AVIAN PREDATION ON JUVENILE SALMONIDS: EVALUATION OF THE CASPIAN TERN MANAGEMENT PLAN IN THE COLUMBIA RIVER ESTUARY

2016 Final Annual Report

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Avian Predation on Juvenile Salmonids: Evaluation of the Caspian Tern Management Plan in the Columbia River Estuary

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EXECUTIVE SUMMARY

The primary objectives of this study in 2016 were to monitor, evaluate, and adaptively manage initiatives implemented to reduce the number of Caspian tern (*Hydroprogne caspia*) nesting on East Sand Island and, therefore, reduce tern predation rates on ESA-listed juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River estuary. First, with guidance from resource managers, we prepared 1 acre of tern nesting habitat for terns to use on East Sand Island and attempted to prevent nesting by terns outside that designated nesting area. Second, we monitored tern nesting activity on East Sand Island and evaluated their predation rates on ESA-listed juvenile salmonids. Third, we evaluated movement rates of previously color-banded Caspian terns to and from the East Sand Island colony to assess the efficacy of management initiatives implemented to relocate nesting terns to sites outside the Columbia River basin. Lastly, we monitored the effects of Caspian tern management actions implemented on East Sand Island on the other colonial waterbirds that nest and roost on the island.

The management plan entitled, *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary* was first implemented in 2008, and implementation continued in 2016. The objective of this plan is to reduce the size of Caspian tern colony on East Sand Island to 3,125 - 4,375 breeding pairs, while preventing Caspian terns from colonizing other sites in the Columbia River estuary. As part of this plan, we prepared 1.0 acre of suitable nesting habitat for Caspian terns on East Sand Island prior to the 2016 nesting season, the same area of nesting habitat that was provided for terns in 2015, and an 80% reduction in what was provided for terns on East Sand Island prior to implementation of the management plan. The estimate of Caspian tern colony size on the 1.0-acre designated colony area in 2016 was 5,215 breeding pairs (95% c.i. = 5,000 – 5,430 pairs), slightly lower than the colony size in 2015 (5,430 breeding pairs; 95% c.i. = 5,200 – 5,660 pairs), and about a 50% reduction from the peak size of the tern colony on East Sand Island (ca. 10,670 pairs), which occurred in 2008.

We attempted to limit tern nesting on East Sand Island to the 1.0-acre designated colony area using passive dissuasion (stakes, rope, and flagging) and active dissuasion (human hazing). A total of 5.1 acres of passive dissuasion was installed on East Sand Island prior to the 2016 nesting season, 2.4 acres of which was installed on the east end of the island near the Caspian tern colony. Intensive human hazing was implemented in areas where terns prospected for nest sites. Despite these efforts, two satellite tern colonies formed late in the 2016 nesting season, one adjacent to the main colony area on the upper beach and the other adjacent to a ring-billed gull (*Larus delawarensis*) colony at the northeast tip of the island. Combined, these two satellite tern colonies consisted of an additional 700 breeding pairs, when the size of the satellite colonies was at its peak. Thus, the estimated total number of Caspian terns that attempted to nest on East Sand Island in 2016 was 5,915 pairs (95% c.i. = 5,410 – 6,425 pairs), which was slightly lower than the total number of Caspian terns nesting on East Sand Island in 2015 (6,240 pairs).

In 2016, the average nesting density of Caspian terns in the 1-acre designated colony area on East Sand Island was 1.36 nests/m^2, similar to the average nesting density in 2015 (1.32 nests/m^2), and the highest average nesting density ever recorded for Caspian terns nesting on East Sand Island. The peak nesting density on the tern colony in 2016 was 1.50 nests/m^2, the same as in 2015. These results suggest that Caspian tern nesting density on the designated colony area is approaching the maximum. Given the more than 30-year history of Caspian terns nesting in the Columbia River estuary, it is expected that some, perhaps most, terns will initially adapt to reductions in suitable nesting habitat on East Sand Island by nesting at higher densities and/or attempting to nest in other, sometimes marginal, nesting habitat on East Sand Island (e.g., upper beaches) and elsewhere in the Columbia River estuary (e.g., Rice Island). Efforts to reduce Caspian tern predation rates on juvenile salmonids in the Columbia River estuary to levels stipulated in the management plan will likely require that all Caspian terns nesting in the Columbia River estuary be restricted to just the designated colony area on East Sand Island, and that the area of designated Caspian tern nesting habitat be reduced to about two-thirds of an acre, thereby forcing terns displaced from East Sand Island to relocate to alternative colony sites outside the Columbia River estuary.

As was the case in 2015, Caspian terns nesting on East Sand Island in 2016 were relatively resilient to disturbances by bald eagles (*Haliaeetus leucocephalus*) and associated gull (*Larus* spp.) depredation of tern eggs and chicks. These limiting factors caused the Caspian tern colony on East Sand Island to fail or nearly fail during 2010-2012. In 2016, the Caspian tern colony on the 1-acre designated colony site produced about 2,870 fledglings (average of about 0.55 young raised/breeding pair; 95% c.i. = 0.38 – 0.61), similar to the average productivity during 2015 (0.63 young raised/breeding pair).

To assess the efficacy of management implemented to disperse Caspian terns from nest sites within the Columbia River basin to alternative colony sites outside the basin, we monitored Caspian tern movements by re-sighting terns previously banded with field-readable leg bands at colonies both inside and outside the basin. Most resighted Caspian terns exhibited site fidelity to the colony on East Sand Island in 2016, although some banded individuals dispersed to colonies in the Columbia Plateau region and in the Salish Sea region. Estimated numbers of Caspian terns that moved from the Corps-constructed alternative colony sites in interior Oregon and northeastern California to the Columbia River estuary and to the Columbia Plateau region were high in 2016, probably due to continued severe drought that has negatively affected tern nesting and foraging habitat in interior Oregon and northeastern California during 2014-2016.

Predation rates on specific populations of anadromous salmonids (ESUs/DPSs) by Caspian terns nesting on East Sand Island in 2016 were some of the lowest ever recorded, particularly predation rates on steelhead (*O. mykiss*) populations. For example, predation rates on Snake River steelhead in 2016 were 6.1% (95% credible interval = 4.8 – 8.8), compared with an average of 22.2% (95% CI = 20.3 – 24.8) observed prior to implementation of management to reduce the size of the tern colony on East Sand Island. Reductions in tern predation rates were commensurate with reductions in tern colony size, indicating that Caspian tern management actions to reduce tern nesting habitat on East Sand Island are resulting in lower average annual predation rates on salmonid smolts. Like predation rates measured in previous years, Caspian tern predation rates in 2016 were significantly higher on populations of steelhead (6.1 – 8.8%, depending on DPS) compared with populations of salmon (0.7 – 1.4%, depending on ESU). An investigation of variation in predation rates based on fish rear-type (hatchery, wild), out-migration history (in-river, transported), run-timing, and smolt abundance (density) indicated that multiple factors influence a fish's susceptibility to tern predation; reflecting dynamic and complex predator-prey interactions in the Columbia River estuary.

To further reduce predation rates by Caspian terns nesting at East Sand Island on salmonid smolts in the Columbia River estuary, more Caspian terns will need to be relocated to colonies outside the estuary. Based on the size of the East Sand Island colony in 2016 (5,915 breeding pairs) relative to the target colony size stipulated in the Management Plan (3,125 – 4,375 breeding pairs), an additional 1,500 – 2,800 breeding pairs will need to be relocated outside the estuary. This will likely require an increased effort to prevent Caspian terns from nesting outside the designated 1-acre designated colony area on East Sand Island. The potential for the formation of satellite tern colonies on East Sand Island can be reduced by (1) installing pre-season passive dissuasion more strategically, (2) move the designated tern nesting habitat further from the beach, and (3) collect a limited number of tern eggs (under permit) at incipient satellite colonies. In addition, the designated colony area will need to be reduced to less than 1 acre of nesting habitat (ca. 0.67 acres) to meet the management objective for colony size stipulated in the Plan.

INTRODUCTION

Piscivorous colonial waterbirds (i.e., terns, cormorants, gulls, pelicans) are having a significant impact on survival of juvenile salmonids (*Oncorhynchus* spp.; salmon and steelhead) in the lower Columbia River (BRNW 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014a, 2015a, 2016a). Prior to management, Caspian terns (*Hydroprogne caspia*) at the nesting colony on Rice Island, an artificial dredged material disposal island in the Columbia River estuary, consumed an estimated 5.4 - 14.2 million juvenile salmonids in both 1997 and 1998. This represents about 5 - 15% of all salmonid smolts reaching the estuary during those two migration years. Due to growing concern regarding the impacts of avian predation on recovery of ESA-listed salmonids, in 1999 regional fish and wildlife managers called for immediate management action to reduce losses of juvenile salmonids to Caspian tern predation in the Columbia River estuary.

A management plan first implemented in 1999 sought to relocate the Caspian tern colony on Rice Island, the largest colony of its kind in the world, to a restored colony site on East Sand Island, 21 km closer to the ocean, where it was believed terns would consume significantly fewer juvenile salmonids. Over 94% of the nesting Caspian terns shifted from Rice Island to East Sand Island in 2000, where juvenile salmonids comprised 47% of tern prey items, compared to

90% of prey items at Rice Island (Roby et al. 2002). During 2001–2014, all Caspian terns nesting in the Columbia River estuary used East Sand Island, except for three nesting pairs that laid a total of four eggs on Rice Island in 2011 (BRNW 2012). In 2015, a larger number of terns attempted to nest on Rice Island, but were unsuccessful in rearing any young (P. Schmidt, USACE, pers. comm.). During 2001-2015, estimated consumption of juvenile salmonids by Caspian terns nesting on East Sand Island averaged 5.1 million smolts per year (SD = 0.8 million, n = 15 years), a ca. 59% reduction in annual consumption of salmonid smolts compared to when the Caspian tern colony was on Rice Island (12.4 million smolts consumed in 1998; Roby et al. 2003).

Further management of Caspian terns to reduce losses of juvenile salmonids in the Columbia River estuary is currently in progress; the Records of Decision (RODs) for *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary*, signed in November 2006, stipulated the redistribution of approximately 60% of the East Sand Island tern colony to alternative colony sites outside the Columbia Basin in Oregon and California (USFWS 2005, 2006). This management action is intended to further reduce smolt losses to Caspian terns in the estuary, while maintaining the long-term viability of the Pacific Flyway population of Caspian terns. By the beginning of the 2012 breeding season, the U.S. Army Corps of Engineers – Portland District had constructed nine islands, six in interior Oregon and three in northeastern California, as alternative nesting habitat for Caspian terns nesting on East Sand Island. Construction of additional Caspian tern colony sites in the southern portion of San Francisco Bay at Don Edwards South San Francisco Bay National Wildlife Refuge (DENWR) was completed prior to the 2015 breeding season, and was available to nesting Caspian terns for the first time during the 2015 nesting season. Concurrent with island construction outside the Columbia Basin, the Corps has gradually reduced the area of suitable nesting habitat for Caspian terns on East Sand Island from 5 acres in 2008 to 1 acre in 2015, and has implemented nest dissuasion measures to prevent Caspian terns from establishing new nesting colonies elsewhere in the Columbia River estuary.

The primary objectives of this study in 2016 were to monitor, evaluate, and adaptively manage initiatives implemented to reduce the number of Caspian tern (*Hydroprogne caspia*) nesting on East Sand Island and, therefore, reduce tern predation on ESA-listed juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River estuary. First, with guidance from resource managers, we prepared habitat for terns to nest on East Sand Island and attempted to prevent nesting by terns outside that designated nesting area. Second, we monitored tern nesting activity on East Sand Island and measured tern predation rates on ESA-listed juvenile salmonids. Third, we evaluated movement rates of previously color-banded Caspian terns to and from the East Sand Island colony to assess the efficacy of management initiatives implemented to relocate nesting terns to sites outside the Columbia River basin. Lastly, we monitored the effects of Caspian tern management actions implemented on East Sand Island on the other colonial waterbirds that nest and roost on the island.

STUDY AREA

This study, funded by the Bonneville Power Administration, focused on the nesting activities of Caspian terns at East Sand Island in the Columbia River estuary (*Map 1*). Additionally, this report provides limited information on roosting California brown pelicans (*Pelecanus occidentalis californicus*), nesting glaucous-winged/western gulls (*Larus glaucescens/occidentalis*), and nesting ring-billed gulls (*L. delawarensis*) on East Sand Island.

This work is part of a comprehensive program to monitor and evaluate the management plans entitled, *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary* (USFWS 2005, 2006) and the *Inland Avian Predation Management Plan* (USACE 2014; BRNW 2014b, 2015b); both plans seek to reduce Caspian tern predation on ESA-listed juvenile salmonids from the Columbia River basin by relocating nesting Caspian terns from colonies within the basin to alternative colonies outside the basin. Results from related studies funded by the U.S. Army Corps of Engineers (USACE) – Walla Walla District (BRNW 2016b) and the Grant County Public Utility District (GPUD)/Priest Rapids Coordinating Committee (PRCC; BRNW 2017) are provided in separate reports.

SECTION 1: CASPIAN TERNS

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

The Caspian Tern Management Plan for the Columbia River estuary called for the creation of approximately 5 acres of new or restored Caspian tern nesting habitat (islands) and to actively attract Caspian terns to nest at these sites. As alternative tern nesting habitat is created or restored outside the Columbia Basin, the available nesting habitat for Caspian terns on East Sand Island would be reduced from its initial size (approximately 5 acres in 2008) to 1.0 – 1.5 acres.

The specific objectives of the Plan are to reduce the size of the East Sand Island Caspian tern colony to 3,125 – 4,375 breeding pairs by limiting the availability of suitable nesting habitat, while providing new nesting habitat for Caspian terns at alternative colony sites outside the Columbia River estuary. These objectives were identified as the preferred alternative in the Final Environmental Impact Statement released in early 2005 (USFWS 2005). Caspian terns displaced by habitat reduction on East Sand Island are expected to relocate to alternative colony sites, including the nine Corps-constructed tern islands in interior Oregon and northeastern California (i.e., Fern Ridge Reservoir, Crump Lake, Summer Lake Wildlife Area [3 separate islands], Tule Lake NWR, Lower Klamath NWR [2 separate islands], and Malheur NWR) and the five Corps-constructed tern islands in DENWR.

1.1. Habitat Preparations

Methods: As part of the plan entitled *Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary*, we prepared 1.0 acre of suitable bare-sand nesting habitat for Caspian terns on East Sand Island in 2016 *(Map 3*).

Boundaries of the prepared habitat were adjusted in 2016 through the removal and placement of fabric fencing to create a visual barrier for Caspian terns that might land on the ground near the fences. Fences were constructed by driving 6-foot fence posts into the ground to depths of at least two feet, spaced six feet apart, with each length of fence securely anchored at both ends using angle brackets (Wedge-Loc®). Runs of taught, barbless wire were then secured to the fence posts at ground level, 18 inches above ground level (AGL), and 36 inches AGL. Commercial grade knitted fabric material (PAK Unlimited Inc.; 90% privacy screen), constructed with finished and grommeted edges, was used on East Sand Island for the first time in 2016 replacing woven fabric “silt” fence or “landscape fabric” material used in previous years. The knitted fabric material, which is more durable and not prone to fraying like woven silt fence material, was attached with heavy duty UV resistant zip ties to the top and bottom wire strands. Placement of fabric fences served to both delineate the 1.0-acre prepared colony area and to dissuade Caspian tern nesting. A fabric fence that had delineated the eastern edge of the prepared 2015 1.0-acre colony area was removed extending the prepared 2016 colony approximately five meters further east to the long access tunnel to the southeastern observation blind. In addition, 12 meters along the western edge of the prepared 2015 colony area was excluded from the prepared 2016 area by increasing the number of fabric fence rows installed in that location. The southern edge of the prepared 1.0 acre was defined by 73 meters of east/west oriented fabric fence installed just north of the eroded island edge. An additional 23 meters of fence was installed across the southern edge of five north/south running fence rows as an additional visual barrier for terns that might prospect for nesting sites between the fence rows.

Preparation of bare-sand nesting habitat for Caspian terns was accomplished by utilizing a 4-wheel drive ATV and disking the 1.0-acre area to overturn poorly established vegetation and to scarify the surface to a depth of approximately six inches. While equipment used was not effective on areas of densely established European beach grass (*Ammophila arenaria*), one to two meters of sparsely distributed beach grass encroaching along the northern edge of the managed colony area was successfully disked under. Following 4 to 5 complete passes of the 1-acre nesting area with the disk, the sand was smoothed by dragging a section of chain-link fence over the colony area. As was the case during 2013-2015, the colony area was not sprayed with pre-emergent herbicide during the spring of 2016. The area of Caspian tern nesting habitat prepared on East Sand Island in 2015 and 2016 was 1.0 acre and represented an 80% reduction from what had been provided prior to implementation of the management plan in 2008.

Results and Discussion: Preparation of 1.0 acre of suitable bare-sand nesting habitat for Caspian terns on East Sand Island was completed during 30 March - 9 April. Although erosion from rainwater runoff and vegetation growth occurred on limited areas of the prepared colony surface, dense tern nesting occurred over the full extent of the prepared colony area. Fabric fencing that was installed in combination with adjacent passive dissuasion materials to delimit the boundaries of the prepared habitat remained intact and effective over the entire tern nesting season. This was part of planned reductions in area of tern nesting habitat provided on East Sand Island as part of the Caspian Tern Management Plan for the Columbia River estuary (*Map 3*; USFWS 2005, 2006).

1.2. Passive Nest Dissuasion

Methods: To restrict Caspian tern nesting on East Sand Island to the designated 1.0-acre prepared colony area in 2016, we deployed passive dissuasion materials on potentially suitable tern nesting habitat prior to the initiation of nesting.

Maps depicting passive dissuasion placement in 2015 were used as the basis for placement of materials in 2016, with adjustments made for changes in the location of suitable tern nesting habitat. Thus, passive dissuasion was not re-installed on areas where vegetation encroachment had eliminated the possibility of Caspian tern nesting, but passive dissuasion was placed in new areas identified as suitable nesting substrate, including locations where annual accretion of shifting sand created nesting habitat not present in 2015. During on-island consultations with representatives from the Army Corps of Engineers - Portland District and the Bonneville Power Administration, areas at the east and west ends of East Sand Island were approved for placement of passive end of the island, respectively (*Map 4*). Thus, a total of 5.1 acres of passive dissuasion was deployed on East Sand Island prior to the initiation of nesting by Caspian terns in 2016.

On the east side of East Sand Island, passive dissuasion materials were deployed during 30 March - 11 April. The materials used consisted of a combination of posts, ropes, and flagging that were installed extensively, and parallel rows of fabric fencing use in a single location adjacent to the designated tern nesting area. Passive dissuasion was placed on both upland areas (around the prepared 1.0-acre area) and beach areas extending to, and sometimes below, the approximate high tide line. The vast majority of area covered by passive dissuasion on East Sand Island, including all materials placed on the east end beach areas, consisted of a grid of 4-

to 6-foot metal t-posts and u-posts (supplied by the USACE) connected with yellow twisted 0.25-inch polypropylene rope to form a grid of squares (cells) 10 feet on a side. Ropes were attached to posts using clove hitch knots that allowed for rapid installation, secure attachment, and easy removal. Each cell was crossed with a diagonal length of poly rope and four-foot lengths of industrial barricade tape (polyethylene flagging; hereafter "flagging") were inserted between strands of the poly rope at approximately 3-foot intervals leaving 2-foot lengths to move freely with the wind. More liberal deployments of passive dissuasion materials were installed directly adjacent to the designated 1.0-acre colony area and in the approximate locations where satellite tern colonies formed in 2015. Liberal applications of passive dissuasion included fence rows installed to create visual barriers, a double layer of ropes and flagging, and placement of passive dissuasion (posts, ropes, and flagging) on areas below the high tide line. Five fabric fence rows (13 to 24 meters in length) oriented north/south and spaced 6 meters apart were installed on a portion of the historical colony area to create visual barriers on highly suitable nesting substrate directly adjacent to the prepared 1.0-acre area. A double layer of ropes and flagging was suspended between the five fence rows as an additional nesting deterrent.

On the west side of East Sand Island, passive dissuasion materials were deployed during 22-26 March, and a small amount of additional dissuasion was installed on 9 April. Dissuasion materials deployed on the west end of the island were restricted to a standard array of posts with a single layer of ropes; flagging (installed as described above) was installed largely on upland areas above, and down to, the high tide line (*Map 4*).

Supplemental passive dissuasion materials were held in reserve, to be deployed as a response to Caspian tern nest prospecting on any non-dissuaded areas outside of the prepared 1.0-acre area. Daily active hazing and on-island monitoring for Caspian tern nesting activity outside of the designated colony area was conducted on the east end of East Sand Island only. Observations of tern breeding behaviors elicited consultation with the USACE POC regarding the potential for in-season installation of supplemental passive dissuasion materials.

From 22 August through 8 October, following a protracted breeding seasons by Caspian terns, double-crested cormorants, and Brandt's cormorants on East Sand Island, all posts, ropes, flagging, and all fabric fences that were installed as passive tern dissuasion in 2016 were disassembled and consolidated for storage. All the used flagging, heavily worn or frayed rope, and a limited number of broken and bent posts were removed from the island and discarded. Most of the serviceable posts and ropes were stacked neatly and covered with tarps for storage on the east and west ends of East Sand Island. Remaining materials, including all the woven fabric fencing were removed from the island and stored at the USACE warehouse on Liberty Lane in Astoria, OR.

Results and Discussion: Liberal installation of fence rows and double layers of passive dissuasion in locations of highest risk for tern nesting contributed to successful nest dissuasion directly adjacent to the designated tern nesting habitat. Unlike 2015, when Caspian terns established a satellite colony directly south of the prepared 1.0-acre of suitable nesting habitat, terns were excluded from nesting adjacent to the prepared habitat in 2016. The primary factors that prohibited tern nesting directly adjacent to the 1.0-acre colony area in 2016 included dense beach grass to the north; installed fence rows, and double layered ropes and flagging to the west; the researcher access tunnel and installed double layered posts, ropes, and flagging to the east; and a combination of installed double layered posts, ropes, and flagging, the steep eroded island edge, and densely accumulated driftwood to the south (*Map 5*).

Field observations of Caspian tern breeding behaviors, including repeated egg-laying on beach areas, resulted in consultations with the USACE COR and installment of supplemental passive dissuasion materials during 9-23 May. All the supplemental dissuasion materials that were deployed were directly adjacent to and attached to existing passive dissuasion installed prior to the tern nesting season. On 9 May, 20 cells of supplemental passive dissuasion were installed on the southeast beach in response to Caspian tern nest prospecting and egg-laying. On 10 May, 18 cells of supplemental passive dissuasion were added east of the south beach access tunnel and 10 cells were added west of the tunnel in response to tern nest prospecting. On 12 May, 24 additional cells of supplemental dissuasion material were added on the south beach in response to nest prospecting and egg-laying by Caspian terns. The final installment of supplemental passive dissuasion was completed on 23 May, when 7 cells were added on the south beach. In 2016, area covered by supplemental passive dissuasion installed during breeding season totaled 0.2 acres, bringing the total area of passive dissuasion deployed on East Sand Island to 5.3 acres.

