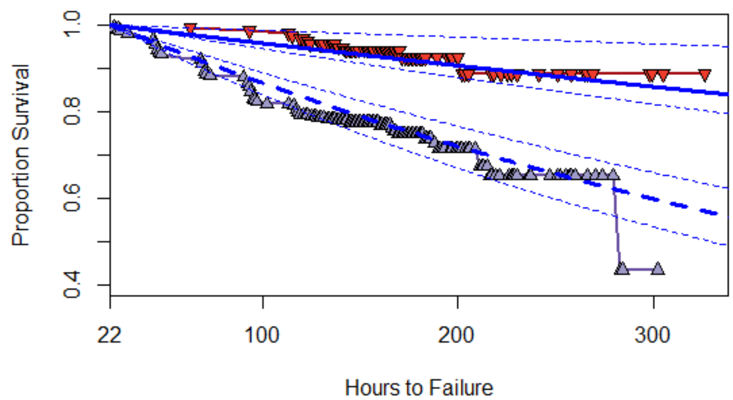
and

$$t_{ij} \sim \text{Weibull}\ (\lambda_j, K_j)$$

where δ_{rwj} represents the probability that an active tag is detected at array *j,* $\kappa_{ij} = \frac{1}{\beta_b} e^{-\frac{t_{ij}}{\beta_b}}$ is the probability that tag *i* fails in segment *j,* and β_b represents the average failure rate for tags in batch *b*.

This results in estimates of β_{normal}= 541 (95% CI: 443-667) and β_{bad}= 1,807 (95% CI: 1,379-6,245; *Figure A3*).

Figure A3. Kaplan—Meier tag-life curves for all test tags and implanted tags known to have survived the study area. The solid blue lines represent the estimated survival curves of the exponential failure model for each batch. The dotted lines represent 95% credible intervals.



Sampling from the posterior distributions gives estimates for each κ_{bj}. The distributions of estimates for each κ_{bj} can be approximated by Beta distributions (*Table A1*). Tag failure rates can then be incorporated in the full MS-MRR model by specifying these Beta distributions as the priors for the probability of tag failure.

Table A1. Parameters defining the prior Beta distributions associated with tag failure probabilities for each batch over the six river segments of the study area.

Segment	Beta Parameters			
	Group 1		Group 2	
	a_{bj}	d_{bj}	a_{bj}	d_{bj}
RIS - rkm 669	1.9	1314.3	5.7	1142
rkm 669 - rkm 639	1.2	1441.7	2.4	846.5
rkm 639 - rkm 625	0.4	1069	0.6	493.6
rkm 625 - rkm 595	1.1	8474	2.4	5477.4
rkm 595 - rkm 545	1.7	8603	5.1	7520
rkm 545 - rkm 527	1.5	10748.6	3.7	7608.2

This model was evaluated with 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).