Measuring Estuary Avian Predation Impacts on Juvenile Salmon by Electronic Recovery of ISO-PIT Tags from Bird Colonies on East Sand Island, Oregon, 2012

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EXECUTIVE SUMMARY

A factor which is limiting recovery of threatened and endangered populations of Columbia River Basin salmon is avian predation on juvenile salmon. To measure, monitor, and manage the effects of avian predation, predation rates for individual Evolutionarily Significant Units (ESUs) and Distinct Population Segments (DPSs) of populations must be calculated. One method to calculate predation rates uses Passive Integrated Transponder (PIT) tag codes deposited on nesting colonies of bird predators and compares those codes with all the codes which were detected in the geographic area of interest. Our report presents results from a NOAA Fisheries project which recovered PIT tag codes from seabird colonies located on East Sand Island, OR in the Columbia River Estuary. Tag codes recoveries were used by both NOAA Fisheries and collaborators with Bird Research Northwest to derive estimates of estuary predation by Caspian terns (*Hydroprogne caspia*), double-crested cormorants (*Phalacrocorax auritus*), and Brandt's cormorants (*P. penicillatus*) on juvenile salmon.

We present results from on three primary study components:

(1) PIT-tagging of three groups of Lower Columbia River ESU subyearling fall Chinook salmon (*Oncorhynchus tshawytscha*)

(2) Recovery of PIT tag codes from East Sand Island, OR

(3) Estimation of estuary predation rates, including calculations of

   i. Tag code detection efficiency adjustments
   ii. Off-colony tag deposition adjustments
   iii. Estuary predation rate estimates for ESU/DPS groups originating entirely above Bonneville Dam (Columbia River) or above Sullivan Dam (Willamette River)
   iv. Estuary predation rate estimates for PIT-tagged Lower Columbia River Chinook salmon
   v. Estuary predation rate estimates for barge-transported vs. in-river migrant Snake River ESU fall Chinook salmon originating above Lower Granite Dam

In May and June 2012, 8,885 Lower Columbia River ESU fall Chinook salmon were tagged and released below Bonneville Dam directly into the estuary. Of these releases, we estimated Caspian terns consumed 2.6%, double-crested cormorants 14.9% of these releases, and mixed species including Brandt's cormorants 0.8%.

On the Caspian tern colony, we recovered 15,298 unique tag codes from fish which migrated downstream in 2012. Codes were found from all 13 ESU/DPS groups listed by the Endangered Species Act as threatened or endangered. On the double-crested cormorant colony, we recovered 13,829 unique tag codes, also representing all 13 listed ESU/DPS groups. Date-dependent detection efficiencies on the Caspian tern colony ranged from 42% to 90%; those on the double-crested cormorant colony ranged from 56% to 81%. These efficiencies were comparable to prior years' measurements. Biologists from BRNW used our tag code recoveries from experiments designed to measure off-colony tag deposition rates for double-crested cormorants. They reported an estimated 44% of tags being deposited on the colony, implying up to 56% of tags consumed by double-crested cormorants are deposited off the colony. Data from the deposition study were used to refine estimation of avian predation rates by making an adjustment to account for off-colony deposition.

Estimates of estuary predation rates for tag groups with geographical origins entirely above Bonneville Dam (Columbia River) or Sullivan Dam (Willamette River) showed Caspian terns having the greatest impact on steelhead (7.4%-10.0%), with a lesser impact on other groups (0.7%-2.2%). Double-crested cormorants had the greatest impact on upper Columbia River ESU steelhead (7.2%), with a range of impacts on other ESU/DPS groups (0.6%-5.4%). In general, Upper Willamette spring Chinook salmon experienced the least avian predation impact (<1%). Brandt's cormorants appeared to have minimal impact on any of the population groups we examined (<1%).

Fifty-two different sources contributed to PIT-tagged tagged Lower Columbia River ESU Chinook salmon during migration year 2012, yet only three hatcheries above Bonneville Dam accounted for 66.3% of tagged fish released into the Columbia River. We estimated overall predation rates on tagged fish from this ESU to be 0.91% for Caspian terns, 2.9% for double-crested cormorants, and 0.15% for mixed species including Brandt's cormorants. It was noted that due to the complexity of the life history types included in this ESU, and the lack of a comprehensive, representative tagging program for the ESU as a whole, generalizing these predation rates to the entire Lower Columbia River ESU should be done with extreme caution.

Comparisons of barge-transported vs. in-river migrant Snake River ESU fall Chinook salmon were made in two ways. First, annual predation estimates were calculated using all available data from 2012. Second, paired daily comparisons were made on days when at least 100 fish were detected entering the estuary from both transported and naturally-migrating fish. Caspian terns and double-crested cormorants both had higher impacts on barge-transported fish (0.7% and 3.3%, respectively) than on in-river migrants (0.5% and 1.3%, respectively); mixed species including Brandt's cormorants had similar impacts on in-river migrants (0.1%) than on barged fish (<0.1%). Paired comparisons also showed tern predation and double-crested cormorant predation were higher on transported fish (0.5% and 2.7%, respectively) than on migrants (0.3% and 1.0%, respectively), although the difference was only statistically significant for cormorants. For mixed species including Brandt's cormorants, transported vs. migrant rates were identical (0.2%). The implication is that barging is not necessarily an effective tool for decreasing estuary avian predation on Snake River ESU fall Chinook salmon. However, it was noted that a significant number of PIT tag codes from in-river migrants were recovered from East Sand Island (n = 1,891) which had not been detected at Bonneville Dam, suggesting there may be more predation happening on in-river migrants than we could measure in this study.

To improve future understanding of estuary avian predation on Columbia River salmon, we recommend that future work include support for deriving a mechanistic understanding of seasonal and annual variation in estuary predation rates. We also recommend that (1) the use of deposition adjustments be applied to all predation rate estimates, (2) a comprehensive tagging program for Lower Columbia River ESU Chinook salmon be developed to more accurately characterize estuary predation on the ESU overall, and (3) an effort be made to improve detection numbers for estuary entry timing of in-river migrant Snake River fall Chinook salmon.

INTRODUCTION

Beginning in 1987, research biologists started tagging juvenile Pacific salmon (*Onchorhynchus* spp.) with Passive Integrated Transponder (PIT) tags to measure fish survival through the Federal Columbia River Power System (FCRPS) (Prentice et al. 1990, Marvin 2012). Dams and fishways managed by the FCRPS have been instrumented with PIT tag detectors. These detectors allow scientists and mangers to track survival of juvenile fish as they migrate seaward through FCRPS, as well as allowing them to track adult fish returning through FCRPS during the spawning migration. Annual releases of PIT-tagged juvenile salmon have grown from an initial number less than 50,000 to over 2 million (Marvin 2012). When fish are tagged, data specifying the species, origin, release site, and release date for each tagged individual are recorded into a basin-wide regional database known as the PIT Tag Information System (PTAGIS 2013, http://www.ptagis.org). Subsequent PIT tag detections or tag recoveries are also recorded in this database.

Survival measurements derived from PIT tag data have been used to identify times, places, and agents of salmon mortality. These data in turn allow development of action plans whose aims are to identify the factors limiting population recovery of threatened or endangered salmon, and to implement recovery actions for listed populations (NMFS 2008, 2010) .

One potential limiting factor affecting salmon recovery was identified in 1998, when fisheries biologists discovered thousands of PIT tags from juvenile salmon being deposited on colonies of Caspian terns (*Hydroprogne caspia*) and double-crested cormorants (*Phalacrocorax auritus*) nesting on Rice Island (rkm 34) in the lower Columbia River (Collis et al. 2001). NOAA Fisheries biologists developed flat-plate and hand-held PIT tag detectors that would allow large-scale recovery of PIT tag codes from avian colonies beginning in 1998 (Ryan et al. 2001). Results from this work demonstrated that birds were consuming millions of salmon annually (Collis et al. 2001, Ryan et al. 2003) and justified removing the birds from Rice Island - where the fish available to them were primarily juvenile salmon – and encouraging them to nest further downstream on East Sand Island (rkm 8), where alternative prey such as marine forage fish were known to be available (Bottom and Jones 1990). The expectation was that moving birds closer to a non-salmonid food source would reduce avian predation impacts on salmon survival.

Data from PIT tag recoveries showed that estuary avian predation impacts were reduced by moving the nesting areas to East Sand Island; however, basin-wide assessments continue to indicate estuary avian predation is a factor limiting recovery of certain Evolutionarily Significant Units (ESUs) or Distinct Population Segments (DPSs) of salmon. The 2008 Biological Opinion (NMFS 2008), the 2010 Supplemental Biological Opinion (NMFS 2010), and the 2009 Adaptive Management Implementation Plan (AMIP; NMFS 2009) all require FCRPS action agencies to support recovery of PIT tag codes from estuary bird colonies as well as the subsequent data processing and analysis necessary to estimate avian predation rates on Columbia River Basin ESU/DPS groups. Specifically AMIP Actions 45 and 46 require estimation of Caspian tern and double-crested cormorant predation rates, respectively. AMIP Action 66 requires ongoing monitoring of estuary tern population impacts on juvenile salmon.

The tasks necessary to address freshwater and estuary avian predation issues have historically been shared among biologists at NOAA Fisheries Point Adams Research Station (rkm 13; http://www.nwfsc.noaa.gov/research/facilities/ptadams/index.cfm) and Bird Research

Northwest (BRNW, formerly Columbia Bird Research, http://www.birdresearchnw.org). Each research group publishes companion data reports according to how tasks were partitioned on yearly research contracts with Action Agencies. During 2012, NOAA Fisheries assumed all responsibility for PIT-tag code recoveries on East Sand Island bird colonies, and BRNW, in addition to performing other research during the nesting season, assumed responsibility for PIT tag code recoveries in all other colony locations. Summary results of NOAA Fisheries tasks are presented in this report; companion results for BRNW tasks are presented in (Roby et al. 2013).

It should also be noted predation rates in this report are calculated by ESU/DPS groups, to better meet management needs and to provide direct comparability with the BRNW companion report. The reporting of predation rates by ESU/DPS group is a change from how they were previously reported in recent NOAA Fisheries documents (i.e., by species/run/rear types, not by ESU/DPS group; see Sebring et al. 2009, Sebring et al. 2010a, Sebring et al. 2010b, Sebring et al. 2012) .

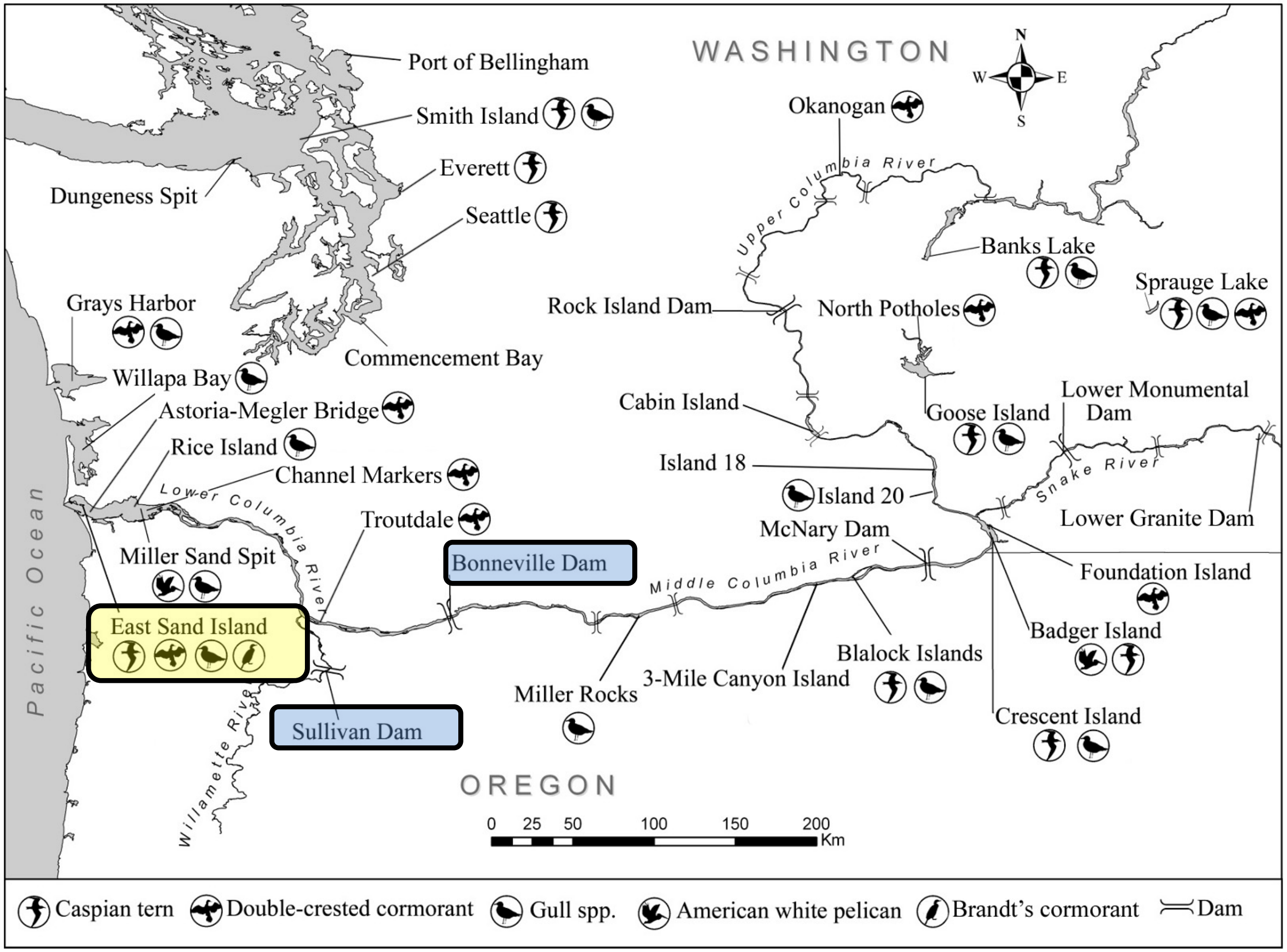
STUDY AREA

Piscivorous waterbirds have established numerous nesting colonies throughout the Columbia River Basin (Figure 1). Most colonies are still active (e.g. East Sand Island, Crescent Island), although of some are no longer active (e.g. Rice Island). Individual colonies have all been studied, at one time or another, by Bird Research Northwest, a research partnership between Oregon State University, the US Geological Service, and Real Time Research; NOAA Fisheries; or the University of Washington. Of all the avian nesting colonies, the largest are those in the lower Columbia River Estuary on East Sand Island, OR. NOAA Fisheries had responsibility for recovering PIT-tag codes from this location in 2012.

East Sand Island

During 2012, all PIT tag code recovery efforts for this project took place on East Sand Island, Oregon (rkm 8). This 2.02×10^6 m^{-2} (~ 50 acres) island consists primarily of coarse sand with some topsoil and vegetation. The west end of the island is armored with a stone jetty and rip-rap on the southern shoreline. Access to the island requires the use of a small boat and inflatable landing skiff. These vessels were moored at the Chinook Marina in Chinook, Washington, the closest port to East Sand Island.