Although most of the deployed passive dissuasion appeared to be highly effective in excluding Caspian tern nest prospecting and egg-laying, a small number of tern nests were established within the boundaries of the original and supplemental passive dissuasion materials deployed on the south beach. The first tern nest containing an egg that was confirmed under passive dissuasion was discovered with the formation of an incipient satellite colony on the beach just south of the main tern colony, when 14 nests with eggs were found on 22 June. Prior to the formation of the two satellite colonies, field personnel conducting active hazing sessions had nearly complete access to the east side of the island, and could determine if Caspian tern nesting attempts occurred inside or outside areas of installed passive dissuasion. Although our ability to assess tern use of passive dissuasion areas was limited by restricted access, field observers used the southeast observation blind as a limited vantage to estimate satellite colony size and location relative to passive dissuasion materials. On 1 July, during the peak in tern breeding on the south beach satellite colony, about 100 (25%) of ca. 400 tern nests counted were under the passive dissuasion materials.

On 22 June, the same date that the south beach Caspian tern satellite colony became established, a satellite colony was initiated on the northeast beach adjacent to an active ring-billed gull colony. The northeast beach satellite colony formed on a wet, low-lying inlet anticipated to be inundated during most high tides, but where a small area remained above water during high tides in 2016. Unlike the south beach satellite colony, Caspian tern nests on the northeast beach satellite colony were adjacent to installed passive dissuasion materials, but few or none of the nests occurred under dissuasion materials. Like the south beach satellite colony, Caspian terns nesting attempts and formation of an incipient breeding colony on the northeast beach was facilitated through social attraction, in this case by nesting ring-billed gulls. Thus, active hazing of terns was limited near the gull colony to avoid disturbance that might result in loss of gull eggs. For the same reason, placement of supplemental passive dissuasion was not carried out directly adjacent to the ring-bill gull colony, where the first gull egg was confirmed on 4 May.

We found no evidence of brown pelican or other avian species becoming entangled in passive dissuasion materials in 2016. No avian entanglements in passive dissuasion materials were detected by field personnel during the breeding season and no evidence of entanglements was discovered when all the materials were later disassembled for storage.

1.3. Active Nest Dissuasion

Methods: In addition to passive nest dissuasion methods, we used active dissuasion (human hazing) to prevent Caspian terns from prospecting for nesting sites outside of the designated 1.0-acre colony area at the east side of East Sand Island. Surveys of the east end of East Sand Island for prospecting terns were conducted daily from 14 April to June 30, and less frequently through July. The number of sessions, timing, duration, and extent of daily active hazing conducted by field technicians was adjusted based on the number, location, and behaviors of Caspian terns located outside the prepared habitat. Additionally, we monitored the presence and nesting status of other species, and adapted active hazing activities to avoid disturbance that might cause egg loss (un-permitted take) at Caspian tern, California brown pelican, or gull nests that were initiated on or outside the prepared 1.0-acre tern colony.

We installed two structures to facilitate researcher access for active hazing of the south beach (*Map 5*) and to minimize potential disturbance of terns or other species on or near the prepared colony area. A nine-meter-long above-ground tunnel was installed to allow researcher movement between the southeastern observation blind and the south beach. Additionally, a 30-meter-long, four-foot-tall plywood fence, secured to 6- and 7-foot tall t-posts, was installed as a visual barrier running from the tunnel to the east along the upper beach. The plywood fence was installed to allow active dissuasion of the adjacent south beach area with minimal disturbance to brown pelicans and gulls, which we anticipated (based on historical breeding attempts) might attempt to nest on upland areas east of the designated Caspian tern colony area.

The primary technique of active dissuasion was human hazing to flush Caspian terns from potential nesting substrate outside the designated colony area. Surveys for prospecting Caspian terns were conducted on foot by field personnel. If prospecting Caspian terns were discovered during a survey, field staff first attempted to determine if tern eggs had been laid in the area. If it was determined that no eggs had been laid, field personnel hazed terns by approaching slowly to flush the birds and then searched the area for evidence of nest scraping. If nest scrapes were found, they were counted and covered over (e.g., rubbed out or filled with sand). If tern eggs were discovered, personnel counted the numbers of eggs and nest scrapes, covered empty scrapes, and left the area immediately to avoid causing nest failure (loss of eggs) due to abandonment or depredation by gulls. When Caspian tern behavior suggested the potential for incipient colony formation, field personnel notified project supervisory staff who consulted with the Corps' COR regarding the need to install additional supplemental passive dissuasion at the site where terns were prospecting.

The eastern portion of East Sand Island was subdivided into eight areas for data collection during active hazing. The eight areas were identified as the north beach, northeast beach, east beach, southeast beach, south beach, west inland, east inland, and below tide line (*Map 6*). Although area below the tide line would not support the formation of a satellite colony due to daily inundation, we monitored Caspian tern numbers and activity below the tide line to document trends in the total numbers of Caspian terns located outside of the designated 1.0 acre of tern nesting habitat on the east side of the island.

Results and Discussion: Caspian tern numbers and observations of breeding activities varied among areas monitored on the east side of East Sand Island in 2016 (*Table 1*). The two inland areas located near the designated colony area were virtually unused by Caspian terns during 2016, with a total of three terns observed on the east inland area in late July. The north beach area was used by low numbers of Caspian terns. On the north beach, researchers counted 6-45 terns during seven hazing sessions and 1-4 nest scrapes during five hazing sessions during 15-26 May. Tern use of the east beach area was similarly limited, with 16-45 terns and 1-4 nest scrapes counted during hazing session conducted during 20-24 May. Limited additional tern observations occurred on the east beach during 13-28 July, when 1-8 nest scrapes were found during five hazing sessions, but a total of only seven terns were counted.

By contrast, the southeast, south, and northeast areas were used by large numbers of Caspian terns that made large numbers of nest scrapes over an extended portion of the breeding season (*Table 1*), including egg-laying in all three areas and the establishment of satellite colonies in two of the three areas (*Map 7*). On the southeast beach area, monitoring and active hazing sessions resulted in counts of 1-595 Caspian terns and 1-126 nest scrapes from 25 April to 21 July. Caspian tern nest prospecting on the southeast beach resulted in the detection of 17 eggs laid during 2-27 May (*Table 2*). Although a few nests retained eggs between successive hazing sessions, no tern eggs that were confirmed on the southeast beach persisted for more than a day; thus, no satellite tern colonies formed on this part of the island. Caspian tern nesting activity was higher on the northeast beach where 1-395 terns and up to 72 nest scrapes (48 that contained eggs) were counted by field personnel from 15 May to 28 July. Caspian tern nest prospecting on the northeast beach resulted in the discovery of nine Caspian tern eggs that were laid and subsequently lost from 18 May to 21 June. However, access by researchers for active hazing and for the deployment supplemental passive dissuasion materials was limited near the large ring-billed gull colony on the northeast tip of the island, contributing to the formation of a satellite tern colony there on 22 June. The intensity of Caspian tern nest prospecting activity was greatest on the south beach area, where 1-1127 terns and 1-398 nest scrapes and/or attended nests were counted by field personnel from 18 April to 1 August. A high count of 84 nests with eggs was made on the eastern portion of south beach satellite colony when field crew entered the nesting area during a natural disturbance event on 6 July. However, this was an incomplete count because access was very brief and limited in area to avoid causing a prolonged disturbance to the larger satellite colony and the 1.0-acre designated colony area. Following the formation of the two satellite colonies on the northeast and south beach areas on 22 June, Caspian tern nesting activities on East Sand Island were confined to the designated colony area and the two satellite colony areas, with very limited instances of nest scraping in other areas.

Active hazing was successful at limiting establishment of new nests with eggs when access was possible, but levels of habituation by Caspian terns nesting on the main colony to the presence of personnel conducting hazing varied during the season, hampering efforts to dissuade tern nesting on the south beach. On 18 April, four days after the initiation of active hazing, the first observations of Caspian tern nest scraping outside the designated colony area were noted on the south beach. Copulations by terns on the south beach were first observed on 20 April. Initially, movements by field personnel on the south beach to conduct hazing resulted in flushes of 5-40% of the Caspian terns on the main colony area. However, flushes of the main colony lessened to 0% by 27 April, as field personnel employed slower movements and crawling during active hazing, and as terns became habituated to their daily presence. Another factor in the degree of flushing by the main colony may have been a series of night-time visits by great horned owls (Bubo *virginianus*) in mid-April. Nonetheless, from May through about mid-June personnel could walk slowly across the entire length of the south beach and conduct active hazing without causing terns to flush from the main colony about 20 meters to the north. Because the Caspian terns establishing nests on the main colony habituated quickly to the presence of researchers nearby, personnel were relatively unconstrained while conducting active hazing and confirmed a total of 66 Caspian tern eggs laid outside of passive dissuasion from 2 May to 21 June (*Table 2*). Of the 66 eggs detected, the maximum number of tern eggs counted in a single location was four and all were lost within a day, primarily due to gull depredation during disturbances or from flooding during high tides.

During June, increased eagle disturbances to terns nesting on the main colony coincided with the apparent loss of the main colony's habituation to the presence of personnel conducting active hazing nearby. On 9 June, a harbor seal carcass washed up on the east tip of the island, and field personnel noted that this event coincided with increased bald eagle presence and disturbance to Caspian terns. Due to observed losses of Caspian tern eggs (taken by gulls) on the main colony during renewed researcher-caused flushes, access for hazing the beach near the main colony was curtailed beginning on 14 June. Although south beach access was limited over the remainder of the breeding season, field personnel took advantage of complete flushes of the main tern colony caused by natural predators (typically bald eagles), and on several occasions, they opportunistically entered satellite colony areas to estimate nest numbers and contents. Ultimately, the combination of curtailed hazing to avoid egg take and social attraction by of thousands of Caspian tern pairs nesting 20 meters away, resulted in intense and unmitigated nest prospecting and the formation of an incipient satellite colony along the high tide line just south of the passive dissuasion on the south beach.

After 21 June, the presence of tern eggs prevented close inspection of incipient satellite tern colonies to count scrapes and eggs. In areas of potential tern nesting habitat that remained accessible for hazing, very few observations of prospecting Caspian terns were recorded. Our estimate of the size of the south beach satellite colony was based on a count 398 apparent attended nests made by field observers from the southeastern observation blind on 1 July. Our estimate of the size of the northeast beach satellite colony was based on an estimate of 300 apparent attended nests from a vertical aerial image taken on 3 July.

Finally, monitoring of other waterbird species during active hazing indicated that only nesting ring-billed gulls were at significant risk of egg loss due to active Caspian tern nest dissuasion activities in 2016. As described above, the large ring-bill gull colony on the northeast beach attracted and shielded prospecting Caspian terns from active dissuasion to avoid researcher-induced loss of ring-billed gull nests. Loafing ring-billed gulls, glaucous-winged/western gulls, and California brown pelicans were all regularly observed and flushed by personnel conducting active hazing. Nesting by glaucous-winged/western gulls occurred primarily in upland locations that researchers could avoid during hazing sessions, and California brown pelicans initiated nests so late in the tern breeding period that active daily active hazing was terminated before two brown pelican nests with eggs were found in early August.

1.4. Nesting Distribution, Colony Size, Productivity, & Limiting Factors

Methods: The number of Caspian terns breeding on East Sand Island in the Columbia River estuary was estimated using low-altitude, high-resolution, vertical aerial photography of the colony taken near the end of the incubation period (6 June). The average of 3 direct counts of all adult terns on the colony in aerial photography, corrected using ground counts of the ratio of incubating to non-incubating terns on 12 different plots within the colony area, was used to estimate the number of breeding pairs on the colony at the time of the photography. Confidence intervals for the number of breeding pairs were calculated using a Monte Carlo simulation procedure to incorporate the variance in the multiple counts from the aerial photography and the variance in the ratios of incubating to non-incubating adult terns among the 12 plots. Estimates of the number of breeding pairs were calculated one thousand times using random draws from the sample distributions of the total number of terns on-colony and the ratio of incubating to non-incubating adult terns on plots. Standard errors and confidence intervals for the number of breeding pairs were derived from the resulting distribution.

Nesting success (average number of young raised per breeding pair) at the East Sand Island tern colony was estimated using aerial photography taken of the colony just prior to the fledging period (17 July). The average of 3 direct counts of all terns (adults and juveniles) on the colony in aerial photography, corrected using ground counts of the ratio of fledglings to adults on 12 different plots within the colony area, was used to estimate the number of fledglings on the colony at the time of the photography. To estimate nesting success, the total number of fledglings counted on-colony was divided by the number of breeding pairs estimated during late incubation (see above). Confidence intervals for nesting success were calculated using a Monte Carlo simulation procedure to incorporate the variance in the multiple counts from the aerial photography and the variance in the ratios of fledglings to adults on the plots. Monte Carlo calculations were performed using Visual Basic within Microsoft Excel (Microsoft Corp., Redmond, WA); 1000 iterations were performed and 95% bootstrap percentile limits were used for confidence intervals.

A custom application developed in ArcGIS was used to count adults and fledglings on the aerial photography taken to estimate colony size and nesting success at the East Sand Island Caspian tern colony.

Results and Discussion: We estimate that 5,215 breeding pairs of Caspian terns (95% c.i. = 5,000 – 5,430 pairs) were nesting on the 1-acre designated colony area on East Sand Island at the peak of nesting activity (early – mid June) in 2016 (*Figure 1*). This is slightly lower than the colony size in 2015 (5,430 pairs; 95% c.i. = 5,200 – 5,660 pairs; *Table 3*). Despite efforts to limit tern nesting on East Sand Island to the 1-acre core colony area using passive dissuasion (stakes, ropes, and flagging) and active dissuasion (human hazing), two satellite Caspian tern colonies formed outside the core colony area and supported an additional 700 breeding pairs at their peak in the first week of July (*Map 7*). Thus, the total number of Caspian terns that attempted to nest on East Sand Island in 2016 was about 5,915 pairs (95% c.i. = 5,410 – 6,425 pairs), slightly lower than the total number of Caspian terns nesting on East Sand Island in 2015 (6,240 pairs; 95% c.i. = 6,010 – 6,460 pairs). Nevertheless, 5,915 breeding pairs is the smallest point estimate for Caspian terns nesting at East Sand Island since the reduction in tern nesting habitat was first implemented on the island in 2008. The number of terns nesting in the 1-acre core colony area in 2016 (5,215 breeding pairs) represents a 51% decline from the peak Caspian tern colony size on East Sand Island, which was observed in 2008 (ca. 10,670 pairs; *Figure 2; Table 3*). Nevertheless, tern colony size in 2016 was still larger than the target colony size specified in the Caspian Tern Management Plan for the Columbia River estuary (3,125 – 4,375 breeding pairs; USFWS 2005, 2006).

The overall decline in tern colony size at East Sand Island during 2008-2016 can be attributed to the planned reductions in area of tern nesting habitat provided on East Sand Island as part of the Caspian Tern Management Plan for the Columbia River estuary (USFWS 2005, 2006). During 2008-2012, the amount of nesting habitat prepared for terns on East Sand Island was incrementally reduced, from approximately 5 acres in 2008 to 1.58 acres in 2012 and 2013. In 2014, the amount of nesting habitat prepared for Caspian terns on East Sand Island was reduced slightly (1.55 acres) from what was prepared the previous two years, and in 2015-2016 the amount of nesting habitat prepared was reduced to the minimum colony area specified in the management plan (1 acre). In response to the decline in available nesting habitat for Caspian terns on East Sand Island, there has been a near doubling in nesting density, from 0.72 nests/m^2 in 2008 to 1.36 nests/m^2 in 2016, the highest average nesting density ever recorded at the East Sand Island Caspian tern colony (*Figure 3*; *Table 3*). Nesting densities for Caspian terns on East Sand Island in recent years are now well above the nesting densities used to establish the colony size and colony area targets in the Caspian Tern Management Plan for the Columbia River estuary (0.55 – 0.78 nests/m^2; USFWS 2005, 2006). Based on current nesting densities, the area of Caspian tern nesting habitat provided on East Sand Island will likely need to be reduced to about two-thirds of an acre to realize the goal of reducing the size of the East Sand Island tern colony to 3,125 – 4,375 breeding pairs, as prescribed in the Caspian Tern Management Plan (USFWS 2005, 2006).

We estimate that ca. 2,870 fledgling Caspian terns were produced on East Sand Island in 2016, nearly all on the main tern colony. All nests on the south beach satellite colony failed to produce young and only 15 young were estimated to have fledged from the northeast beach satellite colony. This corresponds to an average nesting success of 0.55 young raised per breeding pair (95% c.i. = 0.38 – 0.61 fledglings/breeding pair) on the main colony. Compared to Caspian tern nesting success at East Sand Island in previous years and at other Caspian tern colonies in the region, this is considered average productivity, but higher than the average productivity observed at this colony during the previous six years (0.20 fledglings/breeding pair; *Figure 4*). Nesting success at the East Sand Island Caspian tern colony peaked in 2001 and has trended downward since then (*Figure 4*). At least two factors have contributed to the decline in productivity of the Caspian tern colony at East Sand Island: (1) ocean conditions and/or high river flows as they influence the availability of marine forage fishes in the estuary and (2) predation on tern eggs and chicks by gulls, especially during tern colony disturbance events caused by bald eagles (*Haliaeetus leucocephalus*; Collar 2013).

As was the case prior to 2013-2015, Caspian terns were observed prospecting for nest sites at dredged material disposal sites on Rice Island in the upper Columbia River estuary during 2016. Data on nesting attempts by Caspian terns in the upper Columbia River estuary were collected by another contractor and will be presented in a separate report.

1.5. Inter-colony Movements & Dispersal Patterns

Methods: In 2016, we continued our efforts to resight color-banded Caspian terns for on-going demographic studies and to evaluate movement probabilities by adult Caspian terns among breeding colonies. Results presented here describe movements of banded Caspian terns among colonies, either within or between years, to better assess the consequences of management initiatives implemented as part of the Caspian Tern Management Plan for the Columbia River estuary.

Caspian terns were 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 during 2005–2015. This compliment of leg bands allowed us to individually identify each banded tern from a distance, such that the banding location (colony) and banding year were known. Banding was conducted at colonies both within the Columbia River basin and outside the basin. Banded adult Caspian terns were resighted on the East Sand Island tern colony by researchers using binoculars and spotting scopes during 5-7 days per week throughout 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 Flyway during 2016 to evaluate movements of Caspian terns to and from the Columbia River estuary.

Summaries of band resighting data collected at East Sand Island and at a loafing site in the Columbia River estuary during the 2016 field season are presented in this report, along with information on where those individuals were originally banded. The summaries represent dispersal or site fidelity across years, between the time when each tern was banded and when it was observed again in 2016. This report also includes a summary of banded Caspian terns observed at East Sand Island in 2015 and locations where those terns were observed again in 2016. The summary provides information on inter-annual dispersal from, or fidelity to, the tern colony on East Sand Island.

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

Results and Discussion: In 2016, a total of 595 previously color-banded Caspian terns were resighted on East Sand Island. Of these resighted terns, 89% were banded at East Sand Island (181 as adults and 348 as chicks), 6% were banded at Crescent Island in the mid-Columbia River (22 as adults and 13 as chicks), 2% were banded at Goose Island-Potholes Reservoir, Washington (12 as adults and 2 as chicks), 2% were banded at the Port of Bellingham, Washington (12 as chicks), and < 1% were banded as chicks each at Brooks Island in San Francisco Bay, Crump Lake in the Warner Valley, Oregon, Sheepy Lake tern island in Lower Klamath NWR, California, and Kokinhenik Bar in the Copper River Delta, Alaska (*Table 4*). Eleven previously color-banded Caspian terns were resighted at Tongue Point Pier, a non-breeding site 15 km upriver from East Sand Island; 8 of these were also resighted at East Sand Island. Three banded terns resighted only at Tongue Point Pier were banded as adults either at East Sand Island, Crescent Island, or Goose Island. These resightings of banded Caspian terns at the East Sand Island colony and at the Tongue Point Pier loafing site indicate that some Caspian terns are moving from both inland and coastal colonies to the Columbia River estuary.

Of a total of 482 color-banded Caspian terns seen on East Sand Island in 2015, 390 terns were resighted again at East Sand Island or elsewhere in 2016; some of these individuals were resighted at multiple locations in 2016. Of a total of 412 resighting records of these birds in 2016, 86% were resighted at East Sand Island, 5% were resighted at the Blalock Islands in the mid-Columbia River, 4% were resighted at an active colony in Everett, Washington, 2% were resighted each at Tongue Point Pier and Potholes Reservoir (either at Goose Island or islands in North Potholes Reservoir), and < 1% were resighted at an active colony on Rat Island in the Puget Sound area, Washington (*Table 5*).

Out of 34 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. However, only the effect of drought was significant based on evaluation of the 95% confidence limits for the coefficient. 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 of "drought" and "management" for affecting movements.

Movement probabilities from the Columbia River estuary to the Columbia Plateau region for Caspian terns banded as adults were < 1% prior to 2012. During 2012-2016, there were limited movements from the estuary to the Columbia Plateau region, ranging from 1.1% to 1.5%, with the highest movement probabilities observed in 2015 and 2016. 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) between the Columbia River estuary and the Columbia Plateau region in 2016 was 137 individuals from the estuary to the Plateau (*Table 6*). Although this number is small, it could have partially off-set benefits to salmonids of tern management in the Plateau region and in the estuary. This is because per bird impacts on smolt survival 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, etc.) tend to dominate the diet.

Based on the best model selected to estimate inter-colony movements (see above), movement probabilities of Caspian terns banded as adults on Corps-constructed tern islands in southern Oregon and northeastern California (SONEC) to the Columbia River estuary ranged from < 0.1% to 14% per year during 2009-2016, with the highest movement probability observed in 2014 and the second highest movement probability observed in 2016. The movement probability in 2016 translates into an estimated 233 adult Caspian terns moving from the Corps-constructed sites in the SONEC region to the Columbia River estuary in 2016 (*Table 6*). Insufficient data collection at the SONEC Corps-constructed tern islands in 2016 made accurate estimation of the movement rate from the Columbia River estuary to the Corps-constructed islands impossible; thus, net movement between the two regions is unknown. Movement probabilities from colonies on the SONEC Corps-constructed tern islands to the Columbia Plateau region ranged from < 3% to 18% during 2009-2016, with the highest probabilities observed in 2015 and 2016, despite management actions to reduce colony size at both Crescent Island and Goose Island in the Columbia Plateau region. The estimated number of adult Caspian terns that moved from the SONEC Corps-constructed tern islands to the Columbia Plateau region in 2016 was 375 individuals. Net movement between the two regions is unknown due to the reasons described above. 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, 2015c). 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 probability from the Corps-constructed islands to the Columbia Plateau region might have been at least partly due to available nesting habitat at the Blalock Islands in John Day Reservoir and the strong fidelity by terns to Goose Island in Potholes Reservoir.

