Measuring Estuary Avian Predation Impacts on Juvenile Salmon by Electronic Recovery of Passive Integrated Transponder (PIT) Tags from Bird Colonies on East Sand Island, 2012

Jeannette E. Zamon, Tiffanie A. Cross, Benjamin P. Sandford, Allen Evans,[†]
and Bradley Cramer[†]

Report of research by

Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Blvd. E, Seattle, Washington 98112-2097

and

[†] Real Time Research, Inc.
52 Southwest Roosevelt, Bend, Oregon 97702

for

Portland District
Northwestern Division
U.S. Army Corps of Engineers
333 SW 1st Avenue
Portland, Oregon 97204
Contract W66QKZ21581490

March 2014

EXECUTIVE SUMMARY

Avian predation on juvenile salmon and steelhead is one factor limiting the recovery of threatened and endangered populations of Pacific salmon *Oncorhynchus* spp. in the Columbia River Basin. To measure, monitor, and manage the effects of avian predation, estimated predation rates are needed for individual Evolutionarily Significant Units (ESUs) and Distinct Population Segments (DPSs) of Pacific salmon. One method to estimate predation rates compares codes from passive integrated transponder (PIT) tags deposited on avian nesting colonies after fish are consumed by birds to all codes detected on presumed live fish in the geographic area of interest.

This report presents results from our project to recover PIT-tag codes from seabird colonies on East Sand Island in the Columbia River Estuary. Tag-code recoveries were used in collaboration with Bird Research Northwest to derive estimates of estuary predation on juvenile salmon by Caspian terns *Hydroprogne caspia*, double-crested cormorants *Phalacrocorax auritus*, and Brandt's cormorants *P. penicillatus*.

Here we present results from three primary study components:

1. PIT-tagging three groups of subyearling fall Chinook salmon *O. tshawytscha* from the Lower Columbia River ESU.
2. Recovery of PIT-tag codes from nesting colonies on East Sand Island
3. Estimation of estuary predation rates, including
    - i. Adjustments for tag-code detection efficiency and off-colony deposition rates where available
    - ii. Estuary predation rate estimates for ESU/DPS groups originating entirely above Bonneville Dam (Columbia River) or above Sullivan Dam (Willamette River)
    - iii. Estuary predation rate estimates for PIT-tagged Lower Columbia River Chinook salmon
    - iv. Estuary predation rate estimates for barge-transported vs. in-river migrant Snake River fall Chinook salmon originating above Lower Granite Dam

In May and June 2012, we PIT-tagged 8,885 Lower Columbia River fall Chinook salmon and released them directly into the estuary below Bonneville Dam. A subset of tags from these fish was subsequently detected on avian colonies. From these detections, we estimated that of the fish we released, 2.6% were consumed by Caspian terns, 14.9% by double-crested cormorants, and 0.8% by mixed species, including Brandt's cormorants.

On the East Sand Island Caspian tern colony, we recovered 15,298 unique tag codes from juvenile fish that migrated downstream in 2012. Tag codes recovered included those of fish from 13 Pacific salmon ESU/DPS groups listed as threatened or endangered under the U.S. Endangered Species Act. On the double-crested cormorant colony, we recovered 13,829 unique tag codes, also representing all 13 listed ESU/DPS groups.

Detection efficiencies varied through the season, and ranged from 42 to 90% on the Caspian tern colony and 56 to 81% on the double-crested cormorant colony. These efficiencies were comparable to those measured in prior years. Biologists from Bird Research Northwest used our tag-code recoveries for experiments designed to measure off-colony tag deposition of tags by double-crested cormorants. They estimated that 44% of tags consumed by double-crested cormorants were deposited on the colony, implying up to 56% of the tags consumed by these birds were deposited elsewhere. Data from this study were used to adjust estimated predation rates to account for off-colony deposition in groups originating above Bonneville Dam and Sullivan Dam.

We estimated estuary predation rates for groups of fish with geographical origins entirely above Bonneville Dam (Columbia River) or Sullivan Dam (Willamette River). These estimates 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 steelhead from the upper Columbia River ESU (7.2%), with a range of impacts on other fish groups (0.6-5.4%). In general, Upper Willamette spring Chinook salmon experienced the least avian predation impact (<1%), and Brandt's cormorants appeared to have minimal impacts on all population groups we examined (<1%).

Fifty-two different sources contributed to PIT-tagged fish from the Lower Columbia River Chinook salmon ESU during migration year 2012; however, only three hatcheries above Bonneville Dam accounted for 66.3% of these fish. Estimated overall predation on tagged Lower Columbia River Chinook salmon was 0.91% for Caspian terns, 2.9% for double-crested cormorants, and 0.15% for mixed species including Brandt's cormorants. Fish included in the Lower Columbia River Chinook salmon ESU exhibit complex life history types, and there is no comprehensive, representative tagging program for the ESU as a whole. Therefore, inferences from these predation rates should not be made to the entire Lower Columbia River ESU, and generalizations to specific populations within the ESU should be made with caution.

All fall Chinook salmon that originate in the Snake River are included in the Snake River fall Chinook salmon ESU. For fish from this ESU, we compared predation impacts between barge-transported fish vs. in-river migrants in three ways. First, we calculated annual predation estimates using all available data from 2012. Second, we compared estimated weekly predation rates with weekly barge releases and detections at Bonneville Dam, where releases or detections exceeded 100 fish per week. Third, we compared estimates of daily predation for calendar days on which at least 100 fish from both barge-transported and naturally-migrating life histories occurred. Caspian terns and double-crested cormorants both had higher annual 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%) and barged fish (<0.1%).

Paired comparisons of weekly estimated predation rates did not show any statistically significant differences between barged vs. in-river migrant fish for terns, cormorants, or mixed species/Brandt's cormorants. However, paired comparisons of daily predation rates showed tern and double-crested cormorant predation were higher on transported fish (0.5 and 2.7%, respectively) than on in-river migrants (0.3 and 1.0%, respectively), although the difference was statistically significant only for cormorants. For mixed species including Brandt's cormorants, predation rates were identical for transported vs. in-river migrant fish (0.2%). The implication is that barging in 2012 did not necessarily decrease estuary avian predation on Snake River fall Chinook salmon. However, on East Sand Island, a significant number of PIT-tag codes from in-river migrants were recovered (n = 1,891) that had not been detected at Bonneville Dam. Thus, there may be more predation on in-river migrants than we could measure in this study.

To improve understanding of estuary avian predation on Columbia River salmon, we recommend that future work include support to determine the mechanisms driving variation in seasonal and annual predation rates. We also recommend that

1) A comprehensive tagging program be developed for Lower Columbia River Chinook salmon to more accurately characterize overall estuary predation for this ESU
2) An effort be made to improve detection numbers at Bonneville Dam for estuary entry timing of in-river migrant Snake River fall Chinook salmon.

CONTENTS

INTRODUCTION

In 1987, research biologists began tagging juvenile Pacific salmon *Onchorhynchus* spp. with passive integrated transponder (PIT) tags to measure survival through the Federal Columbia River Power System (Prentice et al. 1990; Marvin 2012). Dams and fishways managed by the U.S. Army Corps of Engineers have been instrumented with PIT-tag detection systems. These systems allow scientists and mangers to track survival of juvenile fish as they migrate seaward through dams within the system, as well as allowing them to track adult fish passing these dams 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). Subsequent detections or recoveries of individual PIT tags are also recorded in this database.

Survival estimates 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 vacant seabird colonies (Collis et al. 2001). These included colonies of Caspian terns *Hydroprogne caspia* and double-crested cormorants *Phalacrocorax auritus* on Rice Island (rkm 34) in the lower Columbia River. In 1998, we developed land-based PIT-tag detectors to allow large-scale recovery of PIT-tag codes from avian colonies (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).

Resource managers responded to this finding by initiating a program to relocate the birds from Rice Island, where the prey fish available were primarily juvenile salmon, to 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 continued to indicate that estuary avian predation is a factor limiting recovery of ESA-listed species of Pacific salmon. Resource managers are required to support recovery of PIT-tag codes from estuary bird colonies by mandates of the National Marine Fisheries Service Biological Opinion (NMFS 2008), supplemental Biological Opinion (NMFS 2010), and the Adaptive Management Implementation Plan (AMIP; NMFS 2009). Management agencies also need to support the data processing and analysis necessary to estimate avian predation rates on Columbia River Basin salmonid 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 NMFS biologists and Bird Research Northwest (BRNW, formerly Columbia Bird Research). Each research group publishes reports according to tasks partitioned to them under yearly research contracted by the U.S. Army Corps of Engineers. During 2012, we assumed all responsibility for PIT-tag code recoveries on East Sand Island bird colonies, and BRNW assumed responsibility for recoveries on all other colonies, in addition to their research on colonies during the nesting season. In this report we summarize results from our recovery efforts and East Sand Island and from our experimental tagging effort for Lower Columbia River Chinook salmon. Companion results for BRNW tasks are presented by Roby et al. (2013).

It should also be noted that for the first time in 2012, we report estimated predation rates by ESU or DPS to better meet management needs and to provide direct comparability with the BRNW companion report. Our estimates of predation were previously reported by species/run/rear types, not by ESU/DPS group (Sebring et al. 2009, 2010a,b, 2012).

STUDY AREA

Piscivorous waterbirds have established numerous nesting colonies throughout the Columbia River Basin (Figure 1). Most of these colonies are active (e.g. East Sand Island, Crescent Island), although some are no longer in use (e.g. Rice Island). Nearly all individual colonies have been studied at one time or another by three collaborative groups: Bird Research Northwest, a research partnership between Oregon State University, the U.S. Geological Service, and Real Time Research; NOAA Fisheries, and the University of Washington. Of all avian nesting colonies, the largest are those in the lower Columbia River estuary on East Sand Island, OR. We recovered PIT-tag codes from this location in 2012.

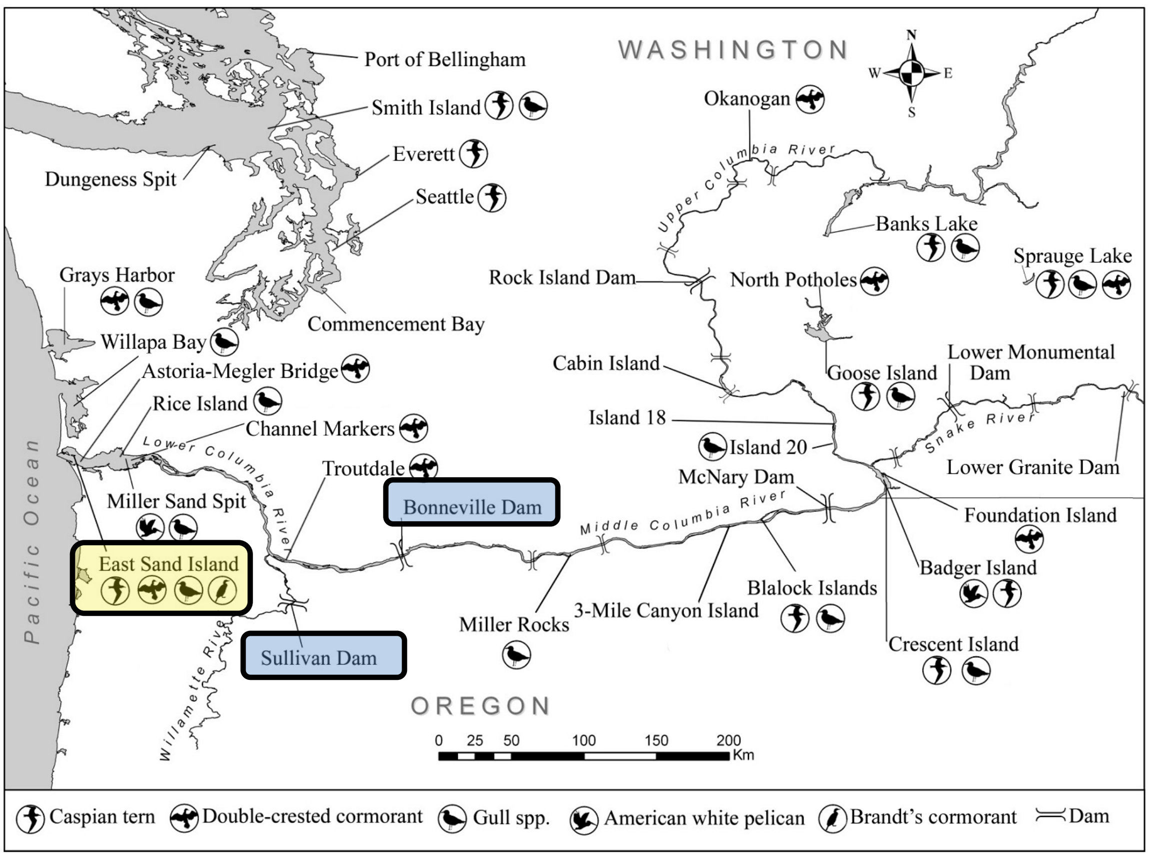

Figure 1. Map of Columbia River Basin and coastal Washington showing the location of active and former breeding colonies of piscivorous waterbirds studied by Bird Research Northwest (BRNW), NOAA Fisheries, or the University of Washington. The study site for this report is East Sand Island (indicated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

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

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). This area represents a reduction in colony size of nearly 50% from the 12,545 m^{-2} (3.1 acres) available in 2010 (Figure 3). Prior to initiation of nesting, the area is actively managed by the U.S. Army Corps of Engineers to control colony size, maintain bare sand habitat, and eliminate vegetation. The middle section of the island contains dense vegetation with small trees, shrubs, and grass. No waterbirds nest in this section of the island.