Figure 1. Map of Columbia River Basin and coastal Washington showing the location of active and former breeding colonies of piscivorous waterbirds that have been studied by Bird Research Northwest (BRNW), NOAA Fisheries, or the University of Washington. The study site for this report is East Sand Island, indicated in yellow, at the mouth of the Columbia River. The FCRPS dams closest to East Sand Island (Bonneville, Sullivan) are indicated in blue. Map provided courtesy of BRNW.



The Caspian tern nesting colony is located on the eastern end of East Sand Island. The colony includes 6,394 m^{-2} (1.58 acres) of vegetation-free bare sand (Figure 2), which represents a nearly 50% reduction in colony size from the 12,545 m^{-2} (3.1 acres) available in 2010 (Figure 3). Prior to initiation of nesting, the colony area is actively managed by the US Army Corps of Engineers to control colony size, maintain bare sand habitat, and eliminate vegetation on the colony.

Figure 2. Bare sand habitat on the Caspian tern colony. This habitat is actively groomed to maintain a relatively flat surface without vegetation. Black fencing marks the edge of the colony. This picture was taken facing northwest, towards the town of Chinook, WA.

The middle section of the island contains dense vegetation with small trees, shrubs, and grass. No waterbirds nest in this section of the island.

Double-crested and Brandt's cormorants nest on the west end of East Sand Island in bare sand (Figure 4) or on the stone rip-rap (Figure 5). Originally, cormorants had access to 15,782 m^{-2} (3.9 acres) of nesting habitat, but in 2012 a combination of fencing and hazing dissuaded birds from using ~ 5,665 m^{-2} (1.4 acres) and restricted active nesting to an area of 10,117 m^{-2} (2.5 acres; Figure 6). In this report, we refer to the area of active nesting habitat as the cormorant colony, and the area where cormorants were discouraged from nesting as the dissuasion area.

Figure 3. Schematic of Caspian tern colony size and shape from 2010 to 2012. This figure shows the sequential 50% reduction of colony size. The inset immediately below the legend shows the location of the colony on the east end of East Sand Island. Figure provided courtesy of BRNW.

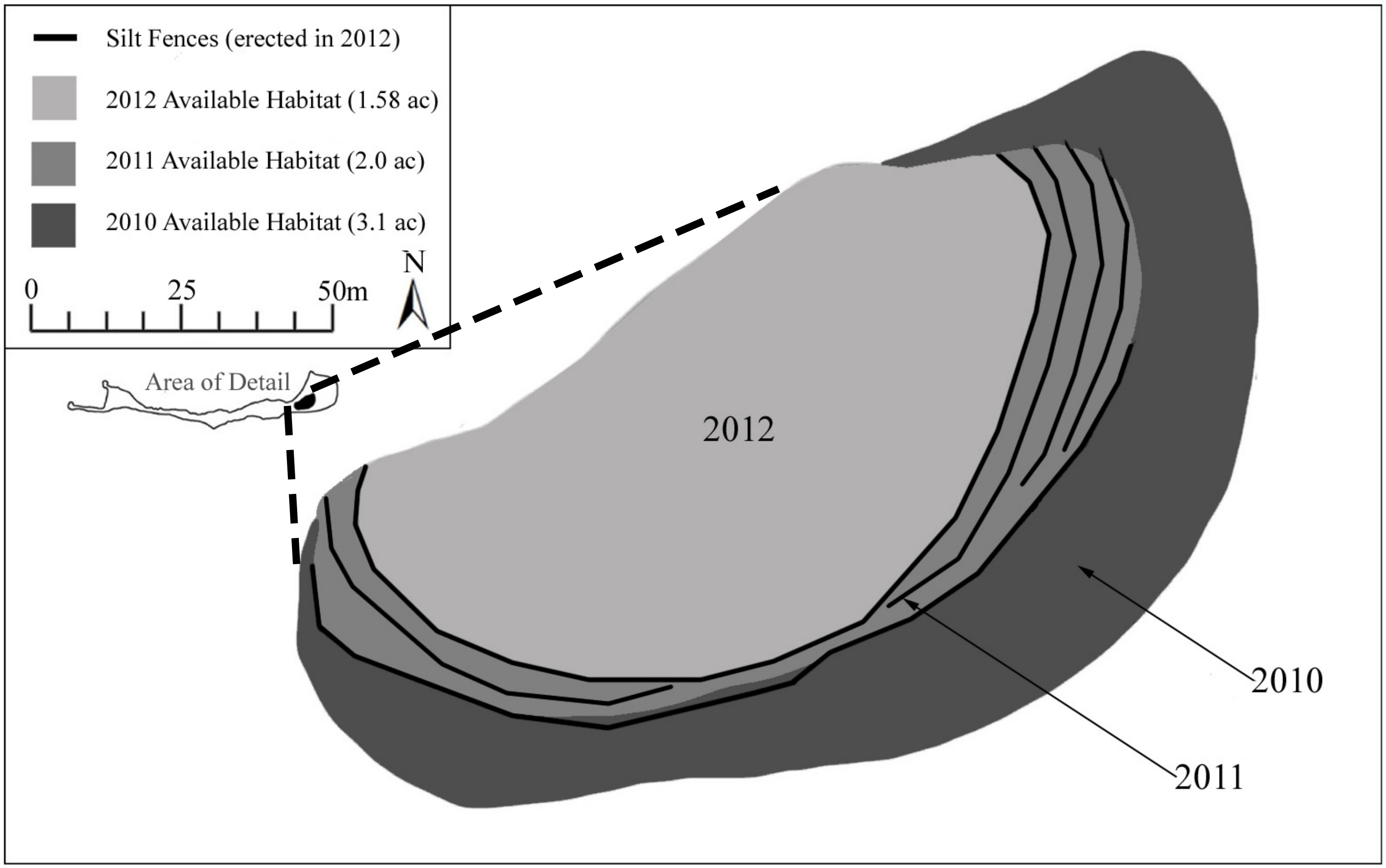
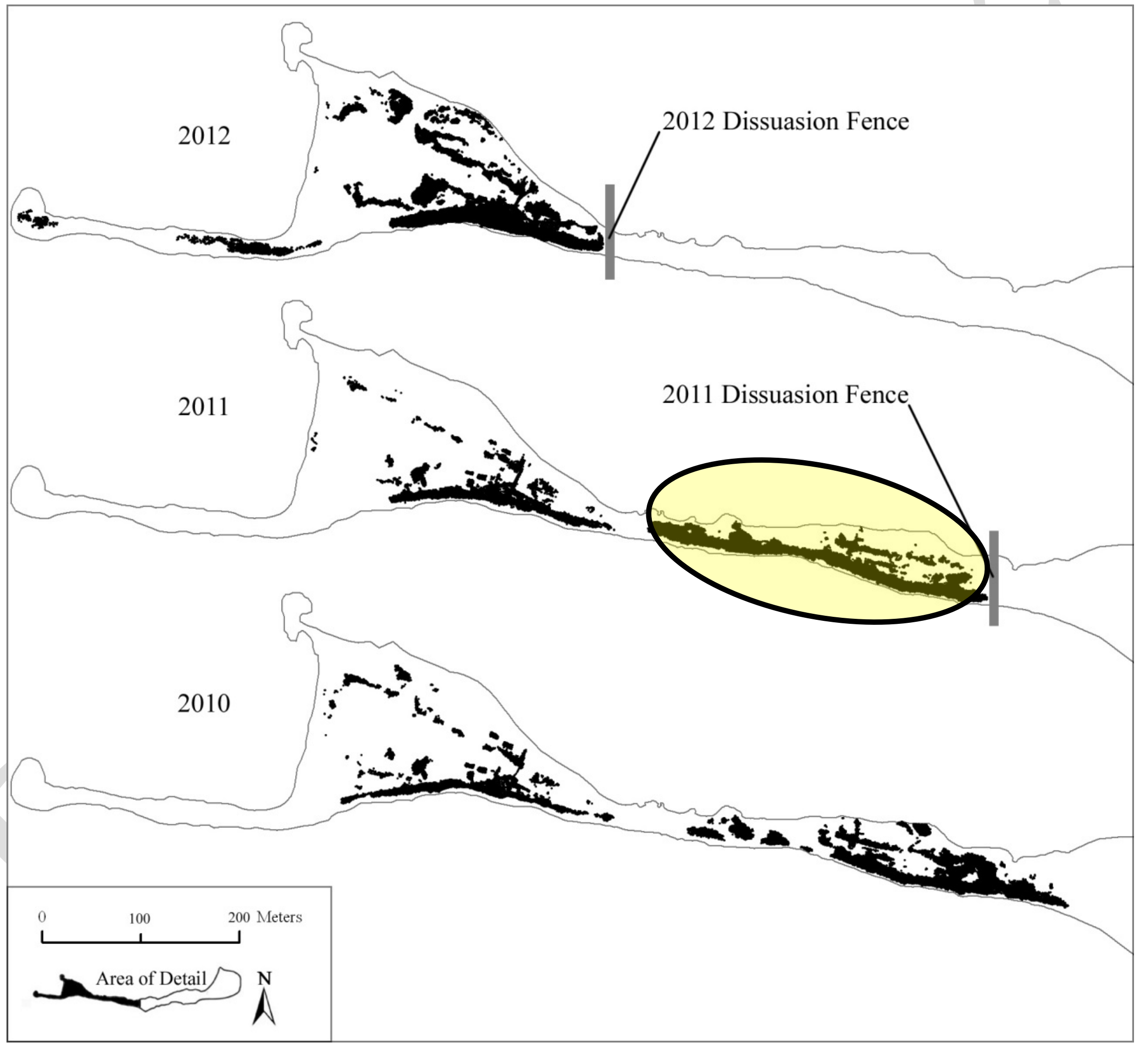


Figure 4. Bare sand habitat on the cormorant colony. Unlike bare sand habitat on the tern colony, bare sand habitaton the cormorant colony is not actively managed to maintain a flat surface without vegetation or rocks. The upright sticks marked with arrows in the foreground indicate the edge of an area that was surveyed with a hand-held PIT tag detector.

Figure 5. Rip-rap habitat on the cormorant colony. This habitat type is found primarily on the southwestern portion of East Sand Island, where the shoreline is armored with stone and where driftwood and other flotsam accumulate in significant quantities.

Figure 6. Map of the distribution of double-crested and Brandt's cormorants nests on the west end of East Sand Island. Maps show the sequential reduction in colony area through the use of dissuasion fencing and hazing during the breeding season. In this report, the area between the 2012 dissuasion fence and the 2011 dissuasion fence (circled in yellow) is referred to as the Dissuasion Area. Maps provided courtesy of BRNW.



TAGGING OF LOWER COLUMBIA RIVER SUBYEARLING CHINOOK SALMON

Methods

During May and June of 2012, 9,000 PIT tags were available from the US Army Corps of Engineers to mark hatchery-raised, subyearling fall Chinook salmon from the lower Columbia River ESU.

Tagging activity followed the same protocol used in previous work where hatchery fish were PIT-tagged (e.g. Sebring et al. 2011, Sebring et al. 2010). A team of four biologists, including at least two experienced taggers, worked with single-use, pre-loaded surgical needles to inject PIT tags into the body cavity of individual fish. Single-use needles minimized fish-to-fish transfer of disease or pathogens during tag implantation.

The tagging sequence proceeded as follows. First, using a large dip net, untagged fish were moved from the hatchery holding tank containing fish of appropriate size (> 60 mm fork length) into a 55 gallon tank supplied with flow-through water. Next, several fish at a time were transferred, via small dip net, in a smaller tub where they were anesthetized with a dose of 50 mg/l of tricaine methane-sulfonate (MS-222) (Neiffer and Stamper 2009). After about two minutes, when fish stopped swimming and rolled gently onto their sides, tagging personnel removed fish by hand from the anesthetic bath, and a PIT tag was inserted into the ventral body cavity using pre-loaded needles. This method, due to the small gauge of the needle, required no sutures or other manipulations of the fish.

After the PIT tag was inserted, the PIT tag identification code was entered into a laptop computer by passing the fish through a circular PIT detector. Fish were then placed into a five-gallon recovery bucket with flow-through water and monitored for recovery from anesthesia as well as any incidental tag loss. Once all fish in the recovery bucket were swimming upright and in a normal fashion, they were transferred to the hatchery raceway specified for tagged fish. Any tag loss was recorded by retrieving ejected PIT tags from the recovery bucket and re-running the tags through the PIT detector so that the tag ID was recorded. Release of tagged fish took place according to the original hatchery release schedule, but no sooner than 12 hours after tagging.

Data files containing tag-and-release information were uploaded to directly to the PTAGIS web site (PTAGIS 2013), the publicly available site where all Columbia Basin PIT tag records are archived.

Results

A total of 8,885 subyearling Chinook salmon from three hatcheries were PIT-tagged during 2012; of these, 1,121 (12.6%) were subsequently recovered on East Sand Island (Table 1). All of these fish were released into the Columbia River Estuary at sites below Bonneville Dam. For these tag groups, records for PIT tag releases and subsequent recoveries on East Sand Island bird colonies were used in the calculation of estimated predation rates for the Lower Columbia River Chinook salmon ESU (see pages 26 to 33 of this report).

RECOVERY OF PIT TAGS FROM EAST SAND ISLAND

All East Sand Island PIT-tag detection efforts took place between 01 October and 15 November 2012. When sufficient personnel were available to do so, two crews worked simultaneously on the Caspian tern and cormorant colonies. One complete survey of the tern colony, the cormorant colony, or the dissuasion area typically took 4-7 days; each complete survey of an entire colony (or the dissuasion area) was referred to as a "pass." Three passes were completed on the tern colony; two passes were completed on the cormorant colony and the dissuasion area.

Caspian Tern Colony

Methods

Caspian terns nest only on relatively flat bare sand. Therefore, PIT tag surveys on the tern colony were performed with detection gear designed for flat bare sand habitat. To detect PIT tags on or up to 10-15 cm below the sand's surface, we used a 6-coil, flat-plate antenna system that allowed us to record tag detections from a mobile vehicle onto a laptop computer (Ryan et al. 2001). The original 2001 flat plate system has been modified to be towed at a speed of ~ 8 m/min (0.3 mph) by a small tractor driving along overlapping, parallel tracks (Figure 7). In this report, the word "track" refers to the single, continuous swath covered by the flat plate detector as the tractor is driven from one edge of the colony to the opposite edge in a straight line.

Because tag detection can be sensitive to the orientation of the tag in the detector's field relative to the motion of the detector, we varied the direction of scanning with the flat plate system in the following two ways. First, each individual track within a pass was run in two directions: first, with the tractor moving forward and second, with the tractor moving backward over exactly the same track. Second, the orientation of tracks within each of the three passes over the tern colony was different for each pass. In the first pass, tracks ran parallel to the long axis of the colony. In the second pass, tracks ran perpendicular to the long axis of the colony. In the third and final pass, tracks were oriented diagonally from the northwest corner to the southeast corner of the colony. Before starting each pass of straight-line tracks, we also scanned the entire colony perimeter, driving both forwards and backwards along the perimeter track, to scan for any tags which may have been deposited on or washed into the grass on the edges of the colony. Where drift fencing was absent, we scanned at least one plate-width (~1.5 m) into the grassy area bordering the colony.