1.6. Predation Rates on Salmonids Based on Smolt PIT Tag Recoveries

Passive integrated transponder (PIT) tags are placed in out-migrating juvenile salmonids from the Columbia River basin to study their behavior and survival following release. PIT tags provide specific information on individual fish, including species (i.e. steelhead, Chinook, coho, sockeye), run-type (i.e. spring, summer, fall, winter), rear-type (i.e. hatchery, wild), and release information (i.e. date, location). Post-release interrogations of PIT-tagged fish provide information on migration timing, migration histories (e.g., in-river, transported), and survival based on detections of live fish passing hydroelectric dams or other in-river interrogation sites. Recoveries of PIT tags on breeding colonies of piscivorous waterbirds can also be used to calculate predation rates (percentage of available tagged fish consumed by birds) and to evaluate the relative susceptibility of different fish species, populations, rear-types, and migration histories to avian predators (Collis et al. 2001, Ryan et al. 2003, Antolos et al. 2005, Evans et al. 2012, Sebring et al. 2013, Hostetter et al. 2015, Evans et al. 2016b). Predation rates can also be used to compare smolt losses before and after bird management actions, data critical for evaluating the efficacy of management plans aimed at reducing avian predation (USFWS 2015, USACE 2014, USACE 2015, BRNW 2016b, Evans et al. 2016a).

The primary purpose for recovering PIT tags on the tern colony as part of this study is to generate population-specific (hereafter “ESU/DPS-specific”) predation rates on ESA-listed juvenile salmonids by Caspian terns nesting on East Sand Island in 2016, and to compare those estimates with results from previous years. A secondary objective is to evaluate the relative susceptibility of different groups of fish to Caspian tern predation in the Columbia River estuary, with a focus on fish run-timing, abundance, rear-type, and out-migration history, all traits or factors under a modicum of control by fisheries managers in the region. To ensure that estimates of predation rates generated from data collected in 2016 were comparable to estimates from years past, we used the same PIT tag predation rate modeling techniques used in previous years, those of Hostetter et al. (2015) and Evans et al. (2016a). These methods integrated multiple factors of uncertainty in the tag recovery process, including imperfect detection of tags present on bird colonies, on-colony tag deposition probabilities, and temporal changes in fish availability during the nesting season to terns nesting on East Sand Island.

Methods: Following previously established methods (Zamon et al. 2013, Evans et al. 2016a), a custom built eight-coil flat-plate PIT tag antenna attached to an ATV (*Figure 5*) was used to electronically recover PIT tags *in situ* on the East Sand Island Caspian tern colony from 22 September – 4 October 2016, after birds dispersed from the breeding colony. PIT tags were detected by systematically scanning the entire area occupied by nesting terns during the 2016 breeding season (*Map 3*), with nine complete passes or colony sweeps conducted over the sandy substrate. ATV tread marks were used to guide overlapping transects, ensuring all nesting substrate was scanned during each pass. Passes were conducted at a consistent speed and antenna height to optimize antenna performance (see Evans et al. 2016a for additional details).

In addition to the eight-coil flat-plate antenna, portable single antennas (*Biomark,* HPR series; *Figure 5*) were used to recover PIT tags in areas inaccessible to the ATV. These areas included nesting habitat adjacent to dissuasion fencing that surrounded the colony site and semi-vegetated habitat associated with two satellite tern colonies located on the upper beach to the south and northeast of the main tern colony on East Sand Island (*Map 3*).

In addition to electronic detection of PIT tags via antenna systems, PIT tags were also physically recovered (physical removal) from the main Caspian tern colony using a tow-behind sweeper magnet attached to an ATV (*Bluestreak*, Hog Series; *Figure 5*). The physical recovery of PIT tags from the colony surface has been shown to reduce tag collision, a phenomenon that renders PIT tags near each other undetectable using electronics. The physical removal of PIT tags, and subsequent hand scanning of each tag to acquire its unique code, increases tag detections at breeding sites where tag densities are high, like on the East Sand Island Caspian tern colony (Evans et al. 2016a). Both physical and electronic PIT tag recovery were conducted concurrently, when conditions permitted, as the use of the magnet required dry substrate.

Tag codes stored locally on transceivers were transferred to a central storage drive at the completion of each scanning session, along with metadata regarding the date and pass number. Tag data were uploaded to a cloud-based server for redundancy. All newly detected tag codes - those not detected on the tern colony as part of scanning efforts in previous years - were uploaded to the PIT Tag Information System (PTAGIS) using guidelines and protocols established by the PIT-tag Steering Committee (PTAGIS 2015).

Following previously established methods (Hostetter et al. 2015), a Bayesian hierarchical model was used to estimate predation rates based on the number of available (alive) PIT-tagged smolts detected passing upstream dams and the number recovered (dead) on the East Sand Island Caspian tern colony. The model adjusts, or corrects, for the probability that a tag consumed by a Caspian tern was deposited on the East Sand Island colony (referred to as "deposition probability") and the probability that a deposited tag was detected by researchers following the nesting season (referred to as "detection probability;" see *Figure 6* for conceptual illustration). Below is a detailed description of input parameters and model formulas used to calculate predation rates on PIT-tagged juvenile salmonids as part of this study.

Smolt Availability – Smolt availability to terns nesting on East Sand Island was based on interrogations of PIT-tagged fish passing Bonneville Dam (Rkm 234 on the lower Columbia River) and Sullivan Dam (Rkm 203 on the lower Willamette River), referred to as "in-river" migrating fish. At Bonneville Dam, PIT-tagged fish were interrogated within two different passage routes, the Juvenile Bypass System (JBS; a powerhouse route) or the Corner Collector (CC; a spill-like route). At Sullivan Dam fish were interrogated at a juvenile bypass system only. Both Bonneville and Sullivan dams are the nearest upstream dams to East Sand Island with adequate smolt PIT tag interrogation capabilities (Evans et al. 2012), and the location of each dam is considered the upper-most reaches of the Columbia River estuary, as defined by the USACE for the purposes of evaluating avian predation rates (USACE 2015). In addition to in-river migrants, PIT-tagged smolts that were loaded into transportation barges at dams on the lower Snake River and released below Bonneville Dam near Skamania Landing (Rkm 225), were also included in predation rate analyses, referred to as "transported" fish. Availability of transported smolts was based on fish interrogated or tagged at JBSs associated with Lower Granite Dam (Rkm 695), Little Goose Dam (Rkm 635), or Lower Monumental Dam (Rkm 589). Fish were classified as being collected for transportation based on a unique combination of the interrogation site (e.g., detected entering a raceway) and date at each JBS. Downstream interrogation histories, weekly JBS facility reports, and other sources (e.g., NOAA, USACE, and Fish Passage Center Technical Reports) were used to validate and otherwise proof classifications to ensure accurate assignment (in-river, transported). Due to small numbers of PIT-tagged fish and the use of a different transportation method, fish loaded into trucks at a JBS were not included in calculations of predation rates on transported smolts.

For in-river fish, smolt availability was defined as those fish last detected passing Bonneville or Sullivan dams between 1 March and 31 August, which reflects the periods of overlap in active PIT-tagged smolt out-migration and tern nesting activity on East Sand Island (Evans et al. 2012, Adkins et al. 2014). For transported fish, barge collection occurred between 1 May and 17 August. PIT-tagged fish were grouped by ESA-listed ESU/DPS, representing a unique combination of the species (steelhead trout, Chinook salmon, sockeye salmon), run-type (spring, summer, fall, or winter), and river-of-origin (Upper Columbia River, Middle Columbia River, Snake River, or Willamette River). The designation of ESU/DPS follows that of NOAA (2014) and was largely based on the tagging and release location of each fish relative to the geographic boundary of each ESU/DPS. Fish within each ESU/DPS were further grouped by rear-type (hatchery/wild), out-migration history (in-river/transport), and week (see Predation Rate Calculations below for details). Interrogation data from live fish passing Bonneville and Sullivan dams or fish collected at a JBS on the lower Snake River were obtained from PTAGIS (www.ptagis.org).

Not all ESA-listed ESUs/DPSs in the Columbia River Basin were included in predation rate calculations, as four ESUs/DPSs originate wholly or partially below Bonneville and Sullivan dams and were therefore excluded because temporal and spatial interrogation records of live fish were not available. Excluded ESUs/DPSs included (1) Lower Columbia River steelhead trout, (2) Lower Columbia River Chinook salmon, (3) Lower Columbia River coho salmon *O. kisutch*, and (4) Columbia River chum salmon *O. keta*. In addition to ESA-listed salmonids, non-listed salmonids (e.g., sea-run cutthroat trout *O. clarki clarki*) and other fishes (e.g., Pacific lamprey *Lampetra tridentate,* eulachon *Thaleichthys pacificus,* white sturgeon *Acipenser transmontanus*) were available as prey to Caspian terns nesting on East Sand Island, fish that are of cultural, economic, and/or conservation concern. Tags from these other fishes are occasionally recovered on the East Sand Island Caspian tern colony, although some of these species are either not PIT-tagged (e.g., eulachon) or sample sizes are too small for estimation of predation rates (e.g., Pacific lamprey; BRNW 2015a). Including these other fishes was thus beyond the scope of this study, but efforts to reduce the number of Caspian terns nesting on East Sand Island will presumably benefit these other fishes as well (USACE 2015).

PIT Tag Deposition and Detection Probabilities – Not all fish PIT tags that are ingested by colonial waterbirds are subsequently deposited on their nesting colony (Hostetter et al. 2015). For instance, a portion of PIT tags consumed by birds are damaged during digestion or are regurgitated off-colony at loafing, staging, or other areas used by birds during the breeding season. Deposition probability was previously estimated by feeding PIT-tagged fish to Caspian terns nesting on East Sand Island and subsequently recovering those tags on the East Sand Island tern colony (Hostetter et al. 2015). Deposition probabilities measured during these previous experiments were used to infer deposition probabilities for data collected in 2016. Use of deposition probabilities from data collected in previous years was deemed appropriate because results of deposition experiments indicate that deposition probabilities did not vary significantly within or between breeding seasons (see Hostetter et al. 2015 for additional details). Based on research from Hostetter et al. (2015), the distribution of the median deposition probability for Caspian terns on East Sand Island is estimated at 0.71 (95% creditable interval = 0.51–0.89). This means that for every 100 PIT-tagged fish consumed by Caspian terns nesting on East Sand Island, about 70 are deposited on the colony where researchers can recover them following the nesting season.

Not all PIT tags deposited by birds on their nesting colony are subsequently found by researchers after the breeding season (Evans et al. 2012). For example, tags can be blown off the colony during wind storms, washed away during flooding events, or otherwise damaged or lost during the breeding season. Furthermore, the detection methods used to recover PIT tags on bird colonies are not 100% efficient, with some proportion of detectable tags missed by researchers during the scanning process. Unlike deposition probabilities, detection probabilities often vary significantly within and between nesting seasons (Evans et al. 2012; Hostetter et al. 2015), variation that necessitates a direct measure of detection probabilities in each study year. Inter-annual differences in habitat available (e.g., the amount and location of prepared nesting habitat associated with tern management) and habitat use (e.g., the location of nesting birds, including satellite colonies) by terns on East Sand Island prevents the use of previously deposited smolt tags (those naturally deposited by birds during the preceding nesting season) in determining detection probabilities on East Sand Island (Evans et al. 2016a). Instead, detection probabilities are more directly modeled using PIT tags (with known tag codes) intentionally sown by researchers on the East Sand Island Caspian tern colony (hereafter referred to as "control tags") prior to, during, and following each breeding season to quantify PIT tag detection probability (see *Predation Rate Calculations* below). Control tags were the same size and frequency as the clear majority of PIT tags used to mark juvenile salmonids from the Columbia River basin (12 mm, ISO FDXB). During each discrete tag sowing event in 2016, control tags were haphazardly sown throughout the area occupied by nesting terns on East Sand Island. Detections (i.e., recoveries) of control tags during scanning efforts after the breeding season were then used to model the probability of detecting tags that were deposited by birds at different times during the breeding season via logistic regression (see *Predation Rates Calculations* below for details). Following previously established methods (Evans et al. 2012; Hostetter et al. 2015), equal numbers of control tags were sown during each discrete sowing event. Sample sizes of control tags (n = 100 per event) were selected by considering previous releases (see *Results and Discussion* for additional details). This allows direct comparisons of independent detection probabilities, with similar precision between years.

Predation Rate Calculations – Following the methodology of Hostetter et al. (2015), predation rates were modeled independently for each salmonid ESU/DPS. The probability of recovering a PIT tag on the East Sand Island Caspian tern colony was modeled as the product of the three probabilities described above, the probability that (1) the fish was consumed (θ), (2) the PIT tag was deposited on-colony (ϕ), and (3) the PIT tag was detected on-colony (ψ_i) (see also *Figure 6*):

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

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 probability (ψ_i) and predation probability (θ_i) were each modeled as a function of time. The probability, ψ_i, that a tag, consumed in week *i* and then deposited on the colony and detected, was assumed to be a logistic function of week. That is:

$$logit(\psi_i) = \beta_0 + \beta_1 * i$$

where β_0 and β_1 were both derived using non-informative priors (normal [0, 1000]). Weekly predation probability, θ_i, was modeled as a random walk process with mean μ_θ and variance σ_θ^2, where:

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

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

Informative Beta (α, β) priors were used to model deposition probability (ϕ). We assumed α = 16.20 and β = 6.55 (Hostetter et al. 2015).

Weekly predation rate estimates were defined as the estimated number of PIT-tagged smolts consumed divided by the total number last detected passing Bonneville Dam, Sullivan Dam, or released from barges near Skamania landing in each week. Annual predation probabilities 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 at Bonneville Dam, Sullivan Dam, or released from barges:

$$\sum_{i \in breeding\ season} (\theta_i * n_i) \Big/ \sum_{i \in breeding\ season} (n_i)$$

Predation Rates Prior to and Following Management Actions – If given enough time and a significant decrease in the number of nesting birds, it is expected that the management of Caspian tern on East Sand Island will have a measurable effect on predation rates. This hypothesis can be tested by comparing posterior distributions of average annual ESU/DPS-specific predation rates before and after management actions. Comparisons of predation rates by management period were defined as those during 2000-2010 (pre-management) and those during 2011-2016 (post-management). The post-management time was considered to have started in 2011 because this was the first year that reductions in nesting habitat at East Sand Island resulted in a significant reduction in the number of terns below the pre-management average (Evans et al. 2016a; see also *Figure 2*).

Predation Rates by Rear-type, Out-migration History, and Passage Route – Inclusion of a fish's rear-type (hatchery, wild), out-migration history (in-river, transport), and passage route (JBS, CC; for in-river migrants passing Bonneville Dam) was achieved through a re-parameterization such that

$$k_{iv} \sim Binomial(n_{iv}, \theta_{iv} * \phi * \psi_i)$$

where k_{iv} is the number of smolt PIT tags in category *v* recovered from the number available (n_{iv}) in week *i*. This approach allows a common estimate of deposition and detection across categories, which facilitates increased precision (i.e., smaller bounds around the estimate). Annual and weekly predation probabilities for each category can then be calculated using the methods described above.

Building on this approach and to evaluate whether one subset or category of fish (e.g., hatchery fish) was more susceptible to Caspian tern predation than another (i.e., wild fish), comparisons of rates were made on weekly and annual bases. Comparisons between groups were made letting ρ represent the average proportional difference in the odds of predation over the study period, with a value less than or greater than 1.0 indicating a preference for a group of fish, and a value of 1.0 showing no preference. For instance, a value of 1.55 indicates that the odds of a fish being consumed are 55% greater for that category of fish. We tested for statistically significant differences using logistic regression. The weekly estimates of predation were treated as mutually independent, allowing the focus to be limited to only the proportion of recovered tags (corrected for detection and deposition probabilities) from those last detected at the nearest upstream dam or release site. Therefore

$$k_{iv_0} \sim Binomial(n_{iv_0}, \theta_{iv} * \phi * \psi_i)$$
and
$$k_{iv_1} \sim Binomial\left(n_{iv_1}, \rho * \theta_{iv} * \phi * \psi_i\right)$$

and we are testing the hypothesis H_0: $\rho = 1.0$. This test was applied to all appropriate ESUs/DPSs for each comparison. To simplify visual comparisons of output, data were plotted as the log-odds ratio, with values greater than or less than 0 indicating a preference for a group of fish (95% confidence intervals that over-lap 0 were not statistically significant).

Density-dependent Predation – Prior research on Caspian terns suggests that predation rates are influenced by the number or density of prey available, whereby as the number of prey available increases, predation rates decrease. Hostetter et al. (2012) theorized that this inverse relationship was due to predator swamping, with the probability of an individual fish being consumed decreasing as the number or density of prey increases. This functional relationship most closely resembles a Type II predation response or mortality curve (ISAB 2016). Data to support or refute this functional response to prey availability in Caspian terns, however, has been based on small sample sizes of fish and a limited number of study years.

To more thoroughly investigate the response of Caspian tern predation rates to varying levels of smolt availability, we reexamined weekly predation rates on all PIT-tagged steelhead arriving at Bonneville Dam between 2006 and 2016. This temporally expansive dataset allowed for an effective evaluation of the fit of the model and a precise enumeration of the relationship. We implement this functional relationship into the standard predation rate model using logistic regression. That is, we model θ_{yi}, the predation rate from week *i* in year *y,* as a function of the number of PIT-tagged steelhead interrogated a Bonneville Dam (n_{yi}) in the same week:

$$logit\left(\theta_{yi}\right) = \mu_{\theta_y} + \beta_{available} * \frac{n_{yi}}{\sum_w n_{yw}} + \sum_{w \le i} \varepsilon_{yw}.$$

Due to varying numbers of PIT-tagged steelhead annually interrogated passing Bonneville Dam, we incorporated the proportional availability (i.e., proportion of the total number interrogated passing Bonneville Dam) into the model rather than using weekly numbers of tagged fish directly. However, letting N_y represent the actual total number of steelhead released from Bonneville in year *y* and letting ρ_{yi} represent the actual proportion of fish passing Bonneville Dam in week *i* of year *y,* and assuming $\frac{n_{yi}}{\sum_w n_{yw}}$ to be an accurate measure of ρ_{yi}, then this model is equivalent to

$$logit(\theta_{yi}) = \mu^*_{\theta_y} + \beta_{available} * \frac{n_{yi}}{\sum_w n_{yw}} N_y + \sum_{w \leq i} \varepsilon_{yw}$$

where $\mu^*_{\theta_y} = \mu_{\theta_y} + \frac{\beta_{available}}{N_y}$ and, therefore, is equivalent to the Type II predation availability response model. The estimate of $\beta_{available}$ was derived using a non-informative prior (normal [0, 1000]).

All predation rate models described above were implemented using the software JAGS (Plummer 2003) accessed through R version 3.1.3 (R Core Team 2015) using the R2jags (Su 2015) and dclone (Solymos 2013) R packages. Three parallel chains were run for 80,000 iterations each, after an initial 10,000 iteration burn-in, to diagnose and confirm convergence. Chain convergence was tested using the Gelman-Rubin statistic ($\hat{R}$; Gelman et al. 2004). A single "long-run" of 150,000 Markov Chain Monte Carlo iterations were run to produce the final posterior distribution from which final estimates were derived (Raferty 1992). Chains were thinned by 20 to reduce autocorrelation inherent to successive MCMC samples. Results were reported as posterior medians along with the 2.5 and 97.5 percentiles, which are referred to as 95% credible intervals (95% CI). Annual predation rates were calculated for salmonid ESUs/DPSs where ≥ 500 PIT-tagged individuals were considered available to birds in each year to avoid imprecise results that may occur from small sample sizes of available PIT-tagged smolts (Evans et al. 2012).

Model Assumptions – Estimated predation rates were based on the following model assumptions:

A1. Information from PTAGIS on release and interrogation of PIT-tagged salmonids were complete and accurate.

A2. PIT-tagged smolts detected passing Bonneville Dam, Sullivan Dam, or released from barges were available to birds nesting downstream.

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

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

A5. The deposition probabilities for PIT tags measured in previous years were equal to those of smolt PIT tags consumed by birds during the current study year.

A6. PIT tags from consumed fish were egested by avian predators within a relatively short time period (one week) of the PIT-tagged fish being detected passing an upstream dam or released from a barge.

A7. PIT-tagged fish are representative of non-tagged fish belonging to the same ESU/DPS and passing the same detection (dam), release site (barge) or passage route (JBS, CC).

To help meet the first assumption (A1), irregular entries in PTAGIS were either verified by the respective coordinator of the PIT-tagging effort or were censored from the analysis. Detections of PIT-tagged salmonids at dams or release sites upstream of bird colonies is deemed the most appropriate measure of fish availability given the downstream movement of smolts, the ability to standardize data across sites, and the ability to define unique groups of salmonids by a known location and passage date (Assumption A2). Assumption A2 assumes all PIT-tagged fish last detected passing a dam or released via barge were alive and available to predators downstream. If large numbers of fish halt their out-migration or died immediately following passage/release and prior to reaching the foraging range of Caspian terns nesting on East Sand Island, predation rates would be biased low. The fate of each PIT tag implanted in a smolt is assumed to be independent (A3). Lack of independence among PIT-tagged fish could potentially bias predation probabilities and overinflate measures of precision (i.e., credibility intervals). Detection probability estimates (A4) on tern colony were high (ca. 80%; see *Results and Discussion*), indicating that any possible violations of assumption A4 would have little effect on estimates of predation rates. Deposition rate data collected in year's past (when multiple estimates of deposition rates were measured for terns over the course several time periods and years; see Hostetter et al. 2015) showed no evidence of inter- or intra-annual trends in deposition probabilities (Assumption A5).

Assumption A6 relates to the use of the last date of live fish detection as a proxy for the date a PIT tag was deposited on a bird colony. This assumption needs to be only roughly true because detection efficiency did not change dramatically on a weekly basis (see *Results and Discussion)*. Assumption A7 relates to inference regarding the susceptibility of a PIT-tagged fish to consumption as it relates to all fish (tagged, untagged) from the same cohort (ESU/DPS, rear-type, etc.). There are few empirical data to support or refute assumption A7, except that the general run-timing and abundance of PIT-tagged fish is often in agreement with the run-timing and abundance of untagged fish passing dams in the Columbia River Basin. For some populations, smolts were intentionally PIT-tagged in concert with the run passing a given dam to better ensure that a representative sample of fish were available for analyses (see Evans et al. 2014). For other groups of fish, however, individuals may have been culled for tagging based on their condition or size or only a small number or proportion of available fish were PIT-tagged of a given cohort or stock due to a lack of funding and/or due to shifting regional research, monitoring, and evaluation priorities each year.

Results and Discussion: Following the breeding season, 9,093 PIT tags from 2016 migration year smolts (Chinook salmon, coho salmon, sockeye salmon, and steelhead combined) were recovered (detected electronically with antennas or physically removed with magnets) on the East Sand Island Caspian tern colony (*Table 7*). Numbers of PIT tags recovered from the Caspian tern colony in 2016 were similar – albeit lower – to numbers recovered in 2015 (n = 13,990 PIT tags) and substantially lower than the average number recovered during 2000-2014 (mean = 27,596 PIT tags; Evans et al. 2016a).