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.

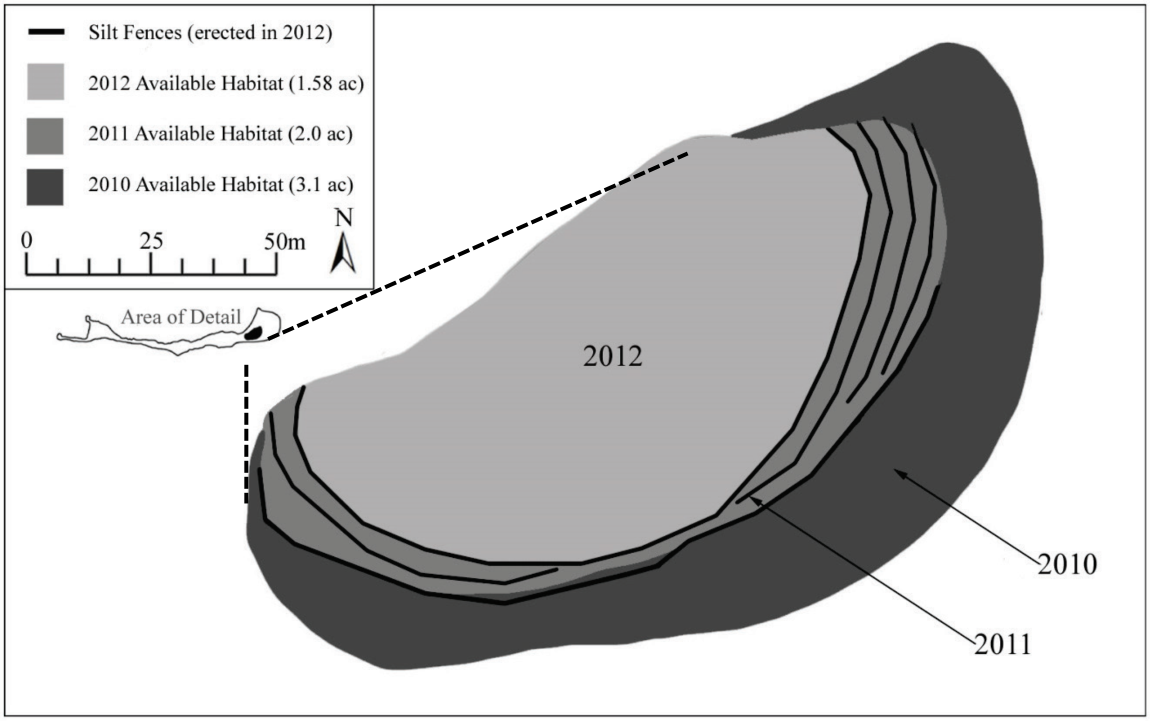

Figure 3. Schematic of Caspian tern colony size and shape from 2010 to 2012. This figure shows the sequential 50% reduction of colony size. The inset immediately below the legend shows the location of the colony on the east end of East Sand Island. Figure provided courtesy of Bird Research Northwest.

Double-crested and Brandt's cormorants nest on the west end of East Sand Island in bare sand (Figure 4) or on 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 4. Bare sand habitat on the East Sand Island cormorant colony. Unlike habitat on the tern colony, this bare sand is not actively managed to maintain a flat surface without vegetation or rocks. Upright sticks marked with arrows indicate the edges of an area surveyed with a hand-held PIT-tag detector.

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

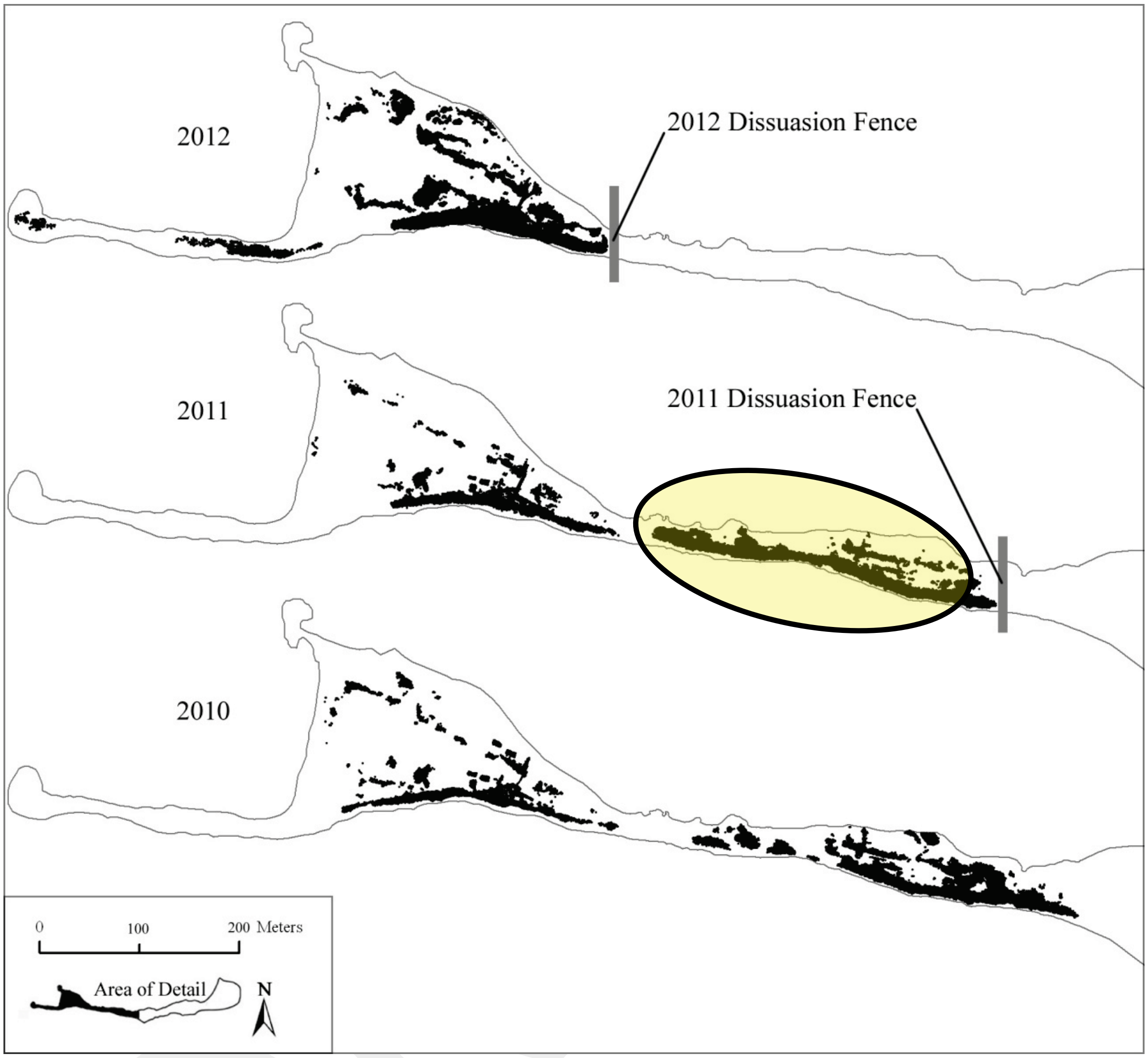

Figure 6. Distributions of the double-crested and Brandt's cormorants nest areas on the west end of East Sand Island. A sequential reduction in colony area was achieved through the use of dissuasion fencing and hazing during the breeding season. In this report, the area between the 2012 dissuasion fence and the 2011 dissuasion fence (circled in yellow) is referred to as the dissuasion area. Maps provided courtesy of Bird Research Northwest.

TAGGING OF LOWER COLUMBIA RIVER SUBYEARLING CHINOOK SALMON

During May and June 2012, 9,000 PIT tags were available from the U.S. Army Corps of Engineers to mark hatchery subyearling fall Chinook salmon from the lower Columbia River ESU. Hatchery tagging followed the same protocol used in previous years of this study (Sebring et al. 2011, 2010). A team of four biologists, including at least two experienced taggers, employed single-use, pre-loaded hypodermic 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 a 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 into 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 2 minutes, when fish stopped swimming and rolled gently onto their sides, tagging personnel removed fish by hand from the anesthetic bath, and inserted a PIT tag into the ventral body cavity. This method required no sutures or other manipulations of the fish due to the small gauge of the needle.

After the tag was inserted, the PIT-tag identification code was recorded into a laptop computer automatically by passing the fish through a circular PIT detector. Fish were then placed into a 5-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 a hatchery raceway specified for tagged fish. Any tag loss was recorded by retrieving ejected PIT tags from the recovery bucket and re-running them through the detector so that the tag code was recorded. Releases of tagged fish took place according to the original hatchery release schedule, but no sooner than 12 h after tagging.
Data files containing tag-and-release information were uploaded to directly to the PTAGIS database (PTAGIS 2013) through a publicly available website where all Columbia Basin PIT-tag records are archived.

A total of 8,885 subyearling Chinook salmon from three hatcheries were PIT-tagged during 2012; of these fish, 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 of release and subsequent recovery on East Sand Island bird colonies were used to estimate predation rates for the Lower Columbia River Chinook salmon ESU (reported here).

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

Hatchery tagging site	Tagging date	Release site	Release date	Fish released (n)	Tags recovered (n) by colony		
					Caspian tern	Double-crested cormorant	Mixed/ Brandt's cormorant
Warrenton High School	1 May	Skipanon River, OR	13 May	2,978	70	384	13
Big Creek	3 May	Big Creek Hatchery, OR	7 May	2,921	33	286	13
Kalama Falls	25 Jun	Kalama Falls Hatchery, WA	26 Jun	2,986	63	248	11

RECOVERY OF PIT TAGS FROM EAST SAND ISLAND

All East Sand Island PIT-tag detection efforts took place between 1 October and 15 November 2012. When sufficient personnel were available to do so, two crews worked simultaneously on the tern and cormorant colonies. One complete survey of the tern colony, the cormorant colony, or the dissuasion area typically took 4-7 d; 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 and two passes each on the cormorant colony and 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 this habitat. To detect PIT tags on or up to 10-15 cm below the surface, we used a 6-coil, flat-plate antenna system deployed from a vehicle, which allowed us to record detections 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 reading range is most sensitive to the orientation of a tag relative to the antenna detection field, 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 both forward and backward over exactly the same terrain. Second, for each of the three passes over the tern colony, a different orientation was used for the tracks. 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 the tracks for each pass, we scanned the entire colony perimeter, driving both forwards and backwards along the perimeter track, for any tags that may have been deposited 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. 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 detection system used on East Sand Island Caspian tern colony. The custom aluminum housing on the rear of the tractor is connected to the tractor 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

Between 1 October and 8 November 2012, we completed three passes over the Caspian tern colony and recorded a total of 20,279 PIT-tag codes with no prior history of detection. Of these detections, 15,298 (73.8%) were from juvenile salmon that migrated in 2012. A breakdown of raw tag-code recoveries by ESA-listed group 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 from fish with no species identification in PTAGIS.

