Detection of Passive Integrated Transponder (PIT) Tags on Piscivorous Avian Colonies in the Columbia River Basin, 2011

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EXECUTIVE SUMMARY

In 2011, the National Marine Fisheries Service, in collaboration with Oregon State University and Real Time Research, Inc., continued a multi-year project to recover passive integrated transponder (PIT) tags from piscivorous bird colonies in the Columbia River Basin. Recovered PIT tags had been originally implanted into juvenile Pacific salmon *Oncorhynchus* spp. throughout the basin for various studies. During 2011, collaborators recovered 274,801 unique PIT-tag codes from colonies of piscivorous waterbirds. Of these tags, 89,098 had no previous history of detection on an avian colony and 64,330 originated from fish released for migration in 2011. These latter tags were used to assess annual and temporal avian predation rates on juvenile salmonids in the Columbia River basin.

Of the 64,330 tags recovered from fish migrating in 2011, 65% were recovered from Caspian tern *Hydroprogne caspia*, double-crested cormorant *Phalacrocorax auritas* and Brandt's cormorant *Phalacrocorax penicillatus* colonies on East Sand Island in the Columbia River estuary. Other locations with substantial numbers of tags recovered were a cormorant colony on Foundation Island, tern colonies on Goose and Crescent Islands and a California gull *Larus californicus* colony, also on Crescent Island. Crescent and Foundation Islands are located in Lake Wallula, the reservoir upstream from McNary Dam, and Goose Island is located in the Potholes Reservoir, southeast of Rocky Reach Dam. PIT tags recovered from these three islands accounted for approximately 32% of all recoveries. Three percent of PIT tags were recovered from a gull colony on Miller Rocks Island in Lake Celilo (The Dalles Dam reservoir). Less than 2% of PIT tags were recovered from avian colonies at other locations in the Columbia River basin.

As in previous years, our analyses provide minimum estimates of predation because sampling efficiency on avian colonies was not 100% and we could not adjust estimates for tags deposited at off-colony locations. Rates of predation on PIT-tagged fish were generally highest by birds nesting on East Sand Island in the Columbia River estuary because larger numbers of terns and cormorants nested at this location. Predation rates of inriver migrating fish available to birds nesting in the Columbia River estuary were generally 3-4% for Chinook salmon and 8-12% for steelhead. In contrast, predation rates on fish available to birds nesting in Lake Wallula were generally 1-2% for Chinook salmon and 3-4% for steelhead.

In the estuary, waterbirds (primarily terns) preyed on PIT-tagged steelhead at generally higher rates than on other salmonid species. For example, the mean weekly predation rate for PIT-tagged steelhead detected passing Bonneville Dam was 11%, while that for cohorts transported and released just downstream from the dam was 8.5%. These two rates of predation were not significantly different ($P = 0.3$). In comparison, predation rates of PIT-tagged Chinook, coho, and sockeye salmon detected passing Bonneville Dam by birds (both terns and cormorants) nesting on East Sand Island were less than 4%. Predation rates of these species released from transport barges near Skamania Landing were low (<3%) and not significantly different from their inriver migrating counterparts ($P > 0.05$).

Subyearling fall Chinook salmon originating from hatcheries downstream from Bonneville Dam were among the most heavily preyed upon salmonid groups in the Columbia River basin during 2011. Mean weekly predation on these lower Columbia River (LCR) hatchery fish by birds on East Sand Island was 20.5%. This rate was significantly different (higher) than that of subyearling fall Chinook salmon detected passing Bonneville Dam (mean 4.0%; $P < 0.05$). In contrast, the mean predation rate by birds nesting on East Sand Island of PIT-tagged hatchery coho salmon released into the LCR (9.5%) was not significantly different ($P = 0.2$) in comparison to PIT-tagged coho salmon detected passing Bonneville Dam (6.6%).

CONTENTS

INTRODUCTION

Since 1987, juvenile Pacific salmon *Oncorhynchus* spp. have been tagged with passive integrated transponder (PIT) tags to evaluate measures implemented to improve their survival through the Federal Columbia River Power System. Detections of these tags have also aided in identifying the causes of decline for salmonid populations at different life history stages (NMFS 2000). The number of PIT-tagged juvenile salmonids released into the Columbia River basin varies annually, but has increased from less than 50,000 in 1987 to over 2 million by 2003 (PSMFC 2011). At the time of tagging, individual tag codes and information such as species and origin are recorded in a regional database, the PIT Tag Information System (PTAGIS) for the Columbia River Basin (PSMFC 2011). After tag codes are entered in PTAGIS, they can be matched with subsequent detection records at dams and other interrogation sites. These data can then be used to establish the migration history and often the ultimate fate of individual fish.

Since the mid-1960s, colonies of Caspian terns *Hydroprogne caspia* have shifted northward from California, and by the 1980s these colonies had begun to breed in significant numbers on small islands in the Columbia River estuary (Gill and Mewaldt 1983). By 2001, over 12,000 terns were reported along the north Pacific coast (USACE 2001). Colonies of double-crested cormorants *Phalacrocorax auritas* have also expanded rapidly in the Columbia River estuary, from initial sightings in the 1980s (Carter et al. 1995) to approximately 14,000 breeding pairs in 2007 (BRN 2010). For both the Caspian terns and double-crested cormorants, these colonies are considered to be the largest of their respective species in North America.

Large-scale efforts to detect PIT tags from juvenile salmonids deposited on avian colonies in the Columbia estuary began in 1998 (Ryan et al. 2001). One goal of these efforts was to obtain PIT-tag data with which to compare the vulnerability to predation of different salmonid species, runs or rear types, and areas of origin (Collis et al. 2001; Ryan et al. 2003). Results from this research indicated that avian piscivores breeding in the Columbia River estuary had consumed large numbers of salmonids (Collis et al. 2001; Ryan et al. 2003). These initial findings prompted management agencies to relocate the Caspian tern colony from Rice Island, located in a freshwater reach of the Columbia River estuary at river kilometer (rkm) 35, to East Sand Island, which is located in a brackish water reach at rkm 8. The relocation was intended to mitigate predation on salmonids by moving terns closer to food sources of non-salmonid, marine forage fishes (USACE 2001).

PIT-tag detection efforts continued on the estuarine avian nesting colonies and were expanded to colonies further upstream. These efforts remained focused on evaluating the relative vulnerability of salmonids to avian predation. Recovery efforts are now focused primarily on the larger avian colonies responsible for the majority of predation on juvenile salmonids in the Columbia River basin. This approach was intended to develop data for better evaluation of management alternatives for avian colonies.

In 2011, we continued this research using modified PIT-tag detection equipment (Prentice et al. 1990a,b) and techniques described by Ryan et al. (2001). Researchers from Oregon State University (OSU) and Real Time Research, Inc. (RTR) collaborated with NOAA Fisheries on PIT-tag recovery efforts (Robe et al. 2012). The recovery efforts themselves were divided among research groups stationed within different regions of the basin and the pooled detection information used for our respective analyses. Field personnel with OSU/RTR also assisted our analysis by manually spreading PIT tags over the colonies during the nesting season to measure sampling efficiency.

In this report, we summarize detection effort, methodology, and compile data to assess general vulnerabilities of juvenile salmonids to avian predators in 2011. Data obtained during this study contributed to relative analyses of smolt consumption rates by birds and contributed to a larger analysis of piscivorous colonial waterbird population dynamics, colony size, and nesting success covering the entire Columbia River basin (Roby et al. 2011). It is important to note that these analyses provide *minimum* estimates of predation: detection efficiency on avian colonies is always assumed to be less than 100%, and we have no reasonable method of accounting for the proportion of tags deposited at off-colony locations.

STUDY AREA

The study area consisted of distinct avian breeding colonies and five loafing sites on 14 islands within the Columbia River Basin (Table 1). Detection efforts began after the breeding season in summer and fall, when birds had completely vacated the various nesting colonies. Locations of avian colonies ranged from East Sand Island at rkm 8 in the Columbia River estuary, to Potholes Reservoir, located approximately 40 km east of the upper Columbia River and approximately 665 rkm upstream from the Pacific Ocean (Figure 1). Most detection effort was concentrated on the largest avian predator colonies on islands in the Columbia River estuary and on islands in Lake Wallula (McNary Dam reservoir) near the confluence of the Columbia and Snake Rivers.

Table 1. Location of avian breeding colonies and loafing areas sampled for PIT-tags in 2011 with distance in river kilometer (rkm) from the Pacific Ocean.

River reach	Island	Distance from Pacific Ocean (km)
Columbia River estuary		
	East Sand Island	8
	Miller Sands	38
Lake Celilo (The Dalles reservoir)		
	Miller Rocks Island	331
Lake Umatilla (John Day reservoir)		
	Central Blaylock Island	441
Lake Wallula (McNary reservoir)		
	Crescent Island	510
	Badger Island	512
	West Side Island	517
	Foundation Island	518
	Snake River Breakwater	525
	Wade Island	533
	Goose Island (Snake River)	536
	Island 20	545
Interior Columbia Plateau		
	Goose Island (Potholes Reservoir)	665*
	North Potholes	655*

* Approximate distances listed for sites not located on the Columbia River.

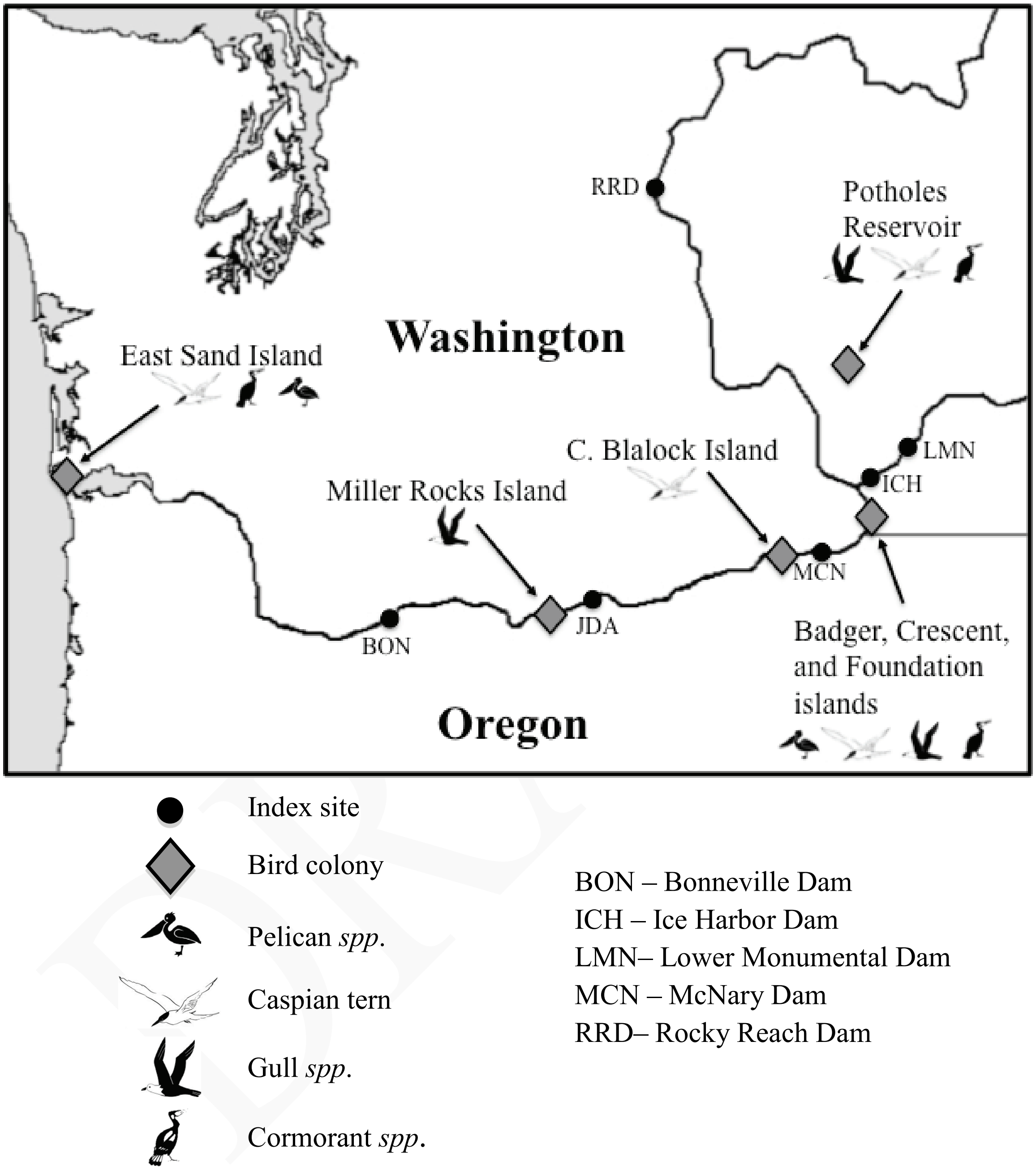

Figure 1. Location of avian colonies where post-breeding season PIT-tag recovery efforts occurred and instream detection sites used as an index of fish available within specific reaches of the Columbia River basin, 2011. Loafing areas not shown.