Table 1. Tag, release, and recovery information for Lower Columbia River fall Chinook salmon released below Bonneville Dam into the Columbia River Estuary, migration year 2012.

					# tags recovered		
Tagging site	Tagging date	Release site	Release date	# released	Caspian terns	Double-crested cormorants	Mixed
Warrenton High School Hatchery	01 May	Skipanon River, OR	13 May	2978	70	384	13
Big Creek Hatchery	03 May	Big Creek Hatchery, OR	07 May	2921	33	286	13
Kalama Falls Hatchery	25 Jun	Kalama Falls Hatchery, WA	26 Jun	2986	63	248	11

In a few cases, obstacles such as old tire fragments or cables made it difficult to determine whether the flat plate was close enough to the substrate (10-12 cm) to detect potentially buried tags. For these small areas, we employed a hand-scanner to ensure proper coverage near the obstacle.

Figure 7. Flat-plate PIT detector system for East Sand Island Caspian tern colony. The custom aluminum housing on the rear of the tractor is connected to the tractor's alternator and contains AC/DC power systems necessary to power the antenna, multiplexing receiver, and laptop computer. Overlapping tracks are visible on the sand surface.

Results

Three complete passes over the Caspian tern colony were accomplished between 01 October and 08 November 2012. We recorded a total of 20,279 PIT tag codes on the tern colony with no prior history of tag code recovery. Of these, 15,298 (73.8%) were from juvenile salmon that migrated downstream in 2012. A breakdown of raw tag code recoveries by ESA-listed ESU/DPS groups is provided in Table 2. It should be noted that tag codes were recovered from all 13 groups of ESA-listed salmon in the Columbia River Basin.

PIT tag codes from 10 cutthroat trout (*Oncorhynchus clarkii*) were also recovered, as well as 127 codes reported in PTAGIS from unidentified species.

Cormorant Colony

Methods

The cormorant colony is a fundamentally different site compared to the tern colony. The tern colony contains a single species and a single nesting habitat type (bare sand), whereas the cormorant colony contains two species (double-crested and Brandt's cormorants), two nesting habitat types (bare sand, rip-rap), and two experimental treatment areas (dissuasion area, deposition areas). In addition, cormorant nests – which are built with sticks, vegetation, fecal matter, and other materials - have a more complex three-dimensional structure than tern nests, where a simple sand scape serves as a nest. Because the larger flat-plate detector cannot be used in most of the more complex, three-dimensional structure of the cormorant colony, all scanning for PIT tags on this colony used small, hand-held scanners (Figure 8).

Figure 8. Use of hand-held PIT detector system for East Sand Island rip-rap habitat on the cormorant colonies. Battery-powered transceivers were carried in a backpack system.

Table 2. Summary of PIT tag detections from East Sand Island seabird colonies, migration year 2012. Tags were recovered from all 13 possible ESA-listed groups. The category "mixed species" refers to areas where either (1) Brandt's cormorants were nesting, but it was likely an unknown but low amount of deposition by double-crested cormorants occurred or (2) the dissuasion areas on the cormorant colony where mixed species of birds (including gulls) were loafing but not nesting.

	Total PIT tags detected in each colony area		
ESU/DPS group, sorted by species	Caspian tern	Double-crested cormorant	Mixed species
Snake River sockeye	175	404	17
Snake River spring/summer Chinook	2082	2028	75
Upper Columbia River spring Chinook	202	244	6
Mid-Columbia River spring Chinook	145	138	2
Snake River fall Chinook	1069	2686	174
Upper Columbia River summer/fall Chinook	340	418	40
Upper Willamette River spring Chinook	32	40	7
Lower Columbia River Chinook	714	2416	93
Snake River steelhead	7183	2985	114
Upper Columbia River steelhead	1215	697	26
Mid-Columbia River steelhead	1806	645	24
Lower Columbia River steelhead	644	195	4
Lower Columbia River coho	4	25	0

To proceed in a systematic way with on-colony surveys for PIT tag detections, hand-scanning teams were assigned to one of four possible categories in a species-by-habitat matrix (Table 3). NOAA Fisheries staff and collaborators at BRWN used a combination of aerial photographs and on-the-ground reconnaissance to determine which areas fell into each species and habitat designation. Field crews consulted these maps and discussed the strategy for scanning each habitat each day before data collection began and as necessary throughout the day. While scanning for tags, staff manually moved detectors back and forth across the surface of the substrate, in a manner described as "aggressive vacuum-cleaning" when training new technicians (B. Cramer, pers.comm.). Whenever possible, personnel walked systematically along parallel, overlapping, tracks within the area being scanned. To ensure large areas were not missed during hand-scanning, personnel used a combination of maps, visual landmarks, sticks, and scuff marks in the sand to delineate which sections of habitat had been surveyed.

At the end of each day, the survey area covered was marked on laminated copies of the aerial colony maps. Exposed rip-rap habitat was given the highest scanning priority, because this habitat type is most vulnerable to tag loss due to wind, rain, and waves associated with fall storm events.

In 2012, there was an additional level of complexity because Brandt's cormorants constructed individual nests near or within areas that were primarily occupied by double-crested cormorants. It was necessary to use combination of contractors' flagging and colored non-toxic spray paint to mark individual nests nests or nesting areas as belonging to one species or the other.

Table 3. Species-by-habitat matrix for hand-scanning PIT tag detection on the cormorant colony.

Species	Habitat type or experimental treatment
Double-crested cormorant	Bare sand
	Rip-rap
Mixed double-crested/Brandt's cormorants	Bare sand
	Rip-rap
Mixed species	Bare sand – dissuasion experiment
	Rip-rap – dissuasion experiment
Double-crested cormorant	Deposition experiment Site 1
	Deposition experiment Site 2
	Deposition experiment Site 3

Results

Between 10 October and 15 November 2012, we completed two passes covering approximately 10,117 m^2 (2.5 acres) of cormorant nesting habitat as well as 5,665 m^2 (1.4 acres) of habitat in the experimental dissuasion area. The first pass was completed on 18 October 2012, prior to any fall storm systems affecting the island (e.g. rain, high wind, high seas). Heavy weather is a concern because wave action, rain, or flooding can wash PIT tags from nest areas, especially on exposed rip-rap habitat. The second pass was completed after the first storms of the fall occurred between 18 October and 31 October 2012.

Hand-scanning recovered a total of 17,191 unique tag codes with no prior history of tag code detection. Of those, 13,829 (80.4%) were from juvenile salmon which migrated downstream in 2012. A breakdown of raw tag code recoveries by ESA-listed ESU/DPS groups is provided in Table 2. Tag codes were recovered from all 13 groups of ESA-listed salmonids in the Columbia River Basin. Two PIT tag codes from cutthroat trout were also recovered, as well as one tag from a white sturgeon (*Acipenser transmontanus*), three codes from northern pikeminnow (*Ptychocheilus oregonensis*), and 191 codes reported in PTAGIS as unidentified species.

ESTUARY PREDATION RATE ESTIMATES

To more accurately calculate predation rates from PIT tag detections, it is important to make adjustments for two types of uncertainties in tag detections. The first type of uncertainty relates to the fact that PIT detection systems are not 100% efficient; some proportion of tags on the colony are missed during any given survey. We refer to calculations that account for this phenomenon as the “detection efficiency adjustment”.

The second type of uncertainty relates to the fact that some proportion of PIT-tagged salmon captured or ingested by birds will have their associated tags deposited off the colony itself; we refer to calculations which account for this phenomenon as the “deposition adjustment”.

Detection efficiency adjustments to predation rate estimates have been made in all prior years of work on East Sand Island (e.g. Ryan et al. 2001, Sebring et al. 2012, Roby et al. 2013). However, off-colony deposition adjustments have never been made for double-crested cormorants, and adjustments for Caspian terns have only been made in a few cases (see Roby et al. 2013, Appendix A). This year (2012) is the first time that both types of predation rate adjustments have been applied to Caspian terns and as well as double-crested cormorants.

Tag Detection Efficiency Adjustment

Methods

PIT tag detectors are not 100% efficient in the field. Even with the best of scanning techniques, some PIT tags located on the colonies will not be successfully detected and read into the data file. For example, if two or more tags are located very close to each other and detected at exactly the same time, then a “tag code collision” occurs, and the electronic reader is unable to distinguish one or more of the codes in the detection field. Other tags may break over the course of the season. Still other tags may be too deeply buried to be detected. Therefore, it is necessary to measure detection efficiency by putting a known number of tags with known codes onto the colony before, during, and after the nesting season.

As in previous years, our collaborators with BRNW randomly sowed groups of 100 control tags on the East Sand Island tern and cormorant colonies. Because there were two habitat types on the cormorant colony and in the dissuasion area, tags for these two areas were subdivided into two subgroups of 50 tags each – one subgroup each for bare sand and rip-rap habitats. Two periods of tag placements occurred: one in April before egg-laying began, and one in late September or early October, after all chick-rearing activity ended and adult birds vacate the colonies.

Although it is possible in some years to sow control tags during egg incubation or chick-rearing on the tern colony, it was not possible to do so during the 2012 nesting season because doing so was judged to cause too much disturbance, potentially resulting in nest or colony abandonment. Similarly, due to the disturbance necessary to sow tags, control tags were not sown during incubation or chick-rearing periods on the cormorant colony.

Because detection efficiency can vary with time elapsed since the initial deposition of a PIT tag (i.e., the longer a tag is on the colony, the higher the probability the tag is buried, damaged, or washed away from the original deposition site), recent best practice uses a logistic regression equation to model time-dependent, daily detection probabilities derived from the raw detection efficiencies measured by control tag code recoveries (Evans et al. 2012). For details of this method, we refer the reader to Ryan et al. (2003) and Evans et al. (2012). We made detection efficiency adjustments for all predation rate calculations with formulas we specified in a spreadsheet program.

Results

Six hundred control tags were deployed across tern and cormorant nesting colonies during 2012. Tag deployments and recoveries, as well as raw detection efficiencies for each period, are summarized in Table 4. Mean raw detection efficiencies measured in 2012 on the Caspian tern (77%) and double-crested cormorant (74%) colonies were similar in magnitude to recent years' detection efficiencies (c.f. Appendix Table 4 in Sebring et al. 2012).

Date-adjusted daily detection efficiencies for East Sand Island species during the period between 01 March 2012 and 31 August 2012 were calculated using a logistic regression model as per Evans et al. (2012). Coefficients for the equations used in this report are provided in Table 5. Daily detection efficiencies for the Caspian tern colony ranged between 42% and 90%. Daily detection efficiencies for the double-crested cormorant colony (exclusive of the dissuasion area) ranged between 56% and 81%. Daily detection efficiencies for the dissuasion area ranged between 43% and 66%.

Table 4. Recovery of detection efficiency tag codes from East Sand Island. Pre-season tags were placed on the colonies before nesting activities began; post-season tags were placed on the colonies after adults and fledglings left the colony, but before tag recovery surveys began. Data from this table were used to generate the logistic regression equation for date-specific detection efficiencies.

Species	Habitat	Date control tags sown		Control tags sown		Control tags recovered		% Control tags recovered	
		Pre-season	Post-season	Pre-season	Post-season	Pre-season	Post-season	Pre-season	Post-season
Caspian tern	Bare sand	17 Apr 12	27 Sep 12	100	100	60	94	60%	94%
Double-crested cormorant	Bare sand	11 Apr 12	09 Oct 12	50	50	28	43	56%	86%
	Rip-rap	11 Apr 12	09 Oct 12	50	50	35	42	70%	84%
	Bare sand (dissuasion area)	03 May 12	09 Oct 12	50	50	17	36	34%	72%
	Rip-rap (dissuasion area)	03 May 12	09 Oct 12	50	50	33	30	66%	60%

Table 5. Species-specific coefficients for the binomial logistic regression used to estimate daily detection efficiencies. Nomenclature is as per Evans et al. (2012), Equation 2.

Species	β_0	β_i
Caspian tern	-579.23	0.01413
Double-crested cormorant	-271.90	0.00664
Dissuasion area	-171.17	0.00417

Off-colony Tag Deposition Adjustment

Methods

In 2012, a new adjustment to predation rate calculations was introduced by Roby et al. (2013), with the goal of providing more accurate estimates of predation rates derived from PIT tag recoveries. This adjustment accounts for PIT tags that are consumed by birds but deposited at sites away from the breeding colonies. Because birds do not spend 100% of their time on the colony, it is reasonable to expect that some proportion of PIT tags consumed by birds will be deposited off the colony, and those tag codes will not be recovered by on-colony PIT detection surveys. For example, PIT tags passing through the digestive tract may be egested into the water during a foraging trip. Due to variation in colony attendance patterns and foraging trip duration, it is also reasonable to expect that realistic adjustments for off-colony deposition rates need to account for species-specific variation in on vs. off-colony time budgets.

Detailed methodology describing experiments and calculations necessary to calculate species-specific adjustments to Caspian tern and double-crested cormorant predation rates are presented in Appendix A, “Incorporation of PIT Tag Deposition Rate Data to Quantify Avian Predation Rates”, in Roby et al. (2013).

Briefly, birds are fed fish containing PIT tags with known codes, and on-colony recoveries of those tags are used to estimate the probability of on-colony vs. off-colony deposition with a logistic regression model. Bootstrapping techniques were used to calculate a 95% confidence interval about the estimated deposition rate.

Results

Detailed results describing species-specific adjustments to Caspian tern and double-crested cormorant predation rates from three deposition experiments are presented in Appendix A, “Incorporation of PIT Tag Deposition Rate Data to Quantify Avian Predation Rates” of (Roby et al. 2013).

Briefly, results are summarized as follows. Caspian terns from 2005-2006 experiments conducted at Crescent Island and East Sand Island, where birds were force-fed tagged trout, deposited an estimated 86% of tags on their colony (95% confidence interval around the estimate: 73-100%). In the 2005-2006 experiment conducted near the Crescent Island tern colony, where terns volitionally fed upon tagged fish in net pens located near the colony, terns deposited and estimated 54% of tags on the colony (95% confidence interval around the estimate: 42-67%).

In the new 2012 experiments conducted by BRNW on East Sand Island, double-crested cormorants volitionally consumed a total of 301 PIT-tagged trout on the colony, and based on subsequent PIT tag recoveries, an estimated 44% of consumed PIT tags were deposited on the East Sand Island colony (95% confidence interval around the estimate: 36-51%).

Estuary Predation Rate Estimates for ESU/DPS Groups Originating Entirely Above Bonneville Dam (Columbia River) or Sullivan Dam (Willamette River)

Methods

In 2012, the mechanics of calculations for estimated predation rates and the reporting of PIT-tagged groups have changed from prior years' reports. The two changes are as follows.