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

	PIT tag detections by colony (n)		
ESU or DPS	Caspian tern	Double-crested cormorant	Mixed/Brandt's cormorant
Snake River sockeye	175	404	17
Chinook salmon			
Snake River spring/summer	2,082	2,028	75
Upper Columbia River spring	202	244	6
Middle Columbia River spring	145	138	2
Snake River fall	1,069	2,686	174
Upper Columbia River summer/fall	340	418	40
Upper Willamette River spring	32	40	7
Lower Columbia River	714	2,416	93
Steelhead			
Snake River Basin	7,183	2,985	114
Upper Columbia River	1,215	697	26
Middle Columbia River	1,806	645	24
Lower Columbia River	644	195	4
Lower Columbia River coho	4	25	0
Total	15,611	12,921	582

Cormorant Colony

Methods

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

Figure 8. Hand-held PIT detector system used for East Sand Island rip-rap habitat on cormorant colonies. Battery-powered transceivers were carried in a backpack system. Tiffanie Cross is the operator.

To systematically survey the colonies, hand-scanning teams were assigned to one of four possible categories in a species-by-habitat matrix (Table 3). Along with collaborators at Bird Research Northwest, we 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 strategy for scanning habitat each day before data collection began and as necessary throughout the day.

Table 3. Species-by-habitat matrix for hand-scanning PIT tags 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

While scanning for tags, hand-scanning teams manually moved detectors back and forth across the surface of the substrate in a manner best described as "aggressive vacuum-cleaning." Whenever possible, we walked systematically along parallel, overlapping, tracks within the area being scanned. To ensure large areas were not missed during hand-scanning, we used a combination of maps, visual landmarks, sticks, and scuff marks in the sand to delineate sections of habitat that had already 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 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 primarily occupied by double-crested cormorants. We used a combination of contractor flags and non-toxic spray paint to mark individual nests or nesting areas as belonging to one species or the other.

Results

Between 10 October and 15 November 2012, we completed two passes over the approximately 10,117 m^2 (2.5 acres) of cormorant nesting habitat, as well as the 5,665 m^2 (1.4 acres) of habitat in the 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 fall storms occurred between 18 and 31 October 2012.

Hand-scanning recovered a total of 17,191 unique tag codes with no prior history of detection. Of those, 13,829 (80.4%) were from juvenile salmon that migrated in 2012. A breakdown of all tag-code recoveries by ESA-listed group 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.

ESTIMATED RATES OF PREDATION

To more accurately calculate predation rates from estuary PIT-tag detections, we adjusted our estimates for two types of uncertainties. The first type of uncertainty relates to the fact that detection efficiencies on bird colonies are less than 100%; some proportion of PIT tags on a colony are not successfully detected 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-tags from salmon captured or ingested by birds will have their associated tags deposited off the colony; we refer to calculations which account for this phenomenon as the "deposition adjustment."

Adjustments for detection efficiency have been made to estimates of predation on East Sand Island in most prior years of this study (e.g. Ryan et al. 2001; Sebring et al. 2012; Roby et al. 2013). However, adjustments for off-colony deposition have never been made for double-crested cormorants, and those for Caspian terns have been made in only a few cases (see Roby et al. 2013, Appendix A). In 2012, both types of adjustments were applied for the first time to estimated predation rates on ESA-listed salmonid groups originating above Bonneville and Sullivan Dams.

Adjustments to Tag Recovery Data

Detection Efficiency Adjustments

Methods**—**Detection efficiencies for land-based PIT-tags in the field are not 100%, and even with the best of scanning techniques, some PIT tags on avian colonies will go undetected. For example, if two or more tags are located very close to each other, their transponders may be excited and emit a tag code at exactly the same time, resulting in a "tag-code collision" wherein the transceiver cannot read either code correctly. Other tags may break over the course of the season, and still other tags may be buried so deeply that they are beyond reading range of the detector. Therefore, detection efficiency was estimated by planting a known number of "control" tags, or tags with known codes, onto the colony before, during, and after the nesting season.

As in previous years, Bird Research Northwest personnel 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, control tags for these two areas were divided into two subgroups of 50 tags, with one subgroup each for bare sand and rip-rap habitats. Tags were placed once in April before egg-laying began, and again in late September or early October, after all chick-rearing activity had ended and adult birds had vacated the colonies.

Although it is possible in some years to sow control tags during egg incubation or chick-rearing on the tern colony, this was not done 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.

Detection efficiency may drop with time elapsed since the initial deposition of a PIT tag because the longer a tag remains on a colony, the higher the probability that it will be buried, damaged, or washed away from the original deposition site. Therefore, Evans et al. (2012) developed a logistic regression equation to model time-dependent, daily detection probabilities derived from detection efficiencies measured by control-tag recoveries. We adjusted our detection efficiency estimates for all estimated predation rates using this logistic regression method (Evans et al. 2012).

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 detection efficiencies measured in 2012 were 77% for Caspian tern and 74% for double-crested cormorant colonies. These detection efficiencies were similar in magnitude to those measured in recent years (c.f. Appendix Table 4 in Sebring et al. 2012).

Date-adjusted daily detection efficiencies for East Sand Island colonies were calculated for the period between 1 March and 31 August 2012 using a logistic regression model as per Evans et al. (2012). Coefficients for the equations used in this report are provided in Table 5. Adjusted daily detection efficiencies for the Caspian tern colony ranged between 42 and 90% for the Caspian tern colony and between 56 and 81% for the double-crested cormorant colony (exclusive of the dissuasion area). Adjusted daily detection efficiencies for the dissuasion area ranged between 43 and 66%.

Table 4. Detection efficiency for tag–code recovery on 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.

	Control tags							
	Date sown in 2012		Tags sown (n)		Detections (n)		Detections (%)	
Habitat	Pre-season	Post-season	Pre-season	Post-season	Pre-season	Post-season	Pre-season	Post-season
Caspian tern								
Bare sand	17 Apr	27 Sep	100	100	60	94	60	94
Double-crested cormorant								
Bare sand	11 Apr	9 Oct	50	50	28	43	56	86
Rip-rap	11 Apr	9 Oct	50	50	35	42	70	84
Dissuasion area								
Bare sand	3 May	9 Oct	50	50	17	36	34	72
Rip-rap	3 May	9 Oct	50	50	33	30	66	60

Table 5. Colony-specific coefficients used for the binomial logistic regression used to adjust estimates of daily detection efficiency. Nomenclature is as per Evans et al. (2012), Equation 2.

Colony	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 Deposition Adjustments

***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 method accounts for PIT tags 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 tags they consume will be deposited off the colony. Such tags cannot be recovered during on-colony PIT detection surveys. For example, a PIT tags that has passed through the digestive tract may be egested into the water during a foraging trip. Due to variation among bird species 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.

An overview of the methodology for calculating species-specific adjustments to Caspian tern and double-crested cormorant predation rates are presented in Roby et al. (2013, Appendix A, *Incorporation of PIT Tag Deposition Rate Data to Quantify Avian Predation Rates*). 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 Roby et al. (2013, Appendix A *Incorporation of PIT Tag Deposition Rate Data to Quantify Avian Predation Rates*).

Briefly, during 2005-2006, experiments were conducted at Crescent and East Sand Island wherein Caspian terns were force-fed tagged trout. These birds deposited an estimated 86% of the force-fed tags on their colony (95% confidence interval around the estimate: 73-100%). In a second experiment during 2005-2006 near the Crescent Island tern colony, terns volitionally fed upon tagged fish in net pens. These terns deposited an estimated 54% of tags on the colony (95% confidence interval around the estimate: 42-67%). In 2012, new experiments were conducted by BRNW on East Sand Island wherein double-crested cormorants volitionally consumed a total of 301 PIT-tagged trout on the colony. Based on subsequent PIT-tag recoveries, an estimated 44% of consumed PIT tags were deposited on the colony (95% confidence interval around the estimate: 36-51%).

Estimated Annual Predation for ESA-Listed Groups originating above Bonneville or Sullivan Dam

Methods

In 2012, the method of estimating predation rates and the reporting of PIT-tagged groups were changed from prior years' reports. These two changes are as follows.

First, we estimated predation rates by Evolutionarily Significant Unit (ESU) or Distinct Population Segment (DPS) by assigning tag release groups to ESA listings as posted on the NOAA Fisheries West Coast Regional Office website (NMFS 2014). We assigned individual tag groups to an ESU/DPS unit based on the Columbia Basin Hydrologic Unit Code (HUC) reported for a tag group in the PTAGIS (2013) database. This change was part of a basin-wide effort to align research project reporting with ESU or DPS management units. Thirteen of 19 populations from the Columbia River Basin are listed as threatened or endangered. Because all Columbia River Basin juvenile salmon must pass through the Columbia River estuary to reach the ocean, all populations are potentially subject to estuary avian predation. However, not all of these 13 groups are PIT-tagged in a representative fashion, which could possibly result in biased predation rate estimates for those ESU/DPS groups without representative tagging programs.

Second, predation rates estimated in 2012 were adjusted not only for PIT-tag detection efficiencies, but also for newly available estimates of 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 with BRNW avian predation program. Details on these adjustments are presented in detail in Roby et al. (2013; Sections 1.4 and 2.4 for terns and cormorants, respectively).

Briefly, predation rates were estimated using a two-step process:

1) Estimate how many PIT-tagged fish from each ESU/DPS were *available* to birds in the estuary during the nesting season. This was done 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) Estimate how many PIT-tagged fish were *consumed* by birds on East Sand Island during the nesting season. This was done for each ESU/DPS by adjusting PIT-tag code recovery numbers by estimated detection efficiency and estimated on-colony tag deposition rates for East Sand Island.

Adjusted predation rates were 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 some listed ESU/DPS groups, all populations entered the Columbia and Willamette Rivers above the PIT-tag detectors at Bonneville Dam (Columbia River, rkm 235) or Sullivan Dam (Willamette River, rkm 206). For these groups we used the total number of fish detected passing either of these two dams between 1 March and 31 August 2012 to estimate fish availability to birds in the estuary (Evans et al. 2012). Following the methodology of Evans et al. (2012), we estimated predation rates only for groups with ≥500 PIT-tagged individuals 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).

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

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 Chinook salmon are presented on page 26-33 of this report.

		Caspian tern		Double-crested cormorant		Mixed/Brandt's cormorant	
ESU/DPS	Detection at dams (n)	Adjusted predation rate (%)	95% CI	Adjusted predation rate (%)	95% CI	Adjusted predation rate (%)	95% CI
Snake River sockeye	1,457	2.1	1.1-3.2	4.0	2.2-6.1	<0.1	n/a
Chinook salmon							
Snake River spring/summer	17,929	2.2	1.8-2.7	4.2	3.4-5.2	<0.1	n/a
Upper Columbia River spring	3,227	1.2	0.7-1.7	2.3	1.4-3.4	<0.1	n/a
Middle Columbia River spring	4,433	1.6	1.0-2.2	2.4	1.5-3.4	0.1	<0.1-0.2
Snake River Fall	10,742	0.7	0.5-0.9	3.0	2.3-3.8	0.1	<0.1-0.1
Upper Columbia River summer/fall	3,986	1.4	0.9-2.0	2.2	1.3-3.1	0.1	<0.1-0.2
Upper Willamette River	3,731	0.7	0.4-1.1	0.6	0.2-1.2	0.2	<0.1-0.4
Steelhead							
Snake River Basin	4,768	10.0	8.4-11.9	5.4	4.0-7.0	<0.1	n/a
Upper Columbia River	3,357	7.4	6.0-9.1	7.2	5.4-9.6	0.1	<0.1-0.3
Middle Columbia River	1,084	9.3	6.7-12.3	3.4	1.6-5.8	0.2	<0.1-0.6

Estimated Predation for Lower Columbia River Chinook Salmon

Methods

Chinook salmon populations included in the Lower Columbia River ESU are extremely diverse in their life history characteristics. There are eight possible combinations of juvenile life history type (yearling or subyearling), rear type (hatchery-raised or naturally spawned), and geographic origin (broadly divided as above or 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 Lower Columbia River Chinook salmon do not follow the same method as for ESU/DPS groups above Bonneville or Sullivan Dams. First, PIT-tagged fish from other ESU/DPS groups enter the Columbia or Willamette River upstream from a detection facility (i.e. Bonneville or Sullivan Dam) used to document entry of PIT-tagged fish into the foraging range of bird colonies in the estuary. In contrast, Lower Columbia River Chinook salmon may enter the mainstem Columbia River from populations originating below a terminal dam. Therefore, the availability of these fish to birds in the estuary cannot be calculated using only the number of fish detected at dams (Lyons et al. 2012).