DATA ANALYSIS

Predation rates of Caspian terns and double-crested cormorants on juvenile salmonids are thought to vary throughout the season, with changes in the availability of alternate prey and the metabolic requirements of recently hatched young. Therefore, comparisons of predation rate were generally limited to groups of fish that had entered a given reach during the same week. For example, we compared predation rates between fish we released into the lower Columbia River downstream of Bonneville Dam with those of fish detected at Bonneville Dam or released from transport barges downstream of the dam on the same dates.

Comparisons between various groups of fish (by hatchery, origin, or migration history) were made using a two-tailed *t*-test ($\alpha < 0.05$). To obtain sufficient sample sizes for analyses of temporal predation, we pooled hatchery and wild fish by species or run type on a weekly basis. Temporal predation was evaluated only during weeks for which there was a minimum number of fish (N = 100) detected in each comparison group (Ryan et al. 2003). We displayed seasonal mean predation rates, weighted by week, for all fish groups fulfilling the minimum 100 fish detection criteria at specific upstream "virtual release" sites (Skalski et al. 2010). Virtual release sites were the nearest detection site upstream from an avian colony, typically a juvenile bypass system at a hydroelectric facility. This methodology allowed us to pool weekly numbers of fish available for consumption by avian predators into comparable groups.

Due to abnormally high flow and debris in 2011, the juvenile bypass detection facilities at Bonneville Dam recorded only about 60,000 PIT-tagged fish, in comparison to over 207,000 fish detected during the previous year. Therefore, for analyses of predation on fish originating upstream from Bonneville Dam, we combined PIT-tagged fish detected at the dam with those detected in the estuary pair-trawl detection system. The pair trawl was operated between rkm 61 and 83 and detected 14,123 fish in 2011 (Morris et al. 2012). We assumed that PIT-tagged fish originating upstream of either location were equally vulnerable to avian predators nesting on East Sand Island.

To evaluate the vulnerability of coho salmon and subyearling fall Chinook salmon stocks originating in the lower Columbia River, we also PIT-tagged and released fish from hatcheries downstream from Bonneville Dam. We compared weekly predation rates of lower river fish to those of fish originating upstream from Bonneville Dam. In addition, we compared vulnerability of subyearling fall Chinook salmon stocks (tule and upriver bright) because we noted differences in predation rates between these stocks during previous years (Sebring et al. 2009; 2010a,b).

COLLECTION OF TAGS FROM AVIAN COLONIES

Detection and Recovery Efforts

Methods

In 2011, PIT-tag detection and recovery efforts were conducted jointly with researchers from Oregon State University (OSU) and Real Time Research (RTR). Personnel with NOAA Fisheries detected tags on East Sand Island and provided a tractor-towed, flat-plate antenna system to assist OSU and RTR in recovery of tags on Crescent Island. Researchers from OSU and RTR recovered PIT tags from avian colonies in the mid- and upper Columbia River primarily by using handheld detectors, although magnetized rakes were also used to reduce tag density on the Crescent Island Caspian tern colony. Researchers from OSU and RTR also recovered PIT tags from a small breeding colony of American white pelicans nesting on Miller Sands Island in the Columbia River estuary and from a Brown pelican roosting site on East Sand Island.

PIT-tag recovery efforts occurred primarily on avian colonies where large numbers of tags had been recovered during previous years (i.e., Crescent Island, Goose Island, Foundation Island, and East Sand Island; Ryan et al. 2003, 2006, 2007). Also sampled were smaller avian colonies (i.e., Miller Sands Island, North Potholes, and Island 20) where PIT-tag recovery efforts during previous years had been sporadic because nesting at these locations is often ephemeral (Sebring et al. 2009, 2010a,b). Finally, some PIT tags were recovered from observed loafing areas and other minor non-colony sites in 2011 (Roby et. al 2012).

We used two primary methods to electronically recover PIT tags from avian breeding colonies: 1) hand-held antennas passed back and forth over the colony and 2) a flat-plate antenna, which was dragged over the colony using a motorized vehicle (Ryan et al. 2001). The flat-plate antenna system was used on Crescent Island (tern and gull colonies) and East Sand Island (tern, and to a limited extent, cormorant colony) because these areas generally had level terrain that posed few obstructions to motorized vehicles.

During 2011, we also constructed a more light-weight detection system mounted on an all-terrain vehicle (ATV) that was maneuverable enough to tow a flat-plate antenna on portions of the East Sand Island cormorant colony where the tractor system could not be used. The ATV had an automatic transmission capable of very slow speeds, which allowed us to use the flat-plate antenna system on flat, non-riprap portions of this colony. We supplemented the ATV method by sweeping with hand-held antennas on nesting areas that were inaccessible to the ATV to assure full coverage of the entire cormorant colony.

On Crescent Island, the tern colony was located in an area of compact soil substrate and high PIT tag density, unlike the conditions encountered on other colonies. These conditions increased the likelihood of tag-code collision and presented the potential for destruction of PIT tags from heavy vehicles towing flat-plate antennas. Tag-code collision occurs when two or more PIT tags are present in the detection field simultaneously; interference between tag-codes is produced, which results in neither code being correctly recorded (Brännäs et al. 1994). Therefore, we used magnetized rakes to physically remove PIT tags and decrease tag density before scanning with the flat-plate antenna system. Data from PIT-tags physically removed using magnetized rakes were later decoded using hand-held scanners identical to those used for in-situ detection.

Regardless of which recovery technique was used on a colony, we made at least two individual passes to improve coverage. With the towed flat-plate antenna, we were able to make several systematic passes in different directions over the entire colony surface. This method varied the orientation of the antenna to the tags, and thus improved the likelihood that PIT tags would be at the optimal angle for detection. The number of passes used on each colony was judged in part by the number of additional unique tag codes recovered with each subsequent pass. Depending on weather conditions and the cost per pass, we generally ceased running passes when less than 10% of the tags recovered on a pass were new.

Results

Using physical and electronic recovery techniques, we recorded 274,801 PIT-tag codes during 2011 (Appendix Table 1). However, PIT tags are decoded in-situ on avian colonies, and physically removed only from the Crescent Island tern colony. Therefore, many PIT tags are re-detected during subsequent years. Of those recorded in 2011, 89,098 had no previous detection history on an avian breeding colony (Appendix Table 2) and 64,330 of those were from fish released for migration in 2011 (Table 2). Only PIT-tag codes from fish migrating during 2011 were used for analyses. These analyses provided *minimum* estimates of predation because sampling efficiency on avian colonies was not 100% and we could not accurately estimate numbers of tags deposited at off-colony locations.

Table 2. Number of PIT-tag codes recovered from salmonids released for migration in 2011 and the proportion recovered on each avian colony and loafing site.

	White pelican	Brown pelican	Caspian tern	Double crested cormorant	Brandt's cormorant	Gull species	Mixed avian Species	Total N	Total (%)
Columbia estuary									
East Sand Island		1	18,076	21,650	429			40,156	62.4
Miller Sands	15							15	<0.1
Lake Celilo (The Dalles Dam reservoir)									
Miller Rocks Island						1,676	34	1,710	2.7
Lake Umatilla (John Day Dam reservoir)									
Central Blalock Islands			292					292	0.5
Lake Wallula (McNary Dam reservoir)									
Badger Island	2,450						670	3,120	4.8
Crescent Island			8,921			1,939	258	11,118	17.3
West Side Island (across channel from Foundation Island)							5	5	<0.1
Foundation Island				4,294			70	4,364	6.8
Snake River Breakwater							3	3	<0.1
Wade Island (Near Blue Bridge in Kennewick)							11	11	<0.1
Goose Island (Snake River, near Ice Harbor Dam)							3	3	<0.1
Island 20 (Richland)							5	5	<0.1
Interior Columbia Plateau									
Goose Island (Potholes Reservoir)			3,433				57	3,490	5.4
North Potholes				38				38	<0.1
Total (N)	2,465	1	30,722	25,982	429	3,615	1,116	64,330	
Percent (%)	3.8	<0.1	47.8	40.4	0.7	5.6	1.7		

Detection Efficiency

Methods

As in previous years, OSU and RTR researchers sowed "control" PIT tags of known identification on avian colonies throughout the breeding season. Multiple groups of control tags were sown on large colonies where seasonal changes in deposition of PIT tags had been noted during previous years. Within-season sowing of control tags was possible only in areas where sowing could be accomplished without disturbing nesting activity of the birds. These locations included tern colonies on Crescent Island, East Sand Island, and Goose Island (Sebring 2010a,b). Seasonal changes in PIT-tag deposition rate could potentially bias calculations of predation rates. However, mid-season releases of control tags were limited to tern colonies because this species tolerate minor levels of human disturbance without abandoning nests and creating opportunities for other bird species to depredate eggs or nestlings.

Caspian terns nested within a single colony with well-defined boundaries at most locations. Control tags were randomly sown on tern colonies a maximum of four times per year, including one release before and one after the nesting season. Based on visual inspection of the data, for each colony where mid-season sowing of control tags was possible, we used linear regression models to interpolate weekly changes in detection efficiencies. These linear regression models allowed us to adjust predation rates throughout the migration season.

On cormorant colonies, only pre- and post-season sowings of control tags was possible. We calculated detection efficiency on these colonies by dividing the total number of control tags detected by the total number originally sown. Post-season sowing of control tags was done after birds had vacated the colonies and just prior to our electronic recovery efforts. Data from post-season sowing was used to adjust weekly values for predation rates on tern colonies where our linear projections exceed this maximum.

Results

Mean detection efficiency estimates on all avian colonies ranged 40-80% (Table 3). In general, these efficiencies were similar to those measured during recent years (Ryan et al. 2007; Roby et al. 2011). We found a significant relationship between the percentage of control tags detected and the date PIT tags were sown on the Crescent Island and Goose Island tern colonies (Figure 2). This relationship was used to interpolate values to adjust predation rates throughout the migration season for these colonies. There was no temporal effect on detection of control-tag release groups planted on the East Sand Island tern colony. Therefore, we used the mean detection efficiency of control tags (77%) to adjust predation rates for this colony.

On Goose Island, Caspian terns nested in two distinct sub-colonies separated by vegetation during 2011. The majority of terns, 366 breeding pairs, nested on the western side of the island, and only 56 breeding pairs nested on the eastern side (Peter Loschl, Oregon State Univ., personal communication, March 2012). Pre- and post-season control tags were sown at both locations to evaluate detection efficiency, but mid-season tags were sown only on the larger western sub-colony. We used results of the linear regression model to adjust predation rates for the west sub-colony but not for the eastern sub-colony.

Table 3. Number of control PIT tags planted and number detected on colonies of various avian species throughout the Columbia River basin during 2011. Recoveries sites and avian colonies are listed in ascending order of distance from the Pacific Ocean.