First, as part of basin-wide efforts to align FCRPS research project reporting with management for Evolutionarily Significant Unit (ESU) or Distinct Population Segment (DPS) designations, we now present predation rates by ESU or DPS group. Thirteen of 19 populations from the Columbia River Basin are listed as threatened or endangered under the Endangered Species Act (ESA). Because all Columbia River Basin juvenile salmon must pass through the Lower Columbia River Estuary to reach the ocean, all populations are potentially subject to estuary avian predation. However, not all of these thirteen groups are PIT-tagged in a representative fashion, making predation rate estimates very tenuous for those ESU/DPS groups

Second, the 2012 predation rate calculations now incorporate adjustments not only for PIT tag detection efficiencies, but also for newly available adjustments for off-colony deposition of PIT tags consumed by Caspian terns or double-crested cormorants. Deposition adjustments were performed by Real Time Research, Inc. staff as part of their contract within BRNW avian predation program. The multiple steps, adjustments, and equations used in these calculations are presented in detail in (Roby et al. 2013), Section 1.4 Predation Rates Based on PIT Tag Recoveries (Caspian terns) and Section 2.4 Predation Rates Based on PIT Tag Recoveries (double-crested cormorants).

Briefly, predation rate calculations involved a two-step process: (1) estimating how many PIT-tagged fish for each ESU/DPS are *available* to birds in the estuary during the nesting season, by compiling tag codes from fish known to have been detected at a dam or released into the estuary on any given day, and (2) estimating how many PIT-tagged fish were *consumed* by birds on East Sand Island during the nesting season, by adjusting raw PIT tag code recoveries from each ESU/DPS recovered from East Sand Island colonies to account for known sources of error in tag detection and on-colony tag deposition. Predation rates are then calculated by comparing the proportion of PIT-tagged fish consumed by birds to the proportion of PIT-tagged fish available to birds in the estuary.

For ESU/DPS groups where all populations enter the Columbia and Willamette Rivers above the PIT tag detectors at Bonneville Dam (Columbia River, rkm 235) or Sullivan Dam (Willamette River, rkm 206), it is accepted practice to use the total numbers of detections for PIT-tagged fish passing through these two dams between 01 March 2012 and 31 August 2012 to estimate fish availability to birds in the estuary (Evans et al. 2012). We followed the methodology of Evans et al. (2012) and present only predation rate estimates where a sample size of ≥500 PIT-tagged individuals was available to birds in the estuary during the season.

Results

We calculated predation rates for 10 of the 13 listed ESU/DPS groups (Table 6). These calculations included adjustments for both tag code detection efficiency and off-colony tag deposition. The same predation rates are reported in Roby et al. (2013).

The tagged fish experiencing the highest predation by Caspian terns were steelhead from the Snake River ESU/DPS (predation rate of 8.4%-11.9%). The tagged fish experiencing the highest predation by double-crested cormorants were steelhead from the Upper Columbia River ESU/DPS (predation rate of 5.4%-9.6%). The tagged fish experiencing the lowest predation by Caspian terns were Chinook salmon from the Snake River fall ESU/DPS and the Upper Willamette spring ESU/DPS (predation rates of 0.4% -1.1%). The tagged fish experiencing the lowest predation by double-crested cormorants were Chinook salmon from the Upper Willamette spring ESU/DPS (predation rate of 0.2%-1.2%). Overall, mixed-species areas containing Brandt's cormorants appeared to have low predation rates on all ESU/DPSs (predation rates <0.1% to 0.6%).

Table 6. Estimated predation rates for ESU/DPS groups with population origins above Bonneville or Sullivan Dams, migration year 2012.Calculations include adjustments for both tag detection efficiency and off-colony tag deposition. Results for the Lower Columbia River ESU Chinook salmon are presented on page 26-33 of this report.

		Caspian tern		Double-crested cormorant		Mixed, Brandt's cormorant	
ESU/DPS	PIT-tagged fish detected at dams as available to estuary birds	Adjusted predation rate as % of available	95% confidence interval	Adjusted predation rate as % of available	95% confidence interval	Adjusted predation rate as % of available	95% confidence interval
Snake River sockeye	1457	2.1%	1.1%-3.2%	4.0%	2.2%-6.1%	<0.1%	n/a
Snake River spring/summer Chinook	17929	2.2%	1.8%-2.7%	4.2%	3.4%-5.2%	<0.1%	n/a
Upper Columbia River spring Chinook	3227	1.2%	0.7%-1.7%	2.3%	1.4%-3.4%	<0.1%	n/a
Mid-Columbia River spring Chinook	4433	1.6%	1.0%-2.2%	2.4%	1.5%-3.4%	0.1%	<0.1%-0.2%
Snake River fall Chinook	10742	0.7%	0.5%-0.9%	3.0%	2.3%-3.8%	0.1%	<0.1%-0.1%
Upper Columbia River summer/fall Chinook	3986	1.4%	0.9%-2.0%	2.2%	1.3%-3.1%	0.1%	<0.1%-0.2%
Upper Willamette River spring Chinook	3731	0.7%	0.4%-1.1%	0.6%	0.2%-1.2%	0.2%	<0.1%-0.4%
Snake River steelhead	4768	10.0%	8.4%-11.9%	5.4%	4.0%-7.0%	<0.1%	n/a
Upper Columbia River steelhead	3357	7.4%	6.0%-9.1%	7.2%	5.4%-9.6%	0.1%	<0.1%-0.3%
Mid-Columbia River steelhead	1084	9.3%	6.7%-12.3%	3.4%	1.6%-5.8%	0.2%	<0.1%-0.6%

Predation Rate Estimates for Lower Columbia River ESU Chinook Salmon

Methods

The Chinook salmon populations included in the Lower Columbia River ESU are extremely diverse in their life history characteristics. There are eight possible combinations of yearlings and subyearlings, hatchery-raised and naturally spawned fish, and geographic origins in Columbia River both above and below Bonneville Dam (Appendix A in Lyons et al. 2012). The lack of a coordinated tagging program for this ESU, where each life history subgroup would be tagged in proportion to its contribution to the ESU as a whole, means that predation rate calculations based on PIT tag code recoveries belonging to this ESU are more complicated and less precise than for other ESU/DPS groups. Depending on how one chooses to address this diversity with respect to currently available tag data, there are different assumptions associated with different calculation methods.

There are three primary reasons why the calculations for the Lower Columbia River ESU do not follow the same methods as for ESU/DPS groups above Bonneville or Sullivan Dams. First, unlike other ESU/DPS groups where all PIT-tagged fish enter the Columbia or Willamette River above a PIT tag detection facility associated with a terminal dam, populations in the Lower Columbia River ESU enter the mainstem Columbia River both above Bonneville Dam and below Bonneville Dam. Therefore, fish availability to birds in the estuary cannot necessarily be calculated using the number of fish detected at dams (Lyons et al. 2012).

Second, because there is not a coordinated effort to PIT tag fish within the Lower Columbia River ESU in proportion to their population contributions in that ESU, many groups (most notably naturally-produced fish) are not well-represented with PIT-tagged fish. Those groups which are PIT tagged in any given year are not necessarily tagged in proportion to their contribution to the entire ESU. Therefore, predation estimates calculated from PIT tag recoveries do not provide the most precise picture of what is happening to the ESU as a whole. In the absence of a PIT-tagging program for the Lower Columbia River ESU, any data available for PIT-tag groups from this ESU are considered the best available data at the present time. However, generalizations to avian impacts on the Lower Columbia River ESU as a whole need to be made with caution.

Third, the total numbers of fish tagged and released on an annual basis within this ESU are relatively small compared to those tagged and released in other ESUs, and therefore sample sizes for analyses are inherently are less robust and precise than for groups where greater numbers of fish in the ESU are PIT-tagged. For example, to obtain sample sizes sufficient to compare predation rates among Lower Columbia River subgroups, in the past it has been necessary to compile data from several years, and to accept a less stringent sample size criterion for those subgroups (100 PIT-tagged fish available) than for other ESU/DPS groups (500 PIT-tagged fish available) (c.f. Appendix A in Lyons et al. 2012).

To make calculations of impacts to the Lower Columbia River ESU, some investigators have chosen to measure availability of Lower Columbia River ESU fish by exclusively using PIT tag release numbers for all fish, regardless of geographic origin in the Lower Columbia River ESU (e.g. Lyons et al. 2012). This has the advantage of starting with larger sample sizes of available fish, but the disadvantage of assuming that any mortality between release and entry into the mainstem below Bonneville Dam is negligible. Predation rate estimates made with this method are of necessity *minimum* estimates of predation rate, as the number of fish actually available to birds is likely to be less than the number of fish originally released, due to unmeasured mortality caused by non-avian sources.

Other investigators have used two different measures of availability in their predation rate calculations, depending on the geographic origin of the fish (e.g. Ryan et al. 2003, Sebring et al. 2012). For this calculation, availability of fish to birds in the estuary is calculated using both dates of detection at Bonneville or Sullivan Dams (for those components of the ESU originating above the dams) and the dates of releases of PIT-tagged fish (for those components released below the dams). This method has the advantage of using the same availability measure that is used for all other ESU/DPS groups entering the Columbia River mainstem above Bonneville or Sullivan Dams, but it has the primary disadvantages of (1) using different measures for availability for groups above vs. below the dams and (2) beginning with significantly smaller sample sizes for groups released above the dams.

Both methods assume that the date on which a tagged fish was consumed by a bird was the same day on which that tagged fish became available in the estuary. This assumption is likely to be incorrect to some unknown degree, but it is not yet possible to directly observe either a tag-specific predation event or the date on which a PIT tag is deposited on East Sand Island.

For this report, we followed the general method of Lyons et al. (2012) as outlined (with errata corrections) in Appendix A, "Assessment of potential benefits to ESA-listed Lower Columbia River Chinook and coho salmon populations." To determine how many fish in this ESU were available to birds in the estuary on any given day, we summed up all PIT-tagged Chinook released within the geographic boundaries of the Lower Columbia River ESU on each day between 01 March 2012 and 31 August 2012. This included the hatchery subyearling Chinook PIT-tagged in the spring of 2012 as part of our project (see Table 1). Because a single year does not provide a large enough sample size to partition sub-groups within the ESU by run type, rear type, and geographic origin (a difference from Lyons et al. 2012 because they used pooled data from multiple years), we pooled all available PIT-tagged fish in Lower Columbia River ESU into a single predation rate estimate for that sample group in 2012. Note, given the methodological caveats above due to the lack of a coordinated tagging program for the Lower Columbia River ESU, this predation rate estimate does not necessarily represent the avian predation impact to Chinook salmon in the ESU as a whole; that would require a more in-depth analysis of subgroups, as per Lyons et al. (2012).

To determine a minimum estimate of how many fish were consumed by birds on East Sand Island, we adjusted raw tag code recoveries for each day between 01 March 2012 and 31 August 2012 by the daily detection efficiency adjustment specified by the logistic regression equation method on pages 19-22 of this report. This allowed us to sum daily estimates of the total number of PIT-tags from this ESU consumed by birds, and thus compute an annual minimum predation rate estimate for Caspian terns and double-crested cormorants, adjusted for detection efficiency.

We also calculated predation rates for the three individual Lower Columbia River subyearling fall Chinook salmon tag groups PIT-tagged as part of this study, and presented these separately.

Adjustments for off-colony deposition were not made to predation rate calculations because 2012 deposition data were not available to NOAA Fisheries at the time of this report.

Results

Between the dates of 01 March and 31 August 2012, there were 52 sources of PIT-tagged Chinook salmon releases in the Lower Columbia River ESU. The earliest date on which tagged fish from this ESU were released was 23 March 2013; no PIT-tagged fish in this ESU were released prior to that day. A total of 122,544 PIT-tagged Chinook salmon from migration year 2012 were released within the Lower Columbia River ESU. Of these releases, 66.3% came from three hatchery sources, all of which entered the mainstem Columbia River above Bonneville Dam. These “top three” sources included Carson National Fish Hatchery, Little White Salmon National Fish Hatchery, and Spring Creek National Fish Hatchery (Table 7, Figure 9). Thirteen sources contributed at least 1% to the tagged population; these sources accounted for 97.9% (n = 119,879) of all tagged fish in the Lower Columbia River ESU. All other sources combined accounted for 2.1% (n= 2,665) of tagged fish in this ESU.

Daily totals of fish released from Lower Columbia River ESU sources are provided in Figure 9. For purposes of predation rate calculations, these totals represent the daily numbers of PIT-tagged Chinook salmon available to birds nesting on East Sand Island. The median daily release size was 107.5 fish. The minimum daily release size was one fish; the maximum daily release size was 29,481 fish. Of all days on which fish were released (n=130 days), 51.5% (n = 67 days) had release sizes greater than 100 fish.

A total of 3,221 PIT tag codes were recovered from the Lower Columbia River ESU on East Sand Island bird colonies as follows: 714 from the Caspian tern colony; 2,414 from the double-crested cormorant colony; and 93 from mixed species areas. Of these tags, 1,121 recoveries came from groups tagged as part of this study (Table 1). Estimated daily predation events on PIT-tagged fish from the Lower Columbia River ESU, adjusted for daily detection efficiency, are presented in Figure 10. Annual predation rates for the three experimental tag groups released as part of this study are presented individually in Table 8.

For Caspian terns, the estimated annual predation rate over all available PIT-tagged Lower Columbia River ESU fish (i.e. subyearling and yearling, hatchery and wild, release sites above and below Bonneville Dam) was 0.91% (n = 1,119 tags after adjustments for detection efficiency). For double-crested cormorants, the estimated annual predation rate was 2.9% (n = 3,551 tags after adjustments for detection efficiency). For mixed species areas containing primarily Brandt’s cormorants with some unknown contribution from double-crested cormorants, the estimated annual predation rate was 0.15% (n = 180 tags after adjustments for detection efficiency). Excluding dates when releases were <100 fish resulted in a total of 120,573 fish being available for the annual predation rate calculation, but doing so did not change the annual estimated predation rates for any of the species.

Compared to the estimated annual predation rates, variation in daily predation rates included days when predation pressure on a release group was much lower or higher than the overall annual estimate (Table 9). On many days, there were no PIT tags detected on East Sand

Table 7. Proportions of PIT-tagged Chinook salmon released from sources within the Lower Columbia River ESU, migration year 2012. Release groups tagged as part of this study are indicated in bold type.