Recoveries of control PIT tags sown on the East Sand Island tern colony indicated that detection probability or efficiency ranged from 56 – 90% for PIT tags deposited on-colony between 1 March and 31 August 2016 (*Table 7*). Average annual detection efficiency in 2016 (82%) was like that in 2015 (84%), but higher than that observed during 2011-2014 (*Figure 7*). Recent increases in detection efficiency on the East Sand Island Caspian tern colony were likely due to efforts to physically remove PIT tags using a sweeper magnet towed behind an ATV (*Figure 5*). Physical recovery was conducted simultaneously with most electronic passes, with > 16,000 functional PIT tags removed during fall scanning efforts in 2016. Many of these removed PIT tags were from previous migration years (> 70% of all removed tags were from smolt migration years prior to 2016). This result indicates that PIT tags were gradually accumulating on the colony, that some PIT tags have remained on-colony since its inception, and that the large number of accumulated PIT tags likely contributes to significant tag collision effects. Results from PIT tag removal efforts to date (2015 and 2016) suggest that future efforts to physically remove PIT tags will improve or maintain high on-colony detection efficiency by minimizing tag collision, as well as recover a significant number of PIT tags that were previously undetected, despite substantial efforts to electronically detect PIT tags in past years (Zamon et al. 2013). Habitat management directed at the East Sand Island Caspian tern colony in recent years (i.e., incremental reduction of colony area) has increased on-colony PIT tag collision due to greater nesting densities of terns, and will likely require the continual removal of PIT tags to ensure the precision of future estimates of predation rates derived from PIT tag recovery on the East Sand Island tern colony.

Based on previous studies that empirically measured deposition rates for Caspian terns nesting on East Sand Island, deposition rates were estimated to be 71% (95% CI = 51–89%; *Table 7* and Hostetter et al. 2015).

Predation Rates – Estimated predation rates on in-river migrants indicated that steelhead were the species of salmonid smolt most susceptible to predation by Caspian terns nesting on East Sand Island in 2016, with predation rates ranging from 6.1% (95% CI. = 4.8 – 8.8%) on Snake River steelhead to 8.8% (95% CI = 6.4 – 13.0%) on Middle Columbia River steelhead (*Table 8*). By comparison, predation rates on salmon ESUs were significantly lower than those on steelhead DPSs, ranging from 0.7% (95% CI = 0.3 – 1.3%) on Snake River Fall Chinook salmon to 1.4% (95% CI = 0.9 – 2.1%) on Upper Columbia River spring Chinook salmon (*Table 8*). ESU/DPS-specific predation rates on in-river migrants were not significantly different amongst steelhead DPSs or amongst salmon ESUs. Predation rate estimates were not available for in-river Snake River sockeye due to inadequate sample size (< 500 PIT-tagged fish; see *Methods*) of available fish passing Bonneville Dam in 2016.

The differences in smolt susceptibility to tern predation observed in 2016 were like those observed in previous years, with Caspian tern predation rates on steelhead DPSs often 5 to 10 times greater than those on salmon ESUs (*Appendix B*, *Table B1-B2*). Higher predation rates by Caspian terns on juvenile steelhead compared with salmon is well documented in the published literature (Collis et al. 2001, Ryan et al. 2003, Evans et al. 2012, Evans et al. 2016b). Possible explanations for the greater susceptibility of steelhead to tern predation include differences in the size (length) and behavior of steelhead compared with other salmonid species. Hostetter et al. (2012) and Evans et al. (2016b) noted size-selectivity amongst avian predators, with larger fish often depredated at a higher rate than smaller fish, and juvenile steelhead are, on average, larger than juvenile salmon. Beeman and Maule (2006) observed that steelhead smolts were more surface-oriented compared with salmon smolts. Surface orientation is believed to render fish more vulnerable to predation by Caspian terns, a plunge diving species that forages in the top meter of the water column (Cuthbert and Wires 1999).

Predation rates on transported smolts from the Snake River in 2016 also indicated that steelhead were disproportionately consumed compared with salmon, with predation rates on transported Snake River steelhead (11.3%; 95% CI = 8.9-16.2) significantly higher than those of Snake River spring/summer-run Chinook salmon (0.8%; 95% CI = 0.6-1.1), Snake River Fall Chinook salmon (1.1%; 95% CI = 0.8-1.6), and Snake River sockeye salmon (5.9%; 95% CI = 4.2-8.7; *Table 8*). Relative to other salmon ESUs, however, predation rates on transported Snake River sockeye salmon were significantly higher than those of transported fall and spring/summer Chinook salmon, an unexpected finding based on the consistently low predation rates observed on Snake River sockeye salmon in previous years. For instance, predation rates on both in-river and transported groups of Snake River sockeye by Caspian terns on East Sand Island in previous years were less than 2.5% of available fish in all years where adequate sample sizes of tagged sockeye were available for analysis (*Appendix B, Tables B1-B2*). Transported sockeye salmon did not arrive in the Columbia River estuary until after most in-river spring migrants had passed through the estuary (*Figure 8*) and, due to the protracted nesting chronology of Caspian terns on East Sand Island in 2016 relative to previous years, transported sockeye salmon were available to terns during the peak of the breeding season (*Figure 1 and Figure 8*). These factors may explain the unusually high predation rates observed on transported Snake River sockeye and, to a lesser degree, transported steelhead in 2016 (see *below*).

In comparison with predation on in-river migrating smolts, predation rates on transported smolts in 2016 were generally higher (*Table 9*). Differences in run-timing (arrival times in the estuary) between in-river and transported smolts largely explains the relative susceptibility of in-river versus transported smolts in 2016, with most in-river fish arriving in the estuary several weeks earlier than transported fish. As noted above for sockeye salmon, the delayed peak onset of breeding in Caspian terns during 2016 was another factor that likely contributed to higher predation rates on transported fish compared with in-river fish. For instance, weekly predation rates on steelhead migrants arriving in the estuary in April were significantly lower than smolts that arrived in May and June, and transportation did not commence on the lower Snake River until 1 May.

Predation Rates Before and After Management Actions – ESU/DPS-specific predation rates in 2016 were some of the lowest ever recorded for Caspian terns nesting on East Sand Island (*Appendix B, Table B1*). Average annual predation rates on PIT-tagged smolts by Caspian terns were significantly lower following management actions on East Sand Island during 2011-2016, compared with predation rates prior to management during 2000-2010 (*Table 10*). Average annual predation rates on Snake River steelhead during 2000-2010 were 22.2 (95% CI = 20.3–24.8%), compared with 10.2% (95% CI = 9.0–11.9%) following management actions to reduce the available tern nesting habitat on East Sand Island during 2011-2016 (*Table 10*). Similar reductions were observed in predation rates on other steelhead and salmon DPSs/ESUs.

Reductions in Caspian tern predation rates during 2011-2016 coincided with proportional reductions in colony size (nesting pairs) at East Sand Island, with evidence of a linear relationship (*Figure 9*). Results indicate that Caspian tern management initiatives aimed at reducing nesting habitat on East Sand Island are resulting in lower average annual predation rates on many ESA-listed salmonid ESUs/DPSs, particularly predation on steelhead DPSs. Post-management reductions in the number of Caspian terns on East Sand Island have not, however, reached management target goals (between 3,125 and 4,375 nesting pairs) because Caspian terns have increased their nesting density on East Sand Island in response to reduced nesting habitat (*Figure 3*). Thus, further reductions in the number of Caspian terns nesting on East Sand Island will likely further reduce Caspian tern predation rates. For instance, if management could achieve the target tern colony size goals, average annual predation rates on steelhead smolts would be about 2-5% per DPS, based on a linear extrapolation of per capita (per bird) predation rate results from data collected during 2000-2016.

Colony size, although an important factor regulating predation rates, is not the only factor affecting predation rates by East Sand Island Caspian terns on PIT-tagged salmonids. In a multiyear analysis of steelhead predation rates, Evans et al. (2016a) concluded that numerous biotic and abiotic factors (covariates) explained variation in annual Caspian tern predation rates. For instance, in addition to colony size, the productivity (number of young raised) of the colony, river flows (spill and discharge), the relative abundance of steelhead in the estuary, and large-scale climate indices (North Pacific Gyre and regional upwelling) were all associated with variation in steelhead predation rates. Lyons (2010), Weitkamp et al. (2012), and Evans et al. (2016a) hypothesized that environmental factors influence the availability of marine forage fish within the estuary and that predation rates on salmonids decrease as marine forage fish availability in the estuary increases. Additional research, however, is needed to more fully understand the influence of biotic conditions on smolt susceptibility to avian predation in the Columbia River estuary (Evans et al. 2016a).

Predation Rates by Rear-type, Out-migration History, and Passage Route – There was strong evidence that hatchery Snake River spring/summer run Chinook salmon and hatchery Upper Columbia River spring Chinook salmon were more susceptible to predation by East Sand Island Caspian terns then their wild counterparts in 2016, as well as in previous years (2006-2015; *Table 10*). For example, the odds of predation were, on average, 62% and 66% greater for hatchery Snake River spring/summer Chinook salmon and hatchery Upper Columbia River spring Chinook salmon, respectively, compared to their wild counterparts over the course of the last decade (*Table 10*). Differences were consistent in all annual and weekly comparisons (2006-2016; *Appendix C*, *Figure C1*). Conversely, there was no evidence of a consistent difference in the relative susceptibility of hatchery and wild Snake and Upper Columbia River steelhead to predation by East Sand Island Caspian terns (*Table 10* and *Appendix C*, *Figure C1*). For example, in some years (e.g., 2016) wild steelhead were more susceptible to tern predation than hatchery steelhead, but in other years (e.g., 2011), the reverse trend was observed. In most years, differences were not statistically significant, and when data from all weeks and all years were considered, there is no evidence of a difference in tern predation rate based on steelhead rear-type.

Data from other studies indicate that both behavior and physical traits associated with hatchery-raised salmonids may enhance susceptibility to predation (Olla and Davis 1989, Fritts et al. 2007, Hostetter et al. 2012, Evans et al. 2016a). Evans et al. (2016a) attributed the increased susceptibility of hatchery Chinook salmon to Caspian tern predation to differences in the size (fork length) between hatchery and wild spring/summer Chinook salmon last detected passing Bonneville Dam. An analysis of Chinook salmon length data indicated that hatchery fish averaged 144 mm and wild fish 111 mm, and that the odds of Caspian tern predation increased by 12% (95% CI = 11.9–12.6%) for every 10 mm increase in fork-length. Hostetter et al. (2012) also found evidence of size-selectivity in Caspian terns nesting at Crescent Island (Rkm 509) in McNary Reservoir, with larger PIT-tagged fish more likely to be preyed upon than smaller PIT-tagged fish up to about 175 mm, at which point fish were equally susceptible to predation up to about 225 mm. Predation rates on steelhead > 225 mm then rapidly decreased as fish reached or exceeded the maximum prey size for Caspian terns of about 275 mm (Cuthbert and Wires 1999, Lyons 2010). The majority (> 80%) of hatchery and wild PIT-tagged steelhead included in this study, those with length data recorded during the smolt out-migration period, were between 175 and 225 mm, fish with similar length-dependent selectivity profiles.

There was some evidence that Caspian terns disproportionately consumed transported Snake River steelhead relative to in-river steelhead in 2016, with the odds of predation 19% greater for transported fish (*Table 10*). Over the course of the last decade, however, odds-ratios based on out-migration history were close to 1.0 (no preference) for steelhead, with no consistent trend identified across weeks within a given year or across all years (2006-2016; *Table 10* and *Appendix D, Figure D1*). There was also some evidence that in-river Snake River spring/summer Chinook salmon were more likely to be consumed then their transported counterparts, but preferences for in-river fish were relatively small in most weeks and years (*Table 10* and *Appendix D, Figure D1).* There was no evidence of differential predation between in-river and transported Snake River fall Chinook salmon to Caspian tern predation, a finding driven in part by the low overall predation rates on salmon by Caspian terns during 2006-2016. For example, predation rates by Caspian terns on Snake River fall Chinook salmon were < 3% for both groups (in-river and transported; see *Appendix B*, *Table B1* for in-river predation rate estimates and *Appendix B, Table B2* for transport predation rate estimates). A similar finding of no preference was also evident for Snake River sockeye salmon; however, sample sizes of in-river sockeye salmon were inadequate (< 500 PIT-tagged fish) to make comparisons in 2016, a year when predation rates on transported Snake River sockeye salmon (5.9%; 95% CI = 4.2-8.7%) were surprisingly high relative to other salmon ESUs and relative to data from previous years (*Appendix B, Table B2*).

There was no evidence that passage route at Bonneville Dam (JBS versus CC) was associated with differences in predation rates by Caspian terns nesting on East Sand Island, with JBS and CC interrogated smolts exhibiting essentially equal susceptibility to predation during 2006-2016 (*Table 10* and *Appendix E, Figure E1).* In fact, none of 61 weekly comparisons or 11 annual comparisons were statistically significant, indicating that passage route at Bonneville Dam had little or no effect on a fish's susceptibility to Caspian tern predation in the Columbia River estuary. This result is perhaps not surprising given the distance between Bonneville Dam (Rkm 234) and East Sand Island (Rkm 8) and the maximum reported foraging range of 100 km for nesting Caspian terns (BRNW 2015a). In a study of California gull predation on juvenile steelhead, Evans et al. (2016b) observed that fish in the tailrace of dams were more susceptible to gull predation than fish in the open reservoirs. Thus, the location of the colony relative to the dam and the species of avian predator are important factors to consider.

Ultimately, the probability of an individual fish surviving the juvenile life stage is determined by a complex set of factors, including individual fish characteristics and environmental conditions (Muir et al. 2001, Zabel et al. 2005, Hostetter et al. 2011; Hostetter et al. 2012; Evans et al. 2016a; this study). Differences in fish size and condition, run-timing, origin (hatchery, wild), out-migration history, and abundance and spatial distribution have all been linked to susceptibility to bird predation. Due to a lack of empirical data on the condition of smolts in the estuary, the absolute abundance of smolts (as opposed to relative abundance; see below), and spatial distribution of smolts in the Columbia River estuary, additional research will be needed to more fully understand these factors and how (or if) they can be managed to reduce predation rates by Caspian terns above and beyond efforts aimed at reducing colony size on East Sand Island.

Density-dependent Predation – An investigation of weekly predation rates by East Sand Island Caspian terns indicates that predation rates were generally lower when the largest number of PIT-tagged smolts were available as prey in the estuary in 2016 (*Figure 8*). For instance, predation rates on steelhead DPSs were the lowest during the peak of the run and higher before (early April) and after (late May) the peak. For most ESUs/DPSs evaluated, predation rates were particularly high during the last few weeks of the smolt run (*Figure 8*). Trends in weekly predation rates observed in 2016 were like those observed by Hostetter et al. (2012) and Evans et al. (2016a), and are consistent with the predator-swamping hypothesis (Ims 1990). A more robust analysis, whereby weekly predation rates were considered for the last 11 years and a statistical test of the relationship was investigated, indicates that the trend of decreased predation rates at higher levels of availability is statistically significant and persistent across time (*Figure 10*). Using the logistic regression implementation of the Type II predation abundance response model, we estimate that, for each additional 10% increase in the proportion of annual available steelhead each week, the relative odds of predation decline by a factor of 0.82 (95% CI = 0.75-0.89). The lack of information on either the percentage of out-migrating steelhead tagged or the total number of steelhead surviving to the estuary (i.e., absolute abundance) precludes any further evaluations (e.g., predation as a function of the total number of fish consumed or as function of weekly colony attendance). Future research investigating the variation in the total number of consumed steelhead within and among years could be valuable in assessing the full impact of run-timing and other factors on steelhead predation by Caspian terns.

Predation Rates by Other Piscivorous Colonial Waterbirds – Predation rate results presented herein are limited to Caspian terns nesting on East Sand Island, but Caspian terns occasionally nest elsewhere in the estuary (e.g., Rice Island at Rkm 34) and other piscivorous colonial waterbirds nest on East Sand Island, including the largest colony of double-crested cormorants in western North American (BRNW 2015a). Because multiple colonies and multiple predators consume juvenile salmonids, an investigation of cumulative impacts on smolt survival is ultimately needed to characterize the total or net impact of piscivorous waterbirds on ESA-listed smolts in the Columbia River estuary. Cumulative impacts by double-crested cormorants and Caspian terns nesting on East Sand Island during 2006-2015 were estimated to be in excess 10% and 20% of available salmon and steelhead ESUs/DPSs, respectively, in most years (Evans et al. 2016a). Using diet composition data and bioenergetics modeling, BRNW (2014a) estimated that Caspian terns and double-crested cormorants nesting on East Sand Island annually consumed between 7 and 27 million smolts. Results suggest that reductions in the size of the Caspian tern and double-crested cormorant colonies must be both large and sustained before management goals to reduce avian predation can be fully realized in the Columbia River estuary.

Data from multiple predators will also results in a more comprehensive evaluation of factors that influence fish susceptibility to avian predation in the Columbia River basin. For example, a multi-predator evaluation conducted by Evans et al. (2016a) indicated that, unlike Caspian terns, double-crested cormorants nesting on East Sand Island consumed fish in proportion to their availability, with predation rates increasing as the number of smolts availability to them in the estuary increased, more analogous to a Type III mortality curve (ISAB 2016). Double-crested cormorants also consumed a larger proportion of available salmon than Caspian terns, but a lower proportion of available of steelhead. Finally, multiple predator studies indicate that not all colonial waterbirds that reside in the Columbia River estuary pose a significant threat to smolt survival. For instance, Couch and Lance (2004) noted that Brandt's cormorants, a pelagic foraging species, more commonly consumed non-salmonid prey-types (e.g., anchovy, herring, smelt, and others) than salmonid prey-types. Evans et al. (2016a) observed that predation rates by Brandt's cormorants nesting on East Sand Island in 2015 were < 0.6% per salmonid ESU/DPS, despite a recent and steady increase in the size of the East Sand Island colony of Brandt's cormorants.

SECTION 2: GULLS & PELICANS

Methods: Counts of the number of adults on-colony at East Sand Island were not conducted for glaucous-winged/western gulls or for ring-billed gulls in 2016, but these species were monitored during active dissuasion (see above). The peak number of California brown pelicans using East Sand Island in 2016 was determined by conducting periodic boat-based surveys (approximately every two weeks) from mid-May through early November. Because three California brown pelican nests containing eggs were discovered on East Sand Island in 2013 and eleven nests were also initiated in 2014 (although no egg-laying was confirmed), an effort was made to detect any nesting activity by brown pelicans during the 2016 breeding season. In addition to increased direct effort by field researchers, six remote sensing camera traps were positioned to cover areas of prior nesting attempts by pelicans in 2013 and 2014, an area where we suspected brown pelicans might attempt to nest again.

Results and Discussion: As in previous years, large numbers of both glaucous-winged/western gulls and ring-billed gulls nested on East Sand Island. Also, as in previous years, East Sand Island was used as a large post-breeding, nighttime roost by California brown pelicans.

East Sand Island is the largest known post-breeding nighttime roost site for California brown pelicans, and the only known night roost for this species in the Columbia River estuary (Wright 2005). In 2016, the first California brown pelicans were observed roosting on East Sand Island on 23 April. These first pelicans were roosting on the southeast beach above the high-water line, not far from where nests were discovered in 2013-2014. The bi-weekly counts of California brown pelicans on East Sand Island peaked in mid-August at 5,076 individuals (*Figure 11*), appreciably lower than the peak count in 2015 (9,285 individuals) and the 16-year average (8,850 individuals; *Figure 12*).

On 25 August, two brown pelican nests were discovered at the base of the bluff overlooking the southeast beach, just west of the main Caspian tern colony; one of the nests contained three eggs. On 10 September, up to eight (most poorly formed) active brown pelican nest structures were observed in this same area, one containing two eggs. A week later, all the pelican nests were abandoned, including the nests that contained eggs. Nesting behaviors by brown pelicans have been observed on East Sand Island in previous years; as was the case in 2016, all previous nesting attempts were unsuccessful.

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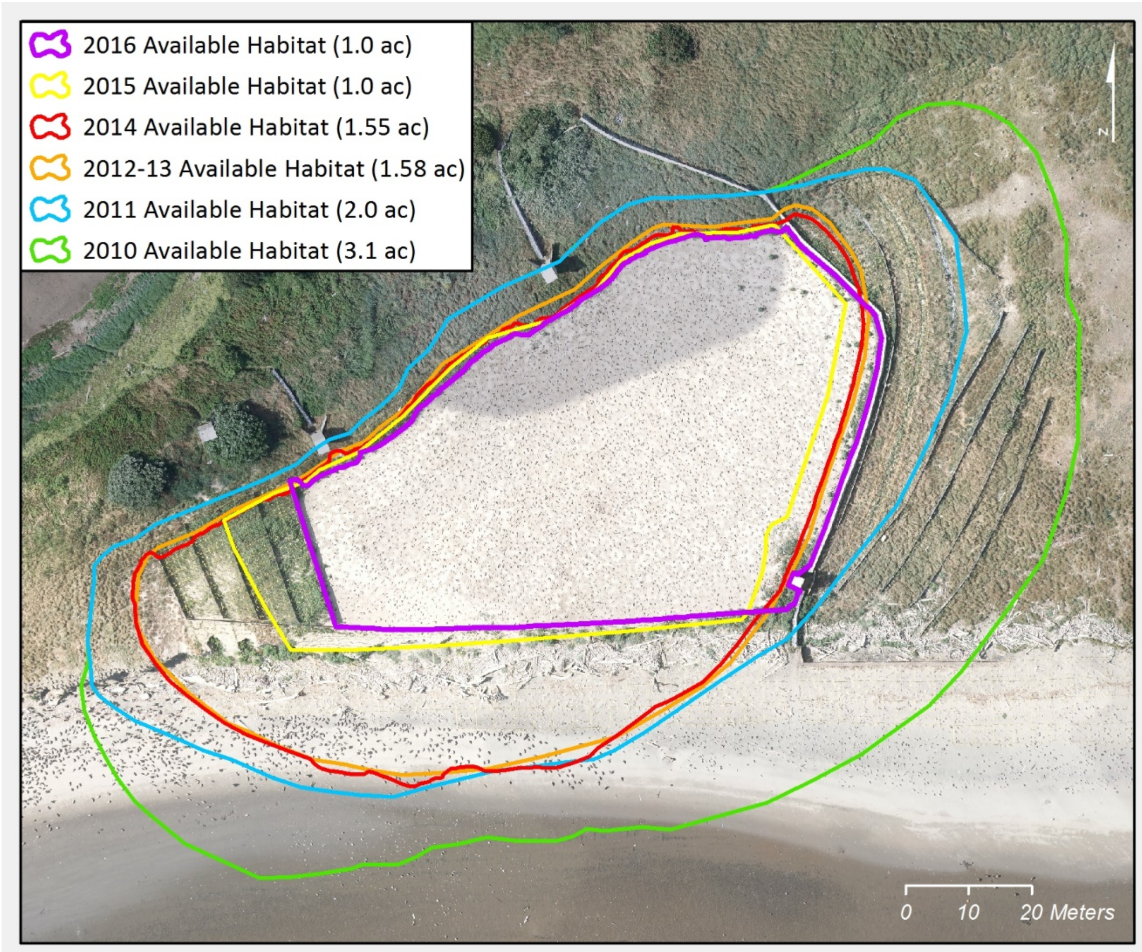
MAPS