		Control tags			
Recovery site	Avian colony	Release intervals (N)	Detected (N)	Sown (N)	Detection efficiency (%)
Columbia River Estuary					
East Sand Island	Brandt's cormorant	2	67	100	67
	Caspian tern	3	232	300	77
	Double-crested cormorant	2	287	400	72
Lake Celilo (The Dalles reservoir)					
Miller Rocks Island	Gull	2	79	200	79
Lake Umatilla (John Day reservoir)					
Central Blaylock Island	Caspian tern	2	82		82
Lake Wallula (McNary reservoir)					
Badger Island	American white pelican	2	37	50	74
Crescent Island	Caspian tern	4	159	200	80
	California gull	2	68	100	68
Foundation Island	Double-crested cormorant	2	107	200	54
Columbia Plateau					
Goose Island (east)	Caspian tern	2	74	100	74
Goose Island (west)	Caspian tern	4	238	400	60
North Potholes	Double-crested cormorant	2	79	200	40

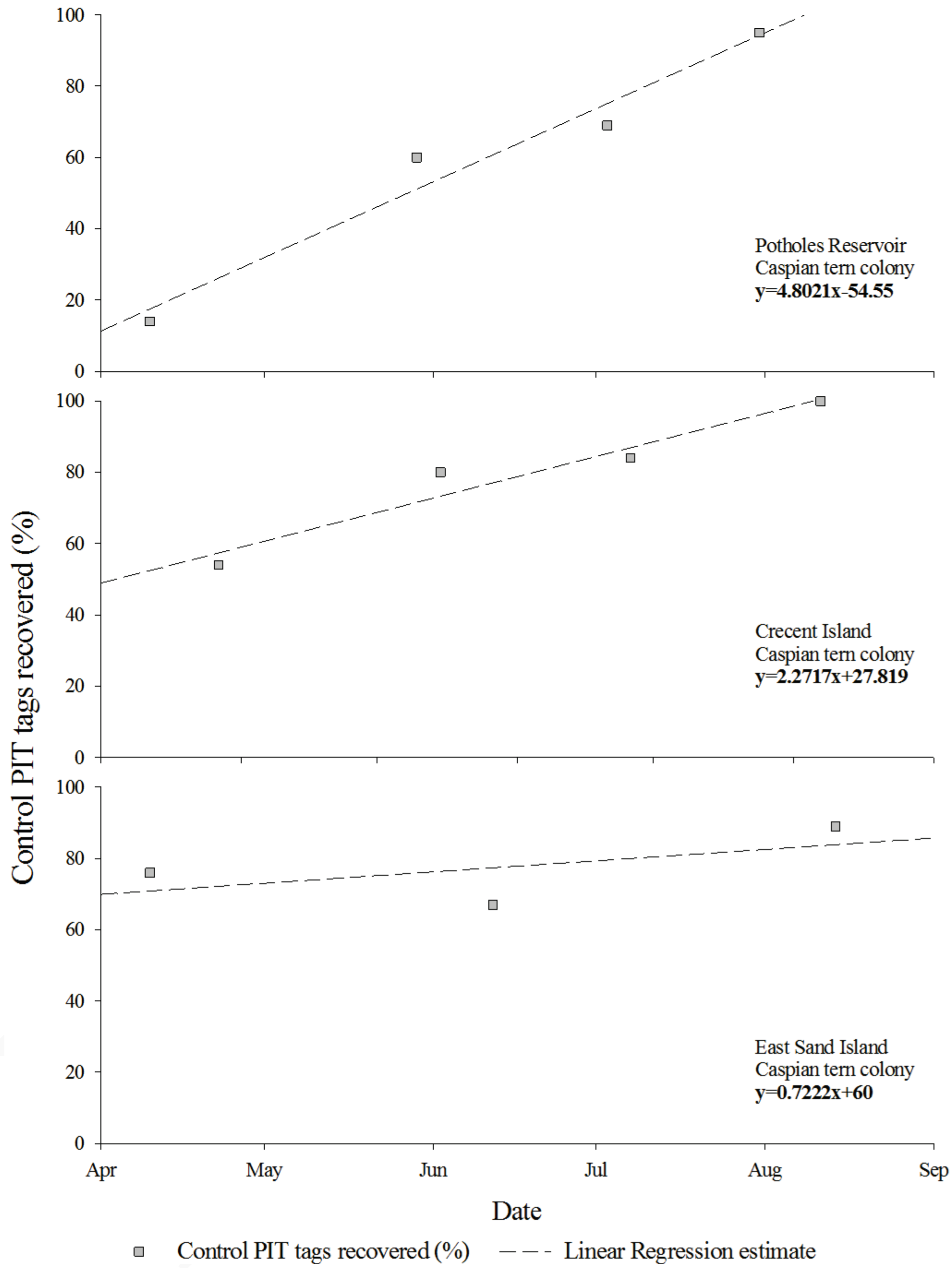

Figure 2. Detection rates of control PIT tags from pre-season, mid-season, and post-season release groups on Goose (west sub-colony), Crescent, and East Sand Island tern colonies. Linear regression was used to interpolate change in detection efficiencies over the migration season.

ESTIMATES OF PREDATION

Indices of Annual Predation

Methods

Most PIT-tagged fish are released far upstream from avian colonies in the Mid- or Lower Columbia River and estuary; considerable mortality can occur between the point of release and the point at which fish come within range of foraging avian predators. For this reason, we pooled fish into virtual release groups comprised of fish detected in close proximity of avian colonies. As previously described, the numbers of PIT-tagged fish (by species, run, and origin) detected at juvenile bypass systems were used as an index of those fish vulnerable to birds nesting within a given river reach.

Detection information was downloaded from PTAGIS in weekly groups from the nearest interrogation site to an avian colony (i.e., juvenile bypass system at a hydropower facility). Fish detected at one of these interrogation sites and subsequently detected on a colony were used to calculate weekly predation rates for the groups of interest, and estimates of annual predation rate were the means of weekly rates for each group, adjusted for detection efficiency.

Relative vulnerability to avian predators was compared by species and run-type for each avian colony using the indices of fish availability. Because these indices were based upon fish assumed to be vulnerable to predation within a given river reach, they were also used for interannual comparisons of avian predation (Evans et al. in review). Comparing predation rates by birds nesting within Lake Wallula between fish originating from the upper Columbia River and Snake River may introduce bias because of different survival rates from the respective index sites to the point where fish are within the foraging range of birds. Therefore, we did not compare predation rates by birds nesting in Lake Wallula between upper Columbia River and Snake River fish.

We identified four areas that contained avian colonies to generate reach-specific indices of predation. These areas were: 1) Potholes Reservoir, 2) Lake Wallula, 3) Lake Celilo and Lake Umatilla, and 4) the Columbia River estuary (Figure 1). We used detections of fish at Rocky Reach Dam (rkm 763) as an index of those originating from the upper Columbia River basin to avian predators nesting in Potholes Reservoir and Lake Wallula because this site was the closest site with instream PIT tag detection capability.

We generally used only detections of fish at a single virtual location to enumerate fish available to bird nesting within a given reach. Generally, we used detections at the closest upstream location to form weekly virtual releases. However, sample sizes at some virtual release locations were limited; thus we combined detections with a second site further upstream to form virtual releases. We used combined detections of fish at Ice Harbor and Lower Monumental Dam (rkm 589) as an index of Snake River fish available to avian predators nesting in Lake Wallula. We also used the combined detections of fish at John Day (rkm 347) and McNary Dam (rkm 470) as an index of those available to predation by gulls nesting on Miller Rocks Island.

There was no comparable instream site capable of detecting large numbers of all fish released into the lower river downstream from Bonneville Dam. Therefore, we used the total numbers of PIT-tagged fish released from hatcheries as an index of those available to predation by birds nesting on East Sand Island. Predation rates for lower river fish were the only estimates not derived from detections in a juvenile bypass system. We used numbers of fish detected at Bonneville Dam or fish detected in the estuary pair-trawl (Morris et al. 2012) to estimate predation rates of fish entering into the Columbia River estuary. Fish originating from the Willamette River, using detections at the Sullivan Plant (rkm 206) were insufficient to estimate an annual predation rate in 2011.

Results

***Potholes Reservoir*—**For Caspian terns nesting on Goose Island, mean annual predation on spring and summer Chinook salmon detected at the Rocky Reach Dam was less than 2% (Table 4). Mean annual predation rates were higher for coho (2.5%) than for Chinook salmon and even higher for hatchery steelhead (9.7%). Mean annual predation rate for wild steelhead was 3.8%. As in previous years, predation rates by birds nesting on Goose Island on upper Columbia River steelhead were higher than for other species originating from this river reach. We did not present predation rates for the double-crested cormorant colony nesting in the Potholes Reservoir because we were unable to survey the entire colony.

Table 4. Numbers of tags recovered from the Caspian tern colonies on Goose Island and estimated seasonal mean predation rates on in-river migrating PIT-tagged salmonids migrating during 2011. Data are adjusted using the weekly colony-specific detection efficiency (DE) measurements (see Figure 2) and presented only for groups (by species, run, rear type, and origin) with at least 100 detections at the Rocky Reach Dam index site.

Goose Island Caspian tern colony					
		PIT tag detections (N)			Estimated
Upper Columbia species/run	Rear type	On colony	Adjusted	At index site	predation rate (%)
Spring Chinook salmon	Hatchery	32	84	6,028	1.4
	Wild				
	Unknown				
Summer Chinook salmon	Hatchery	38	96	7,733	1.1
	Wild	1	11	721	<0.1
	Unknown				
Coho salmon	Hatchery	71	140	7,697	2.5
	Wild				
	Unknown				
Steelhead	Hatchery	414	1,003	12,003	9.7
	Wild	15	37	872	3.8
	Unknown	431	1,045	12,970	9.3

Lake Wallula (McNary Dam Reservoir)—Mean weekly predation rates for birds nesting in Lake Wallula were estimated for colonies of terns and gulls on Crescent Island, cormorants on Foundation Island, and pelicans on Badger Island. Mean weekly predation rates by all avian species nesting within Lake Wallula were generally 2% or less (Tables 5-8). For double-crested cormorants, mean weekly predation rates on most salmonid species- rarely exceeded 2% of available fish, whereas mean weekly predation rates of American white pelicans and California gulls were generally less than 0.5%. In Lake Wallula, Caspian terns nesting on Crescent Island had the greatest impact on steelhead (Table 6) and consumed other fish species in proportions similar to those of Foundation Island cormorants.

Table 5. Numbers of PIT tags recovered from the double-crested cormorant colony on Foundation Island and estimated seasonal mean predation rates on in-river PIT-tagged salmonids migrating in 2011. Data are adjusted for detection efficiency (DE) (54%) and presented only for groups (by species, run, rear type, and origin) with at least 100 detections at Rocky Reach Dam or at Ice Harbor and Lower Monumental Dam index sites.

	Foundation Island double-crested cormorant colony			
Species/origin/run type	Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Estimated mean weekly predation (%)
	Upper Columbia River stocks			
Chinook salmon				
Hatchery spring	3	6	6,028	<0.1
Hatchery summer	3	6	7,733	<0.1
Wild summer	0	0	995	0.0
Coho, hatchery	4	7	7,697	0.7
Steelhead				
Hatchery	7	13	12,003	<0.1
Wild	0	0	872	0.0
	Snake River stocks			
Chinook salmon				
Hatchery spring	150	278	53,965	0.7
Wild spring	31	57	11,686	0.6
Hatchery summer	47	87	16,793	0.7
Wild summer	10	19	7,028	0.4
Hatchery fall	484	896	89,082	0.5
Hatchery unknown run	65	120	18,012	0.7
Wild unknown run	23	43	11,417	0.3
Unknown origin/unkn run	0	0	356	0.0
Coho, hatchery	3	6	568	1.2
Steelhead				
Hatchery	602	1,115	68,541	2.0
Wild	121	224	15,981	1.7
Sockeye, hatchery	78	144	18,050	4.5

Table 6. Number of tags recovered from the Crescent Island Caspian tern colony and estimated seasonal mean predation rates on in-river migrating PIT-tagged salmonids from the 2011 migration year. Data are adjusted for detection efficiency (DE) (see Figure 2) and presented only for groups (by species, run, rear type, and origin) with at least 100 detections at Rocky Reach or Ice Harbor/Lower Monumental Dam index sites.

	Crescent Island Caspian tern colony			
Species/origin/run type	Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Estimated mean weekly predation (%)
	Upper Columbia River stocks			
Chinook salmon				
Hatchery spring	9	14	6,207	0.7
Hatchery summer	4	5	7,733	0.3
Wild summer	0	0	995	0.0
Coho, hatchery	55	72	7,697	1.0
Steelhead				
Hatchery	94	128	12,003	1.6
Wild	1	1	872	0.5
	Snake River stocks			
Chinook salmon				
Hatchery spring	169	231	53,965	0.5
Wild spring	37	79	11,686	0.8
Hatchery summer	65	87	16,793	0.7
Wild summer	11	15	7,028	0.5
Hatchery fall	320	390	89,082	0.5
Hatchery unknown run	48	66	18,012	0.5
Wild unknown run	50	70	11,417	0.7
Unknown origin/unkn. run	4	7	356	1.2
Coho, hatchery	3	4	568	1.5
Steelhead				
Hatchery	915	1,229	68,541	3.5
Wild	271	344	15,981	2.9
Sockeye, hatchery	85	108	18,050	0.6

Table 7. Numbers of tags recovered on the Crescent Island California gull colony and estimated seasonal mean predation rates on PIT-tagged salmonids migrating in 2011. Data are adjusted for detection efficiency (DE) (68%) and presented only for groups (by species, run, rear type, and origin) with at least 100 detections at Rocky Reach or Ice Harbor and Lower Monumental Dams index sites.