Second, because there is no coordinated effort to PIT tag Lower Columbia River Chinook salmon, many groups with this ESU (most notably naturally produced fish) are not well-represented among PIT-tagged fish. Furthermore, groups that 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 necessarily provide an accurate picture of what is happening to the ESU as a whole. In the absence of a PIT-tagging program for Lower Columbia River Chinook salmon, any generalizations as to avian impacts on this ESU need to be made with caution.

Third, the total number of Lower Columbia River Chinook salmon tagged and released on an annual basis is relatively small compared to numbers tagged and released in other ESUs. Therefore, sample sizes for analyses inherently produce less robust and precise estimates than those from groups where greater numbers of fish are PIT-tagged. For example, to obtain sample sizes sufficient to compare predation rates among subgroups of Lower Columbia River Chinook 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 calculate predation impacts to Lower Columbia River Chinook salmon, some investigators have measured the availability of these fish using all PIT-tag release data from this ESU, regardless of geographic origin (e.g. Lyons et al. 2012). This has the advantage of producing larger sample sizes of available fish, but the disadvantage of relying on the assumption that mortality is negligible between release and entry into the mainstem below Bonneville Dam. Thus estimates of predation rate using this method are likely biased low because the number of fish available for consumption by birds is probably less (and thus the proportion consumed greater) than the number originally released due to other unmeasured sources of mortality.

Other investigators have used different measures of availability in estimating predation rates for PIT-tagged fish, depending on geographic origin (e.g. Ryan et al. 2003, Sebring et al. 2012). For components of the ESU originating from upriver areas, these researchers calculated the availability of fish to birds in the estuary using dates of detection at Bonneville or Sullivan Dam. For components of the ESU originating below the dams, they used release date. This method has the advantage of using the same measure of availability used for all upriver PIT-tagged groups that pass Bonneville or Sullivan Dam, but the disadvantages of 1) using different measures of availability for upriver vs. lower river groups and 2) producing significantly smaller sample sizes for upriver groups.

Both methods assume that the date on which a tagged fish was consumed by a bird was the same day, or near the same day, on which that fish became available in the estuary. There is no way to test this assumption, as it is not yet possible to discern either the date of a predation event or the date of deposition on a colony for a specific PIT tag.

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*. Thus, to determine how many fish in the Lower Columbia River Chinook salmon ESU were available to birds in the estuary on any given day, we summed all daily releases of PIT-tagged groups from this ESU within its geographic boundaries between 1 March 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).

Detection data from a single year typically does not provide a large enough sample size to partition sub-groups within an ESU by run type, rear type, and geographic origin. Therefore, we pooled all available data from PIT-tagged Lower Columbia River Chinook salmon to estimate a single predation rate for that ESU in 2012. This method differed from that used by Lyons et al. (2012) in that they used pooled data from multiple years. Given the methodological caveats described above, this predation rate estimate does not necessarily reflect avian predation impacts on the ESU as a whole; that would require an 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 1 March and 31 August 2012 by the daily detection efficiency specified by the logistic regression method described previously (Evans et al. 2012). This allowed us to sum daily estimates of the total number of PIT-tags from Lower Columbia River Chinook salmon that were consumed by birds, and thus estimate an annual minimum predation rate 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 1 March and 31 August 2012, groups of PIT-tagged Chinook salmon from the Lower Columbia River ESU were released from 52 sources. 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 geographic boundaries of this ESU. Of these releases, 66.3% came from three hatcheries, all of which released fish to the mainstem Columbia River above Bonneville Dam. These "top three" hatchery sources were the Carson National Fish Hatchery, Little White Salmon National Fish Hatchery, and Spring Creek National Fish Hatchery (Table 7, Figure 9). Thirteen additional 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 our estimates of predation rates, 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, and the maximum daily release size was 29,481 fish. Of all days on which fish were released (n = 130 d), 51.5% (n = 67 d) had release sizes greater than 100 fish.

A total of 3,221 PIT-tag codes from the Lower Columbia River Chinook salmon were recovered on East Sand Island bird colonies. We recovered 714 of these codes 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, estimated annual predation was 0.91% for all available PIT-tagged Lower Columbia River Chinook salmon (n = 1,119 tags after adjustments for detection efficiency). This estimate included subyearlings and yearlings, fish of hatchery and wild origin, and fish released both above and below Bonneville Dam. For double-crested cormorants, estimated annual predation was 2.9% (n = 3,551 tags after adjustments for detection efficiency). For mixed avian species consisting primarily of 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).

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. WDFW—Washington Department of Fish and Wildlife ODFW—Oregon Department of Fish and Wildlife

	Release site	Run type	Rear type	Origin 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	29,479	24.1	24.1
2	Little White Salmon NFH	Fall	Hatchery	Above	24,953	20.4	44.5
3	Spring Creek National Fish Hatchery	Fall	Hatchery	Above	14,750	12.1	56.5
4	Little White Salmon NFH	Spring	Hatchery	Above	11,959	9.8	66.3
5	Moving Falls Acclimation Pond, Hood R	Spring	Hatchery	Above	10,276	8.4	74.7
6	Bonneville to John Day Dam (rkm 234-347)	Unknown	Unknown	Above	5,535	4.5	79.2
7	Parkdale Hatchery	Spring	Hatchery	Above	5,084	4.2	83.3
8	Lewis River to Bonneville Dam (rkm 140-234)	Unknown	Unknown	Below	4,002	3.3	86.6
9	Kalama Falls Hatchery (WDFW)*	Fall	Hatchery	Below	2,986	2.4	89.0
10	Skipanon River*	Fall	Hatchery	Below	2,978	2.4	91.5
11	Willard National Fish Hatchery	Spring	Hatchery	Above	2,960	2.4	93.9
12	Big Creek Hatchery (ODFW)*	Fall	Hatchery	Below	2,921	2.4	96.3
13	Bonneville Adult Fish Facility	Unknown	Hatchery	Above	1,996	1.6	97.9
14	All other contributors to tagged groups	Mixed	Mixed	Mixed	2,665	2.1	100.0

* PIT-tag releases from this study

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.

Release site	Predation rate (%)		
	Caspian tern	Double-crested cormorant	Mixed/Brandt's cormorant
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

Excluding dates when release sizes were <100 fish resulted in a total of 120,573 fish available for estimates of annual predation (vs. 122,544 using all release dates). However, this did not change the estimated annual predation impact for any avian species.

Variation in daily predation rates was high, and there were days when predation pressure on a release group was much lower or higher than the overall annual estimate (Table 9). On many release days, no PIT tags were detected on East Sand Island from those releases of fish, and the estimated predation rate was therefore zero. On other days, daily predation rates were much greater than the annual rate. For example, 12, 26, and 29 May had the highest daily predation rates from Caspian terns, at 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 primarily above Bonneville Dam (74, 75, 107 total PIT-tagged fish, respectively).

In contrast, 7 and 13 May and 26 June had the highest daily predation rates from double-crested cormorants, at 14.0, 18.7, and 10.4%, respectively. These dates each corresponded a large release of PIT-tagged subyearling Chinook salmon from this study, where fish originated from a single source below Bonneville Dam (Big Creek, Skipanon, and Kalama Falls, respectively; see Figure 9).

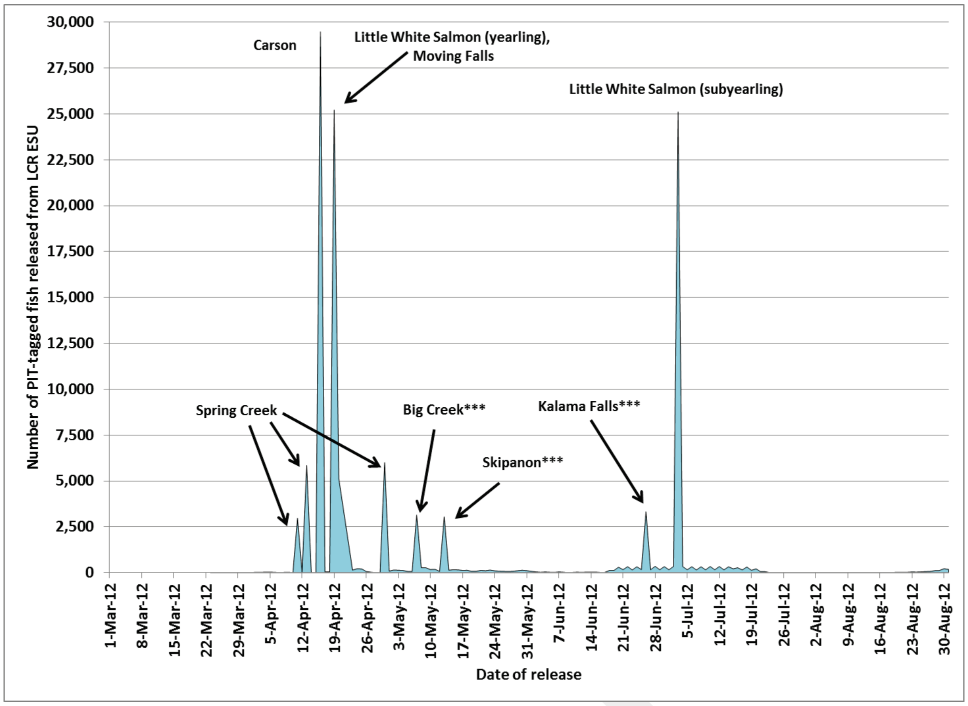

Figure 9. Daily total releases of PIT-tagged Lower Columbia River Chinook salmon between 1 March and 31 August 2012. Hatcheries with releases that dominated the total over a 1-2 d period are identified for those periods. Asterisks (***) indicate releases made as part of this study.

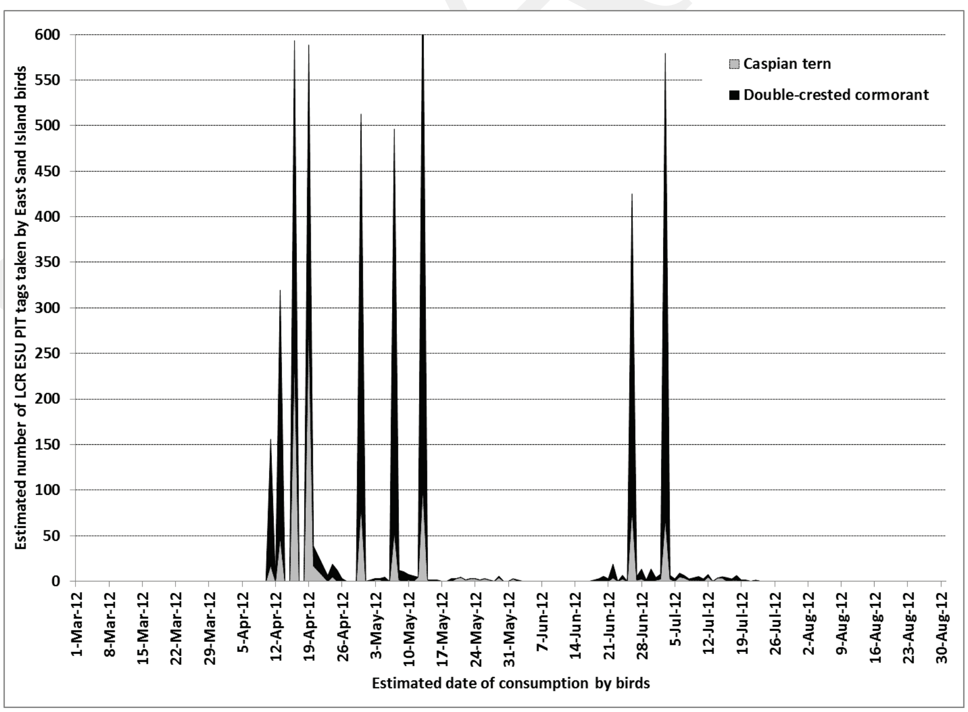

Figure 10. Estimated daily recoveries of PIT-tag codes from Lower Columbia River Chinook salmon on East Sand Island, adjusted for detection efficiency between 1 March and 31 August 2012. Records include only codes from migration year 2012.