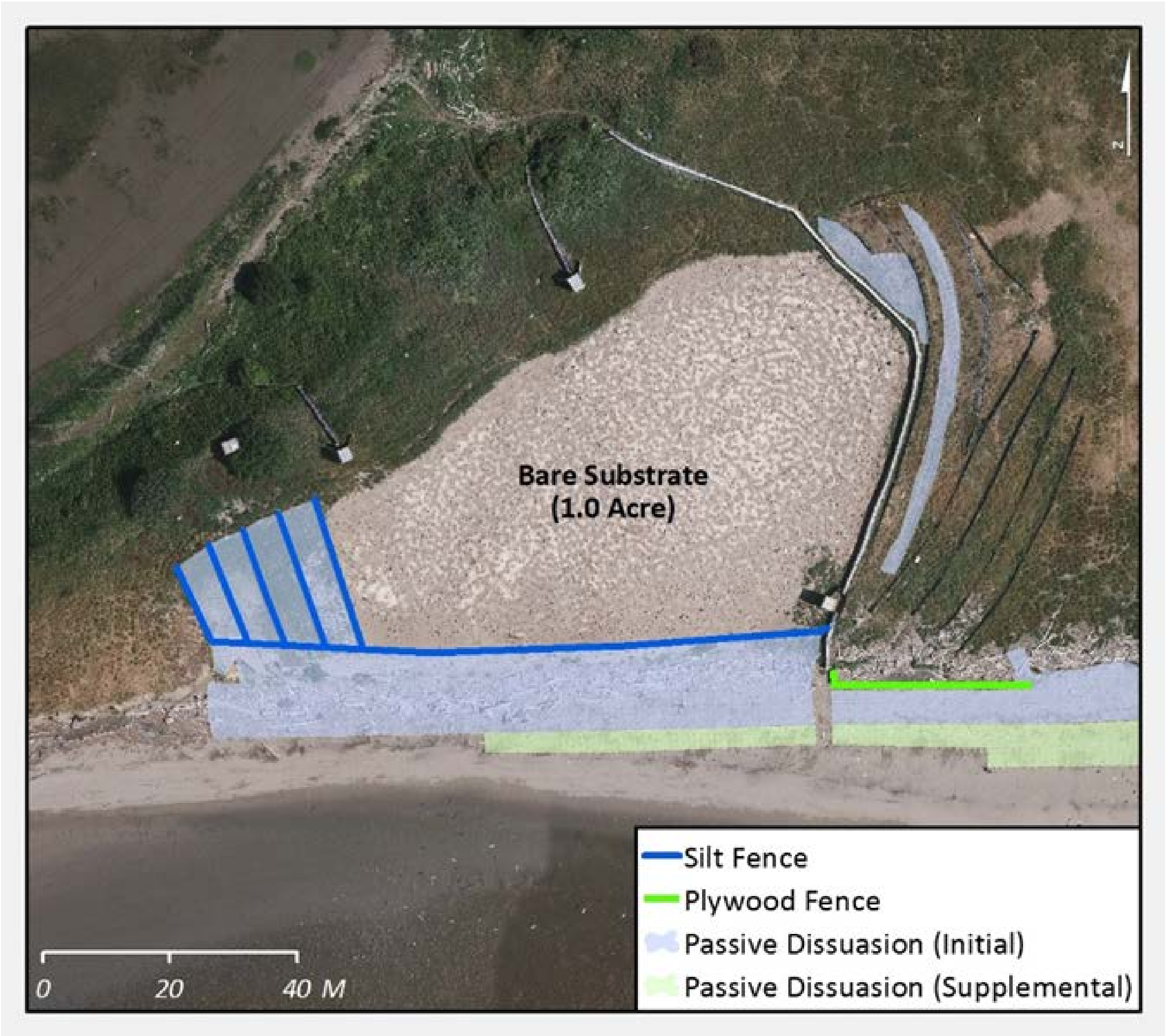
Map 1. Study area in the Columbia River basin showing the locations of active and former breeding colonies of piscivorous colonial waterbirds.

Map 2. East Sand Island and out of basin nesting sites, including Corps-constructed tern islands.

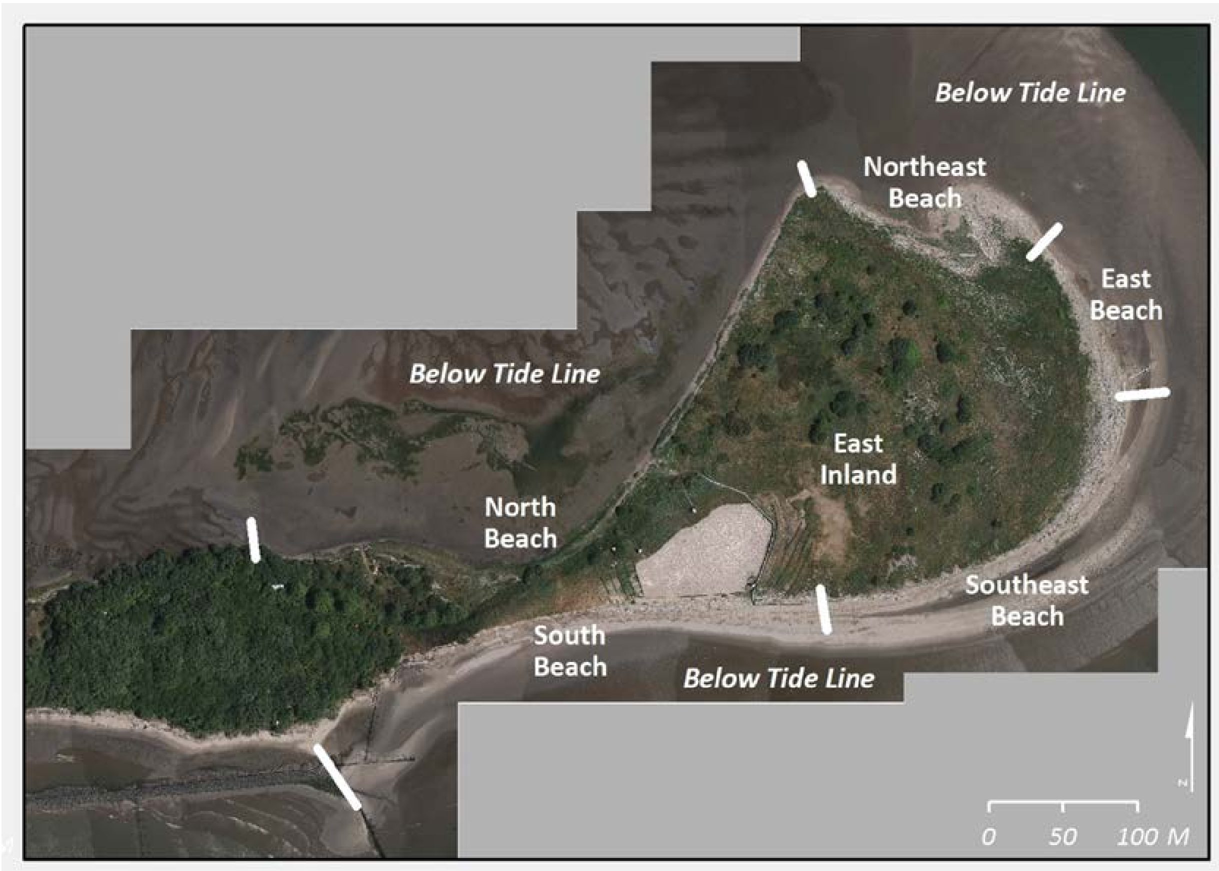


Map 3. Nesting habitat prepared for Caspian terns on the eastern end of East Sand Island in the Columbia River estuary during 2010-2016. Aerial photography was taken on 6 June 2016. Colony delineations depict the area of nesting habitat available to terns each breeding season during 2010-2016 and were overlaid on the 2016 photography. The southern shoreline of East Sand Island has been gradually eroding during each winter since 2010, influencing the area of available habitat in most years during 2010-2016. Passive nest dissuasion materials (i.e. fabric fencing, stakes, ropes, and flagging), invasive vegetation, and island erosion have all served to limit nesting habitat to the acreage specified by resource managers (see map legend and text for details).

Map 4. Locations of passive dissuasion materials installed to prohibit Caspian terns from nesting outside of the 1.0 acre of prepared habitat on East Sand Island in 2016.



Map 5. Map of the 1.0 acre of bare substrate prepared as suitable nesting habitat for Caspian terns on East Sand Island in 2016 showing installed passive dissuasion materials used to exclude nesting on adjacent suitable habitat.



Map 6. Eight sub areas identified for data collection on the eastern portion of East Sand Island during active hazing and monitoring of Caspian terns outside the prepared nesting habitat.

Map 7. Locations of passive nest dissuasion areas and satellite tern colonies on the east end of East Sand Island in 2016.

FIGURES

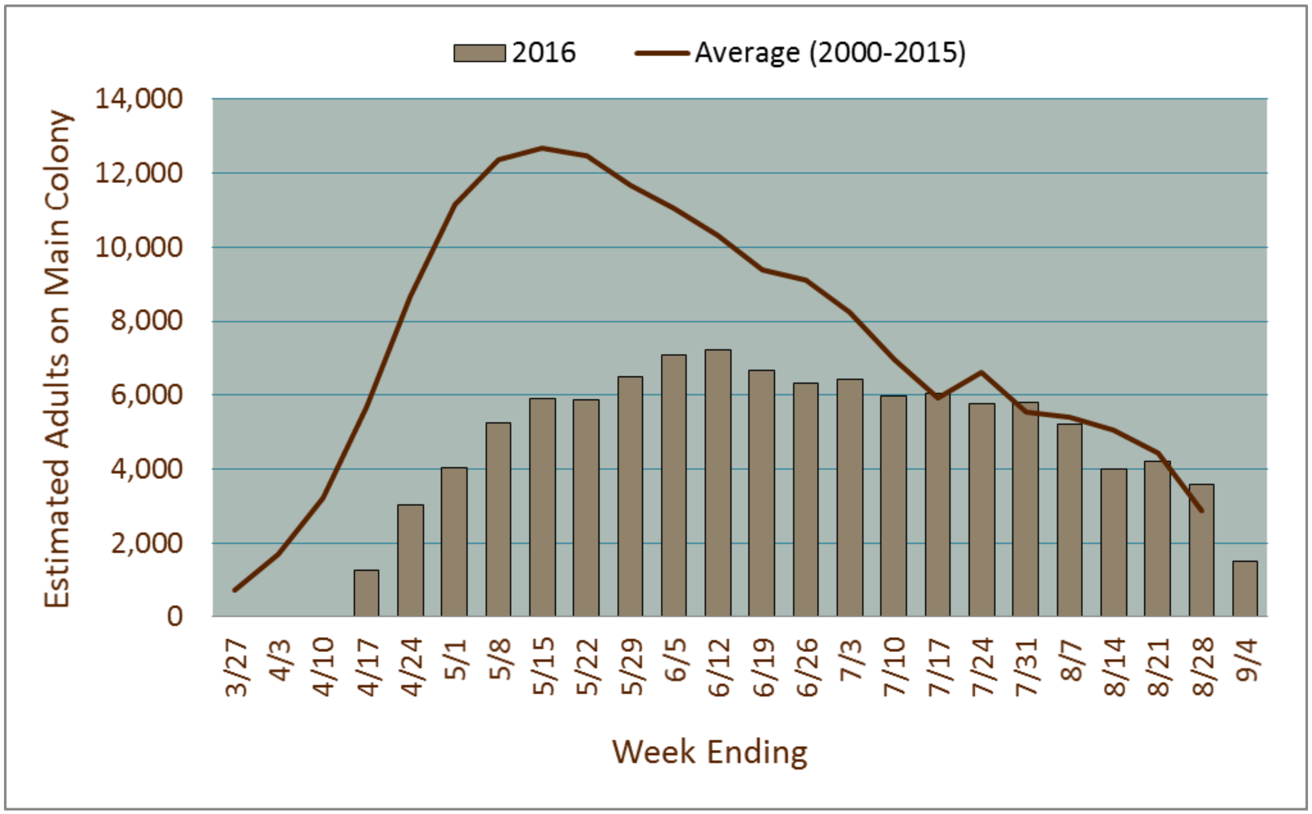


Figure 1. Weekly estimates from the ground of the number of adult Caspian terns on the 1-acre core colony at East Sand Island during the 2016 breeding season.

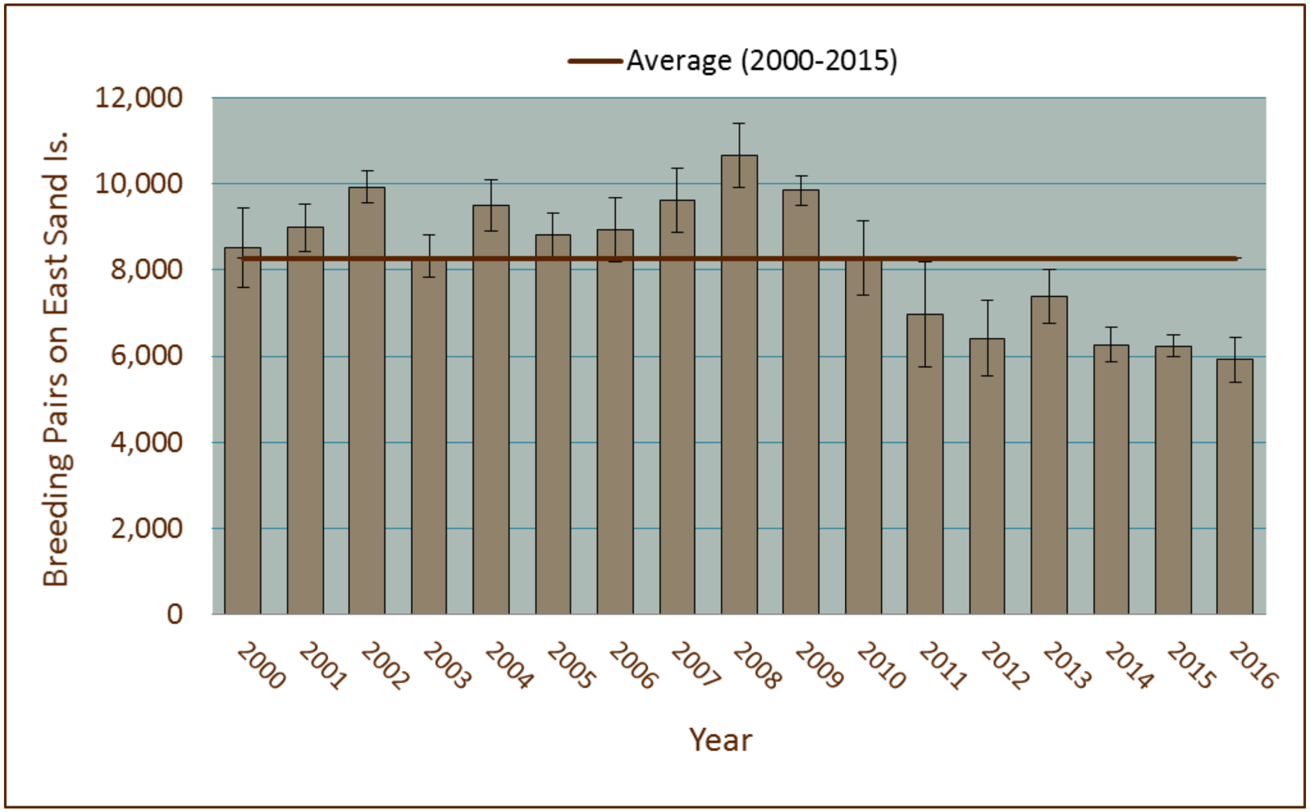


Figure 2. Caspian tern colony size (number of breeding pairs) on East Sand Island in the Columbia River estuary during 2000-2016. The colony size estimate for 2016 includes breeding pairs that nested outside the 1-acre core colony area in two satellite colonies. The error bars represent 95% confidence intervals for the estimate of the number of breeding pairs.

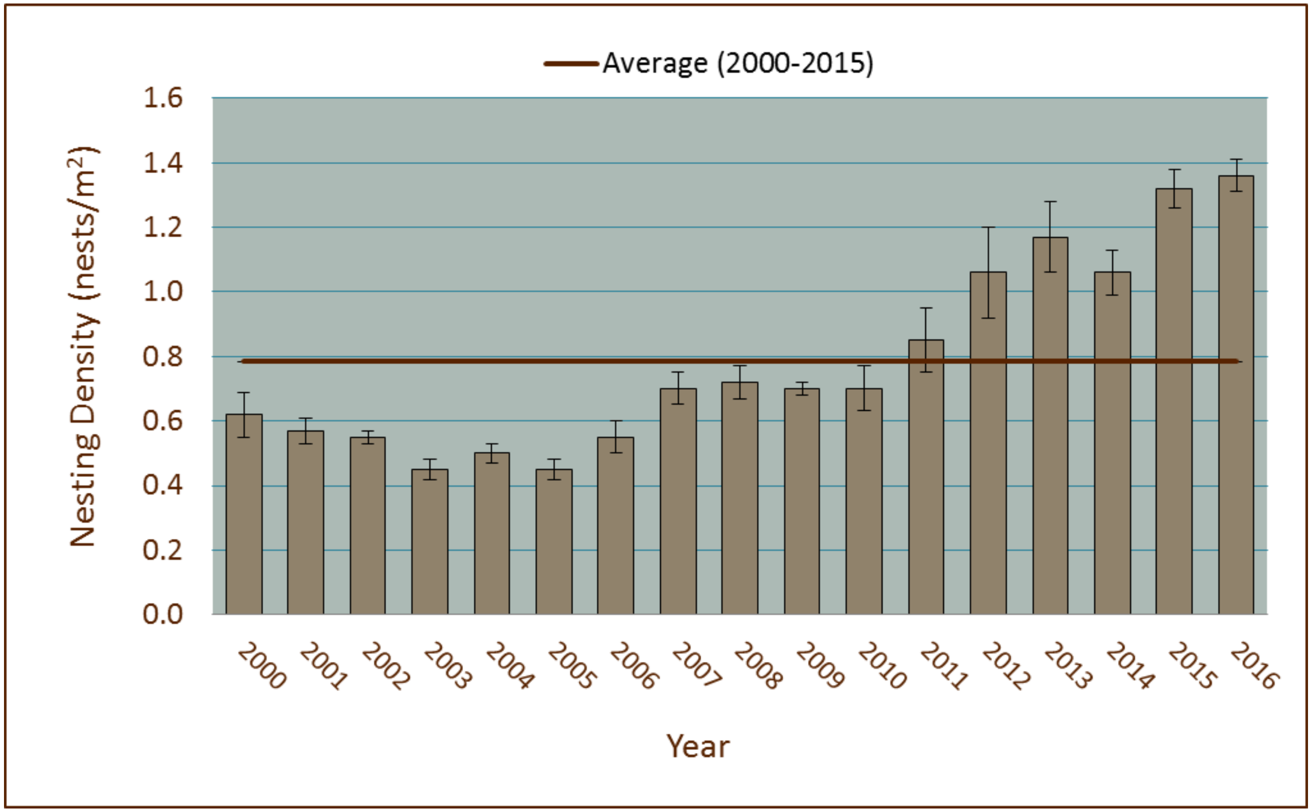


Figure 3. Caspian tern nesting density at the breeding colony on East Sand Island in the Columbia River estuary during 2000-2016. Nesting density in 2016 was measured only in the 1-acre core colony area. The error bars represent 95% confidence intervals for the estimate of nesting density (confidence interval not available for 2011 and based on confidence interval for 2012).

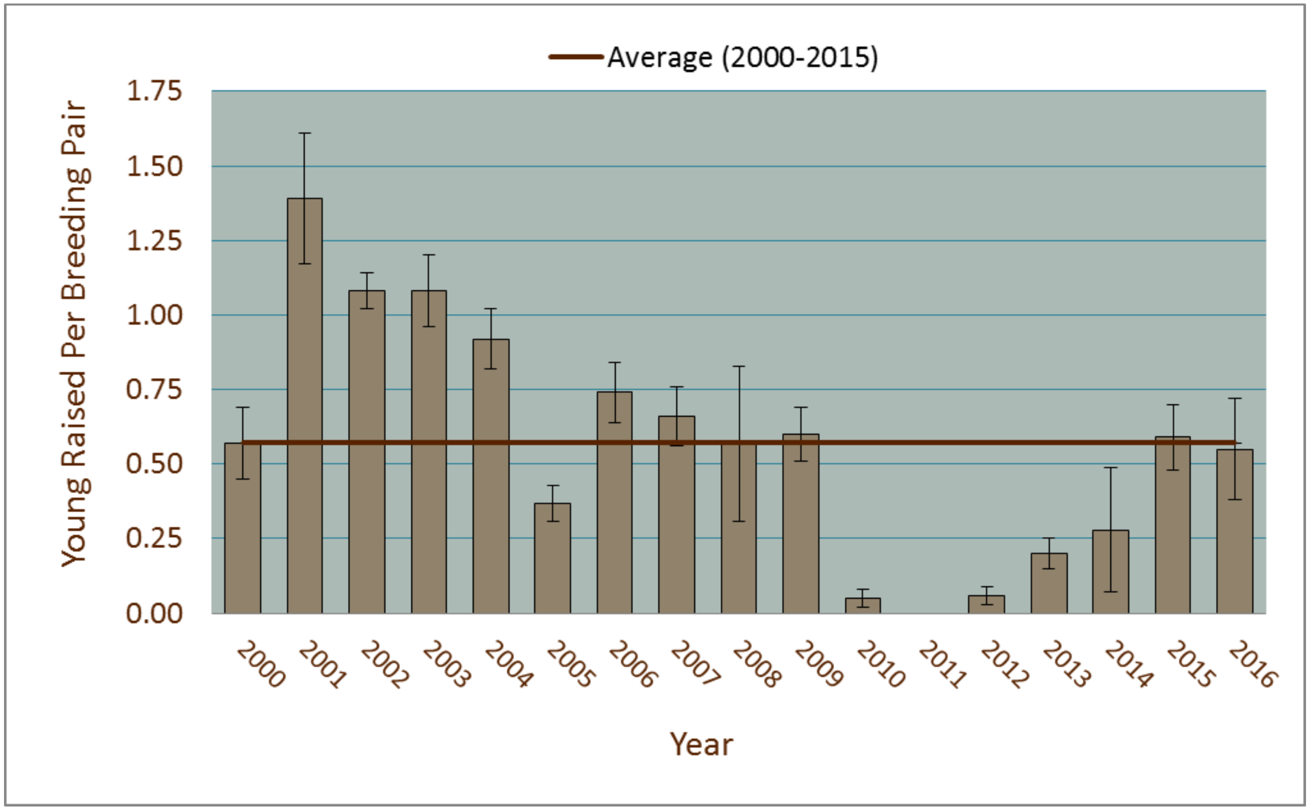


Figure 4. Caspian tern nesting success (average number of young raised per breeding pair) on East Sand Island in the Columbia River estuary during 2000-2016. The error bars represent 95% confidence intervals. No young were raised at the East Sand Island breeding colony in 2011.

Figure 5. PIT tag detection equipment used on the East Sand Island Caspian tern colony in 2016 included a hand-held portable system (bottom left), an eight-coil flat-plate system attached to an ATV (top), and a towable sweeper magnet at ached to an ATV (top and bottom right).