	Crescent Island California gull colony			
Species/origin/run type	Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Estimated mean weekly predation (%)
	Upper Columbia River stocks			
Chinook salmon				
Hatchery spring	1	1	6,207	<0.1
Hatchery summer	3	4	7,733	<0.1
Wild summer	0	0	995	0.0
Coho, hatchery	13	19	7,697	0.3
Steelhead				
Hatchery	55	81	12,003	0.5
Wild	0	0	872	0.0
	Snake River stocks			
Chinook salmon				
Hatchery spring	45	66	53,965	0.1
Wild spring	5	7	11,686	0.2
Hatchery summer	13	19	16,793	0.1
Wild summer	2	3	7,028	<0.1
Hatchery fall	45	66	89,082	0.1
Hatchery unknown run	25	37	18,012	0.2
Wild unknown run	10	15	11,417	0.2
Unknown origin/unkn. run	0	0	356	0.0
Coho, hatchery	0	0	568	0.0
Steelhead				
Hatchery	241	354	68,541	0.4
Wild	25	37	15,981	0.4
Sockeye, hatchery	24	35	18,050	0.1

Table 8. Numbers of tags recovered from the American white pelican colony on Badger Island and estimated seasonal mean predation rates on PIT-tagged salmonids migrating in 2011. Data are adjusted by the mean colony-specific detection efficiency (DE) measurement (74%) and presented only for groups (by species, run, rear type, and origin) with at least 100 detections at Rocky Reach or Ice Harbor/Lower Monumental Dams.

	Badger Island American white pelican colony			
Salmon species/origin/run type	Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Estimated mean weekly predation (%)
	Upper Columbia River stocks			
Chinook				
Hatchery spring	1	1	6,207	<0.1
Hatchery summer	1	1	7,733	<0.1
Wild summer	0	0	995	0.0
Coho, hatchery	2	3	7,697	<0.0
Steelhead				
Hatchery	10	14	12,003	0.2
Wild	0	0	872	0.0
	Snake River stocks			
Chinook				
Hatchery spring	67	91	53,965	0.1
Wild spring	14	19	11,686	0.1
Hatchery summer	31	42	16,793	0.1
Wild summer		5	7,028	0.1
Hatchery fall	52	70	89,082	0.1
Hatchery unknown run	33	45	18,012	0.2
Wild unknown run	7	9	11,417	0.1
Unknown origin/Unkn run	0	0	356	0.0
Coho, hatchery	0	0	568	0.0
Steelhead				
Hatchery	140	189	68,541	0.2
Wild	28	38	15,981	0.3
Sockeye, hatchery	34	46	18,050	<0.1

***Lake Umatilla (The John Day Dam reservoir)*—**For Caspian terns nesting within Lake Umatilla on Central Blalock Island, predation rates on available juvenile salmonids were generally 0.1% or less (Table 9). However, we noted that predation rates on fall Chinook salmon (mean 1.1%) were higher than those on other salmonid species.

***Lake Celilo (The Dalles Dam reservoir)*—**Gulls nesting in the Lake Celilo also consumed a negligible proportion of available juvenile salmonids in comparison to other avian colonies in the Columbia River basin. Predation by the gull colony on Miller Rocks Island was less than 0.5% for all salmon species (Table 10). Miller Rocks gulls did not appear to prefer salmonids of any particular origin, but preyed upon steelhead somewhat more frequently than other salmonids.

***Columbia River estuary*—**Annual predation rates in the estuary were estimated for fish originating upstream of Bonneville Dam as well as for those released from lower Columbia River hatcheries. Predation rates by Caspian terns and double-crested cormorants nesting on East Sand Island were generally greater than those of avian predators elsewhere in the basin for all salmon species (Tables 11-13). In most cases, predation rates by birds nesting on East Sand Island were similar within a particular fish species, regardless of origin or rearing type. For example, Caspian terns generally consumed between 4-8% of available steelhead, regardless of origin or rearing type. Double-crested cormorants generally consumed 3-5% of available steelhead regardless of origin or rearing type. Predation by Brandt's cormorants was generally low, with most predation rates 0.5% or less on all species of salmonids.

Table 9. Numbers of tags recovered from tern colonies on Central Blalock Island and estimated seasonal mean predation rates of PIT-tagged salmonids migrating in 2011. Colony detection numbers were adjusted for detection efficiency (82%) and calculated only for groups with at least 100 detections per week at John Day and McNary Dam index sites.

Salmon species/origin/run type	**Central Blalock Island Caspian tern colony** Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Est mean weekly predation (%)
	Mid-Columbia River stocks			
Chinook				
Hatchery spring	0	0	6,600	0.0
Wild spring	1	1	2,916	0.2
Origin/run unknown	0	0	563	0.0
Coho, hatchery	1	1	3,383	<0.1
Steelhead				
Hatchery	1	1	1,883	<0.1
Wild	0	0	3,100	0.0
Unknown origin	0	0	799	0.0
	Upper Columbia River stocks			
Chinook				
Hatchery spring	0	0	7,361	0.0
Wild spring	0	0	1,472	0.0
Hatchery summer	1	1	15,207	<0.1
Wild summer	0	0	904	0.0
Unknown origin summer	0	0	220	0.0
Hatchery fall	1	1	5,816	1.1
Wild fall	0	0	843	0.0
Coho, hatchery	6	7	5,282	<0.1
Steelhead				
Hatchery	2	2	14,638	<0.1
Wild	0	0	1,194	0.0
Unknown origin	0	0	278	0.0
Sockeye				
Hatchery	0	0	836	0.0
Unknown origin	0	0	472	0.0
	Snake River stocks			
Chinook				
Hatchery spring	10	12	41,839	<0.1
Wild spring	1	1	8,168	<0.2
Hatchery summer	1	1	12,613	<0.1
Wild summer	1	1	5,446	<0.1
Hatchery fall	30	37	72,175	<0.1
Hatchery unknown run	4	5	30,076	<0.1
Wild unknown run	2	2	8,853	<0.1
Coho, hatchery	0	0	480	0.0
Steelhead				
Hatchery	8	10	41,874	<0.1
Wild	5	6	9,317	<0.1
Sockeye, hatchery	5	6	4,442	0.1

Table 10. Numbers of tags recovered from the gull colony on Miller Rocks Island and estimated seasonal mean predation rates of PIT-tagged salmonids migrating in 2011. Colony detection numbers were adjusted for detection efficiency (79%) and calculated only for groups with at least 100 detections per week at John Day and McNary Dam index sites.

	Miller Rocks Island gull colony			
Salmon species/origin/run type	Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Est. mean weekly predation (%)
	Mid-Columbia River stocks			
Chinook				
Hatchery spring	6	8	6,600	<0.1
Wild spring	3	4	2,916	0.1
Origin/run unknown	0	0	563	0.0
Coho, hatchery	2	3	3,383	<0.1
Steelhead				
Hatchery	4	5	1,883	0.3
Wild	1	1	3,100	<0.1
Origin unknown	2	3	779	0.4
	Upper Columbia River stocks			
Chinook				
Hatchery spring	7	9	7,361	0.1
Wild spring	0	0	1,472	0.0
Hatchery summer	20	25	15,207	0.1
Wild summer	0	0	904	0.0
Unknown origin summer	0	0	220	0.0
Hatchery fall	11	14	5,816	0.3
Wild fall	0	0	843	0.0
Coho, hatchery	12	15	5,282	0.2
Steelhead				
Hatchery	37	47	14,683	0.5
Wild	0	0	1,194	0.0
Unknown origin	0	0	278	0.0
Sockeye				
Hatchery	0	0	836	0.0
Unknown origin	2	3	472	0.5
	Snake River stocks			
Chinook				
Hatchery spring	38	48	41,839	<0.1
Wild spring	8	10	8,168	0.1
Hatchery summer	16	20	12,613	0.2
Wild summer	1	1	5,446	<0.1
Hatchery fall	49	62	72,175	<0.1
Hatchery unknown run	31	39	30,076	0.1
Wild unknown run	7	9	8,853	<0.1
Coho, hatchery	1	1	480	0.2
Steelhead				
Hatchery	131	166	41,874	0.4
Wild	26	33	9,317	0.3
Sockeye, hatchery	7	9	4,442	0.2

Table 11. Numbers of tags recovered from the Caspian tern colony on East Sand Island with seasonal mean predation rates of PIT-tagged salmonids migrating in 2011. Data shown are adjusted for colony-specific detection efficiency (DE) (77%) by species and origin (hatchery, wild, unknown) for groups with at least 100 fish released per week from LCR hatcheries or detected at the lower Columbia River index sites.

Salmon species/origin/run type	East Sand Island Caspian tern colony: Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Est mean weekly predation (%)
	Lower Columbia River stocks			
Chinook				
Hatchery spring	347	451	56,901	0.8
Wild spring	6	8	4,834	0.2
Hatchery fall	316	410	51,492	1.1
Wild, unknown run	5	6	2,807	0.2
Origin and run unknown	1	1	3,124	<0.1
Coho, hatchery	31	40	5,694	0.7
Steelhead				
Hatchery	169	219	5,448	6.9
Wild	50	65	1,451	4.7
Origin unknown	28	36	1,474	4.3
	Mid-Columbia River stocks			
Chinook				
Hatchery spring	24	31	2,258	1.3
Wild spring	0	0	141	0.0
Origin and run unknown	2	3	258	<0.1
Steelhead				
Wild	5	6	372	1.7
Origin unknown	10	13	113	11.5
	Upper Columbia River stocks			
Chinook				
Hatchery spring	5	6	458	2.2
Hatchery summer	12	16	1,012	1.3
Hatchery fall	1	1	132	1.0
Steelhead, hatchery	44	57	897	6.3
	Snake River stocks			
Chinook				
Hatchery spring	46	60	3,850	1.7
Wild spring	1	1	460	0.6
Hatchery summer	19	25	1,109	2.4
Wild summer	1	1	232	0.6
Hatchery fall	25	32	5,498	0.6
Hatchery unknown run	28	36	2,294	1.6
Wild unknown run	0	0	731	0.0
Steelhead				
Hatchery	242	314	4,151	7.7
Wild	32	42	800	4.3
Sockeye, hatchery	0	0	559	0.0

Table 12. Numbers of tags recovered from the double-crested cormorant colony located on East Sand Island with seasonal mean predation rates of PIT-tagged salmonids migrating in 2011. Data shown are adjusted for colony-specific detection efficiency (72%) by species and origin (hatchery, wild, unknown) for paired groups with at least 100 fish released per week from LCR hatcheries or detected at the lower Columbia River index sites.

	East Sand Island double-crested cormorant colony			
Salmon species/origin/run type	Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Est mean weekly predation (%)
	Lower Columbia River stocks			
Chinook				
Hatchery spring	565	785	56,901	1.4
Wild spring	3	4	4,834	0.1
Hatchery fall	3,185	4,424	51,492	11.0
Wild, unknown run	12	17	2,807	0.6
Origin and run unknown	21	29	3,124	0.7
Coho, hatchery	362	503	5,694	8.7
Steelhead				
Hatchery	97	135	5,448	2.6
Wild	25	35	1,451	2.6
Origin unknown	36	50	1,474	5.4
	Mid-Columbia River stocks			
Chinook				
Hatchery spring	17	24	2,258	1.3
Wild spring	1	1	141	1.0
Origin and run unknown	0	0	258	0.0
Steelhead				
Wild	12	17	372	5.0
Origin unknown	3	4	113	3.7
	Upper Columbia River stocks			
Chinook				
Hatchery spring	13	18	458	4.0
Hatchery summer	27	38	1,012	4.6
Hatchery fall	7	10	132	7.4
Steelhead, hatchery	51	71	897	8.1
	Snake River stocks			
Chinook				
Hatchery spring	68	94	3,850	2.4
Wild spring	5	7	460	1.4
Hatchery summer	14	19	1,109	2.1
Wild summer	0	0	232	0.0
Hatchery fall	41	57	5,498	1.0
Hatchery unknown run	28	39	2,294	1.7
Wild unknown run	26	36	731	5.3
Steelhead				
Hatchery	114	158	4,151	2.8
Wild	27	38	800	4.7
Sockeye, hatchery	12	17	559	3.3

Table 13. Numbers of tags recovered from the Brandt's cormorant colony located on East Sand Island with seasonal mean predation rates of PIT-tagged salmonids migrating in 2011. Colony detection numbers were adjusted for colony-specific detection efficiency (67%). Results by species and origin (hatchery, wild, unknown) are for paired groups with at least 100 fish released per week from LCR hatcheries or detected at LCR index sites.