	Release site	Run type	Rear type	Entering Columbia River above or below Bonneville Dam	Number PIT tagged	Proportion of total PIT tagged	Cumulative proportion of tagged fish
1	Carson National Fish Hatchery	Spring	Hatchery	Above	29479	24.1%	24.1%
2	Little White Salmon National Fish Hatchery	Fall	Hatchery	Above	24953	20.4%	44.5%
3	Spring Creek National Fish Hatchery	Fall	Hatchery	Above	14750	12.1%	56.5%
4	Little White Salmon National Fish Hatchery	Spring	Hatchery	Above	11959	9.8%	66.3%
5	Moving Falls Acclimation Pond, Hood River	Spring	Hatchery	Above	10276	8.4%	74.7%
6	Bonneville Dam to John Day Dam (rkm 234-347)	Unknown	Unknown	Above	5535	4.5%	79.2%
7	Parkdale Hatchery	Spring	Hatchery	Above	5084	4.2%	83.3%
8	Lewis River to Bonneville Dam (rkm 140-234)	Unknown	Unknown	Below	4002	3.3%	86.6%
9	**Kalama Falls Hatchery (WDFW)*** **	**Fall**	**Hatchery**	**Below**	**2986**	**2.4%**	**89.0%**
10	**Skipanon River*** **	**Fall**	**Hatchery**	**Below**	**2978**	**2.4%**	**91.5%**
11	Willard National Fish Hatchery	Spring	Hatchery	Above	2960	2.4%	93.9%
12	**Big Creek Hatchery (ODFW)*** **	**Fall**	**Hatchery**	**Below**	**2921**	**2.4%**	**96.3%**
13	Bonneville Adult Fish Facility	Unknown	Hatchery	Above	1996	1.6%	97.9%
14	All other contributors to tagged groups	Mixed	Mixed	Mixed	2665	2.1%	100.0%

***PIT tag releases from this study

WDFW - Washington Department of Fish and Wildlife

ODFW – Oregon Department of Fish and Wildlife

Island from releases in the Lower Columbia River ESU, and estimated daily predation rates were zero. On other days, daily predation rates were much greater than the annual rate. For example, the three days (12 May, 26 May, and 29 May) exhibited the highest daily predation rates from Caspian terns (6.1%, 3.8%, and 3.9%, respectively). Those rates all corresponded to tern impacts on days when small numbers of fish were released from 7 or 8 tagging sources found primarily above Bonneville Dam (74, 75, 107 total PIT-tagged fish, respectively). In contrast, the three days (07 May, 13 May, and 26 June) with the highest daily predation rates from double-crested cormorants (14.0%, 18.7%, and 10.4%, respectively) all corresponded to the three larger releases of PIT-tagged subyearling Chinook salmon from this study, where fish originated from single sources below Bonneville Dam (Big Creek, Skipanon, and Kalama Falls, respectively; see Figure 9).

Table 8. Estimated annual predation rates for experimental tag groups of Lower Columbia River ESU subyearling fall Chinook salmon released as part of this study. In this case, because there was only one release date for each individual release group, daily predation rate estimates are identical to annual estimates.

	Predation rates		
Release site	Caspian tern	Double-crested cormorant	Mixed
Big Creek Hatchery, OR	1.66%	14.61%	0.89%
Skipanon River, OR	3.41%	18.96%	0.86%
Kalama Falls Hatchery, OR	2.60%	11.22%	0.66%
Overall annual predation rate	2.56%	14.93%	0.80%

*Figure 9. Daily totals of the number of Lower Columbia River ESU Chinook salmon PIT-tagged and released into the river between 01 March and 31 August 2012. Days when one or two hatcheries dominate the fish released are labeled with text on the figure; releases with "***" indicate releases made as part of this study. Records include only fish from migration year 2012.*

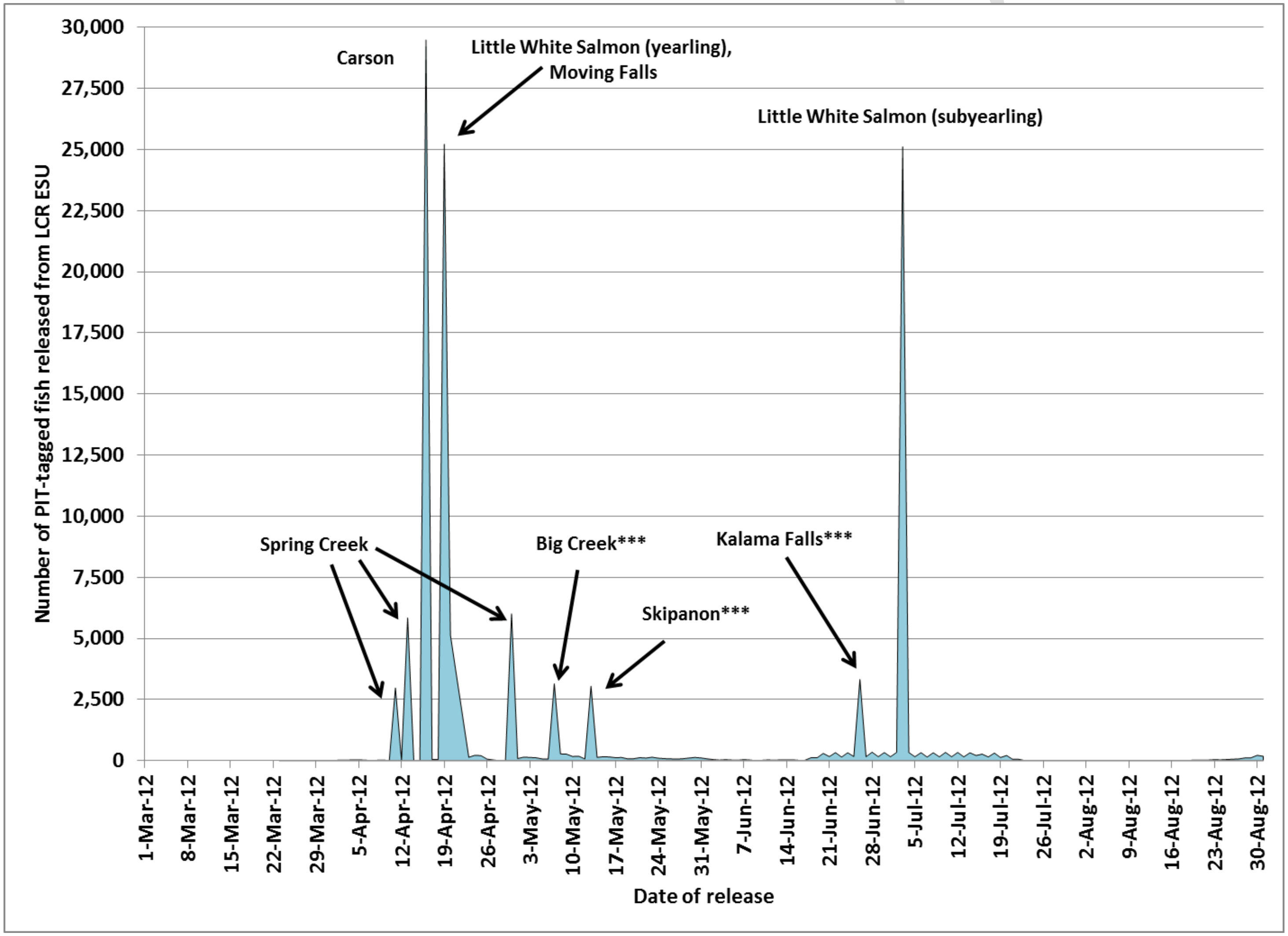


Figure 10. Estimated counts of daily recoveries of PIT tag codes from the Lower Columbia River ESU Chinook salmon on East Sand Island, adjusted for daily availability and detection efficiency between 01 March and 31 August 2012. Records include only codes from migration year 2012.

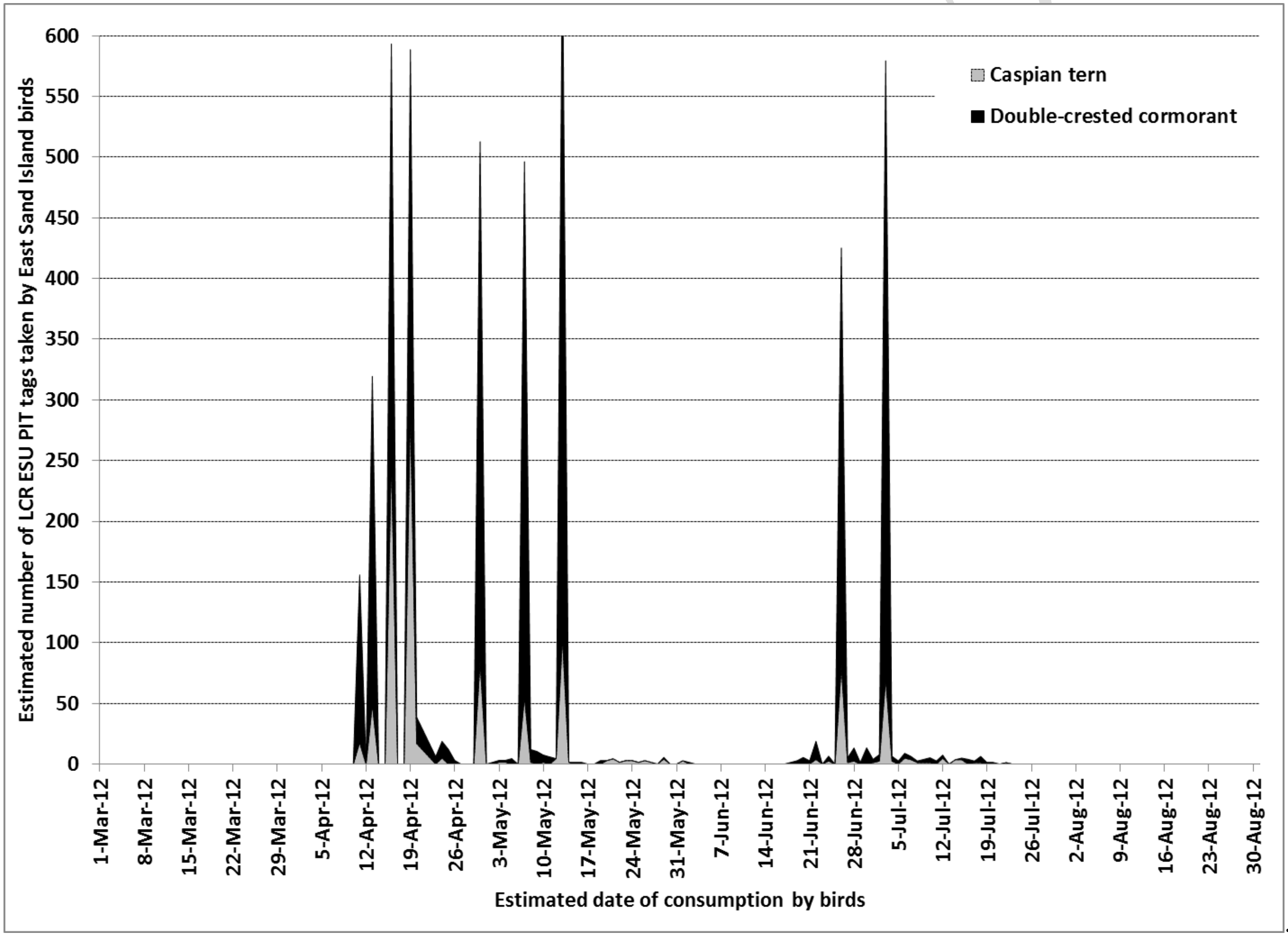


Table 9. Distribution of daily predation rate estimates for Lower Columbia ESU Chinook salmon between 23 March and 31 August 2012.

	Caspian tern		Double-crested cormorant	
Adjusted daily predation rate	Frequency of days observed	Percentage of days observed	Frequency of days observed	Percentage of days observed
0%	85	65.4%	76	58.5%
< 1%	18	13.8%	10	7.7%
1%-2%	13	10.0%	21	16.2%
2%-3%	7	5.4%	3	2.3%
3%-4%	6	4.6%	7	5.4%
4%-5%	0	0.0%	6	4.6%
5%-6%	0	0.0%	1	0.8%
6%-7%	1	0.8%	2	1.5%
7%-8%	0	0.0%	1	0.8%
8%-9%	0	0.0%	0	0.0%
9%-10%	0	0.0%	0	0.0%
>10%	0	0.0%	3	2.3%
Totals	130	100%	130	100%

Estuary Predation Rate Estimates for Snake River ESU Fall Chinook Salmon: Barge Transported vs. In-river Migrants

Methods

We compared estuary avian predation rates on barge-transported vs. in-river migrant Snake River fall Chinook salmon in two ways. First, we calculated the estimated annual predation impact for each group over the entire season by adjusting the number of tag codes recovered on East Sand Island by daily detection efficiencies, summing the adjusted number of tag codes over the entire season, and dividing that sum by the total number of tags available throughout the season. This comparison is analogous to those made in previous sections of this report, and it allowed us to compare cumulative annual predation impacts with all available data.

Second, we performed a paired t-test between daily predation rates for barge-transported vs. in-river migrants on those days when ≥100 tag codes from *both* barge releases and Bonneville detections were recorded on the same day. This paired comparison is a more conservative, between-group measure of predation impact, as it compares predation only on days when (1) the number of available tag codes for both groups meets minimum sample size criteria (≥ 100) used in other studies (citations) and (2) the period over which predation rates are compared (a single day) should represent the same physical and biological conditions in the estuary for both groups.

Other groups of Snake River ESU fish were also transported by barge to be released directly into the tidal freshwater below the last FCRPS dam (e.g., spring and summer Chinook salmon, coho salmon, sockeye salmon, and steelhead), but analysis of those data was beyond the scope of this report.

To measure the availability of barge-transported Snake River ESU fall Chinook salmon to birds in the lower Columbia River Estuary, we obtained records of all PIT-tagged fish originally released above Lower Granite Dam (rkm 695) and subsequently placed on barges at one of the dam facilities on the Snake River. Fish from this ESU were barged between 03 May and 17 Aug 2012. PIT-tagged fish were placed on barges as either (1) fish tagged as part of experimental comparisons of transportation timing (2) fish tagged upstream of Lower Granite Dam (rkm 695, the most upstream dam on the Snake River) as part of a variety of other studies where researchers specified PIT-tag codes for diversion into barges at the dam facilities, or (3) PIT-tagged fish that were intended to remain in the river but were placed onto a barge in error (typically <5% of all fish, Sandford unpublished data). All fish on these barges were released at night near Skamania, WA downstream of Bonneville Dam, between rkm 208 and rkm 226 (median release location rkm 224). Early in the season (May), one barge release occurred in the estuary every 24 hours; later in the season (June-August), one barge release occurred in the estuary every 48 hours.

To measure the estuary availability of non-transported fish (in-river migrants) from the fall Chinook salmon Snake River ESU, we used the number of PIT-tag detections at Bonneville Dam between 01 March and 31 August 2012. Because barged fish from the Snake River ESU are tagged at or above Lower Granite Dam (rkm 695), we only included Bonneville detections in our analysis if those PIT-tag codes came from a fish originally released at or above Lower Granite Dam.

To measure how many PIT-tagged fish were consumed from those known to have entered the estuary, we counted PIT-tag code recoveries from East Sand Island. There are no data on when individual predation or tag deposition events occur; therefore, as has been past practice, we assumed that an individual fish was consumed by a bird on the same day it became available in the river below Bonneville Dam. For barged fish, this availability date was the date of barge release at Skamania, WA. For in-river migrants, the availability date was the date of last detection at Bonneville Dam.

To determine a minimum predation rate estimate of how many fish were consumed by birds on East Sand Island, we adjusted raw PIT-tag code recoveries for each day between 01 March 2012 and 31 August 2012 by the daily detection efficiency adjustment specified by the logistic regression equation method on pages 19-22 of this report. This allowed us to sum daily estimates of the total number of PIT-tags from this ESU consumed by birds, and thus compute daily predation rate estimates.