Table 9. Distribution of estimated daily predation rates by bird species 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	100.0	130	100.0

Estimated Predation for Barge-transported vs. In-river Migrant Snake River Fall Chinook Salmon

Methods

We compared estuary avian predation rates between barge-transported and in-river migrant Snake River fall Chinook salmon in three ways. First, we estimated the 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, and summed the adjusted numbers over the entire season. We then divided each sum by the total number of tags available throughout the season. This calculation was analogous to those described in previous sections of this report, and it allowed us to compare cumulative annual predation impacts with all available data.

Second, we estimated the weekly predation impacts for each group, compared these rates with the timing and magnitude of weekly barge releases and in-river migrants passing Bonneville Dam, and performed a paired *t*-test between weekly predation rates for barged vs in-river migrants. Comparisons were restricted to weeks when ≥100 tag codes were available from barge releases or from detections at Bonneville Dam. The *t*-test was performed only for weeks where *both* barge releases and detections at Bonneville were available. Week 1 began on 1 March, and we computed weekly predation by summing the adjusted number of tag codes originating from releases/detections in that week and recovered on East Sand Island, and then dividing that sum by the total number of tag codes released/detected for that same week.

Third, we performed a paired *t*-test between daily predation rates for barge-transported vs. in-river migrants. These comparisons were restricted to days when ≥100 tag codes from fish of *both* migration histories were present on the same day (e.g., either recorded as having been released from a barge below Bonneville Dam or having been detected at Bonneville Dam). This paired daily comparison provided a more conservative comparison of predation impact, as it was based on a minimum sample size similar to our weekly analysis (≥ 100) and was restricted to 1-d periods during which other physical and biological conditions in the estuary (e.g. flow, predator activity, abundance of alternative prey) should have been similar for both groups.

Other groups of Snake River fish were also PIT-tagged and transported for release below Bonneville Dam or detected at the dam (e.g., spring and summer Chinook salmon, coho salmon, sockeye salmon, and steelhead). Although we present raw counts for these groups of fish in a table, analysis of those data was beyond the scope of this report.

To measure availability of barge-transported fish to birds in the lower Columbia River estuary, we obtained records of all PIT-tagged fish released above Lower Granite Dam (rkm 695) and subsequently routed to transport barges at a Snake River dam. Subyearling Chinook salmon were barged between 3 May and 17 August 2012, and groups of these fish were PIT-tagged either for experimental comparisons of transportation timing or for a variety of other studies. Some PIT-tagged fish that were intended to remain in the river were placed on barges in error (typically <5% of all fish, Sandford unpublished data).

Barge-transported fish 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), releases occurred every 24 h; later in the season (June-August), releases occurred every 48 h.

To measure the estuary availability of in-river migrant Snake River fall Chinook salmon, we used the number of PIT-tag detections at Bonneville Dam between 1 March and 31 August 2012. Because barged fish from this ESU are tagged at or above Lower Granite Dam, we included Bonneville detections in our analysis only from 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 tag-code recoveries from East Sand Island. There are no data on when an individual predation event or tag deposition on a colony occurred; therefore, we assumed that an individual fish was consumed on the same day it became available to avian predators. This availability date was either the date of barge release at Skamania for transported fish or the date of last detection at Bonneville Dam for in-river migrant fish.

To estimate a minimum predation rate for fish consumed by birds on East Sand Island, we adjusted daily detection numbers on East Sand Island between 1 March and 31 August 2012 by the daily detection efficiency specified by the logistic regression equation described previously (Evans et al. 2012). We then summed daily estimated numbers of PIT-tags from this ESU consumed by birds, and thus estimated daily predation rates. Adjustments for off-colony deposition were not included for these estimates because off-colony deposition data for 2012 were not available 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 3 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.

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	11,111	12,860	5,531	29,502
	Wild	900	786	283	1,969
	Unknown	0	2	7	9
Summer	Hatchery	2,555	3,656	1,563	7,774
	Wild	434	373	133	940
Fall	Hatchery	22,981	19,763	7,315	50,059
	Wild	1	0	2	3
	Unknown	0	21	7	28
Unknown	Hatchery	9	15	14	38
	Wild	13,095	475	234	13,804
Total Chinook salmon					104,126

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	1,603
Sockeye salmon	Hatchery	6,521	5,198	2,321	14,040
	Wild	2	6	6	14
Steelhead	Hatchery	22,451	9,117	6,646	38,214
	Wild	15,049	1,358	700	17,107
Total non-Chinook salmon					71,019

Barge-transported fish—Of all PIT-tagged fall Chinook salmon transported on 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. Fifteen of 16 weeks with barge releases had weekly release totals of ≥100 fish. Weekly summaries of barge releases and predation estimates throughout the entire study period are shown in Table 12. There were 45 days when barge releases included at least 100 PIT-tagged fish. The timing and size of daily barge releases for fish used in the analysis are shown in Figure 11.

Table 12. Estimated weekly predation rates for barged and in-river migrant Snake River fall Chinook salmon. A dash indicates a week when no tagged fish were available to birds and no estimate was made. The designation "n/a" indicates weeks where the sample size was too small (<100) for performing an estimate.

			Weekly estimated predation rate (%)					
			Caspain tern		Double-crested cormorant		Mixed/Brandt's cormorant	
Week	Barge releases (n)	Detections, Bonneville Dam (n)	Barged	In-river migrants	Barged	In-river migrants	Barged	In-river migrants
1 Mar	0	0	-	-	-	-	-	-
8 Mar	0	0	-	-	-	-	-	-
15 Mar	0	0	-	-	-	-	-	-
22 Mar	0	0	-	-	-	-	-	-
29 Mar	0	0	-	-	-	-	-	-
5 Apr	0	0	-	-	-	-	-	-
12 Apr	0	19	-	n/a	-	n/a	-	n/a
19 Apr	0	131	-	0	-	0	-	0
26 Apr	0	348	-	0	-	1.30	-	0.58
3 May	1,621	442	0.55	0.34	2.40	2.70	0	0
10 May	830	538	0	0	1.96	3.02	0	0.37
17 May	315	173	0	0	2.31	2.25	0	0
24 May	1,051	50	0.65	n/a	1.22	n/a	0	n/a
31 May	8,539	24	1.05	n/a	4.17	n/a	0.29	n/a
7 Jun	8,749	88	0.67	n/a	3.56	n/a	0.30	n/a
14 Jun	10,595	1,309	0.68	0.10	4.43	1.26	0.31	0.28
21 Jun	5,233	1,792	0.62	0.42	3.70	1.06	0.28	0.20
28 Jun	5,255	1,134	0.61	0.54	3.38	1.78	0.24	0
5 Jul	1,559	1,019	0.31	1.18	1.02	0.52	0.11	0
12 Jul	2,438	553	0.29	0.21	0.32	0.47	0	0
19 Jul	1,457	823	0.64	0.71	0.98	0.31	0.24	0
26 Jul	742	200	0.77	1.15	1.04	2.58	0.23	0
2 Aug	242	43	1.41	n/a	0	n/a	0.69	n/a
9 Aug	212	12	1.06	n/a	2.97	n/a	0	n/a
16 Aug	45	13	n/a	n/a	n/a	n/a	n/a	n/a
23 Aug	0	10	-	n/a	-	n/a	-	n/a
30 Aug	0	0	-	0	-	0	-	0

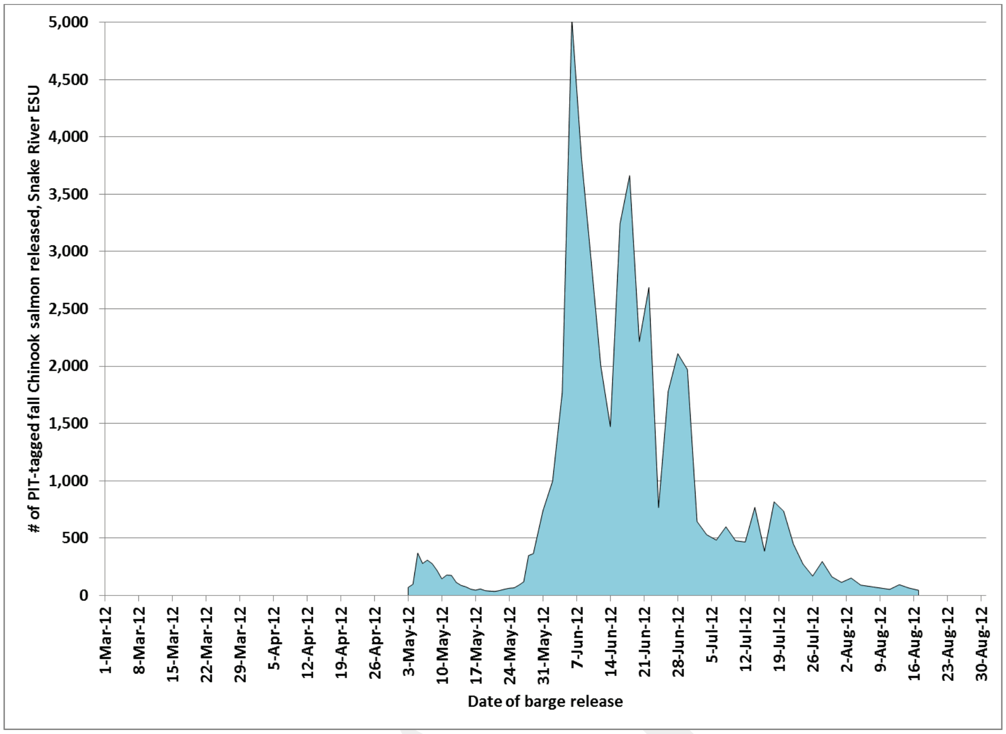

Figure 11. Counts of PIT-tagged Snake River fall Chinook salmon transported by barge and released to the Columbia River estuary, migration year 2012. All fish were released below Bonneville Dam at night near Skamania, WA (rkm 225).