	East Sand Island Brandt's cormorant colony			
Salmon species/origin/run type	Detections on colony (N)	Adjusted colony detections (N)	Detections at index site (N)	Est mean weekly predation (%)
		Lower Columbia River stocks		
Chinook				
Hatchery spring	9	13	56,901	<0.1
Wild spring	0	0	4,834	0.0
Hatchery fall	63	94	51,492	0.3
Wild, unknown run	0	0	2,807	0.0
Origin and run unknown	0	0	3,124	0.0
Coho, hatchery	3	4	5,694	<0.1
Steelhead				
Hatchery	0	0	5,448	0.0
Wild	1	1	1,451	0.5
Origin unknown	1	1	1,474	0.9
		Mid-Columbia River stocks		
Chinook				
Hatchery spring	1	1	2,258	<0.1
Wild spring	0	0	141	0.0
Origin and run unknown	0	0	258	0.0
Steelhead				
Wild	0	0	372	0.0
Origin unknown	0	0	113	0.0
		Upper Columbia River stocks		
Chinook				
Hatchery spring	0	0	458	0.0
Hatchery summer	1	1	1,012	1.0
Hatchery fall	0	0	132	0.0
Steelhead, hatchery	1	1	897	1.3
		Snake River stocks		
Chinook				
Hatchery spring	1	1	3,850	<0.1
Wild spring	0	0	460	0.0
Hatchery summer	1	1	1,109	0.3
Wild summer	0	0	232	0.0
Hatchery fall	0	0	5,498	0.0
Hatchery unknown run	3	4	2,294	0.3
Wild unknown run	1	1	731	0.4
Steelhead				
Hatchery	4	6	4,151	0.5
Wild	0	0	800	0.0
Sockeye, hatchery	0	0	559	0.0

Temporal Estimates of Predation

Methods

We estimated weekly predation rates of avian colonies that consumed significant numbers of juvenile salmonids within a specific river reach. These temporal predation rates were calculated by pooling the number of fish available on a weekly basis to birds nesting within specific river reaches. This methodology allowed us to evaluate temporal trends in avian predation rates throughout the migration season. We pooled numbers of fish from all rear types within a common species/run group to obtain suitable numbers of fish available during the migration season to predation by birds within specified river reaches. We used virtual releases of fish from identical instream detection sites for temporal predation rate analyses as those previously used in analysis of annual predation rates.

In addition, we compared weekly predation rates for fish detected passing Bonneville Dam to those released downstream from the dam from transportation barges (Morris et al. 2012; R. D. Ledgerwood, unpublished data). Transported fish were released near Skamania Landing (rkm 224) and we assumed 100% survival of transported fish between loading at upstream dams and release downstream from Bonneville Dam. Statistical comparisons between predation rates of transported and inriver migrating fish were only made for fish present in the LCR during concurrent periods. We assumed that survival rates to the estuary of fish released from transport barges were similar to those detected passing Bonneville Dam during the same week.

Results

***Potholes Reservoir*—**Caspian terns nesting on Goose Island generally consumed 1% or less of available salmonids previously detected at Rocky Reach Dam, except steelhead (Figure 4). Predation rates on steelhead were considerably higher than those for other species, and regularly exceeded 10%, particularly later in the migration season. Predation by double-crested cormorants and gulls nesting in Potholes Reservoir was minimal (i.e., <0.1%).

***Lake Wallula*—**Predation on upper Columbia River fish by all birds nesting in Lake Wallula did not exceed 5% throughout the migration season (Figure 5). Terns consumed higher proportions of upper Columbia River fishes, particularly coho salmon and steelhead, and mainly later in the migration season. Predation rates of coho salmon originating from the upper Columbia River by birds nesting in Lake Wallula were nearly as high as those of steelhead and followed the same general trend throughout the migration season. Predation on upper Columbia River spring and summer Chinook salmon by bird colonies nesting in Lake Wallula was minimal (<0.5%) throughout the migration season.

We estimated that predation rates of salmonids detected at either Ice Harbor Dam or Lower Monumental Dam by birds nesting in Lake Wallula was generally less than 5% for all fish species (Figure 6). Predation rates of Snake River steelhead during spring, when the majority of juveniles were migrating, ranged 3-12%. Predation rates of other fish species by birds nesting in Lake Wallula showed no apparent trends. Caspian terns on Crescent Island and double-crested cormorants on Foundation Island consumed the majority of Snake River fish. American white pelicans and gulls nesting in Lake Wallula consumed a negligible proportion of available fish in this reach of the Columbia River.

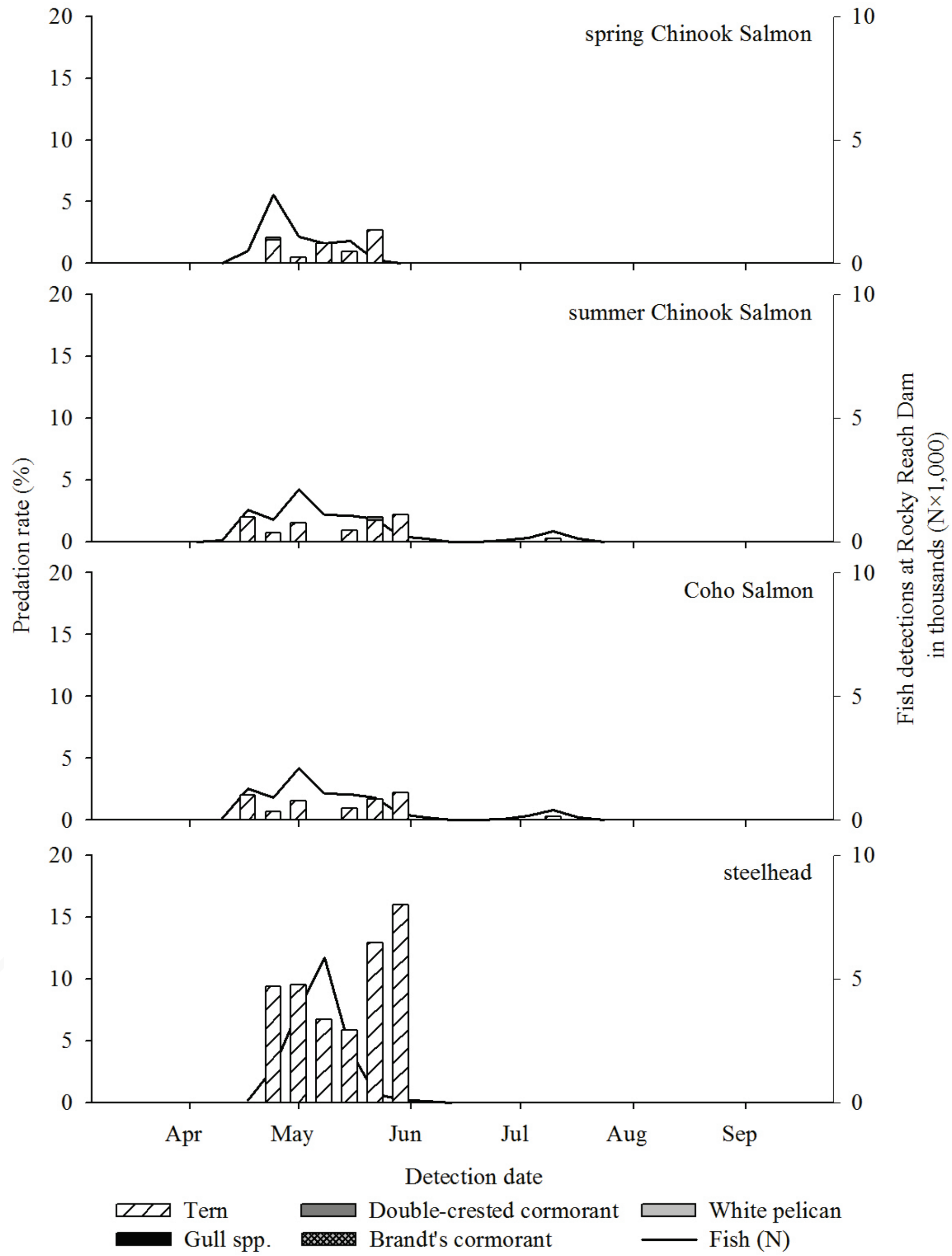

Figure 4. Estimated weekly predation rates (adjusted for detection efficiency) of PIT-tagged salmonids detected at Rocky Reach Dam and subsequently recovered on avian colonies in the Potholes Reservoir.

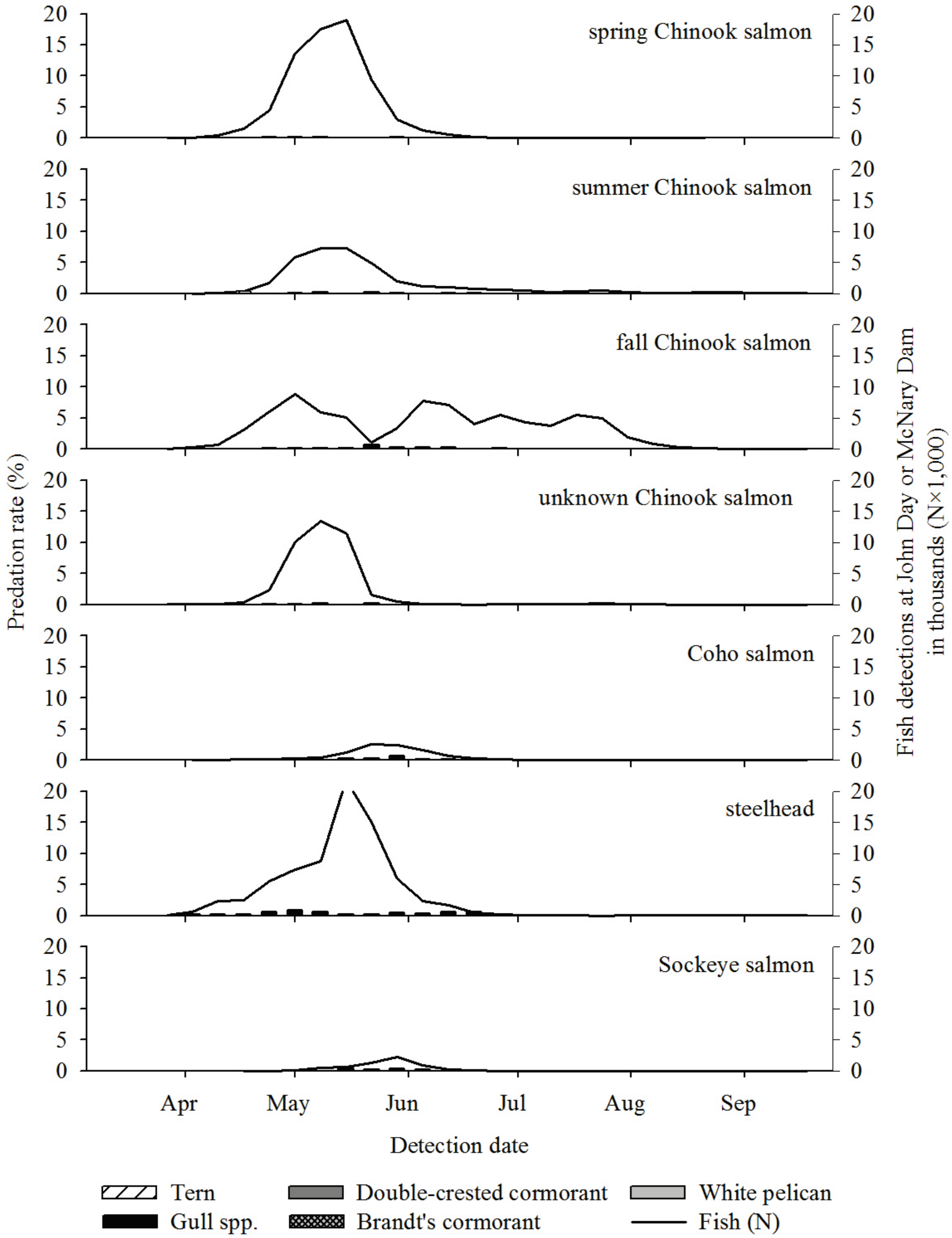

Figure 5. Estimated weekly predation rates (adjusted for detection efficiency) of PIT-tagged salmonids detected at Rocky Reach Dam and subsequently recovered on avian colonies in Lake Wallula.