Adjustments for off-colony deposition were not made in this calculation because 2012 deposition data were not available to NOAA Fisheries at the time of this report.

Results

During migration year 2012, a total of 175,145 PIT-tagged juvenile salmon or juvenile steelhead were transported by barge to the Skamania, WA release site between 13 April and 17 August. No barge releases took place before or after those dates. Of these, 104,126 were Chinook salmon and 50,090 of those fish were fall Chinook salmon (Table 10). Almost all fall Chinook salmon (99.9%) were hatchery-reared fish (Table 10). The first barge release containing fall Chinook salmon occurred on 03 May 2012; the last barge release containing fall Chinook salmon occurred on 17 August 2012. A summary of other salmon species and rear types PIT-tagged and transported by barge is presented in Table 11.

Of the fall Chinook salmon put onto barges, 97.5% (n = 48,883) originated in the Snake River above Lower Granite Dam and were therefore included in our analysis. The median daily barge release size was 279 fish. The minimum daily release size was 35 fish; the maximum daily release size was 5,032 fish. There were 45 days when barge releases included at least 100 fish. The timing and sizes of barge releases for fish used in the analysis are shown in Figure 11.

Table 10. Summary of PIT-tagged Snake River ESU Chinook salmon transported by barge to Skamania, WA, migration year 2012.

		Number of fish placed on barge, by dam			
Run type	Rear type	Lower Granite rkm 695	Little Goose rkm 635	Lower Monumental rkm 589	Totals
Spring	Hatchery	11111	12860	5531	29502
	Wild	900	786	283	1969
	Unknown	0	2	7	9
Summer	Hatchery	2555	3656	1563	7774
	Wild	434	373	133	940
Fall	Hatchery	22981	19763	7315	50059
	Wild	1	0	2	3
	Unknown	0	21	7	28
Unknown	Hatchery	9	15	14	38
	Wild	13095	475	234	13804
Total Chinook salmon					104126

A total of 1,509 PIT tag codes from barged Snake River ESU fall Chinook were subsequently recovered on East Sand Island (rkm 8). All tag codes were from hatchery-reared fish. The distribution of tag codes by species is shown in Table 12. Estimated daily predation events on barge-transported Snake River fall Chinook salmon are presented in Figure 12.

Table 11. Summary of all PIT-tagged Snake River ESU coho salmon, sockeye salmon, and steelhead transported by barge to Skamania, WA, migration year 2012.

		Number of fish placed on barge, by dam			
Species	Rear type	Lower Granite rkm 695	Little Goose rkm 635	Lower Monumental rkm 589	Totals
Coho salmon	Hatchery	628	779	196	1603
Sockeye salmon	Hatchery	6521	5198	2321	14040
	Wild	2	6	6	14
Steelhead	Hatchery	22451	9117	6646	38214
	Wild	15049	1358	700	17107
Total non-Chinook salmon					71019

Table 12. Counts of Snake River ESU fall Chinook salmon PIT tag codes recovered from East Sand Island, migration year 2012. Table only includes fish initially released at or above Lower Granite Dam.

Migration history	Caspian tern	Double-crested cormorant	Mixed	Totals
Barged	261	1182	66	1509
In-river migrants detected at Bonneville Dam	33	79	6	118
In river migrants not detected at Bonneville Dam	658	1151	82	1891
Totals	952	2412	154	3518

A total of 10,456 PIT-tagged Snake River fall Chinook salmon were detected at Bonneville Dam between 01 Mar and 31 Aug 2012. The first fish was detected on 12 Apr 2012; the last fish was detected on 29 Aug 2012. Of these fish, 8,721 were initially released above Lower Granite Dam (rkm 695). The median number of detections per day was 35 fish. The minimum number of detections per day was one fish; the maximum number of detections per day was 322 fish. There were 29 days when at least 100 fish were detected at Bonneville Dam. The timing and numbers of fish detected at Bonneville Dam (rkm 235) which originated above Lower Granite Dam are presented in Figure 13.

Only 118 PIT tag codes from in-river migrants of Snake River fall Chinook salmon released at or above Lower Granite Dam (rkm 695) were subsequently recovered on East Sand Island (rkm 8). This sample represented recovery of 1.35% of the tag codes detected at Bonneville Dam. All tag codes were from hatchery-reared fish. The distribution of these tag codes by species is shown in Table 12. Estimated daily predation events on in-river migrant Snake River ESU fall Chinook salmon are presented in Figure 14.

An additional 1,891 tag codes from Snake River ESU fall Chinook salmon were recovered on East Sand Island, but none of these tag codes were also detected at Bonneville Dam. We could not include this latter set of tag codes in the predation rate calculations because we could not estimate the date these in-river migrants entered the estuary, a step necessary to compute daily and annual predation rate estimates. However, it is clear this group of fish survived past Bonneville Dam, entered the estuary, and was subject to avian predation. We recognize the predation rates reported here for in-river migrants should therefore be interpreted with extreme caution because (1) the sample size recovered on East Sand Island for the entire season is very small (n = 118) and (2) there appears to be an unknown yet significant proportion of PIT-tagged Snake River fall Chinook salmon which are not detected at Bonneville Dam but do enter the estuary and do experience mortality due to estuary avian predation.

Comparisons of estimated annual predation rates for barge-transported vs. in-river migrant fish are presented in Table 13. For both Caspian terns and double-crested cormorants, 2012 annual predation rates were higher on transported fish compared to in-river migrants (0.7% vs 0.47% and 3.3% vs. 1.3%, respectively). For mixed species tag recoveries, the 2012 predation rate on transported fish was lower (0.03%) than for in-river migrants (0.13%).

Table 13. Estimated annual predation rates for barge-transported vs. in-river migrant Snake River fall Chinook originating above Lower Granite Dam, migration year 2012.

	# of tag codes recovered		Annual predation rate	
Species	Barge-transported	In-river migrants	Barge-transported	In-river migrants
Caspian tern	343	41	0.70%	0.47%
Double-crested cormorant	1635	110	3.30%	1.30%
Mixed	120	11	0.03%	0.13%

Paired comparisons of daily predation rates on those 14 dates when at least 100 fish from both barge-transported and in-river migrant fish entered the estuary on the same day are presented in Table 14. For Caspian terns, predation rates on barge-transported fish (mean = 0.543%) were higher than for in-river migrants (mean = 0.343%), but this was not a statistically significant difference (*t*-statistic = 0.1.58, p = 0.13, 13 degrees of freedom). For double-crested cormorants, predation rates for barge-transported fish (mean = 2.71%) were significantly higher than for in-river migrants (mean = 0.97%, *t*-statistic = 5.43, $p < 0.001$, 13 degrees of freedom). For mixed-species areas, predation rates were virtually equal (means = 0.18%) and not statistically different from each other (*t*-statistic = 0.70, p = 0.50, 13 degrees of freedom).

Graphic comparisons of daily predation rates for barge-transported vs. in-river migrant fish over the entire season are presented in Figure 15 and Figure 16. Anomalously high predation rates for in-river migrants occurred on four occasions, all of which resulted from recovery of a single tag code on East Sand Island which originated from a day when less than 12 total tag detections occurred at Bonneville Dam.

Figure 11. Counts of PIT-tagged Snake River ESU juvenile fall Chinook salmon released from barges into the Columbia River Estuary, migration year 2012. All fish were released below Bonneville Dam at night near Skamania, WA (rkm 225).

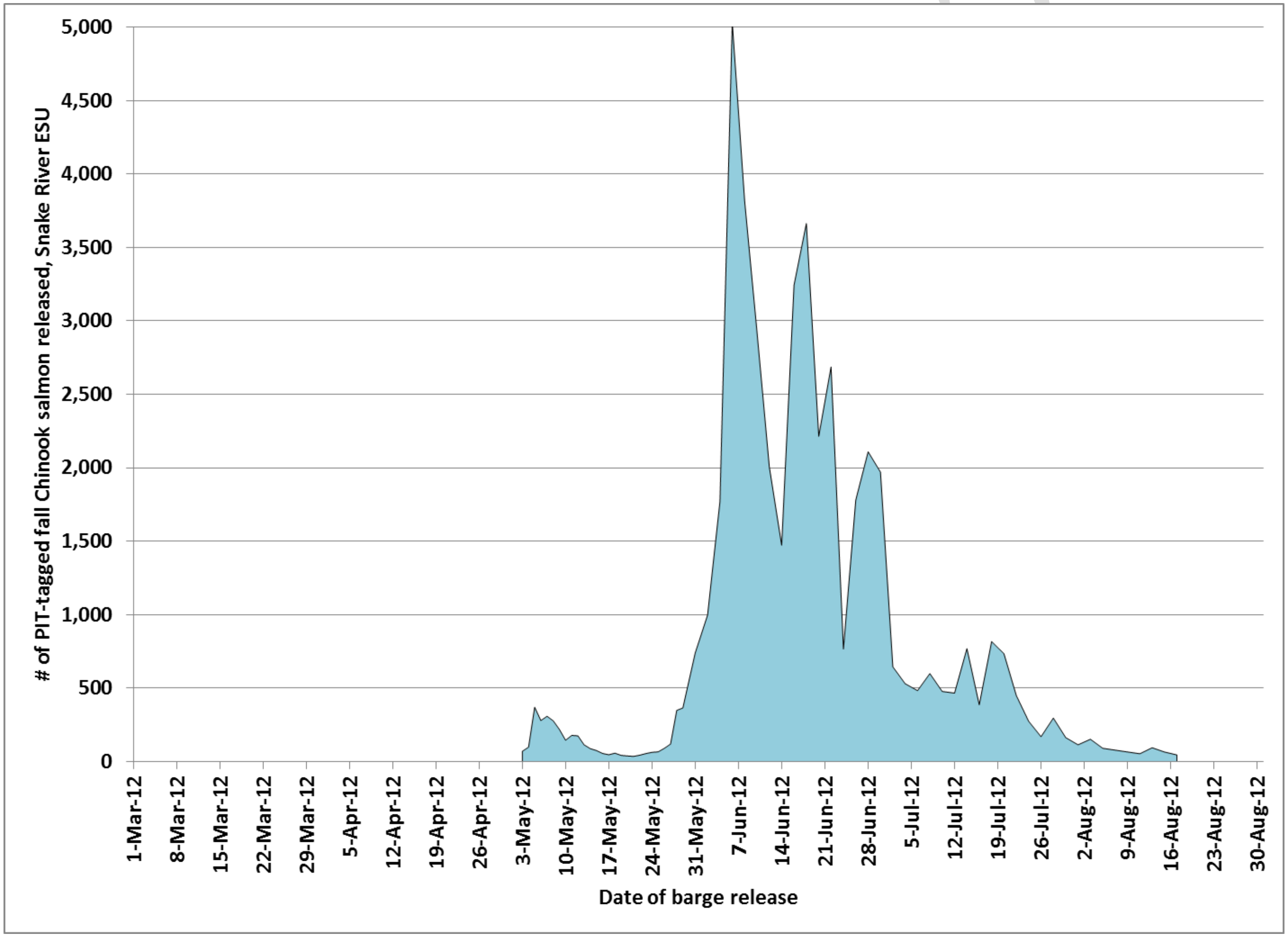


Figure 12. Estimated counts of PIT tag codes recovered from barged Snake River ESU fall Chinook salmon on East Sand Island, adjusted for daily availability and detection efficiency between 01 March and 31 August 2012.

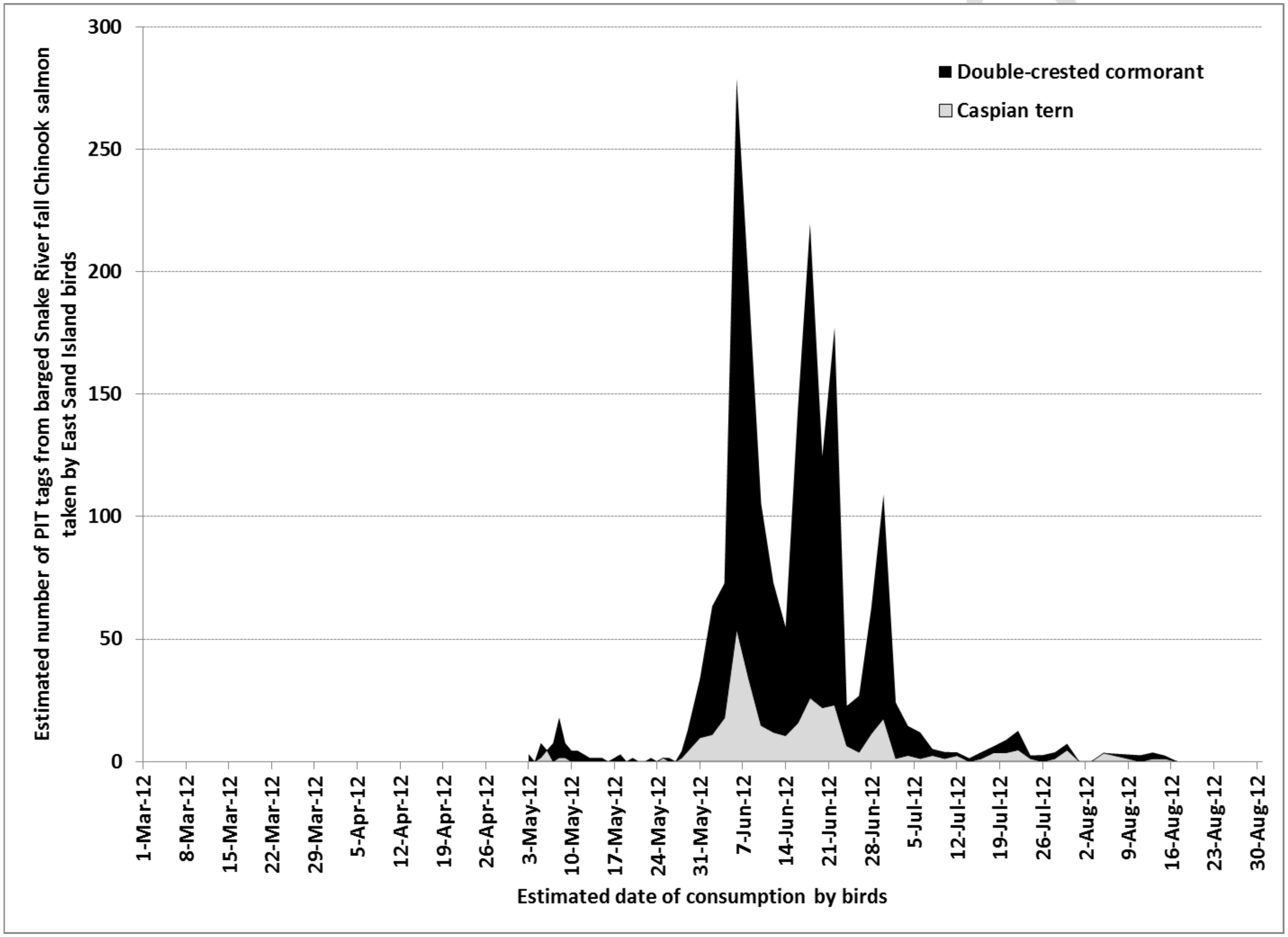


Figure 13. Counts of detections at Bonneville Dam of PIT-tagged Snake River fall Chinook salmon initially released above Lower Granite Dam, migration year 2012.