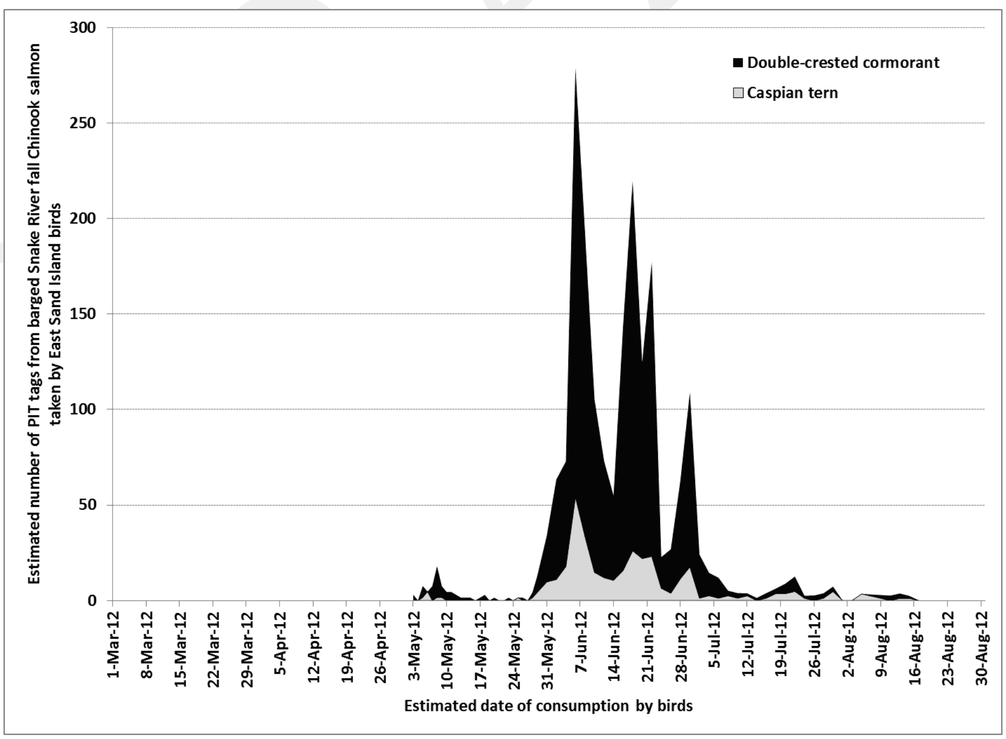

Figure 12. Estimated number of PIT-tag codes recovered from barged Snake River fall Chinook on East Sand Island, adjusted for detection efficiency between 1 March and 31 August 2012.

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 avian colony is shown in Table 13. Estimated daily predation events on barge-transported Snake River fall Chinook salmon are presented in Figure 12. Comparisons of estimated weekly predation rates with weekly barge releases are provided in Figure 13.

Table 13. 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/Brandt's cormorant	Totals
Transported by barge	261	1182	66	1,509
In-river migrant				
Detected at Bonneville	33	79	6	118
Not detected at Bonneville	658	1,151	82	1,891
Totals	952	2,412	154	3,518

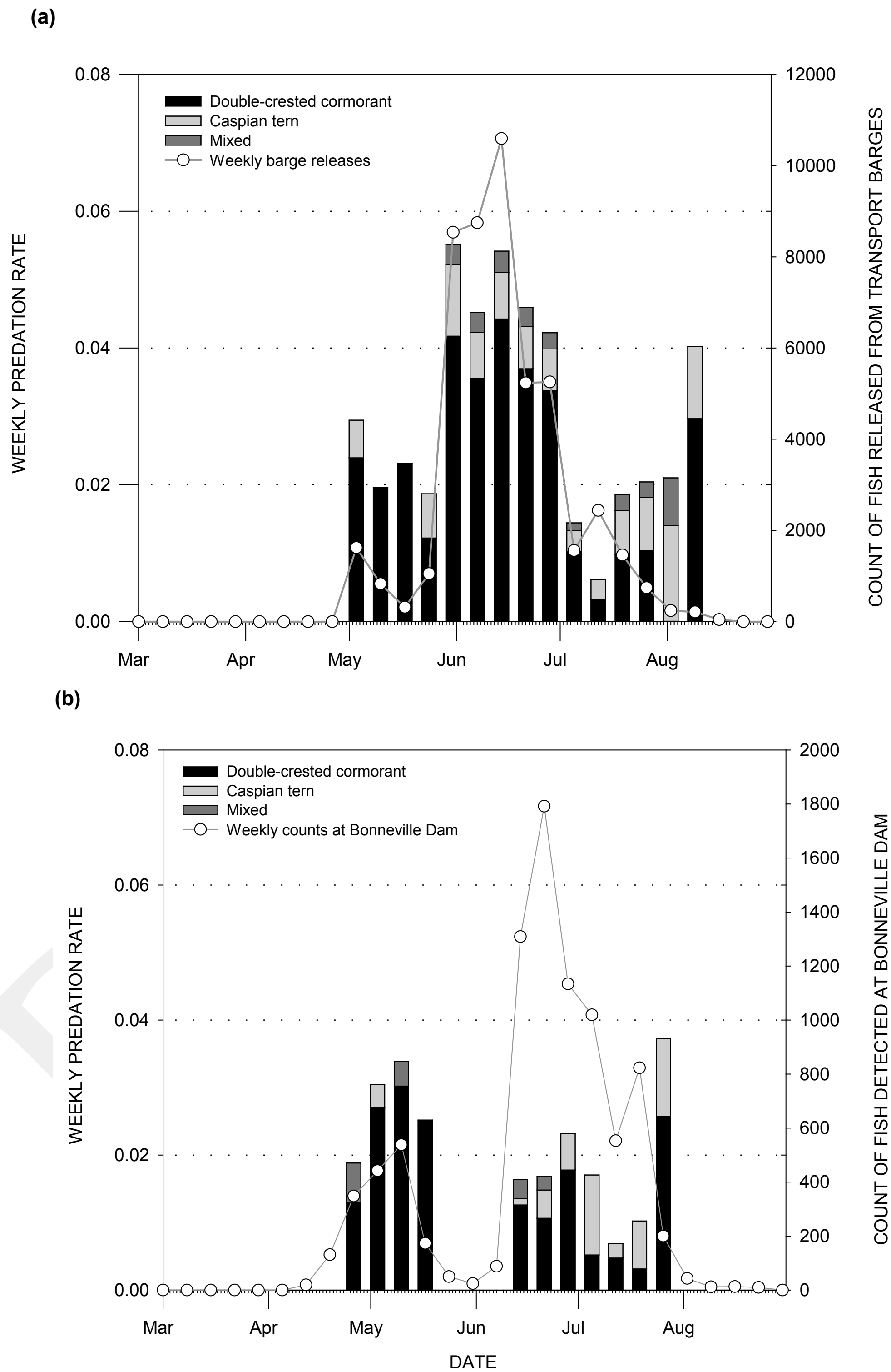

Figure 13. Estimated weekly predation rates for Snake River fall Chinook salmon compared to barge releases and detections at Bonneville Dam. Stacked bars indicate predation rates and open circles indicate releases or detections. Note that the scale on the left y-axis for weekly predation rate is the same in both panels, but the scale for the right y-axis is different in each panel. Panel (a) = barged fish, panel (b) = in-river migrants.

In-river migrants—A total of 10,456 PIT-tagged Snake River fall Chinook salmon were detected at Bonneville Dam between 1 March and 31 August 2012; the first fish was detected on 12 April and the last on 29 August. Of these fish, 8,721 were initially released above Lower Granite Dam (rkm 695). The median number of Bonneville detections per day was 35, with a minimum of 1 and a maximum of 322 fish per day. Twelve of 20 weeks with detections at Bonneville Dam had weekly release totals of ≥100 fish. Weekly summaries of in-river migrant detections and predation estimates throughout the entire study period are shown in Table 12. 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 14.

Only 118 PIT-tag codes from in-river migrant fall Chinook salmon released at or above Lower Granite Dam 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 bird colony is shown in Table 13. Estimated daily predation events on in-river migrant Snake River fall Chinook salmon are presented in Figure 15.

An additional 1,891 tag codes from Snake River fall Chinook were recovered on East Sand Island, but none of these tags had been previously detected at Bonneville Dam. These tags could not be included in estimates of daily predation rate because we had no information on the date these in-river migrants entered the estuary. However, it is clear that these fish survived past Bonneville Dam, entered the estuary, and were subject to avian predation.

Estimated predation rates for in-river migrants should be interpreted with extreme caution for several reasons. First, the sample size of recovered tag codes on East Sand Island for the entire season was very small (n = 118). Second, an unknown yet significant proportion of PIT-tagged Snake River fall Chinook salmon passed Bonneville Dam undetected, perhaps through a surface bypass route, subsequently entered the estuary, and experienced mortality due to avian predation.

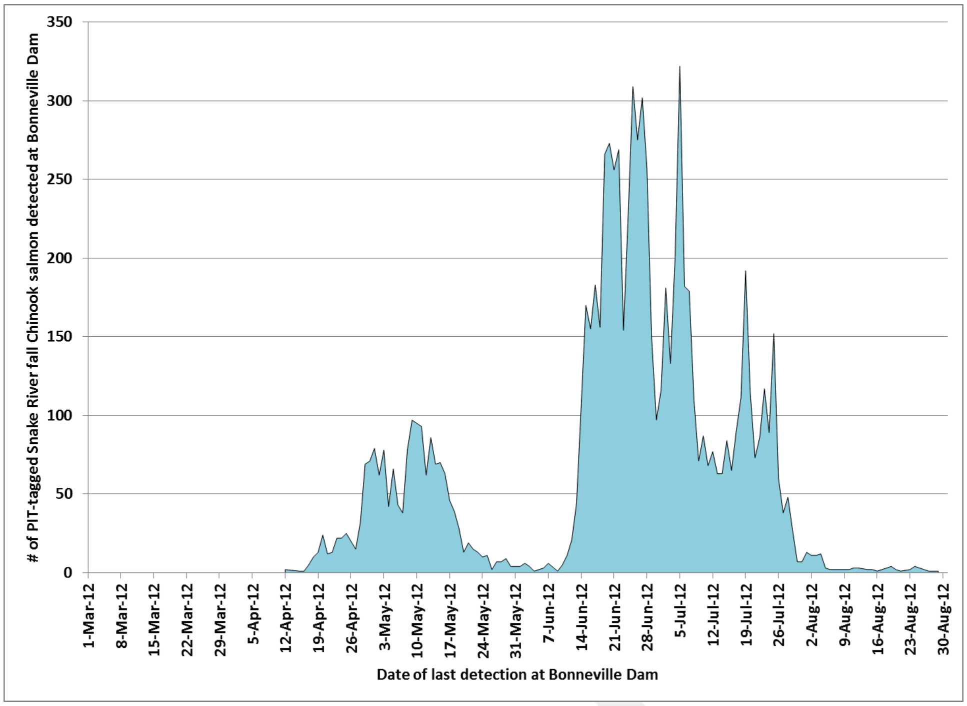

Figure 14. Counts of detections at Bonneville Dam of PIT-tagged Snake River fall Chinook salmon initially released above Lower Granite Dam, migration year 2012.

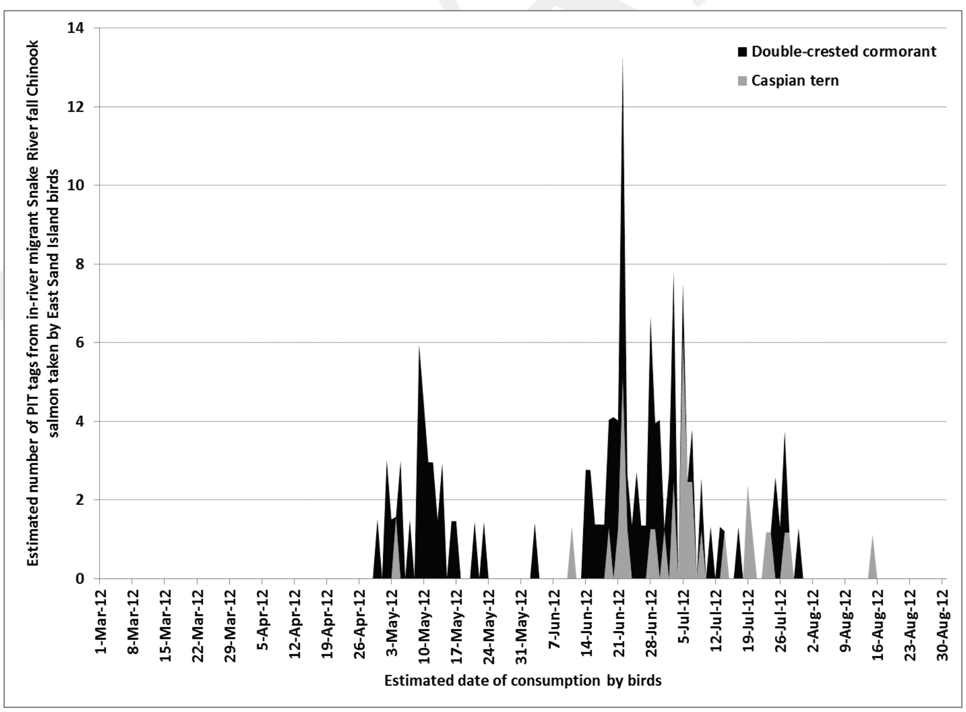

Figure 15. Estimated counts of PIT-tag codes from in-river migrant Snake River ESU fall Chinook salmon recovered on East Sand Island, adjusted for daily availability and detection efficiency between 1 March and 31 August 2012. These data do not include 1,891 tag codes which were also recovered on East Sand Island but were undetected at Bonneville Dam.