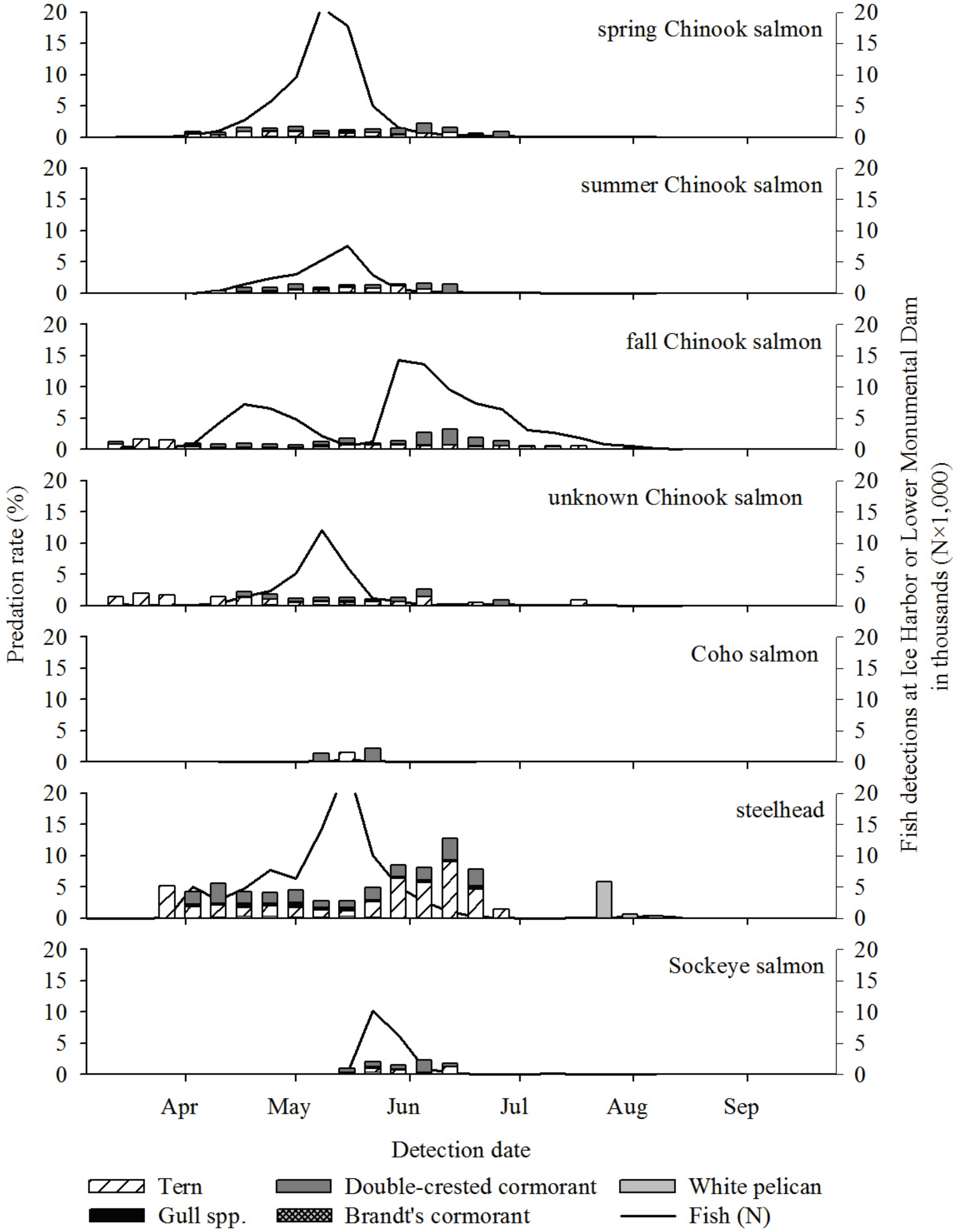

Figure 6. Estimated weekly predation rates (adjusted for detection efficiency) of PIT-tagged salmonids detected at Ice Harbor or Lower Monumental Dam and subsequently recovered on avian colonies in Lake Wallula.

Central Blalock Island**—**Terns nesting on Central Blalock Island had a low predation rate on all salmonids detected at either McNary or John Day Dam. Weekly predation rates were less than 0.5% for all species of salmonids (Figure 7).

Miller Rocks Island**—**Gulls nesting on Miller Rocks Island also had a consistently low predation rate on salmonids detected at either McNary or John Day Dam. Weekly predation rates by gulls on fish detected at McNary or John Day Dam were generally less than 0.5% (Figure 7).

East Sand Island**—**For birds nesting on East Sand Island, the combined weekly predation rate on all salmonid species detected entering the lower Columbia River was frequently greater than 5% throughout of the migration season (Figure 8). The majority of fish were consumed by Caspian terns and double-crested cormorants. Brandt's cormorants consumed less than 1% of the known available salmonids and likely had a minimal effect on survival of fish migrating through the Columbia River estuary.

In general, predation on most salmonid species was divided evenly between Caspian terns and double-crested cormorants except that double-crested cormorants consumed the majority of fall Chinook salmon and terns consumed the majority of steelhead. Predation rates of terns and double-crested cormorants did not follow a consistent pattern during the migration season for most salmonid species, and there were few notable trends in predation rates on most juvenile salmon species through the migration season. However, predation rates of fall Chinook salmon appeared to decrease throughout the migration season, whereas those of spring Chinook salmon appeared to increase as the migration season progressed.

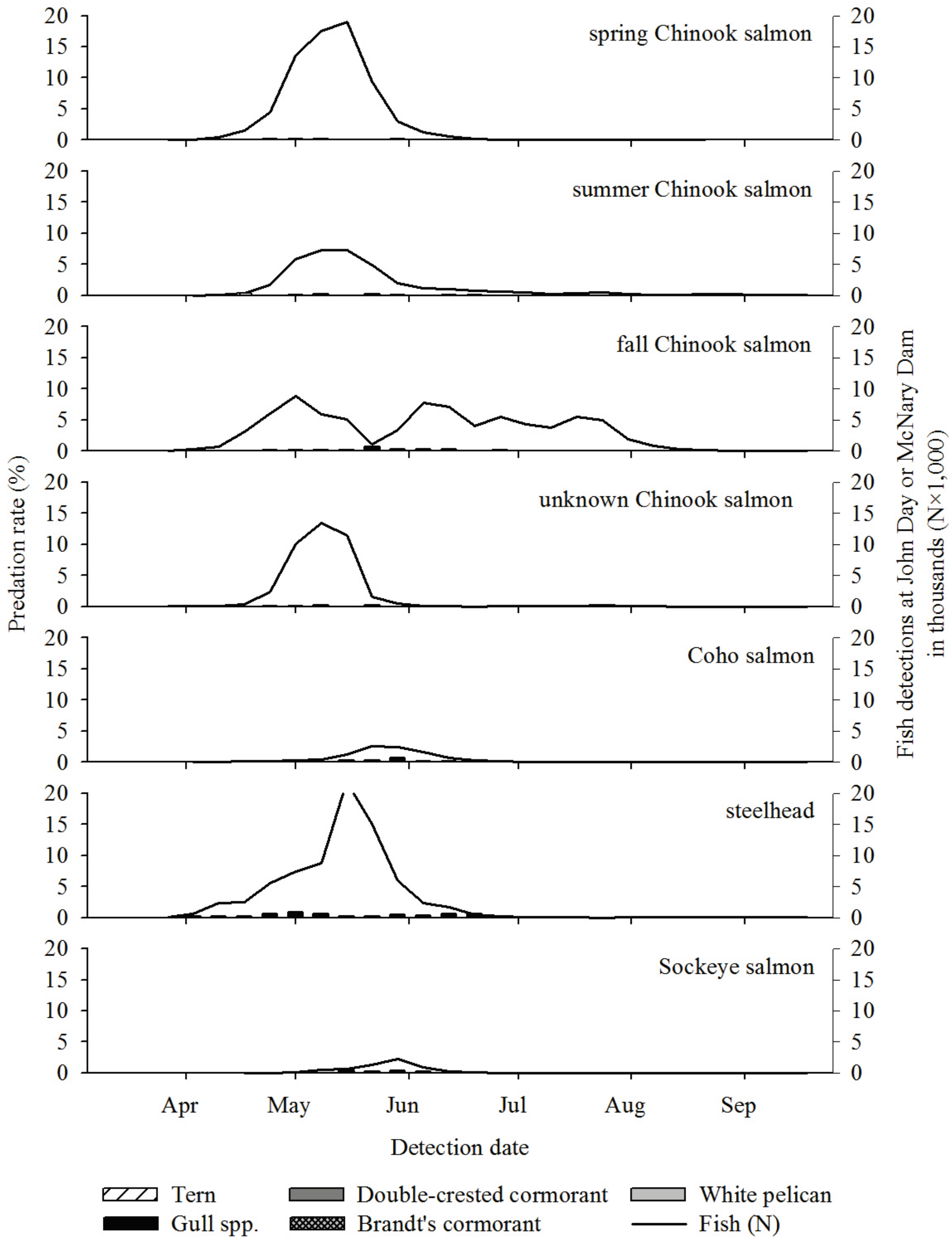

Figure 7. Estimated weekly predation rates (adjusted for detection efficiency) of PIT-tagged salmonids detected at John Day or McNary Dam and subsequently recovered on the Central Blalock Island Caspian tern colony in Lake Umatilla or the Miller Rocks Island gull colony in Lake Celilo.

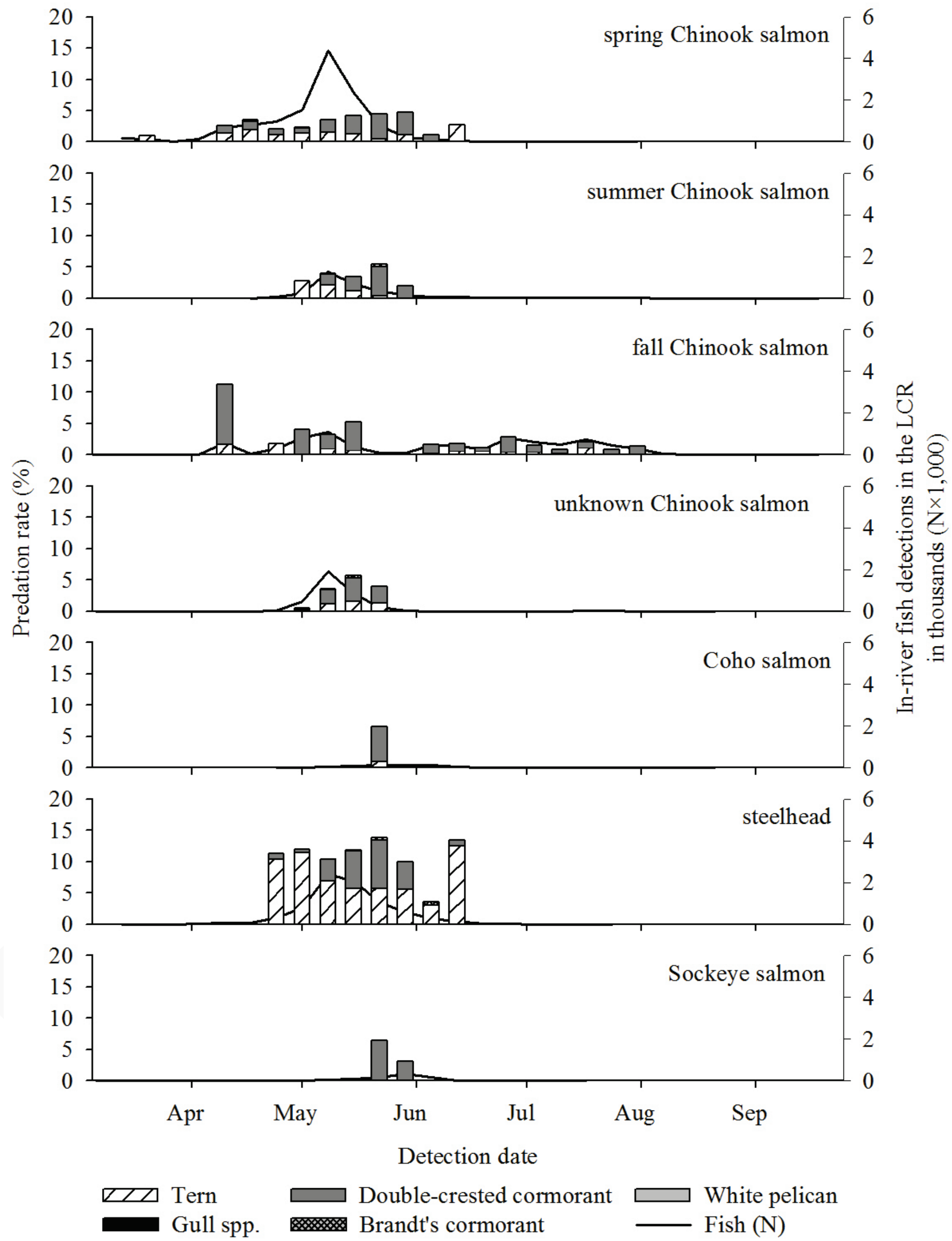

Figure 8. Estimated weekly predation rates (adjusted for detection efficiency) of inriver migrating PIT-tagged salmonids that originated upstream of Bonneville Dam and were recovered from avian colonies on East Sand Island.