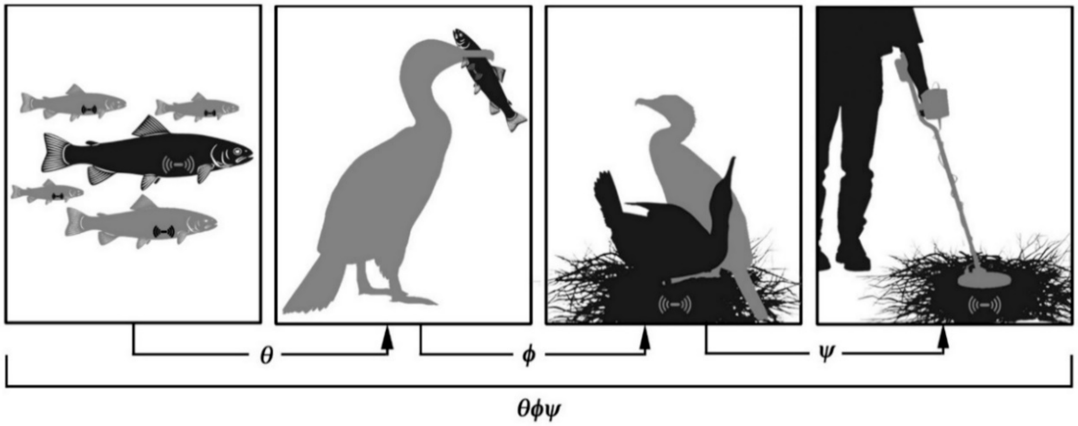


Figure 6. Conceptual model of the tag-recovery process in studies of avian predation. The probability of recovering a fish tag on a bird colony is the product of three probabilities: a fish was consumed (predation probability, θ), deposited on the nesting colony (deposition probability, φ), and detected by researchers (detection probability, ψ). Figure from Hostetter et al. (2015).

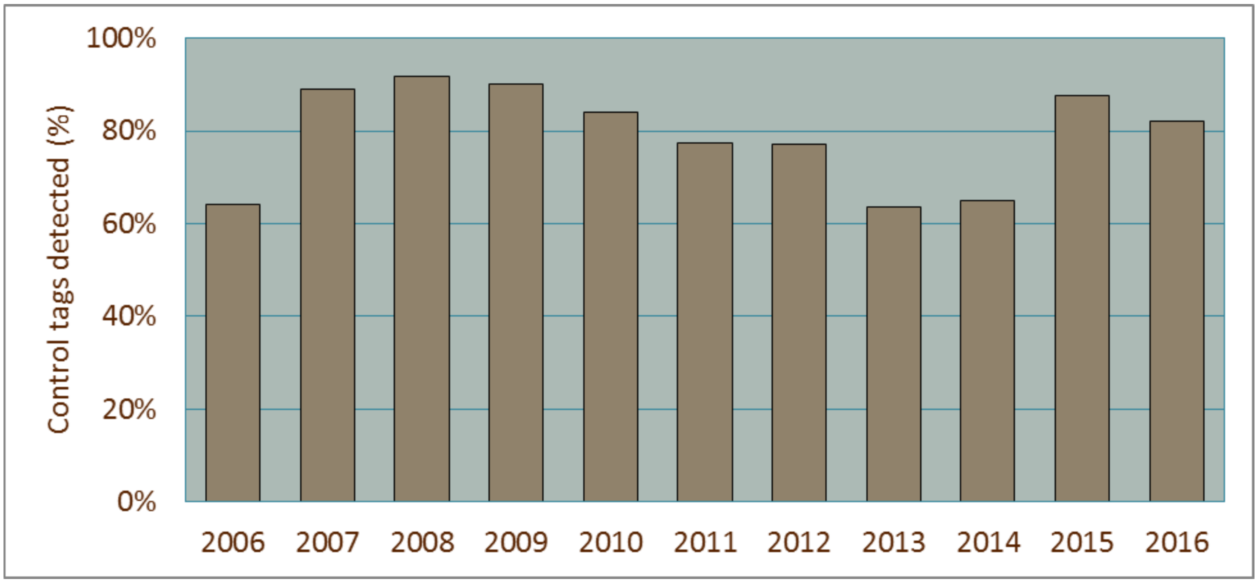


Figure 7. Average annual detection efficiency of PIT-tags on the East Sand Island Caspian tern colony during 2006-2016.

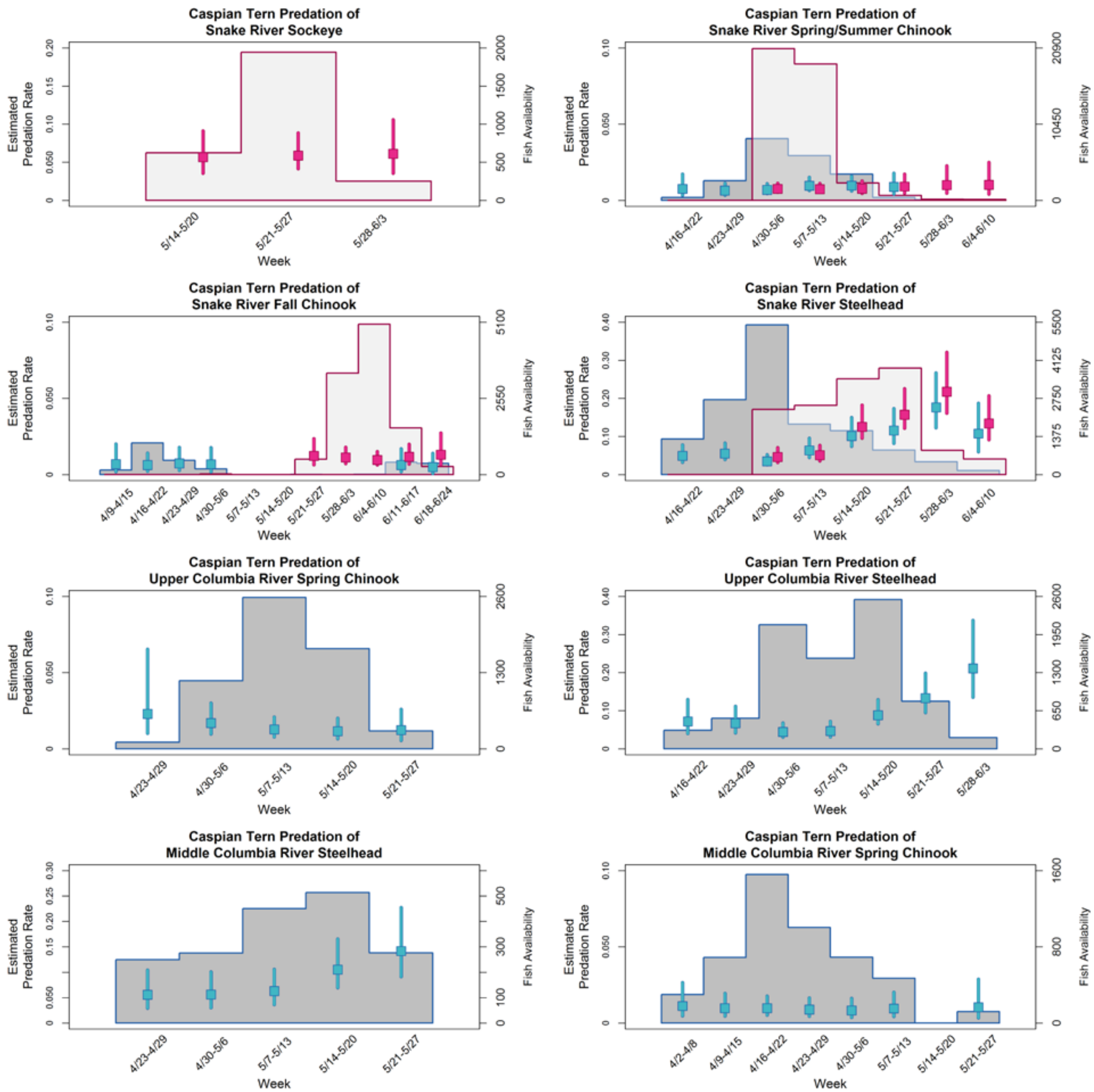


Figure 8. Estimated weekly predation rates (y_1; proportion of fish consumed) on in-river (blue squares) and transported (red squares) PIT-tagged juvenile salmonids last detected passing Bonneville or Sullivan dams (y_2; number available, dark gray bars) or transported from the lower Snake River (y^2; number available; light gray bars) by Caspian terns on East Sand Island during 2016. Error bars represent 95% credible intervals for predation rates.

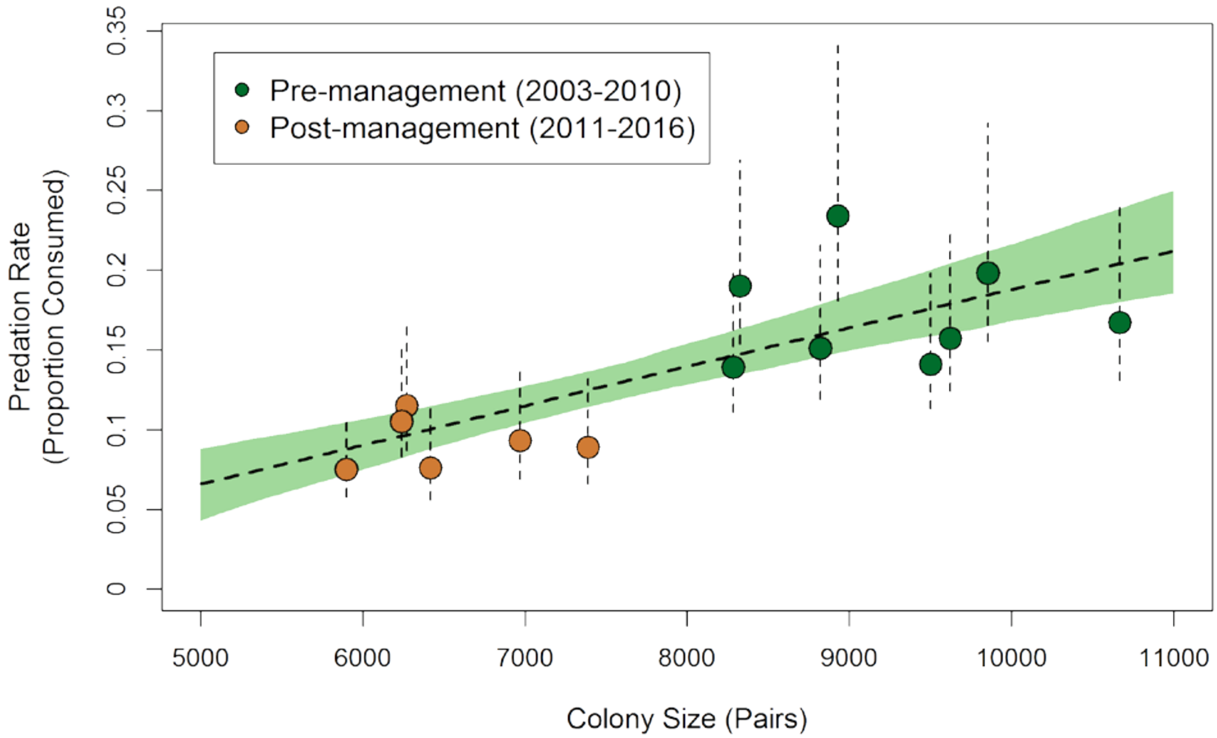


Figure 9. Estimated annual predation rates (95% credible intervals) and Caspian tern colony sizes (nesting pairs) prior to and following management actions to reduce the amount of available nesting habitat on East Sand Island. Predation rates are on PIT-tagged Upper Columbia River steelhead lasted detected passing Bonneville Dam during 2003-2016.

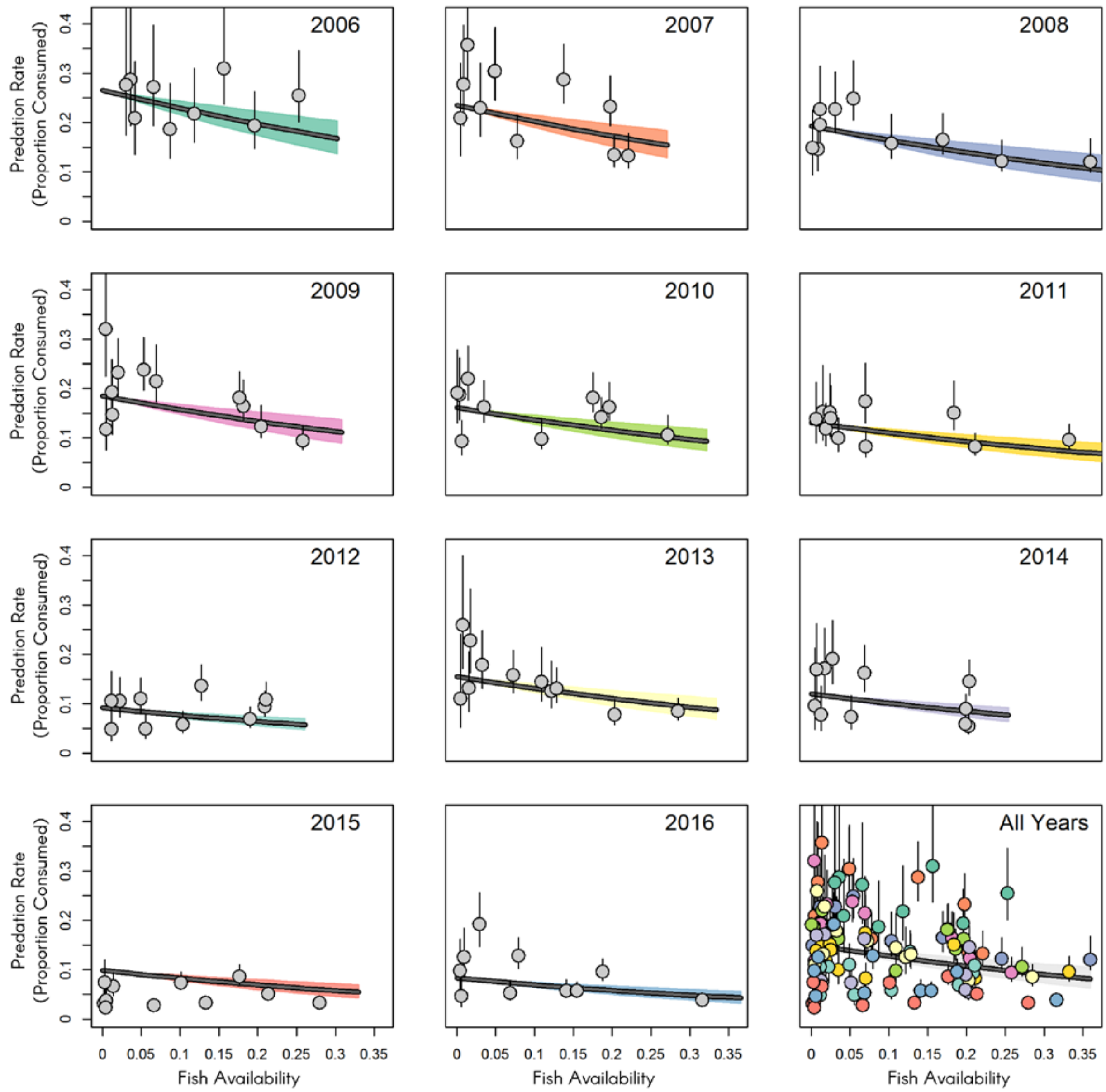


Figure 10. Estimated weekly Caspian tern predation rates on the proportion PIT-tagged steelhead last detected passing Bonneville Dam during 2006-2016. Line represents the estimated relationship between proportional availability of steelhead and predation rates, adjusted for annual differences in total predation (see Methods). The shaded area around the line represents the 95% credible intervals for this relationship.

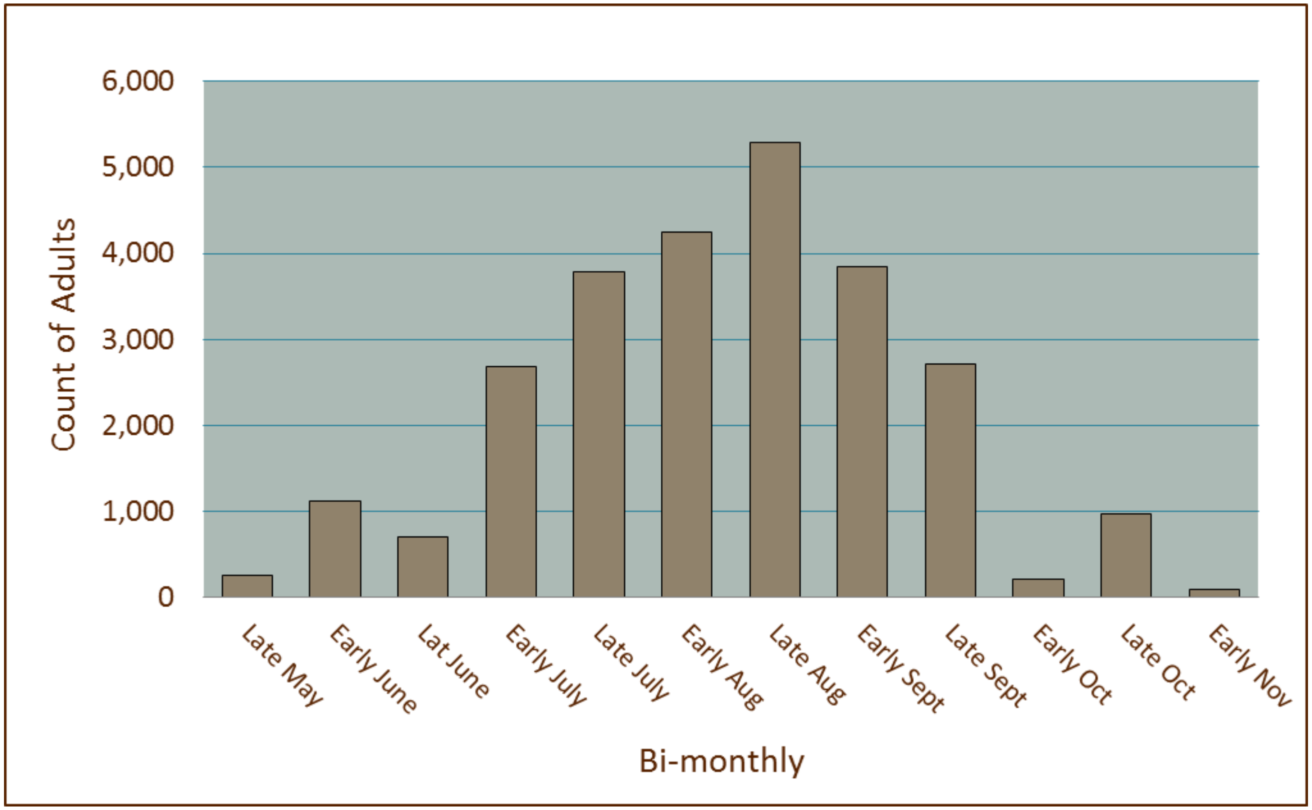


Figure 11. Estimates from boat-based surveys of the number of roosting California brown pelicans on East Sand Island, by 2-week period during the 2016 field season.

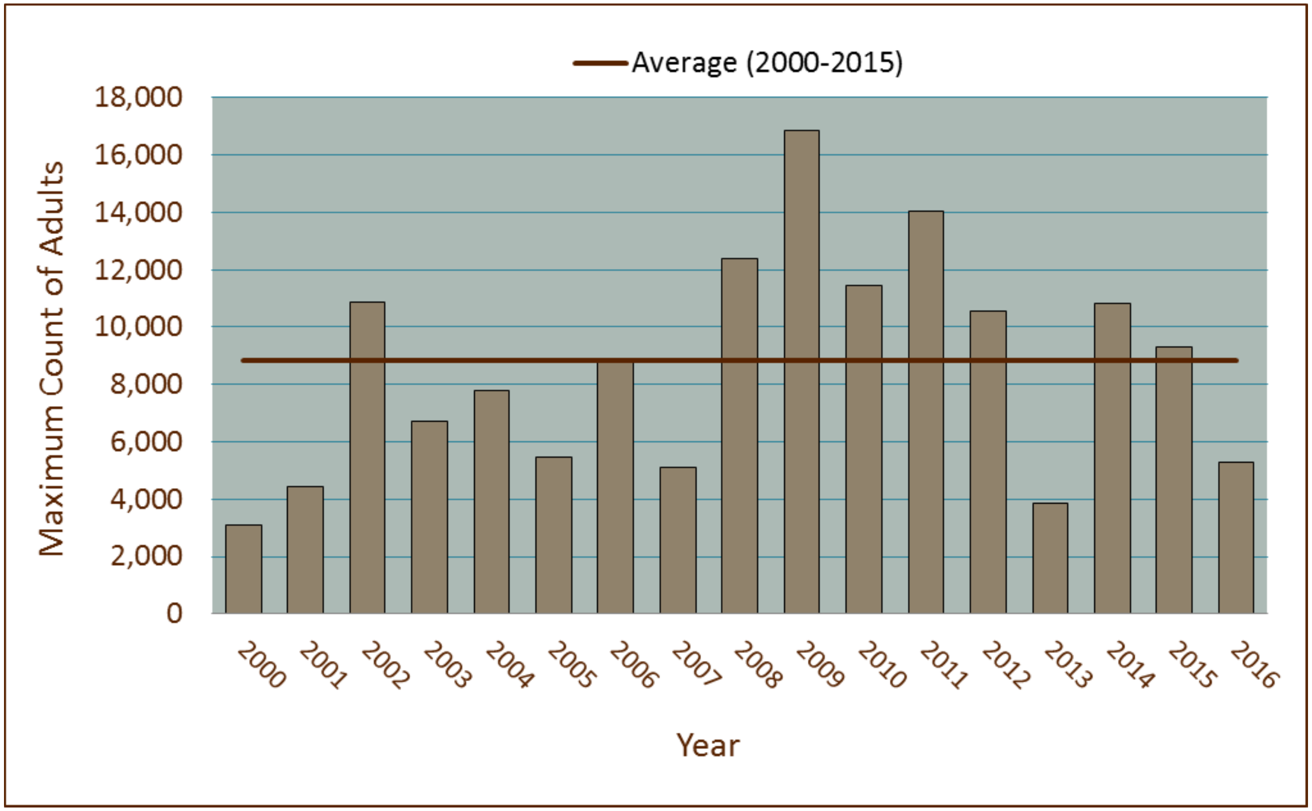


Figure 12. Maximum number of roosting California brown pelicans counted during boat-based surveys at East Sand Island in the Columbia River estuary during the 2000-2016 field seasons.

TABLES

Table 1. Weekly estimates of duration (minutes) and maximum number of Caspian terns counted in each sub area during monitoring or active nest dissuasion sessions on the east side of East Sand Island in 2016. Map 6 indicates the locations where daily counts of Caspian terns were conducted.