Comparisons of estimated annual predation rates for transported vs. in-river migrant fish are presented in Table 14. In 2012, annual predation rates were higher for transported fish than in-river migrants from both Caspian tern (0.7 vs. 0.47%, respectively) and double-crested cormorant colonies (3.3 vs. 1.3%, respectively). For mixed-species/Brandt's cormorant tag recoveries, the 2012 predation rate on transported fish was lower (0.03%) than for in-river migrants (0.13%).

Table 14. Estimated annual predation rates for barge-transported vs. in-river migrant Snake River fall Chinook salmon originating above Lower Granite Dam, migration year 2012.

	Snake River fall Chinook salmon tag codes recovered (n)		Annual predation rate (%)	
Species	Barged	In-river migrant	Barged	In-river migrant
Caspian tern	343	41	0.70	0.47
Double-crested cormorant	1,635	110	3.30	1.30
Mixed/Brandt's cormorant	120	11	0.03	0.13

Paired comparisons of weekly predation rates for the 10 weeks when at least 100 fish entered the estuary from both transported and in-river migration categories are presented in Table 15. None of the three paired *t*-tests between estimated weekly predation rates of barged vs. in-river migrants showed statistically significant differences between the two groups (Table 15), although it is worth noting that the statistical power of the paired tests was relatively weak due to the small sample size ($n = 10$, $\alpha = 0.05$, power < 0.25 in all cases).

Table 15. Results of paired t-tests for differences in estimated weekly predation rates, barged vs. in-river migrants, migration year 2012. The test performed was a one-tailed test.

	Caspian terns	Double-crested cormorants	Mixed/Brandt's cormorants
t-statistic	0.16	1.10	0.98
degrees of freedom	9	9	9
P	0.44	0.15	0.18

Paired comparisons of daily predation rates on the 14 dates when at least 100 fish entered the estuary from both the barged and in-river migration categories are presented in Table 16. For Caspian terns, mean daily predation rates were higher for transported fish (0.54%) than for in-river migrants (0.34%), but this difference was not statistically significant (t = 1.58, P = 0.13, 13 df). For double-crested cormorants, mean predation rates for barged fish (2.71%) were significantly higher than for in-river migrants (0.97%, t = 5.43, P < 0.001, 13 df). For mixed-species/Brandt's cormorant areas, mean predation rates for barged vs. in-river migrant fish were virtually equal (both 0.18%) and not statistically different (t = 0.70, P = 0.50, 13 df).

Table 16. 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 rate (%)					
			Caspian terns		Double-crested cormorants		Mixed/Brandt's cormorants	
Release date	Released from barge (n)	Detected at Bonneville (n)	Barged	In-river migrant	Barged	In-river migrant	Barged	In-river migrant
14 Jun	1,473	106	0.72	0.00	3.01	2.61	0.25	0.00
16 Jun	3,244	155	0.48	0.00	3.95	0.89	0.28	1.18
18 Jun	3,664	156	0.71	0.00	5.29	0.88	0.50	0.00
20 Jun	2,214	273	0.99	0.00	4.64	1.50	0.08	0.00
22 Jun	2,687	269	0.86	1.91	5.74	3.04	0.27	1.35
24 Jun	766	227	0.83	0.00	2.13	0.60	0.47	0.00
26 Jun	1,780	275	0.21	0.00	1.29	0.49	0.20	0.00
28 Jun	2,109	257	0.54	0.49	2.43	2.10	0.26	0.00
2 Jul	645	181	0.19	0.00	3.53	1.48	0.00	0.00
4 Jul	530	201	0.47	0.00	2.27	0.00	0.00	0.00
6 Jul	483	182	0.26	1.36	2.21	0.00	0.00	0.00
8 Jul	599	110	0.41	0.00	0.44	0.00	0.00	0.00
18 Jul	817	111	0.44	0.00	0.32	0.00	0.00	0.00
20 Jul	734	114	0.49	1.05	0.71	0.00	0.24	0.00
Mean	1,553.2	186.9	0.54	0.34	2.71	0.97	0.18	0.18

Graphic comparisons of daily predation rates for transported vs. in-river migrant fish over the entire season are presented in Figures 16 and 17. 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 on a day with less than 12 total tag detections at Bonneville Dam.

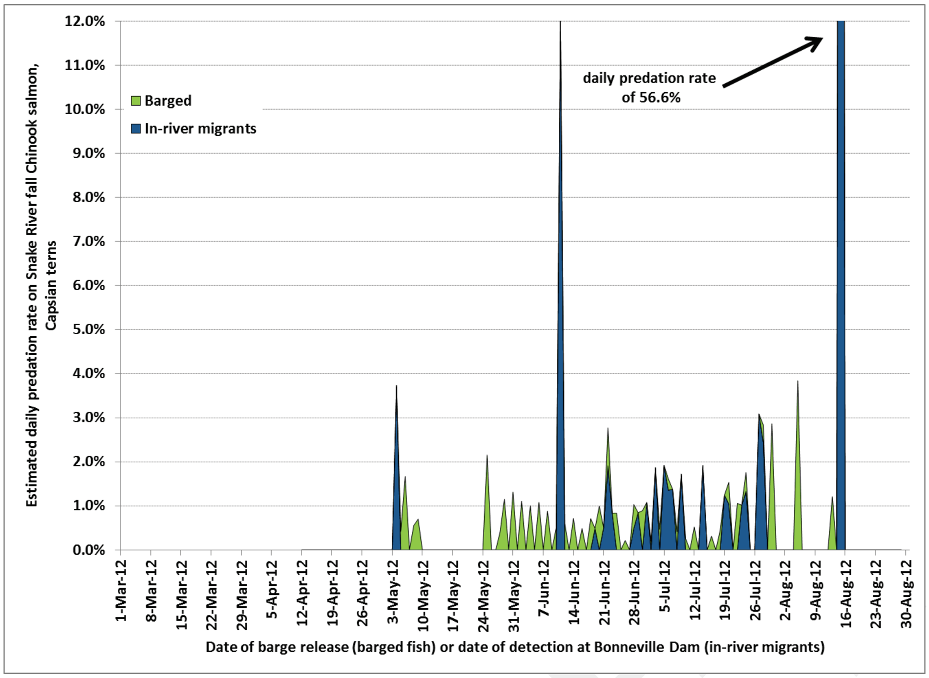

Figure 16. Estimated daily predation by Caspian terns on transported vs. in-river migrant Snake River fall Chinook, migration year 2012. Anomalously high in-river predation rates measured on 11 June and 15 August resulted from recovery of a single tag on a day with <12 detections at Bonneville.

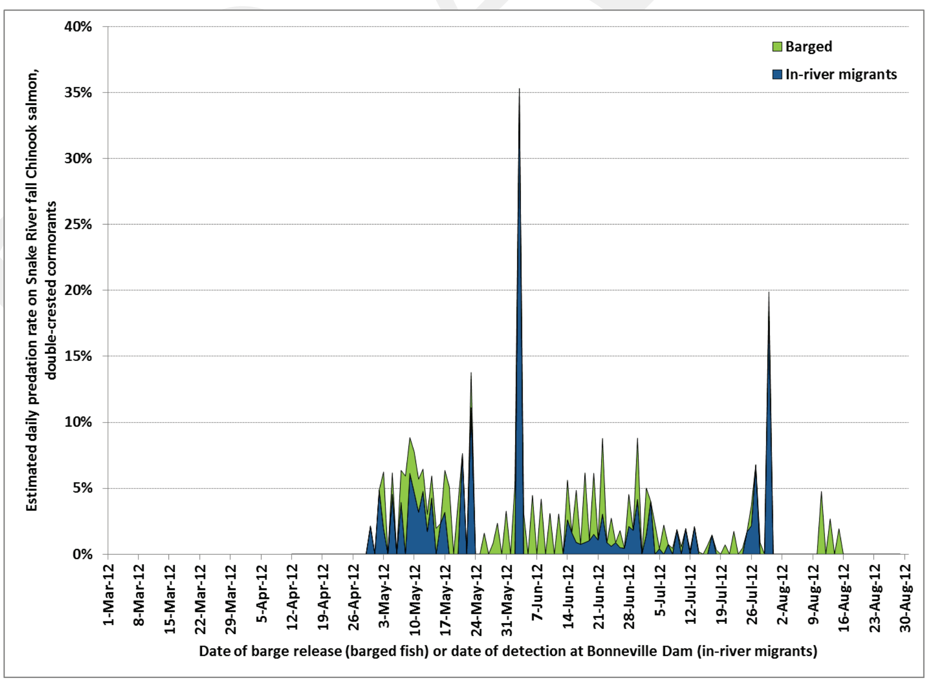

Figure 17. Estimated daily predation by double-crested cormorants on transported vs. in-river migrant Snake River fall Chinook, migration year 2012. Anomalously in-river high predation rates on 3 June and 30 July resulted from recovery of a single tag code on a day with <10 detections at Bonneville Dam.

CONCLUSIONS AND RECOMMENDATIONS

We successfully accomplished the PIT-tag deployment, tag-code recovery, and data analysis objectives for this study year. During May and June 2012, we PIT-tagged Lower Columbia River 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 (6,394 m^{-2}, 1.58 acres), we recorded 15,298 unique codes from Pacific salmon tagged for the 2012 migration year. With hand-held detectors, we recorded 13,829 unique codes from the 15,782 m^{-2} (3.9 acre) double-crested cormorant colony. These recoveries included tag codes from all 13 ESA-listed ESUs or DPSs in the Columbia River Basin. Recovery of tag codes from East Sand Island is required for calculations of estuary avian predation rates on all listed groups of PIT-tagged salmon and steelhead in the Columbia River Basin.

To measure detection efficiency of our recovery efforts, Bird Research Northwest sowed 200 control tags across both the tern and cormorant colonies; half were sown immediately before the nesting season and half immediately after the nesting season finished but before tag-code recovery efforts began. We recovered 77% of control tag codes from the tern colony and 74% from the double-crested cormorant colony. These detection efficiency rates were similar to those achieved during 2011 and were within the range of those estimated in 2002-2011 (Caspian tern colonies: 64-95%; double-crested cormorant colonies: 35-76%; 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.

Our PIT-tag code recoveries in 2012 supported experiments by staff of Bird Research Northwest, 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, with 56% presumably deposited elsewhere. We used these deposition data to adjust detections numbers used to calculate predation rates for ESA-listed groups originating above Bonneville (on the Columbia River) or Sullivan Dam (on the Willamette River).

Sample sizes of fish detected at terminal dams were sufficient to estimate 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, with predation rates of less than 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 Chinook salmon ESUs (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 differences in juvenile migration timing among salmon and steelhead ESU/DPSs, there are likely to be differences among these groups in estuary migration routes and migration behavior as well.

Due to the complex life history and lack of a representative tagging program for of Lower Columbia River Chinook salmon, predation rates on PIT-tagged groups from this ESU were calculated and presented separately from groups whose populations originate exclusively above 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 predation impacts on groups of Lower Columbia River Chinook salmon tagged for purposes other than evaluating avian predation impacts on this ESU as a whole.

During 2012, 52 separate sources contributed to a total of 122,544 PIT-tagged Lower Columbia River Chinook salmon. 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 avian species (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%).