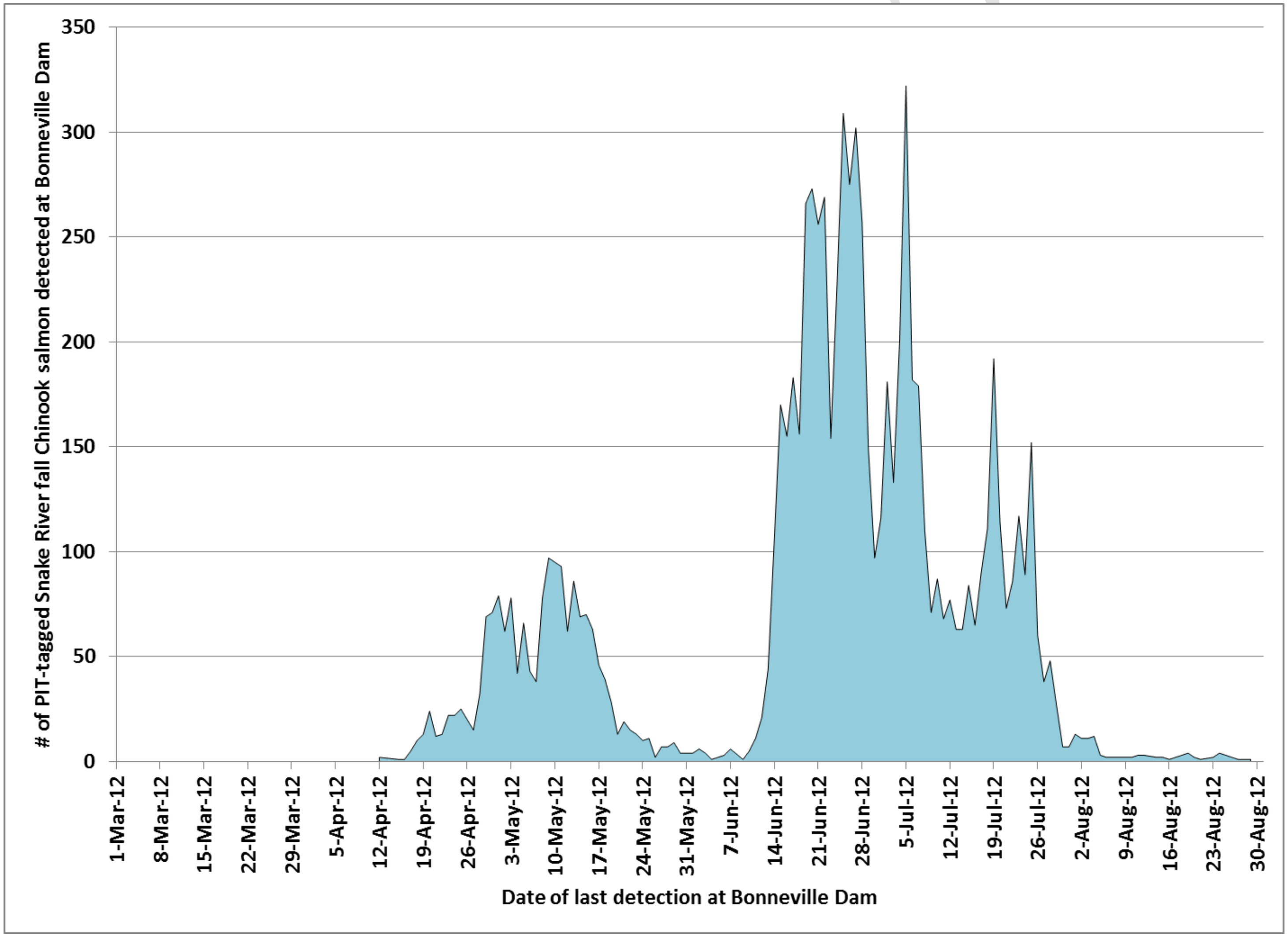


Figure 14. Estimated counts of PIT tag codes from in-river migrant Snake River ESU fall Chinook salmon recovered on East Sand Island, adjusted for daily availability and detection efficiency between 01 March and 31 August 2012. These data do not include 1,891 tag codes which were also recovered on East Sand Island but were undetected at Bonneville Dam.

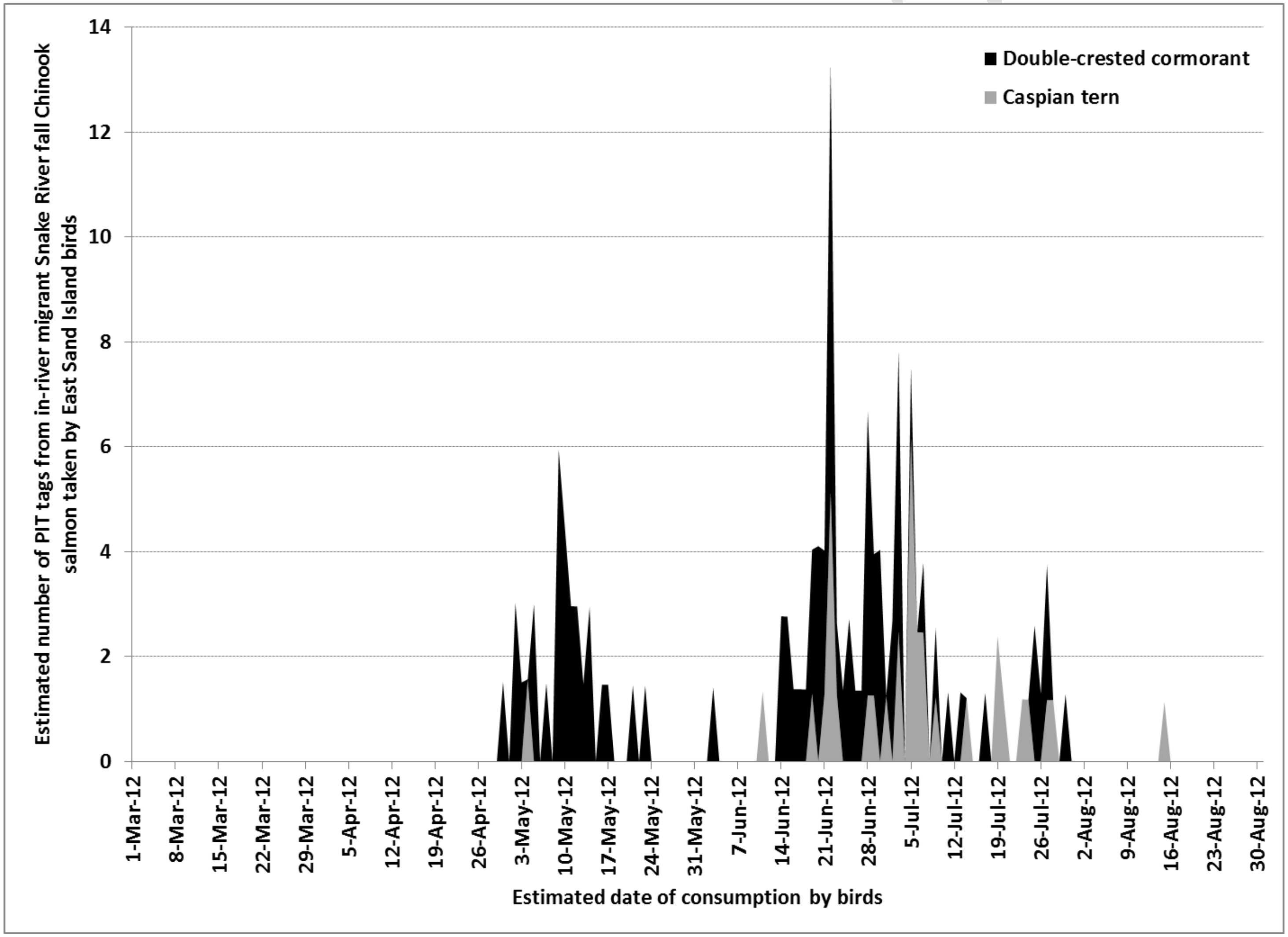


Table 14. Paired comparisons of barge-transported vs. in-river migrant predation rates on Snake River ESU fall Chinook salmon originating above Lower Granite Dam, migration year 2012.

	Source of estuary entry		Predation rates: Caspian terns		Predation rates: double-crested cormorants		Predation rates: mixed	
Release date	# released from barge	# detected at Bonneville	Barge-transported	In-river migrant	Barge-transported	In-river migrant	Barge-transported	In-river migrant
14-Jun-12	1473	106	0.72%	0.00%	3.01%	2.61%	0.25%	0.00%
16-Jun-12	3244	155	0.48%	0.00%	3.95%	0.89%	0.28%	1.18%
18-Jun-12	3664	156	0.71%	0.00%	5.29%	0.88%	0.50%	0.00%
20-Jun-12	2214	273	0.99%	0.00%	4.64%	1.50%	0.08%	0.00%
22-Jun-12	2687	269	0.86%	1.91%	5.74%	3.04%	0.27%	1.35%
24-Jun-12	766	227	0.83%	0.00%	2.13%	0.60%	0.47%	0.00%
26-Jun-12	1780	275	0.21%	0.00%	1.29%	0.49%	0.20%	0.00%
28-Jun-12	2109	257	0.54%	0.49%	2.43%	2.10%	0.26%	0.00%
2-Jul-12	645	181	0.19%	0.00%	3.53%	1.48%	0.00%	0.00%
4-Jul-12	530	201	0.47%	0.00%	2.27%	0.00%	0.00%	0.00%
6-Jul-12	483	182	0.26%	1.36%	2.21%	0.00%	0.00%	0.00%
8-Jul-12	599	110	0.41%	0.00%	0.44%	0.00%	0.00%	0.00%
18-Jul-12	817	111	0.44%	0.00%	0.32%	0.00%	0.00%	0.00%
20-Jul-12	734	114	0.49%	1.05%	0.71%	0.00%	0.24%	0.00%
Means	1553.2	186.9	0.54%	0.34%	2.71%	0.97%	0.18%	0.18%

Figure 15. Estimated daily predation rates of Caspian terns on barge-transported vs. in-river migrant Snake River ESU fall Chinook salmon, migration year 2012.The anomalously high in-river predation rates measured on 11 Jun and 15 Aug resulted from recovery of a single tag code originating on days when less than 12 total detections were recorded at Bonneville Dam.

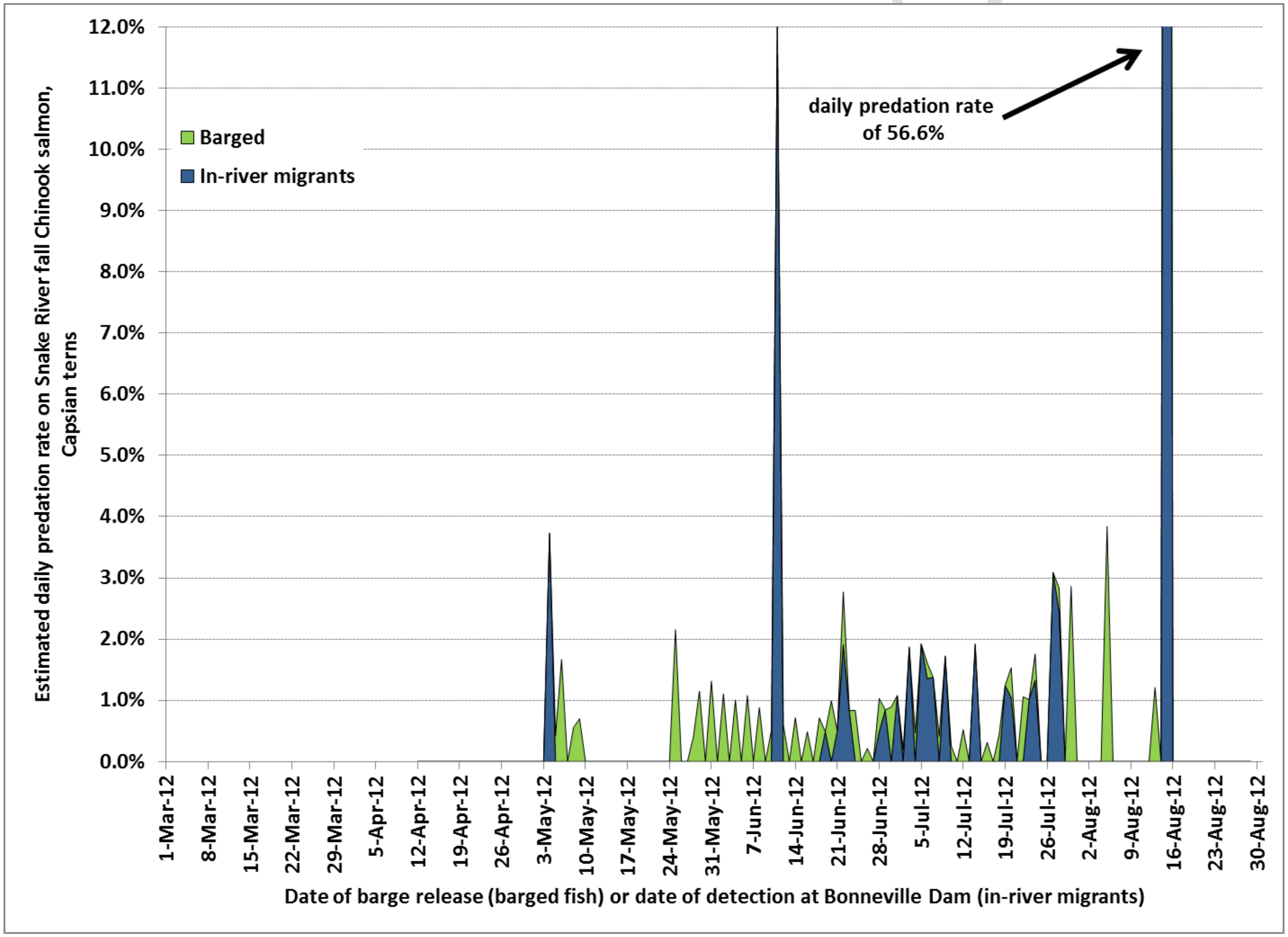
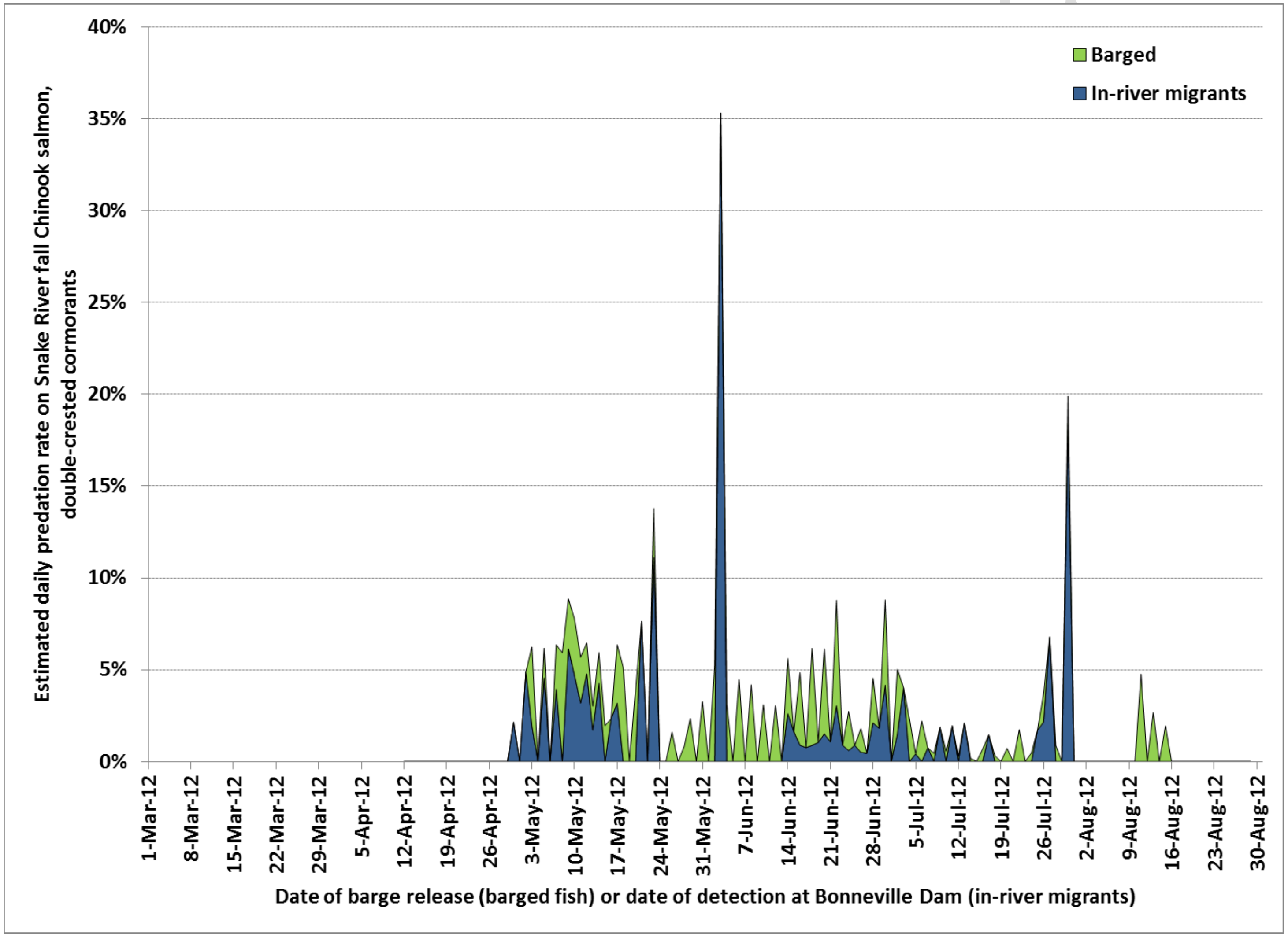