Week	Weekly Hazing Effort (minutes)	Average Daily Hazing Effort (minutes)	North Beach	Northeast Beach	East Beach	Southeast Beach	Soutt Beach	East Inland	West Inland	Below Tide Line
4/11-4/17	597	85	0	0	0	0	0	0	0	750
4/18-4/24	927	132	0	0	0	0	945	0	0	2360
4/25-5/1	1166	167	0	0	0	200	850	0	0	2592
5/2-5/8	3812	545	0	0	0	370	390	0	0	3050
5/9-5/15	4749	678	8	19	0	200	408	0	0	3025
5/16-5/22	2970	424	45	90	45	595	550	0	0	105
5/23-5/29	3218	460	20	68	16	550	610	0	0	940
5/30-6/5	2661	380	0	290	0	0	973	0	0	858
6/6-6/12	1708	244	0	34	0	55	445	0	0	880
6/13-6/19	1099	157	0	0	0	5	560	0	0	1103
6/20-6/26	1085	155	0	395	0	0	1080	0	0	2010
6/27-7/3	953	191	0	374	0	2	1127	0	0	1267
7/4-7/10	1004	143	0	292	0	0	709	0	0	2096
7/11-7/17	1098	183	0	308	0	285	263	2	0	1500
7/18-7/24	1276	182	0	225	4	105	327	1	0	2097
7/25-7/31	943	236	-	205	0	0	457	0	-	1050

Table 2. Caspian tern eggs located outside the prepared 1.0 acre of habitat and their final fate prior formation of satellite nesting colonies on East Sand Island in 2016.

Date	Time	Number of Eggs	Island Sub-area	Fate of Egg(s)	Notes
5/2	8:00	1	SE Beach	Presumed gull take. Gone by 17:00.	SE beach, 2 m below dissuasion
5/5	10:00	4	SE Beach	Washed by high tide event. Gone by 5\6 05:40.	4 eggs in 3 scrapes; SE beach, 2 m below dissuasion
5/11	6:45	1	S Beach	Presumed gull take. Gone by 08:00.	S beach, W end of dissuasion, below main colony. Not in scrape, possibly dropped by gull
5/14	10:45	1	S Beach	Presumed gull take. Gone by 13:20.	15 m E from W end of dissuasion, 1 m below dissuasion
5/16	5:40	2	SE Beach	Gull take. Gone by 09:00.	100 m E from new S beach dissuasion, 20 m below dissuasion
5/16	5:40	1	SE Beach	Presumed gull take. Gone by 09:00.	15 m from SE tip, 10 m below dissuasion
5/16	11:15	1	SE Beach	Presumed gull take. Gone by 12:30.	100 m from SE tip, 20 m below dissuasion
5/16	17:30	1	S Beach	Presumed gull take. Gone by 18:45.	Below main colony. Not in a scrape
5/16	20:00	4	SE Beach	Presumed gull take. Gone by 5\17, 05:30.	3 100 m from S beach dissuasion, 1 100 m from SE beach tip. 20 m below dissuasion. 3 in scrapes, 1 not
5/17	5:20	3	S Beach	Presumed gull take. 2 gone by 07:00, 1 gone by 12:00.	1 below main colony, 2 25 m from E end of S beach dissuasion
5/17	6:10	1	SE Beach	Presumed gull take. Gone by 10:00.	100 m from SE tip. 20 m below dissuasion
5/18	5:30	1	NE Beach	Presumed gull take. Gone by 07:15.	Near RBGU colony inlet. 17 m below dissuasion
5/18	17:35	1	S Beach	Presumed gull take. Gone by 5\19 05:30.	Below main colony. 1-2 m below dissuasion
5/19	5:30	3	NE Beach	Presumed gull take. Gone by 06:45.	Near RBGU colony inlet. All within 6 m of each other. 10 m below dissuasion
5/20	5:30	1	S Beach	Presumed gull take. Gone by 07:25.	Below main colony. 35 m from W end of dissuasion
5/21	15:25	1	S Beach	Gull take. Gone by 15:35.	60 m E from S tunnel entrance, 3 m below dissuasion
5/22	13:09	1	S Beach	Presumed gull take. Gone by 15:03.	Below main colony. In a scrape
5/22	16:03	1	S Beach	Presumed gull take. Gone by 16:45.	Below main colony. Not in a scrape
5/22	20:05	1	S Beach	Presumed gull take. Gone by 20:45.	45 m E of S tunnel. In a scrape
5/23	5:45	1	NE Beach	Presumed gull take. Gone by 08:00.	Near RBGU colony inlet. In a scrape
5/23	5:45	2	S Beach	Presumed gull take. Gone by 08:00.	30 m W of S tunnel
5/23	16:30	1	S Beach	Gull take during eagle flush at 20:56.	45 m E of S tunnel. In a scrape
5/23	20:45	1	S Beach	Gull take during eagle flush at 20:56.	45 m E of S tunnel. In a scrape
5/24	5:00	1	S Beach	Gull take during researcher flush 05:00.	45 m E of S tunnel. 2 m below dissuasion
5/25	18:20	1	S Beach	Gull take during researcher flush 21:15.	45 m E of S tunnel
5/26	4:55	2	S Beach	Presumed gull take. Gone by 06:10.	30 m W of S tunnel
5/26	4:55	1	S Beach	Presumed gull take during eagle flush 10:32. Gone by 10:55.	45 m E of S tunnel
5/26	9:45	1	SE Beach	Washed out prior to discovery, cold and buried in sand.	20 m S of SE tip
5/26	14:40	1	SE Beach	Presumed gull take during eagle flush 16:30. Gone by 16:30.	60 m E of S tunnel
5/26	20:30	1	NE Beach	Presumed gull take. Gone by 10:15.	Near RBGU colony inlet
5/27	4:55	1	S Beach	Gull take during researcher flush. Gone 05:05.	30 m E of S tunnel
5/27	5:05	1	SE Beach	Lost, fate unknown. Gone by 10:08	60 m E of S tunnel. 15 m below dissuasion
5/28	18:45	1	S Beach	Gull take during eagle flush 19:10.	45 m E of S tunnel
6/1	5:45	1	S Beach	Gull take during researcher flush. Gone 05:50.	15 m E of S tunnel
6/1	6:00	1	NE Beach	Presumed gull take. Gone by 20:55.	Near RBGU colony inlet
6/2	20:24	1	S Beach	Presumed gull take. Gone by 19:45 6/3.	45 m W of S tunnel
6/3	5:20	1	S Beach	Presumed gull take. Gone by 19:45 6/3.	45 m W of S tunnel
6/3	5:24	1	S Beach	Presumed gull take. Gone by 08:25.	20 m E of S tunnel, not in a scrape. Cold
6/3	18:45	1	S Beach	Washed by high tide. Gone by 06:00 6/4.	45 m W of S tunnel
6/8	5:32	3	S Beach	Presumed gull take during eagle flush 06:22. Gone by 07:15.	30 m W of S tunnel. 2 in scrapes, 1 not
6/8	5:32	1	S Beach	Presumed gull take during eagle flush 06:22. Gone by 07:15.	10 m below S tunnel. in scrape
6/8	5:32	4	S Beach	3 presumed gull take during eagle flush 06:22. Gone by 07:15. 1 gull take 07:33.	All between 20-35 m E of S tunnel. In scrapes
6/9	21:20	1	S Beach	Presumed gull take during a flush. Gone by 21:50.	20 E of S tunnel. In scrape
6/11	15:30	1	S Beach	Presumed gull take. Gone by 17:18.	30 m E of S tunnel
6/17	1520	1	S Beach	Presumed gull take. Gone by 18:25 6/18.	30 m W of S tunnel
6/18	18:25	1	S Beach	Presumed gull take. Gone by 10:18 06/19.	10 m E of S tunnel
6/21	14:25	2	NE Beach	Presumed gull take. Gone by 06:40 6/22.	Near RBGU colony inlet

Table 3. Estimated colony size (number of breeding pairs) and nesting density (nests/m^2) for Caspian terns nesting on East Sand Island in the Columbia River estuary during 2000-2016. The colony size estimate for 2016 includes breeding pairs that nested outside the 1-acre core colony area in two satellite colonies, whereas nesting density in 2016 was measured only in the 1-acre core colony area. Potential error of the estimates is expressed as the 95% confidence limits (c.i.).

Year	Colony Size	Lower 95% c.i	Upper 95% c.i.	Nesting Density	Lower 95% c.i.	Upper 95% c.i.
2000	8,513	7,597	9,429	0.62	0.55	0.69
2001	8,982	8,427	9,537	0.57	0.53	0.61
2002	9,933	9,552	10,314	0.55	0.53	0.57
2003	8,325	7,838	8,812	0.45	0.42	0.48
2004	9,502	8,905	10,099	0.50	0.47	0.53
2005	8,822	8,325	9,319	0.45	0.42	0.48
2006	8,929	8,188	9,670	0.55	0.50	0.60
2007	9,623	8,880	10,366	0.70	0.65	0.75
2008	10,668	9,923	11,413	0.72	0.67	0.77
2009	9,854	9,509	10,199	0.70	0.68	0.72
2010	8,283	7,412	9,154	0.70	0.63	0.77
2011	6,969	5,759	8,179	0.85	0.75	0.95
2012	6,416	5,545	7,287	1.06	0.92	1.20
2013	7,387	6,776	7,998	1.17	1.06	1.28
2014	6,269	5,858	6,680	1.06	0.99	1.13
2015	6,240	6,000	6,480	1.32	1.26	1.37
2016	5,915	5,410	6,425	1.36	1.31	1.41
Average (2000-2015)	8,240	7,780	9,060	0.75	0.69	0.81

Table 4. Numbers of banded Caspian terns resighted at East Sand Island in 2016 and the colony locations where they were originally marked with unique alphanumeric color leg-bands during 2005-2015.

Colony where banded	Banded as adults	Banded as chicks	Total
East Sand Island, Columbia River estuary, OR	181	348	529
Crescent Island, mid-Columbia River, WA	22	13	35
Goose Island – Potholes Reservoir, WA	12	2	14
Port of Bellingham, WA	0	12	12
Brooks Island, San Francisco Bay, CA	0	2	2
Crump Lake, Warner Valley, OR	0	1	1
Sheepy Lake, Lower Klamath NWR, CA	0	1	1
Kokinhenik Bar, Copper River Delta, AK	0	1	1
Total	215	380	595

Table 5. Numbers of color-banded Caspian terns seen at East Sand Island in 2015 and resighted during the 2016 breeding season at nesting or roosting sites. Terns were banded during 2005-2016 with colored leg-bands engraved with unique alphanumeric codes. A total of 390 banded terns that were seen on East Sand Island in 2015 were resighted in 2016 elsewhere; some of these banded terns were resighted at more than one location in 2016.

Location where resighted in 2016	Banded as adults	Banded as chicks	Total
East Sand Island, Columbia River estuary, OR	191	165	356
Blalock Islands, mid-Columbia River, OR	11	8	19
Everett, WA	3	13	16
Tongue Point Piers, Columbia River estuary, OR	10	0	10
Potholes Reservoir, WA*	8	1	9
Rat Island, Puget Sound, WA	1	1	2
Total	224	188	412

* Potholes Reservoir includes Goose Island and islands in North Potholes Reservoir.

Table 6. Inter-colony movement probabilities for banded 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 two years multiplied by the estimated numbers of adult terns present in the source regions during the 2015 nesting season.

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

Table 7. Numbers of 2016 migration year PIT-tagged juvenile salmonids recovered on the East Sand Island Caspian tern colony and estimates of PIT tag detection (annual range) and deposition (95% creditable interval) probabilities. Sample sizes (N) represent the number of control tags or the number of known consumed PIT-tagged fish used in detection and deposition experiments (see Methods and Hostetter et al. 2015).

Location	Colony	No. Smolt Tags Recovered	PIT Tag Detection Probability	PIT Tag Deposition Probability
East Sand Island	Caspian tern	9,930	0.82 (0.56-0.90) N=300	0.71 (0.51-0.89) N=456

Table 8. Estimated annual predation rates (95% credible interval) of PIT-tagged salmonid smolts last detected at Bonneville Dam on the Columbia River or Sullivan Dam on the Willamette River (In-river) or released from transportation barges (Transported) by Caspian terns nesting on East Sand Island in 2016. Predation rates were adjusted to account for tag loss due to on-colony PIT tag detection and deposition probabilities (see Table 7). The number (N) of in-river and transported PIT-tagged smolts and current U.S. Endangered Species Act (ESA) status of each evolutionarily significant unit (ESU) or distinct population segment (DPS) of PIT-tagged fish are provided. Dash lines indicate inadequate sample sizes of tagged fish (see Methods).

		N		Predation Rate	
ESU/DPS[1]	ESA[2]	In-river	Transported	In-river	Transported
SR Sockeye	E	-	2,829	-	5.9% (4.2-8.7)
SR Spr/Sum Chinook	T	21,874	43,068	0.8% (0.6-1.2)	0.8% (0.6-1.1)
UCR Spr Chinook	E	5,939	-	1.4% (0.9-2.1)	-
SR Fall Chinook	T	2,887	10,948	0.7% (0.3-1.3)	1.1% (0.8-1.6)
UWR Spr Chinook	T	604	-	1.2% (0.4-3.2)	-
SR Steelhead	T	14,473	13,608	6.1% (4.8-8.8)	11.3% (8.9-16.2)
UCR Steelhead	T	8,123	-	7.5% (5.8-10.7)	-
MCR Steelhead	T	2,086	-	8.8% (6.4-13.0)	-

[1] MCR = Middle Columbia River, SR = Snake River, UCR = Upper Columbia River, UWR = Upper Willamette River
[2] E = Endangered, T = Threatened

Table 9. Average annual predation rates (95% credible intervals) by Caspian terns nesting on East Sand Island prior to and following periods of management. Salmonid populations (ESU/DPS) with runs of spring (Sp), summer (Su), and fall (Fall) fish were evaluated, where applicable. Asterisks denotes that differences were statistically significant between management periods.

Salmonid ESU/DPS	Pre-management Period 2000-2010	Post-management Period 2011-2016
Snake River Sockeye [1]	1.5% (0.9-2.2)	1.6% (1.2-2.3)
Snake River Sp/Su Chinook	4.8% (4.3-5.4)	1.7% (1.4-2.0) *
Upper Columbia River Sp Chinook	3.9% (3.4-4.6)	1.6% (1.3-2.1) *
Snake River Fall Chinook	2.5% (2.2-3.0)	0.9% (0.7-1.1) *
Upper Willamette River Sp Chinook [2]	2.5% (1.9-3.3)	1.0% (0.7-1.4) *
Snake River Steelhead	22.2% (20.3-24.8)	10.2% (9.0-11.9) *
Upper Columbia River Steelhead [3]	17.2% (15.7-19.3)	9.4% (8.3-11.0) *
Middle Columbia River Steelhead [4]	14.9% (13.1-17.6)	9.5% (8.1-11.2) *

[1] Predation rate estimates were not available in 2000-2008, 2016
[2] Predation rate estimates were not available in 2000-2006
[3] Predation rate estimates were not available in 2000-2001
[4] Predation rate estimates were not available in 2000, 2002-2006

Table 10. Relative susceptibility of PIT-tagged smolts by rear-type, out-migration history, and passage route at Bonneville Dam to predation by Caspian terns nesting on East Sand Island during 2006-2016. Values represent the odds-ratio of predation, with values < 1 indicating greater predation odds for hatchery fish, in-river fish, and for juvenile bypass facility (JBS) fish and values > 1 indicating greater predation odds for wild fish, transported fish, and for Corner Collector (CC) fish (see Methods). Dashed lines denote years when insufficient sample sizes (< 500 PIT-tagged fish of each category) prevented comparisons within a given year. An asterisk denotes a statistical significance difference (see Appendix C-E, Figure B1-D1 for weekly results with 95% confidence intervals). Salmonid populations included fish from the Snake River (SR) and Upper Columbia River (UCR), with runs of spring (Sp) and summer (Su) fish were evaluated.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2006-2016
Hatchery versus Wild												
SR Sp/Su Chinook	0.23*	0.45*	0.49*	0.34*	0.35*	0.34	0.34*	0.46	0.28	0.51	0.33	0.38 (0.31-0.46)*
UCR Sp Chinook	-	-	0.18*	-	0.37*	-	-	-	0.21	0.70	-	0.34 (0.22-0.54)*
SR Steelhead	-	1.19	0.86	1.03	1.04	0.71	0.97	0.89	0.91	1.27*	1.23	1.03 (0.98-1.09)
UCR Steelhead	-	-	-	-	1.07	-	-	-	-	1.03	-	0.94 (0.79-1.08)
Transport versus In-river												
SR Sp/Su Chinook	0.85	0.68*	1.15	0.83*	0.82*	0.77	1.00	0.83	0.86	0.80	0.89	0.86 (0.81-0.91)*
SR Fall Chinook	0.83	1.07	0.77 *	0.96	1.15	0.9	1.13	1.44	2.06	1.16	1.62	0.92 (0.83-1.01)
SR Sockeye	--	--	--	0.81	--	1.58	0.51	0.56	0.80	1.64	-	0.84 (0.61-1.17)
SR Steelhead	0.73*	0.76*	0.83*	0.92	0.95	0.81*	0.94	0.72*	1.07	0.72*	1.19*	0.88 (0.84-0.91)*
JBS versus CC Passage Route												
SR Steelhead	1.15	0.83	0.84	0.93	1.02	1.09	0.99	0.95	0.97	1.07	1.01	0.98 (0.93-1.03)

APPENDIX A: CASPIAN TERN POPULATION MODELING

Based on the most recent flyway-scale survey of Caspian tern population, there is an evidence of a decline in the Pacific Flyway breeding population. With the current management practices of Caspian tern colonies in the Columbia River estuary and plateau regions, and potential further management in the Columbia Basin in the future to benefit salmonid population recovery, understanding demography, defining the population status, and predicting future trends of the Caspian tern population are necessary as part of adaptive management. The first population model developed by Bird Research Northwest in early 2000s was a simple deterministic model with demography parameters derived from metal band returns of dead individuals (USFWS 2005). We are currently developing a more data-rich model which is based on data collected from band resighting of live individuals. This comprehensive second-generation demographic model incorporates metapopulation dynamics and environmental stochasticity, both are especially important for this highly vagile species in altering environment. This population model also enables us to examine population trajectories based on different future potential management scenarios. In this report, we describe the structure of a preliminary second-generation model and show conceptual model examples constructed based on hypothetical scenarios.

Model structure and data set: The second-generation Caspian tern model is being developed in HexSim modeling framework/software (Schumaker 2016). HexSim is a very versatile population simulator, which has been extensively used for wildlife conservation and management projects such as the population recovery plan of northern spotted owls (Schumaker et al. 2014). During the initial phase for developing the second-generation Caspian tern population model, three regions (Columbia River estuary, Columbia plateau, and Corps-constructed alternative sites in southeastern Oregon and northeastern California) have been included in the model as a closed population. This preliminary model does not yet include the entire Pacific Flyway population. The current model simulates three life stages; juvenile to sub-adults, colony attending adults (breeders), and non-colony attending adults (non-breeders). Using HexSim framework, Caspian tern population in each region is modeled using a life-stage structured 3x3 Leslie matrix (Caswell 2001), and movements are simulated among the 3 regions to model metapopulation dynamics. It is a female only model assuming the sex ratio of Caspian terns in the study area is 1:1.

Demographic parameters (e.g. age at first breeding, survival rates) and inter-regional movement rates estimated from color-band resighting data collected during 2005-2015 have been used in the preliminary model. We have color-banded 6,400 terns and collected nearly 90,000 resighting records from those individuals during the 11-year period. Colony covariates (e.g. colony size, nesting success) used in the model were based on data collected during 2000-2015. HexSim captures impacts of stochastic natural disturbance on population in simulated models. In the preliminary Caspian tern model, natural stressors lower survival and nesting success based on the intensity and frequency of disturbance. The preliminary model also reduces those demographic parameters as the population approaches carrying capacities (density-dependent).

Conceptual model examples: Using the preliminary second-generation model, we have generated outputs of a 3-region study population based on hypothetical management scenarios. The example outputs are meant to provide the conception of this population modeling approach as a potential tool to assist plan and evaluate management practices. Thus, the population trajectories from the example model outputs in this report are not meant to be used for actual decision making process at this stage. We ran model simulations under two hypothetical scenarios; 1) no additional management (status quo) in the future (Fig. A1) and 2) additional management (habitat reduction) at East Sand Island and Columbia Plateau region (Fig. A2). Colony sizes from 2015 breeding season have been used as initial condition of the three regions in the model (East Sand Island: 6,240 breeding pairs, Columbia Plateau: 769 breeding pairs, Corps-constructed sites: 1,057 breeding pairs). The colony sizes at East Sand Island and colonies in the Columbia Plateau region are assumed to be at or near carrying capacity. The model allows the number of breeding pairs at the Corps-constructed alternative sits to increase from the current condition up to 2,500 breeding pairs. Under scenario 2, additional management both at East Sand Island and in the Columbia Plateau region get implemented at year 50 after letting the modeled population stabilize, which is a common practice in population modeling exercise. The hypothetical additional management reduces carrying capacity at East Sand Island to 3,750 breeding pairs and in the Columbia Plateau region to 200 breeding pairs. Each output show average number of females from ten model runs.

Work in progress: on-going work of this second-generation model includes refining input data and demographic parameters for the model. Sub-adult survival, natal dispersal, age at first reproduction, and breeding propensity are main parameters still need to be estimated from data collected from marked live individuals for developing a reliable population model. By incorporating additional field data at least from 2016-2017, we expect that parameter estimates in the model reflects current level of management practices in the Columbia Basin. Some of the constraints in the model, such as natural disturbance and its impact on the population, has been simplified at this initial stage of model development. This model framework can add more complexity to simulate more realistic scenarios. The current model needs to be expanded from the three-region study area (closed system) to the flyway population. We plan to incorporate information from previous surveys of the flyway population, and detailed information from key breeding colonies for management (e.g. DENWR) if applicable. The model must be calibrated and validated to available field data to ensure the model can produce accurate trajectories. Input on potential future management scenarios from management agencies will help construct a population model that can serve as a powerful tool for adaptive management.

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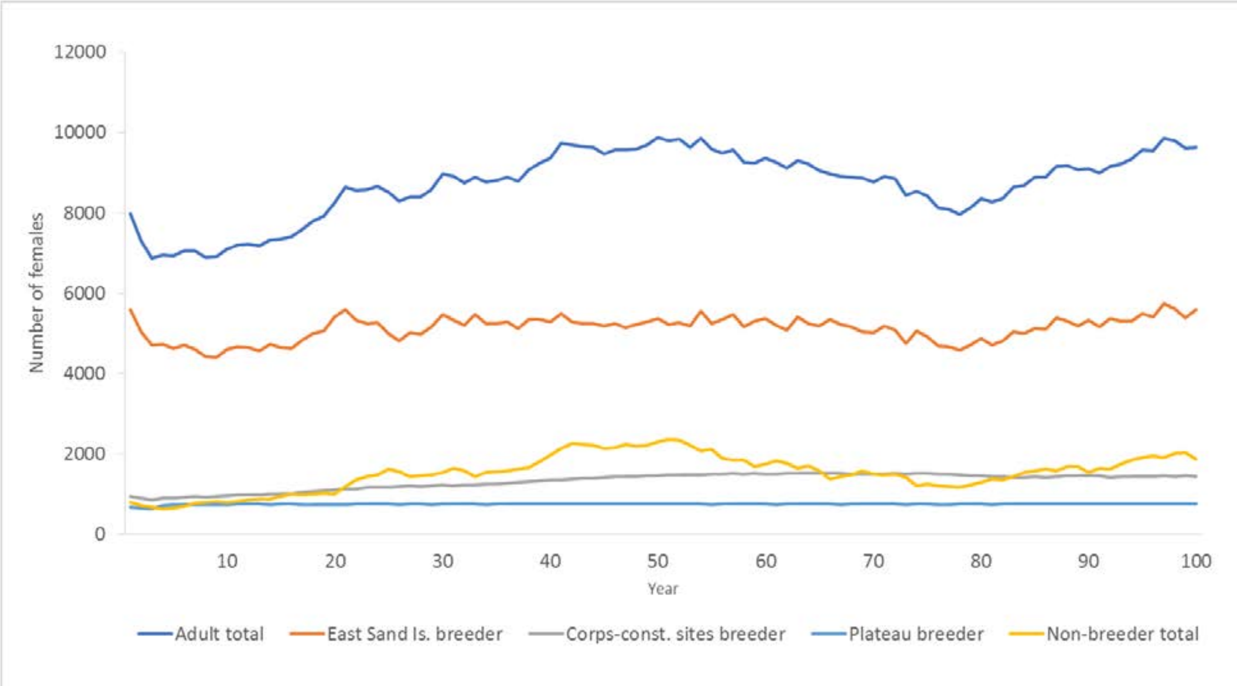

Figure A1. Output from a conceptual model example with a hypothetical scenario that no additional management is planned in the Columbia River basin and nesting habitat is maintained at Corps-constructed islands in interior Oregon and northeastern California in the future (status quo).