Comparison by Migration History**—**To compare weekly predation rates by birds on East Sand Island among fish with varying migration histories, we compared weekly numbers of fish detected at Bonneville Dam with those of fish transported and released at Skamania Landing during the same week. For statistical comparisons, we used data from fish that were released from barges or detected at Bonneville Dam during concurrent periods. Predation rates on transported fish ranged 0.5-9% (Figure 9). Steelhead was typically consumed in higher proportions (6-11%) than other species. Predation rates of transported fish were not significantly different than those of inriver migrants detected at Bonneville Dam ($P > 0.05$; Table 15). We also noted that predation rates of transported hatchery and transported wild fish were generally similar (Appendix Table 2), although there were typically too few numbers of wild fish released from transport barges for analysis.

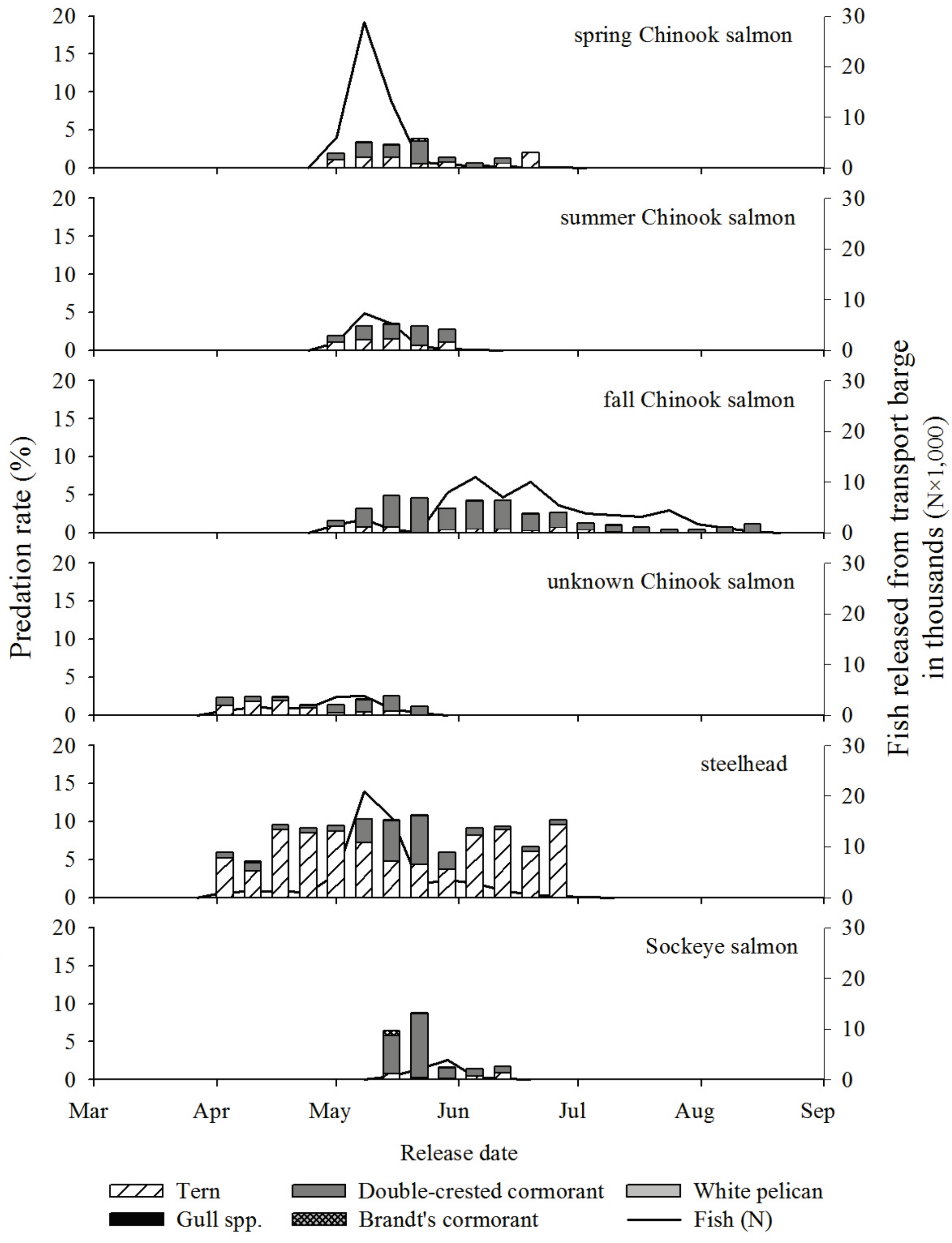

Figure 9. Estimated weekly predation rates (adjusted for detection efficiency) of PIT-tagged salmonids released from transport barges and subsequently recovered from avian colonies on East Sand Island.

Table 15. Mean weekly avian predation rates (adjusted for detection efficiency) of PIT-tagged fish released from transport barges at Skamania Landing and those detected passing Bonneville Dam. We conducted *t*-tests to compare weekly mean predation rates of pooled wild and hatchery fish for transported (T) and inriver migrant (I) groups.

		Spring Chinook	Summer Chinook	Fall Chinook	Unknown Chinook	Steelhead
				Transported fish		
Total colony detections (hatchery & wild)	Tern	644	199	255	106	3,571
	Cormorant	875	269	1,411	157	1,932
Mean adjusted rate of predation (%)	Tern	1.1	1.1	0.5	1.0	6.7
	Cormorant	1.3	1.8	1.9	1.0	1.8
	Total	2.1	2.9	2.3	1.9	8.5
				Inriver migrants		
Total colony detections (hatchery & wild)	Tern	150	42	48	39	527
	Cormorant	240	60	186	82	321
Mean adjusted rate of predation (%)	Tern	1.2	1.6	0.8	1.1	7.7
	Cormorant	2.0	2.7	2.4	2.3	3.4
	Total	2.9	3.4	2.8	3.3	10.6
				P-value		
$Tern_I \times Tern_T$		0.61	0.44	0.29	0.19	0.54
$Cormorant_I \times Cormorant_T$		0.16	0.35	0.58	0.32	0.49
$Tern_I \times Cormorant_I \times Tern_T \times Cormorant_T$		0.17	0.37	0.66	0.18	0.30

Predation of Lower Columbia River Salmon

Methods

During 2011, we continued -tagging subyearling fall Chinook salmon at hatcheries within the lower Columbia River (LCR) to evaluate avian predation on these stocks in comparison to fall Chinook salmon originating from the Snake and upper Columbia River. Fall Chinook salmon in the LCR are generally tule stocks (Narum et al. 2004), which have been poorly represented by PIT-tagging studies. We also compared predation rates of PIT-tagged fall Chinook released below Bonneville Dam to those of PIT-tagged subyearling Chinook salmon released from Spring Creek Hatchery (rkm 269) because both groups are lower Columbia River fall Chinook. Weekly predation rates for Spring Creek fall Chinook salmon were estimated using virtual release groups of fish detected at Bonneville Dam or in the estuary trawl.

Using techniques described in Ryan et al. (2006), we PIT-tagged almost 12,000 tule-stock subyearling migrant fall Chinook salmon during spring and early summer 2011. Tagging occurred at four LCR hatcheries: Big Creek Hatchery (rkm 49); Deep River Net Pen (rkm 37); North Toutle Hatchery (rkm 135); and Warrenton High School Hatchery (rkm 14). Fish tagged at Warrenton High School Hatchery were transported approximately 3 km in oxygenated tanks of recirculating hatchery water. These fish were released below a tide-control device into the Skipanon River about 2 km upstream from its confluence with the Columbia River. Fish tagged at other hatcheries were released directly from the rearing facility with other un-tagged individuals.

We also PIT-tagged and released two groups of 3,000 coho salmon *O. kisutch* in the Columbia River estuary: one at Warrenton High School Hatchery and another at Astoria High School Hatchery (rkm 17). Both groups of PIT-tagged coho salmon were transported in oxygenated tanks of recirculating hatchery water prior to release. Fish from Warrenton High School were released at the same location described above on the Skipanon River, and those reared at Astoria High School were similarly transported about 2 km and released into Young's Bay approximately 19 km from the Pacific Ocean. Similar to predation rate comparisons using Chinook salmon, the comparisons of coho were based on fish released from LCR hatcheries paired with those detected at Bonneville Dam and entering the lower Columbia River during the same week. Records of fish released from transport barges were not included in this analysis.

Results

We PIT-tagged a total of 11,935 subyearling fall Chinook salmon at the four LCR hatcheries from early May through early July 2011 (Table 16). Records obtained from PTAGIS showed that a total of 4,972 PIT-tagged hatchery subyearling fall Chinook salmon originating upstream of Bonneville Dam were detected entering the LCR from April through August 2011. Fish released from Spring Creek Hatchery entered the LCR prior to June, whereas upriver bright stock originating from the Snake River or the upper Columbia River were detected entering the LCR until early June. For avian predators nesting on East Sand Island, the mean weekly predation rate on LCR hatchery subyearlings, adjusted for detection efficiency, was 21%. This rate was similar to those observed in previous years (Ryan et al. 2006, 2007; Sebring et al. 2009, 2010a,b).

Table 16. Estimated predation rate of PIT-tagged subyearling fall Chinook salmon by birds nesting on East Sand Island. Fish were either released from LCR hatcheries or net pens or detected at Bonneville Dam or in the estuary pair-trawl. Predation rates were adjusted for detection efficiency at each colony.

	Fall Chinook PIT tag releases or detections				
	Hatchery releases (N)				Bonneville and trawl
East Sand Island colony	Big Creek	Deep River	North Toutle	Warrenton	detections (N)
	2,992	2,995	2,997	2,951	4,972
	Colony detections (N)				
Caspian tern	34	30	7	68	22
Double-crested cormorant	573	499	163	393	105
Brandt's cormorant	9	5	3	10	0
	Estimated rate of predation (%)				
Caspian tern	1.5	1.3	0.3	3.0	0.5
Double-crested cormorant	26.6	23.1	7.6	18.5	3.5
Brandt's cormorant	0.4	0.2	0.2	0.5	0
Total	28.1	24.4	7.9	21.5	4.0

Weekly predation rates of subyearling fall Chinook salmon detected at Bonneville Dam (mean 4%) were significantly different ($P = 0.004$) and lower than those of subyearlings released from LCR hatcheries (Figure 10). The mean weekly ratio of subyearlings released from LCR hatcheries and consumed by Caspian terns and double-crested cormorants nesting on East Sand Island (tern 7%: double-crested cormorant 93%) was not significantly different ($P = 0.4$) than the mean weekly ratio of subyearlings detected at Bonneville Dam (tern 15%: double-crested cormorant 85%).