We found a similar qualitative pattern when we examined impacts of avian predator species on groups of Lower Columbia River Chinook salmon that we tagged and released below Bonneville Dam. Mixed species/Brandt's cormorants showed the least impact (0.08%), Caspian terns had a moderate impact (2.56%), and double-crested cormorants had the largest impact (14.9%) on these groups. It was not possible to make direct comparisons between our estimates of predation and those reported for 2011 (Sebring et al. 2012) due to methodological differences. However, the rates estimated by Sebring et al. (2012) for spring and fall Chinook salmon showed qualitative trends similar to those estimated by us, with Brandt's cormorants having the least impact (0.0-3.0%), Caspian terns having a moderate impact (0.2-2.2%), and double-crested cormorants having the greatest impact (0.1-11.0%).

Although comparisons of weekly predation rates did not detect significant differences between barged and in-river migrant Snake River fall Chinook salmon, comparisons of annual and paired daily predation rates showed that predation impacts by double-crested cormorants were 2.5-2.8 times higher for transported than for in-river migrant fish. This difference was statistically significant in the paired daily comparisons. Cormorant annual impacts on barged fish were also higher, 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 transported and in-river migrant fish, indicating these species likely have a negligible effect on mortality of stocks from this ESU, regardless of migration history.

For Snake River fall Chinook salmon in-river migrants, our estimated annual predation rates by Caspian terns, double-crested cormorants, and mixed species (including Brandt's cormorants) were virtually identical to rates reported by Roby et al. (2013) in their estimates of "deposited" tags, which were not adjusted for off-colony tag deposition rates (see Roby et al. (2013) Table 5; Caspian terns: 0.5%, double-crested cormorants: 1.3%, Brandt's cormorants: <0.1%). Notably, our analysis excluded Snake River fish that entered the river below Lower Granite Dam.

For in-river migrants, mean daily predation rates used for paired comparisons between Caspian terns (0.54%) and double-crested cormorants (2.71%) were similar to the annual deposited rates reported by Roby et al. (2013). Although different methods were used to estimate predation on barge-transported vs. in-river migrant fall Chinook salmon migrating in 2011 (Sebring et al. 2012), all fall Chinook salmon in the Snake River are members of the Snake River ESU. For PIT-tagged fish from this ESU, Sebring et al. reported respective predation rates for transported vs. in-river migrant fish of 0.6 vs. 0.5% for Caspian terns, 1.0 vs. 1.9% for double-crested cormorants, and 0.0 vs. < 0.1% for Brandt's cormorants; these rates were similar to those we estimated for 2012.

Our results suggest that barging was not necessarily an effective tool for decreasing estuary avian predation on Snake River fall Chinook salmon in 2012, 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 dates on which these events occurred. If in fact a majority of PIT-tagged Snake River fall Chinook salmon is not being detected at terminal dams, then we may be missing important information on avian impacts to this ESU 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.

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 listed groups. 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 temperature, salinity, flow, and turbidity.
2. Physiological condition of individual fish
3. Biological conditions during estuary entry residence, such as
    a. Distribution/abundance of prey resources for juvenile salmon
    b. Distribution/abundance of other juvenile salmon/steelhead with regard to direct or indirect density effects and 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, including date of arrival, dates of residence, and travel time
5. Migratory pathways/habitat use
6. Time and locations of highest avian foraging activity

A variety of established research tools exist for addressing mechanistic questions of predation in the Columbia River estuary. These include telemetry tagging of both fish and birds, net sampling of salmon and forage fish, and hydroacoustic mapping of forage fish distributions. In some cases ocean circulation models and regional bathymetric databases may also be useful and are available to the research community (e.g., web-based data resources of CMOP 2014). We recommend a workshop to prioritize research questions and identify sources of funding to address mechanistic questions 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 mechanisms driving variation in avian predation rates, efforts to research, monitor, and manage estuary avian predation impacts would benefit from the following specific actions:

1. Recovery of PIT-tag codes from the East Sand Island cormorant colony could be completed earlier, and detection efficiency improved, if additional field personnel (n = 5) were available during the first few weeks of fieldwork. This would allow two full detection passes on the cormorant colony before the first heavy weather begins to wash tags off the colony.
2. If estimates of off-colony deposition of PIT tags are going to be continued, then they should be standardized throughout the Columbia River Basin so that colony detection numbers can be adjusted for greater accuracy and comparability of estimated predation rates.
3. It is clear that Lower Columbia River Chinook salmon are especially vulnerable to predation by double-crested cormorants; however, cumulative avian predation impacts on this ESU remain poorly understood. We recommend a well-designed PIT-tagging program to provide proportional representation of the diverse population origins (above/below dam facilities) and life history types (spring/fall migrants, hatchery/wild rear types) within this ESU.

   Such a program should be coupled with surveys or telemetry work to characterize cormorant foraging areas if accurate estimates of avian predation impacts on this ESU are to be obtained.
4. During 2012, a significant number of PIT-tagged, in-river migrant Snake River fall Chinook salmon (n = 1,891) passed Bonneville Dam undetected, entered the estuary, and were taken by East Sand Island birds. Detections indicating estuary entry are needed for fish from this ESU (and others) for accurate assessment of avian predation impacts and robust comparisons of transported and in-river life histories.

   These detections could be obtained by either improving detection capability at or below Bonneville Dam or by increasing efforts to tag in-river migrants.
5. In general, the specific times and locations of most intensive avian foraging activity and the availability of alternative prey 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.
6. At present, there is no established method to measure the timing of a predation event or deposition on a colony for individual tag codes. Finding methods to address this data gap would allow direct comparison of estuary entry timing with the timing of mortality events.

ACKNOWLEDGEMENTS

This work would not have been possible without a diverse support system. We thank the Cynthia Studebaker, our Contract Technical Representative, and the U.S. Army Corps of Engineers Portland District for providing the financial support necessary to complete this work. Dave Trachtenbarg assisted with the transfer of this project from the U.S. Army Corps of Engineers Walla Walla District to the Portland District. For assistance and training on unexpectedly short notice during the 2012 transition period to new project lead and staff, we are grateful to Scott Sebring.

From NOAA Fisheries, we thank former Project Lead Richard Ledgerwood, who provided materials required to make project transitions. NOAA Pt. Adams Station Chief Robert Emmett, Shop Manager Joel Holcomb, Brian Fite, Brian Kelly (PSMFC), and staff from the Pt. Adams Shop provided crucial support necessary to maintain, troubleshoot, and repair the tractor system, ATVs, custom electronics, and small boats required for project tasks. We also thank JoAnne Butzerin for providing valuable editorial assistance which improved the final draft of this report.

Jeremy Bender, Dayé Hix, Amy Wilson, Ethan Schniedermeyer, Adam Peck-Richardson, and Peter Loschl provided critical field assistance during tag recovery efforts on East Sand Island. We also thank Matthew Morris, Jeremy Bender, Bruce Jonasson, and Regan McNatt for their expert assistance with troubleshooting PIT-tag detection equipment during the 2012 field season. Finally, we would specifically like to thank biologists from Birds Research Northwest, especially Dan Roby and Don Lyons, for their support and productive advice and assistance throughout the project.

REFERENCES

Bottom, D. L. and K. K. Jones. 1990. Species composition, distribution, and invertebrate prey of fish assemblages in the Columbia River Estuary. Progress in Oceanography 25:243-270.

CMOP (Center for Coastal Margin Observation and Prediction). 2014. Data center. Suite of web-based interactive databases and time series. Available from www.stccmop.org/datamart (March 2014).

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

Evans, A. F., N. J. Hostetter, D. D. Roby, K. Collis, D. E. Lyons, B. P. Sandford, R. D. Ledgerwood, and S. Sebring. 2012. Systemwide evaluation of avian predation on juvenile salmonids from the Columbia River based on recoveries of passive integrated transponder tags. Transactions of the American Fisheries Society 141:975-989.

Lyons, D. E., D. D. Roby, A. F. Evans, N. J. Hostetter, and K. Collis. 2012. Benefits to Columbia River anadromous salmonids from potential reductions in predation by double-crested cormorants nesting at the East Sand Island colony in the Columbia River Estuary. Report of the Oregon State University Department of Fish and Wildlife to the U.S. Army Corps of Engineers, Portland District.

Marvin, D. P. 2012. The success of the Columbia Basin passive integrated transponder (PIT) tag information system. American Fisheries Society Symposium 76:95-134.

Neiffer, D. L. and M. A. Stamper. 2009. Fish sedation, anesthesia, analgesia, and euthanasia: considerations, methods, and types of drugs. ILAR Journal 50:343-360.

NMFS (National Marine Fisheries Service). 2008. Endangered Species Act Section 7(a)(2) Consultation—Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act. Essential Fish Habitat Consultation. Consultation on Remand for Operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Project in the Columbia Basin, and ESA Section 10(a)(1)(A) Permit for Juvenile Fish Transportation Program. Page 929 F/NWR/2005/05883. Northwest Regional Office—National Marine Fisheries Service, Portland, OR.

NMFS (National Marine Fisheries Service). 2009. FCRPS Adaptive Management Implementation Plan, 2008-2018 Federal Columbia River Power System Biological Opinion. Page 42. Northwest Regional Office—National Marine Fisheries Service, Portland, OR.

NMFS (National Marine Fisheries Service). 2010. Endangered Species Act Section 7(a)(2) Consultation Supplemental Biological Opinion—Supplemental Consultation on Remand for Operation of the Federal Columbia River Power System: 11 Bureau of Reclamation Project in the Columbia Basin, and ESA Section 10(a)(I)(A) Permit for Juvenile Fish Transportation Program. Page 246 F/NWR/2010/02096. Northwest Regional Office—National Marine Fisheries Service, Portland, OR.

NMFS (National Marine Fisheries Service). 2014. West Coast salmon & steelhead listings. Public listing website of the National Oceanic and Atmospheric Administration, NMFS West Coast Region. Available at www.westcoast.fisheries.noaa.gov/protected_species/salmon_steelhead/salmon_and_steelhead_listings/salmon_and_steelhead_listings.html (March 2014).

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. Pages 323-334 *in* N. C. Parker, A. E. Giorgi, R. C. Heidinger, D. G. J. Jester, E. D. Prince, and G. A. Winans, editors. American Fisheries Society Symposium 7: Fish-marking techniques. American Fisheries Society, Bethesda, MD.

PTAGIS (PIT Tag Information System). 2013. Columbia Basin PIT Tag Information System. Pacific States Marine Fisheries Commission, Gladstone, OR.

Roby, D. D., K. Collis, D. E. Lyons, J. Y. Adkins, Y. Suzuki, P. Loschl, T. Lawes, K. Bixler, A. Peck-Richardson, A. Patterson, S. Collar, N. Banet, K. Dickson, G. Gasper, L. Kreiinsieck, K. Atkins, L. Drizd, J. Tennyson, A. Mohoric, A. Evans, B. Cramer, M. Hawbecker, N. Hostetter, J. E. Zamon, and D. Kuligowski. 2013. Research, monitoring, and evaluation of avian predation on salmonid smolts in the Lower and Mid-Columbia River. Report of the Oregon State University Department of Fish and Wildlife and the USGS Cooperative Fish and Wildlife Unit to the U.S. Army Corps of Engineers, Walla Walla District.

Ryan, B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River basin. North American Journal of Fisheries Management 21:417-421.

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

Sebring, S. H., R. D. Ledgerwood, G. M. Murphey, B. P. Sandford, and A. Evans. 2012. Detection of passive integrated transponder (PIT) tags on piscivorous avian colonies in the Columbia River Basin, 2011. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Sebring, S. H., R. D. Ledgerwood, B. P. Sandford, and G. M. Matthews. 2009. Detection of passive integrated transponder (PIT) tags on piscivorous avian colonies in the Columbia River Basin, 2007. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Sebring, S. H., R. D. Ledgerwood, B. P. Sandford, and G. M. Matthews. 2010a. Detection of passive integrated transponder (PIT) tags on piscivorous avian colonies in the Columbia River Basin, 2009. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.

Sebring, S. H., R. D. Ledgerwood, B. P. Sanford, A. Evans, and G. M. Matthews. 2010b. Detection of passive integrated transponder (PIT) tags on piscivorous avian colonies in the Columbia River Basin, 2008. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District.