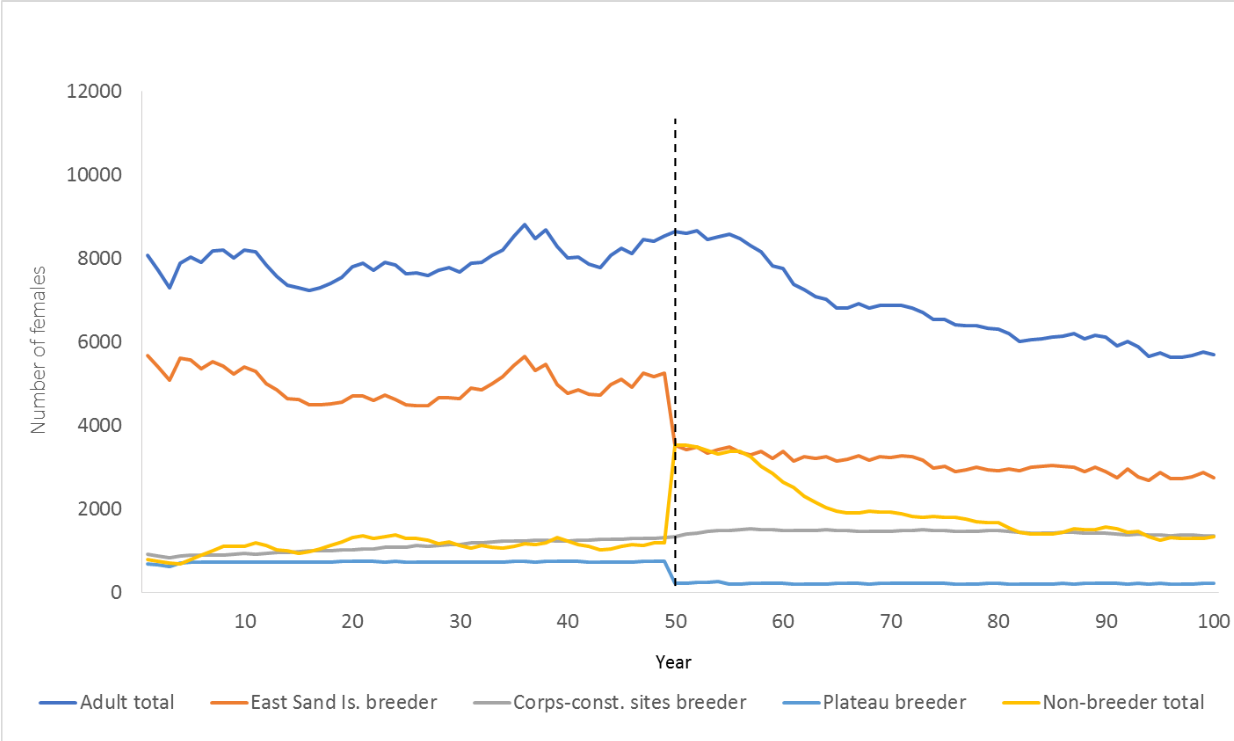

Figure A2. Output from a conceptual model example with a hypothetical scenario that additional management (habitat reduction) is implemented at East Sand Island and in the Columbia Plateau region at year 50 (dash line) and nesting habitat is maintained at Corps-constructed islands in interior Oregon and northeastern California in the future.

APPENDIX B: ANNUAL PREDATION RATES ON SMOLTS

This appendix provides annual predation rate estimates for Caspian terns nesting on East Sand Island. Predation rate estimates were based on the number (N) of PIT-tagged fish interrogated passing Bonneville Dam or Sullivan Dam (in-river migrants) or the number released from barges downstream of Bonneville Dam during 2006-2016. Predation rates were corrected for PIT detection and deposition probabilities (see *Methods*). Dashes denote insufficient sample sizes (< 500 PIT-tagged fish were available) for generating predation rates (see *Methods*). Salmonid populations originating from the Snake River (SR), Upper Columbia River (UCR), Middle Columbia River (MCR) and Upper Willamette River (UWR) were evaluated, with runs of spring (Sp), summer (Su), and fall (Fall) fish included, where applicable.

Historical Caspian tern predation rate estimates (2006-2015) presented herein are those of Evans et al. (2016a). For Caspian tern predation rate estimates dating back to 2000 and for predation rate estimates by double-crested cormorants nesting on East Sand Island during 2000-2015, see Evans et al. (2016a), available at: http://www.birdresearchnw.org/2015%20ESI%20PIT%20Recovery%20FINAL%20Report.pdf.

Table B1. Annual predation rates (95% credible interval) on PIT-tagged juvenile salmonids last detected (N) passing Bonneville or Sullivan dams by Caspian terns nesting on East Sand Island during 2006-2016.

Year	SR Sp/Su Chinook	SR Fall Chinook	UCR Sp Chinook	UWR Sp Chinook	SR Sockeye	MCR Steelhead	SR Steelhead	UCR Steelhead
2006	3.3% (2.4-5.0)	2.5% (1.7-3.9)	3.6% (1.8-6.6)	-	-	-	27.5% (21.0-39.1)	23.4% (18.1-34.1)
N	*5,570*	*4,057*	*731*				*1,100*	*2,064*
2007	3.1% (2.5-4.4)	3.4% (2.3-5.3)	1.9% (1.2-3.2)	1.4% (0.8-2.5)	-	18.7% (14.6-26.8)	22.6% (18.2-32.4)	15.7% (12.4-22.6)
N	*23,830*	*2,005*	*2,268*	*1,505*		*2,234*	*6,391*	*3,042*
2008	2.5% (1.9-3.6)	1.9% (1.5-2.7)	1.7% (1.0-2.9)	4.4% (3.2-6.7)	-	13.5% (10.6-19.2)	14.2% (11.5-19.9)	16.7% (13.1-24.2)
N	*11,425*	*24,136*	*1,662*	*2,509*		*2,291*	*19,572*	*2,513*
2009	4.7% (3.7-6.9)	2.0% (1.5-2.9)	3.7% (2.5-5.6)	1.7% (1.2-2.7)	1.3% (0.7-2.2)	14.1% (11.1-20.0)	14.5% (11.9-20.1)	20.0% (15.6-29.3)
N	*17,396*	*16,314*	*2,064*	*5,573*	*1,845*	*2,700*	*23,311*	*2,265*
2010	3.4% (2.7-4.8)	0.7% (0.5-1.1)	2.9% (2.2-4.3)	1.8% (0.6-4.4)	1.6% (0.8-2.9)	11.9% (9.4-17.4)	14.3% (11.3-20.4)	13.7% (11.0-19.3)
N	*38,441*	*17,974*	*5,972*	*510*	*1,382*	*8,515*	*40,024*	*12,284*
2011	2.5% (1.8-3.6)	0.7% (0.5-1.1)	2.9% (1.4-5.3)	0.9% (0.3-2.0)	0.4% (0.1-1.3)	9.6% (6.6-14.7)	12.0% (9.4-17.3)	9.1% (6.9-13.4)
N	*6,557*	*12,327*	*704*	*1,119*	*826*	*865*	*7,028*	*2,419*
2012	2.2% (1.7-3.3)	0.7% (0.5-1.1)	1.2% (0.7-2.1)	0.7% (0.4-1.3)	2.1% (1.2-3.7)	9.4% (6.5-14.4)	10.2% (7.7-14.9)	7.5% (5.6-11.3)
N	*17,929*	*10,742*	*3,227*	*3,731*	*1,457*	*1,084*	*4,768*	*3,357*
2013	1.2% (0.8-1.8)	0.9% (0.5-1.6)	0.7% (0.3-1.4)	1.0% (0.5-1.8)	0.8% (0.3-2.0)	9.9% (7.0-15.3)	12.7% (9.6-18.5)	8.9% (6.6-13.4)
N	*16,167*	*4,465*	*3,112*	*2,629*	*1,454*	*1,865*	*8,516*	*4,473*
2014	1.1% (0.8-1.7)	1.0% (0.5-1.9)	1.4% (0.7-2.5)	1.2% (0.5-2.5)	1.6% (0.8-3.0)	9.5% (6.5-14.5)	8.6% (6.7-12.5)	11.4% (8.5-16.8)
N	*14,828*	*2,800*	*2,297*	*1,587*	*1,739*	*1,119*	*8,812*	*3,841*
2015	2.0% (1.5-2.9)	0.8% (0.4-1.5)	1.9% (1.3-2.9	0.4% (0.1-1.5)	1.6% (1-2.6)	7.8% (5.9-11.4)	10.2% (8.2-14.6)	10.5% (8.2-15.0)
N	*20,245*	*2,629*	*5,943*	*768*	*3,311*	*3,927*	*16,451*	*6,004*
2016	*0.8% (0.6-1.2)*	*0.7% (0.3-1.3)*	*1.4% (0.9-2.1)*	*1.2% (0.4-3.2)*	-	*8.8% (6.4-13.0)*	*6.1% (4.8-8.8)*	*7.5% (5.8-10.7)*
N	*21,874*	*2,887*	*5,939*	*604*		*2,086*	*14,473*	*8,123*

Table B2. Annual predation rates (95% credible interval) on PIT-tagged juvenile salmonids collected at Lower Granite Dam, Little Goose Dam, and Lower Monumental Dam on the Snake River and released from barges downstream of Bonneville Dam by Caspian terns nesting on East Sand Island during 2006-2016.

Year	SR Sp/Su Chinook	SR Fall Chinook	SR Sockeye	SR Steelhead
2006	4.0% (3.2-5.6)	1.8% (1.4-2.6)	-	22.7% (18.2-31.1)
N	78,532	48,661		70,988
2007	2.3% (1.8-3.4)	3.0% (1.6-5.5)	-	16.7% (13.4-24.5)
N	*32,184*	*607*		*45,276*
2008	4.2% (3.4-5.9)	1.6% (1.2-2.2)	-	18.7% (15.2-26.1)
N	*95,267*	*48,039*		*65,097*
2009	4.3% (3.5-6.3)	1.8% (1.4-2.6)	1.1% (0.8-1.6)	16.1% (13.1-23.1)
N	*51,805*	*34,407*	*10,167*	*22,627*
2010	3.6% (2.9-5.1)	0.9% (0.7-1.3)	-	14.9% (12.0-21.2)
N	*40,996*	*46,843*		*32,904*
2011	1.9% (1.5-2.7)	0.5% (0.4-0.8)	0.4% (0.2-0.7)	9.2% (7.3-13.0)
N	*64,858*	*53,093*	*7,038*	*26,862*
2012	2.4% (1.8-3.4)	1.0% (0.8-1.5)	1.0% (0.7-1.5)	8.2% (6.5-12.0)
N	*38,963*	*41,537*	*14,013*	*30,542*
2013	1.1% (0.8-1.6)	1.3% (0.6-2.5)	0.5% (0.3-0.9)	8.9% (6.8-13.3)
N	*49,592*	*2,106*	*9,280*	*32,490*
2014	1.1% (0.8-1.6)	0.9% (0.4-2.0)	0.8% (0.4-1.3)	9.5% (7.4-13.4)
N	*66,759*	*1,539*	*5,839*	*33,327*
2015	1.3% (1.0-2.0)	2.1% (1.6-3.1)	2.4% (1.7-3.6)	8.9% (7.0-12.8)
N	*20,575*	*8,347*	*4,357*	*10,461*
2016	0.8% (0.6-1.1)	1.1% (0.8-1.6)	5.9% (4.2-8.7)	11.3% (8.9-16.2)
N	43,068	10,948	2,829	13,608

APPENDIX C: WEEKLY HATCHERY VS. WILD

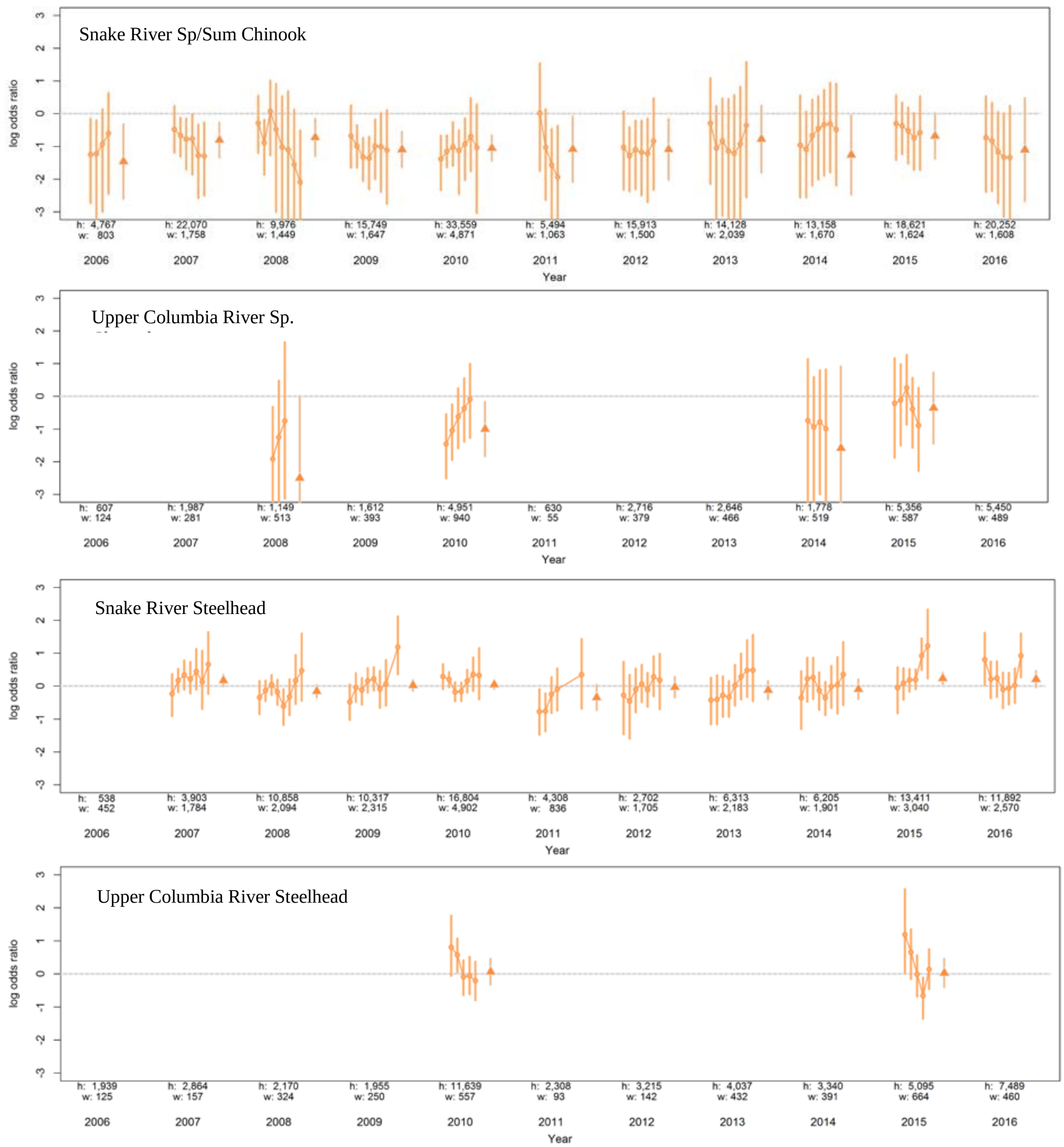

Figure C1. Relative susceptibility of fish by rear-type to predation by Caspian terns nesting on East Sand Island during 2006-2016. Values represent the odds-ratio of predation (y_1), with values < 0 indicating greater predation odds for hatchery fish and values > 0 indicating greater predation odds for wild fish. Error bars represent 95% confidence intervals, with values over-lapping 0 not statistical significant. Only years were > 500 PIT-tagged fish of each rear-type available are presented. Weekly estimates (circles) are followed by an annual estimate (triangles).

APPENDIX D: WEEKLY INRIVER VS. TRANSPORT

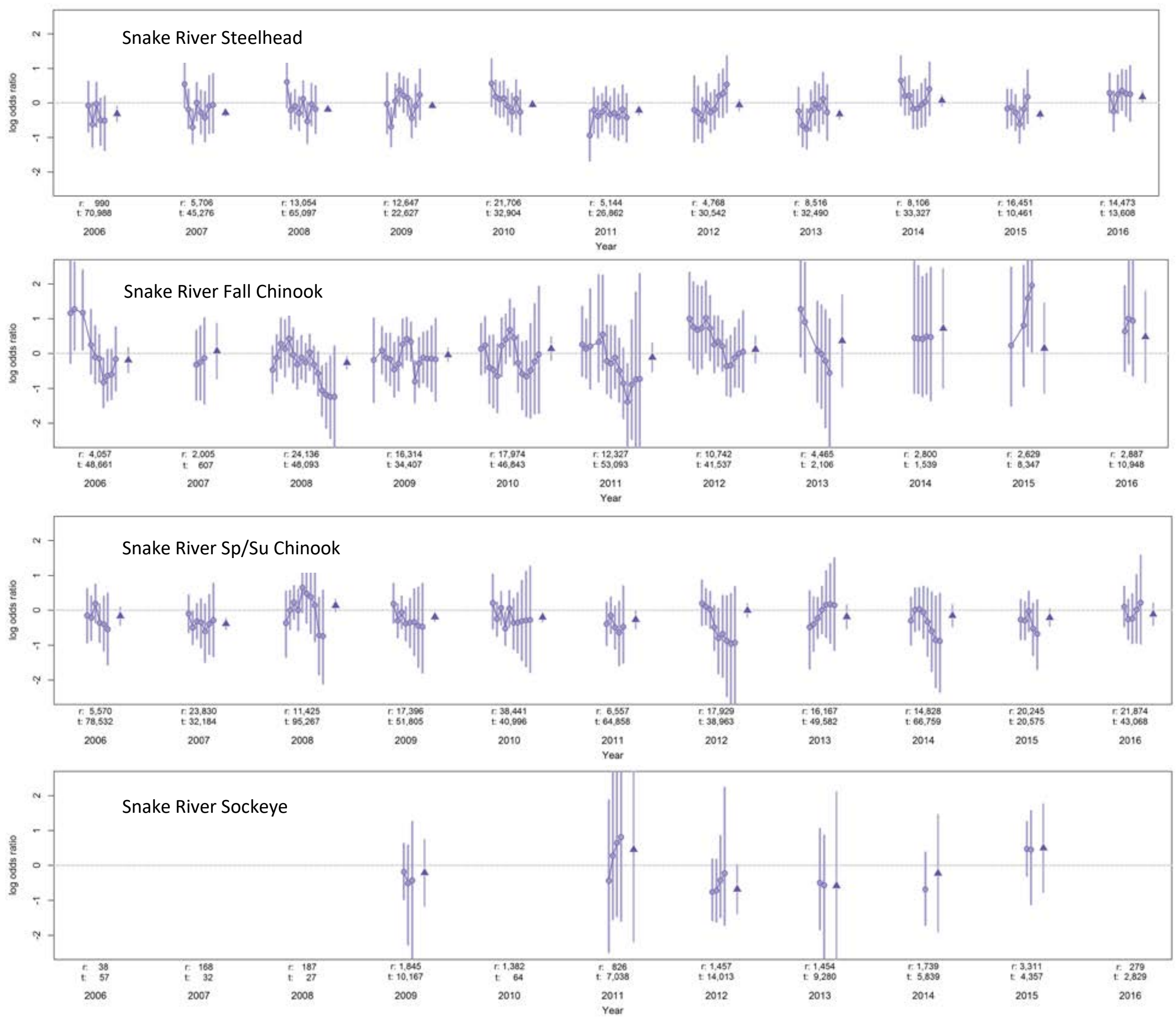

Figure D1. Relative susceptibility of fish by migration history to predation by Caspian terns nesting on East Sand Island during 2006-2016. Values represent the odds-ratio of predation (y_1), with values < 0 indicating greater predation odds for in-river migrating fish and values > 0 indicating greater predation odds for transported fish. Error bars represent 95% confidence intervals, with values over-lapping 0 not statistical significant. Only years were > 500 PIT-tagged fish of each migration history available were presented. Weekly estimates (circles) are followed by an annual estimate (triangles).

APPENDIX E: WEEKLY JBS VS. CORNER COLLECTOR (BONN)

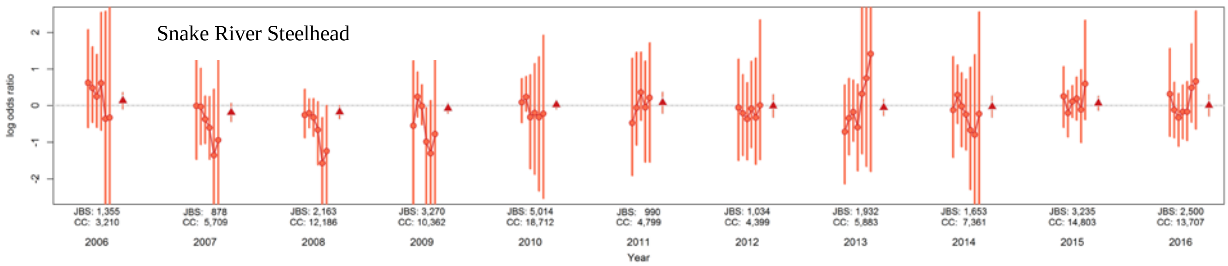

Figure E1. Relative susceptibility of fish by passage route at Bonneville Dam to predation by Caspian terns nesting on East Sand Island during 2006-2016. Values represent the odds-ratio of predation (y_1), with values < 0 indicating greater predation odds for fish last detected passing Juvenile Bypass System (JBS) and values > 0 indicating greater predation odds for fish last detected passing the Corner Collector (CC). Error bars represent 95% confidence intervals, with values over-lapping 0 not statistical significant. Only years were > 500 PIT-tagged fish of each migration history available were presented. Weekly estimates (circles) are followed by an annual estimate (triangles).