Figure 16. Estimated daily predation rates of double-crested cormorants on barge-transported vs. in-river migrant Snake River ESU fall Chinook salmon, migration year 2012.The anomalously in-river high predation rates measured on 03 Jun and 30 Jul resulted from recovery of a single tag code originating on days when less than 10 total tag detections were recorded at Bonneville Dam.



SUMMARY

We successfully accomplished the PIT tag deployment and PIT tag code recovery specified in this study during 2012. PIT-tagging of Lower Columbia River ESU Chinook salmon from Warrenton High School Hatchery, Big Creek Hatchery, and Kalama Falls Hatchery resulted in successful releases of tag groups directly into the Columbia River Estuary during May and June of 2012. This tagging effort accounted for 8,885, or 7.2%, of all PIT-tagged Chinook salmon from the Lower Columbia ESU. One thousand one hundred and twenty-one tag codes from our experimental releases (12.6%) were subsequently recovered on East Sand Island.

Recovery of PIT tag codes from East Sand Island Caspian tern and cormorant colonies was completed on 15 November 2012. On the Caspian tern colony, the flat-plate detector system recorded 15,298 unique codes from migration year 2012 salmon or steelhead over a colony area of 6,394 m^{-2} (1.58 acres). On the double-crested cormorant colony, hand-held detector systems recorded 13,829 unique codes over a colony area of 15,782 m^{-2} (3.9 acres). We recovered tag codes from all 13 ESA-listed ESU/DPS groups in the Columbia River Basin. Recovery of tag codes from East Sand Island is required for calculations of estuary avian predation rates on all ESU/DPS groups of PIT-tagged salmon and steelhead in the Columbia River Basin.

To measure detection efficiency of our recovery efforts, BRNW sowed two hundred control tags across both the tern and cormorant colonies; half were sown immediately before nesting season began, and half were sown immediately after nesting season was finished but before tag code recovery efforts began. We recovered 77% of control tag codes from the tern colony and 74% of control tag codes from the double-crested cormorant colony. Recovery rates were similar to those achieved during 2011, and were within the range of recovery rates seen in 2002-2011 (Caspian terns: 64%-95%; double-crested cormorants: 35%-76%; see Appendix Table 4 in Sebring et al. 2012). We measured date-adjusted detection efficiencies between 42% (early season) to 90% (late season) on the tern colony, and between 56% (early season) and 86% (late season) on the double-crested cormorant colony.

We completed PIT tag code recoveries to support 2012 experiments by BRNW research staff, whose goal was to measure off-colony tag deposition rates by double-crested cormorants. Cormorants volitionally consumed 301 PIT-tagged trout on the colony and BRNW estimated that 44% of these tags were deposited on the colony, while 56% were undetected on the colony. These data were used to adjust predation rate calculations for ESU/DPS groups originating entirely above Bonneville Dam (on the Columbia River) or Sullivan Dam (on the Willamette River).

Sample sizes of fish detected at terminal dams allowed BRNW and NOAA Fisheries biologists to calculate estuary predation rates for 10 of 13 ESA-listed ESU/DPS groups. In general, Upper Willamette River spring Chinook were least impacted by estuary avian predation (predation rates < 1% for all bird species). Caspian terns had a larger impact on steelhead (7.4%-10.0%) than did double-crested cormorants (3.4-7.2%), whereas cormorants had a larger impact on sockeye and Snake and Columbia River Chinook salmon (2.2%-4.2%) than did terns (0.7%-2.2%). Overall, Brandt's cormorants had minimal predation impacts on all ESU/DPS groups (0.2% or less in all cases). These results indicate that in addition to known difference in estuary migration timing among salmon and steelhead ESU/DPSs, there are likely to be differences in estuary migration routes and estuary migration behavior of juvenile fish as well.

Due to the life history complexity present in the Lower Columbia River ESU and the lack of a representative tagging program for this ESU, predation rates on PIT-tagged Chinook salmon from the Lower Columbia River were calculated and presented separately from groups whose populations originate exclusively above or below Bonneville Dam. It is important to note that impacts measured in this report cannot necessarily be extrapolated to the entire ESU. With the exception of three experimental tag groups released as part of this study, data reported here most accurately represent impacts on subgroups tagged in 2012 for purposes other than estimating impacts of avian predation on Lower Columbia River ESU Chinook salmon. During 2012, there were 52 separate sources contributing to a total of 122,544 PIT-tagged Chinook salmon from this ESU. However, two-thirds of these tagged fish came from only three national fish hatcheries located above Bonneville Dam: Carson (spring migrants), Little White Salmon (spring and fall migrants), and Spring Creek (spring migrants). Mixed species impacts (including Brandt's cormorants) had the least predation impact on tagged fish from this ESU (0.15%). Caspian terns had the next largest impact on tagged fish (0.91%), while double-crested cormorants appeared to have the largest impact (2.9%). When examining predation impacts from three groups of Lower Columbia River ESU fall subyearling Chinook salmon experimentally tagged and released below Bonneville Dam, there was a similar qualitative pattern in avian species impacts: mixed species/Brandt's cormorant areas showed the least impact (0.08%), Caspian terns had a moderate impact (2.56%), and double-crested cormorants had the largest impact (14.9%). Although it is not possible to make direct comparisons between the predation rates for migration year 2011 reported by Sebring et al. (2011) due to several methodological differences in how calculations were made, the rates reported there for spring and fall Chinook salmon show similar qualitative trends, with Brandt's cormorants having the least impact (rates of 0.0%-3.0%), Caspian terns having a moderate impact (rates of 0.2% - 2.2%), and double-crested cormorants having the greatest impact (rates of 0.1%-11.0%).

Comparisons of annual and paired daily predation rates between barge-transported vs. in-river migrant Snake River ESU fall Chinook salmon both showed double-crested cormorants having 2.5-2.8 times higher predation impacts on barged fish; this result was statistically significant in the paired comparisons. Cormorant impacts on barged fish were on the order of 2.7%-3.3%, compared to 0.97%-1.3% for in-river migrants. Caspian tern and mixed species (including Brandt's cormorants) had annual predation impacts of <1% for both barge-transported and in-river migrant fish, indicating these species are likely to have a negligible mortality effect on Snake River ESU fall Chinook salmon regardless of migration history. Annual predation rates on in-river migrants by Caspian terns, double-crested cormorants, and mixed species that included Brandt's cormorants were virtually identical to the values reported in the "deposited" calculations – which were not adjusted for off-colony deposition of tags - made by Roby et al. (2013) in their Table 5 (Caspian terns: 0.5%, double-crested cormorants: 1.3%, Brandt's cormorants: <0.1%), even though our data analysis excluded Snake River fish that entered the river below Lower Granite Dam. Mean paired daily predation rates on in-river migrants (Caspian terns: 0.54%, double-created cormorants: 2.71%) were similar to the annual deposited rates reported by Roby et al. (2013), although not identical because the paired calculations used a subset of all the data. Although the migration year 2011 predation rates on barge-transported vs. in-river migrant fall Chinook salmon reported (Sebring et al. 2012) were not calculated in the same manner nor were they based strictly on a Snake River ESU of origin, these rates (Caspian tern: 0.6% vs. 0.5%, double-crested cormorant: 1.0% vs. 1.9%, Brandt's cormorant: 0.0% vs. <

0.1%; see Tables 11-13, Appendix Table 3, Sebring et al. 2012) were similar to the ones we report here.

Our results suggest that barging may not be an effective tool for decreasing estuary avian predation on Snake River fall Chinook salmon, as we see either higher predation on barged fish, or equivalent predation on barged fish. However, it should be noted that avian predation on in-river migrants could be higher than what we were able to measure in 2012, because a significant number of tag codes from in-river migrants (n = 1,891) were recovered from East Sand Island with no detection record from Bonneville Dam. Clearly, these fish entered the estuary and were eaten, even though we have no way to determine the date on which they entered the estuary. If in fact a majority of tagged Snake River fall Chinook salmon is not being detected on estuary entry, then we may be missing important information on avian impacts to juvenile Snake River fall Chinook salmon in the estuary.

Overall, data continue to support the present understanding that (1) Caspian terns have the largest impact on steelhead ESU/DPS groups, taking on the order of 7%-10% of fish originating above Bonneville Dam; (2) double-crested cormorants have the largest impact on other salmon, taking on the order of 2%-15% of any given ESU/DPS; and (3) the current population of Brandt's cormorants is not likely to be having a biologically significant impact on any ESU/DPS group.

Recommendations for future work

What is not yet understood are the specific mechanisms governing variation in seasonal and annual predation impacts of Caspian tern and double-crested cormorants on any given ESU/DPS group. Mechanistically, avian predation impact on a given ESU/DPS is probably a function of the following components:

1. Physical estuary conditions during estuary entry/residence, such as
    a. Temperature
    b. Salinity
    c. Flow
    d. Turbidity
2. Physiological condition of individual fish
3. Biological conditions during estuary entry residence, such as
    a. Distribution/abundance of prey resources
    b. Distribution/abundance of other juvenile salmon/steelhead
        i. Direct or indirect density effects
        ii. As alternative prey for salmon predators
    c. Distribution/abundance of alternative prey for salmon predators, such as marine forage fish
    d. Distribution/abundance of avian predators
4. Timing of estuary residence
    a. Date of arrival
    b. Dates of residence/travel time

5. Migratory pathways/habitat use
6. Time and locations with highest avian foraging activity

A variety of established research tools (e.g. telemetry for both fish and birds, net sampling of salmon and forage fish, hydroacoustic mapping of forage fish distribution) and in some cases existing regional data (e.g. http://www.stccmop.org/datamart), for addressing mechanistic questions already exist in the Columbia River Estuary research community. A workshop prioritizing mechanistic research questions and a source of funding to address the priority questions would begin to build up a mechanistic understanding of avian predation. For example, modest resources could support an initial investigation as to whether or not seasonal changes in predation on juvenile salmon were correlated with changes in river flow and relative forage fish abundance in the estuary.

In addition to encouraging the investigation of the mechanisms driving variation in avian predation rates we outline above, research, monitoring, and management of estuary avian predation impacts would benefit from the following specific actions:

i. Recovery of PIT tag codes from the East Sand Island cormorant colony could be completed earlier, and tag recovery accuracy improved, if additional field personnel (n = 5) were available during the first few weeks of fieldwork to complete two full passes of tag detection on the cormorant colony before the first heavy weather begins to wash tags off the colony.
ii. Accuracy and comparability of predation rate estimates derived from PIT tag code recovery would be enhanced if the Deposition Adjustment for off-colony PIT tags were available for calculation of predation rate estimates throughout the Columbia River Basin.
iii. At present, although it is clear Lower Columbia River ESU Chinook salmon appear especially vulnerable to predation by double-crested cormorants, cumulative avian predation impacts on this ESU remain poorly understood. If accurate estimation of avian predation impacts on Lower Columbia River ESU Chinook salmon is desired, then a well-designed PIT-tagging program which provides proportional representation of the diversity of population origins (above/below FCRPS dam facilities) and life history types (spring/fall migrants, hatchery/wild rear types), coupled with surveys or telemetry work to characterize cormorant foraging areas, will be necessary.
iv. In 2012, a significant number of PIT-tagged, in-river migrant Snake River fall Chinook salmon (n = 1,891) entered the estuary unrecorded by detectors at Bonneville, yet these fish were being taken by East Sand Island birds. Improvements to detection of estuary entry for this ESU (or other ESU/DPS groups), either by improved detections at Bonneville or elsewhere below Bonneville, or by increased tagging efforts for in-river migrants, would allow for more accurate assessment of both avian predation impacts and the effectiveness of barge transportation to the estuary.
v. In general, the specific times and locations of most intensive avian foraging activity in the estuary are not well- understood. Contemporary spatial and temporal information on foraging activity patterns in the estuary is lacking. This type of information would provide insight into when and where along the estuary migration

corridor juvenile salmon are most vulnerable to predation events.

vi. At the present time, there is no established method to measure the timing of predation events on, or the on-colony deposition or, individual tag codes. Finding methods to address this data gap would allow direct comparison of the timing of estuary entry with the timing of mortality events.

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