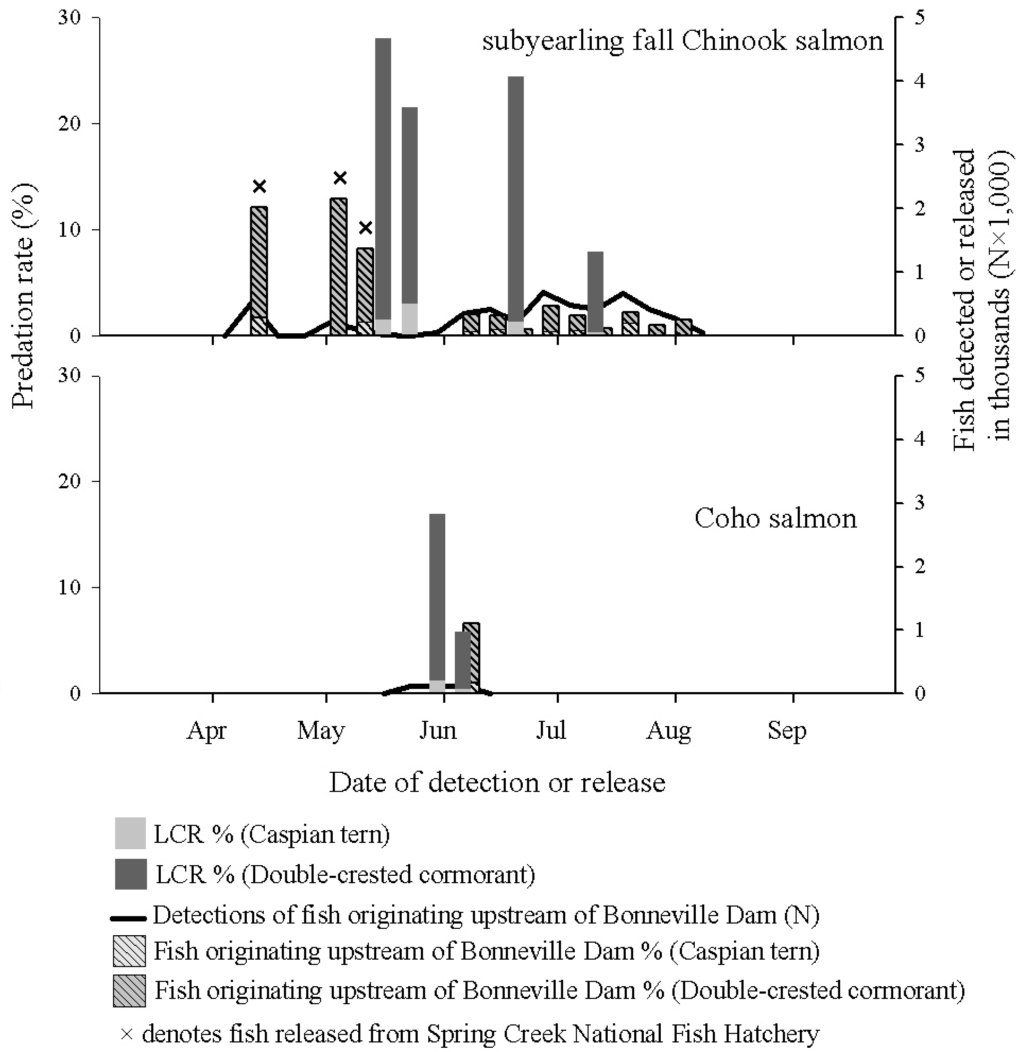

Figure 10. Seasonal predation rates of subyearling fall Chinook salmon and coho salmon released from LCR hatcheries or detected at Bonneville Dam by Caspian terns and double-crested cormorants nesting on East Sand Island during 2011.

We PIT-tagged and released a total of 5,694 coho salmon from two LCR hatcheries during early June 2011 (Table 17). A total of 610 PIT-tagged coho salmon were also detected passing Bonneville Dam or in the estuary trawl during 2011. Mean avian predation rates were approximately 9.3% for coho salmon released into the LCR and 6.6% for coho detected entering the estuary, and the difference was not statistically significant (*P* = 0.20). We noted a large difference in estimated predation rates between coho salmon released from Warrenton Hatchery (4.6%) and those released from Astoria Hatchery (14.1%), even though these two groups were released within 6 d of each other and at release points separated by less than 10 km. However, the ratio of coho salmon released into the LCR and subsequently consumed by Caspian terns and double-crested cormorants nesting on East Sand Island (8% tern: 92% double-crested cormorant) was not significantly different (*P* = 0.17) than the ratio of those detected entering the lower Columbia River (17% tern: 83% double-crested cormorant).

Table 17. Estimated predation rate of PIT-tagged coho salmon by birds nesting on East Sand Island. Fish were either released to the LCR from hatcheries or net pens or detected entering the lower Columbia River. Predation rates were adjusted by detection efficiency at each colony.

	Coho salmon PIT tags released or detected		
East Sand Island colony	Astoria releases (N)	Warrenton releases (N)	Bonneville Dam and pair-trawl detections (N)
	2,993	2,761	610
	Colony detections (N)		
Caspian tern	23	8	4
Double-crested cormorant	274	88	11
Brandt's cormorant	2	1	0
	Estimated rates of predation (%)		
Caspian tern	1.0	0.4	1.8
Double-crested cormorant	13.1	4.2	5.3
Brandt's cormorant	0.1	0.1	0
Total	14.1	4.6	7.1

DISCUSSION

Since 1998, we have provided recovery data from juvenile salmonid PIT-tags for use in annual assessments of avian predation throughout the Columbia River Basin (Ryan et al. 2001, 2002, 2003, 2007; Glabek et al. 2003; Sebring et al. 2009, 2010a,b). In 2011, we continued to provide PIT-tag recovery data via PTAGIS and to analyze avian predation rates by location and avian colony and predation rats on fish by species and migration history.

While reporting any relevant changes in patterns of predation, in recent years we have also focused recovery efforts on specific avian colonies having the greatest effect on mortality of migrating juvenile salmonids. In 2011, these colonies were located on islands in the Columbia estuary, Lake Wallula, and on colonies in the Potholes Reservoir. Data from PIT tags on these colonies provides an annual index of predation, which has been useful in determining the success or failure of management strategies in an overall effort to reduce the number of juvenile salmonids consumed by birds.

For most avian colonies, our detection efficiency estimates in 2011 were similar to those measured during previous years. A trend in decreasing detection efficiency on the East Sand Island Caspian tern colony is of some concern, particularly given that the quantity of nesting substrate available at this location has been systematically decreased each year. This decrease accords with attempts to relocate nesting birds from this location to sites created for nesting in southern Oregon and San Francisco Bay. However, the number of terns nesting on East Sand Island has remained fairly constant despite these relocation efforts (Robe et al. 2011). The trend in declining PIT-tag detection efficiency on the East Sand Island tern colony may be due to increasing tag density and the resulting tag-code collisions.

In contrast, detection efficiency measurements for the double-crested cormorant colony on East Sand Island were the second highest measured to date, with 2010 being the highest (Appendix Table 4). Greater sample effort and the use of improved detection equipment likely resulted in better efficiency on this colony. Detection efficiencies for the Caspian tern colonies on the west end of Goose Island (60%) and on Central Blalock Island (55%) were low in comparison to those for other tern colonies. Additional sampling effort or removal of old tags may be necessary at Goose Island if the trend of increasing numbers of terns nesting at this location continues.

As in previous years, our results indicated that predation rates by birds nesting on East Sand Island were greater for subyearling fall Chinook salmon originating below Bonneville Dam than for their conspecifics originating above the dam (Ryan et al. 2006;

Sebring et al. 2009, 2010a,b). We did not observe a similar trend in heavier predation on LCR coho salmon in comparison to coho salmon originating upstream from Bonneville Dam.

In 2011, over 18,000 juvenile salmonids were released into the Columbia River basin containing both a PIT tag and an acoustic transmitter. Of these, less than 1,000 of the PIT-tags were detected in fish passing Bonneville Dam and even fewer were detected on Caspian tern and cormorant colonies on ESI—insufficient numbers for analysis compared to PIT-only tagged fish detected Bonneville Dam.

Weekly predation rates of tule stock subyearling fall Chinook salmon released from Spring Creek National Fish Hatchery during 2011 (mean 11%) were not significantly different than those of tule stock subyearlings released below Bonneville Dam (mean 21%, Sebring et al. 2010b). Subyearling fall Chinook salmon released from Spring Creek Hatchery have been shown to rear in the estuary for extended periods of time prior to ocean entry (Teel et al. 2009). Therefore, the disparity in vulnerability to avian predation between subyearling fall Chinook salmon originating from the lower and upper Columbia River basin may occur because of differences in fish behavior, release timing, habitat use, and length of estuary residency.

Though management decisions frequently focus on threatened salmonid stocks in the upper Columbia and Snake River basins, it is also important to consider economically valuable lower river stocks, which appear acutely vulnerable to avian predation. Management action to relocate avian colonies outside the estuary may benefit all salmonid migrants in the Columbia River basin.

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APPENDIX

Supplementary Data

Appendix Table 1. Number of PIT tag codes detected on avian colonies during 2011.

Bird colony	American white pelican	Brandt's cormorant	Brown pelican	Caspian tern	Double-crested cormorant	Gull species	Mixed avian species	**Total (N)**
Columbia River estuary								
East Sand Island		450	141	145,963	79,920			226,474
Miller Sands Island	95							95
Lake Celilo								
Miller Rocks Island						2,330	120	2,450
Lake Umatilla								
Central Blalock Island				443				443
Lake Wallula								
Crescent Island				15,163		11,761	1,526	28,450
Badger Island	4,103						1,244	5,347
West Side Island							16	16
Foundation Island					6,126		145	6,271
Snake River Breakwater							9	9
Wade Island							19	19
Goose Island (Snake River)							7	7
Island 20 Island							19	19
Columbia Plateau								
Goose Island/Potholes Reservoir				4,892	79		153	5,124
North Potholes					77			77
Total (N)	4,198	450	141	166,461	86,202	14,091	3,258	274,801

Appendix Table 2. Numbers and proportions of all PIT tags recovered on avian colonies in 2011. Totals include PIT tags with no prior history of detection on an avian colony and include fish released for migration prior to 2011.

Bird colony	American white pelican	Brandt's cormorant	Brown pelican	Caspian tern	Double-crested cormorant	Gull species	Mixed avian species	**Total (N)**
Columbia River estuary								
East Sand Island		442	1	27,672	29,506			57,621
Miller Sands Island	15							15
Lake Celilo								
Miller Rocks Island						2,243	120	2,363
Lake Umatilla								
Central Blalock Island				388				388
Lake Wallula								
Crescent Island				9,481		2,552	420	12,453
Badger Island	4,001						1,244	5,245
West Side Island							16	16
Foundation Island					5,993		145	6,138
Snake River Breakwater							9	9
Wade Island							19	19
Goose Island (Snake River)							7	7
Island 20 Island							19	19
Columbia Plateau								
Goose Island				4,575			153	4,728
North Potholes					77			77
Total (N)	4,016	442	1	42,116	35,576	4,795	2,152	89,098

Appendix Table 3. Number and estimated predation rates of PIT-tagged salmonids transported during 2011 that were recovered on the East Sand Island Caspian tern and double-crested cormorant colonies. Data are presented only for species and rear types with more than 100 fish released from transport barges.

	East Sand Island Caspian tern, Double-crested cormorant and Brandt's cormorant colonies							
		Colony recovery (N)			Estimated predation rate (%)			
Rear type	Transport barge realeases	Brandt's cormornat	Caspian tern	Double-crested cormorant	Brandt's cormornat	Caspian tern	Double-crested cormorant	Total
Spring Chinook salmon								
Hatchery	45,671	10	481	593	<.01	1.2	1.6	2.8
Wild	4,508	2	12	36	0.9	0.5	1.4	2.8
Summer Chinook salmon								
Hatchery	14,015	6	151	186	0.1	1.2	1.9	3.2
Wild	1,009	1	2	8	0.5	0.5	1.5	2.4
Fall Chinook salmon								
Hatchery	63,727	14	196	1,016	<.01	0.5	1.9	2.4
Unknown run Chinook salmon								
Hatchery	344	0	2	4	0	1.6	3.5	5.2
Wild	13,791	4	78	108	0.1	1.0	1.0	2.1
Steelhead								
Hatchery	44,584	22	2,365	1,065	0.1	7.7	1.7	9.6
Wild	12,089	5	385	254	0.2	4.8	2.2	7.1
Sockeye salmon								
Hatchery	7,356	6	15	196	0.3	0.5	3.3	4.1

Appendix Table 4. Proportion of control PIT tags recovered on East Sand Island avian breeding colonies from 2002-2011 that were intentionally sown on the colony surface to measure detection efficiency. The number of control PIT tags sown on each colony is listed in parentheses.

	Percent of control PIT tags recovered	
Year	Double-crested cormorant	Caspian tern
2002	35 (300)	95 (300)
2003	45 (300)	85 (300)
2004	36 (600)	92 (1,100)
2005	55 (800)	83 (1,200)
2006	52 (600)	64 (1,200)
2007	58 (200)	89 (600)
2008	69 (600)	92 (600)
2009	70 (600)	90 (600)
2010	76 (400)	84 (400)
2011	72 (400)	77 (300)
Mean	57	85