Detection of Passive Integrated Transponder (PIT) Tags
on Piscivorous Avian Colonies in the Columbia River Basin, 2009

Fish Ecology Division

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Seattle, Washington

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Report of research by

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Contract 2RL4SPTP00

December 2010

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EXECUTIVE SUMMARY

In 2009, the National Marine Fisheries Service, in collaboration with Oregon State University and Real Time Research, Inc., recovered passive integrated transponder (PIT) tags from piscivorous bird colonies in the Columbia River basin (CRB). The PIT tags had been implanted in juvenile Pacific salmon *Oncorhynchus* spp. for studies of survival and migration behavior. Over 117,000 PIT-tag codes with no previous history of detection on avian colonies were recovered during 2009. Of this total, over 91,000 originated from fish released for migration in 2009. Greater than 68% of all PIT-tag recoveries occurred at the Caspian tern (*Hydroprogne caspia*) and double-crested cormorant (*Phalacrocorax auritas*) colonies located on East Sand Island in the Columbia River estuary. Other important recovery locations were tern colonies on Crescent and Goose Islands and a cormorant colony on Foundation Island. Crescent and Foundation Islands are located in the reservoir upstream from McNary Dam, and PIT tags recovered from these islands accounted for approximately 20% of all recoveries. A significant percentage of PIT tags (5%) were also recovered from a California gull (*Larus californicus*) colony in The Dalles Dam reservoir on Miller Rocks Island. Sampling at other colonies in the CRB yielded an additional 7% of PIT-tag codes collected.

As in previous years, PIT-tagged juvenile steelhead were generally among the most vulnerable to avian predation, regardless of colony location. For example, the mean predation rate of PIT-tagged steelhead detected passing Bonneville Dam was 17%, although this was not significantly different ($P = 0.29$) than the predation rate of PIT-tagged steelhead released from transport barges downstream of Bonneville Dam (15.9%). In comparison, approximately 5% of Chinook, coho, and sockeye salmon detected passing Bonneville Dam in 2009 were subsequently detected on East Sand Island.

The most vulnerable salmonid ESU in the Columbia River basin in 2009 was lower Columbia River subyearling fall Chinook salmon. The mean predation rate of hatchery subyearlings released into the lower Columbia River by birds nesting on East Sand Island was approximately 23%. This predation rate was significantly different than that of subyearlings detected passing Bonneville Dam (5.3%; $P < 0.05$) and was the largest estimated for any salmonid ESU during 2009. Cormorants consumed a larger proportion of subyearlings released into lower Columbia River than terns (75% cormorants, 25% terns). Cormorants also consumed a larger proportion of subyearlings detected passing Bonneville Dam than terns (69% cormorants, 31% terns). However, there was no significant difference in proportional consumption of subyearlings released to the lower Columbia River versus those detected at Bonneville Dam ($P = 0.24$).

The mean predation rate on PIT-tagged coho salmon released to the estuary from three lower Columbia River hatcheries was 18%, which was significantly higher ($P = 0.02$) than that of coho salmon detected passing Bonneville Dam (7%). Cormorants consumed a larger proportion of coho salmon released into the lower Columbia River than terns (87% cormorants, 13% terns). However, terns consumed a larger proportion of coho salmon detected passing Bonneville Dam (20% cormorants, 80% terns). There was a significant difference in proportional consumption of coho salmon released to the Lower Columbia River versus those detected at Bonneville Dam ($P < 0.05$).

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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. PIT-tagging has also aided in identifying causes of decline in salmonid populations at different life history stages (NMFS 2000). The annual number of PIT-tagged juvenile salmonids released in the Columbia River basin (CRB) varies, but has increased from less than 50,000 in 1987 to over 2,000,000 by 2003 (PSMFC 1996). At the time of tagging, individual tag codes and other information, such as species type and origin, are recorded in a regional database, the PIT Tag Information System (PTAGIS) for the Columbia River Basin (PSMFC 1996–). After entry, codes in PTAGIS 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; by the 1980s, these colonies had begun to concentrate on small islands in the Columbia River estuary (Gill and Mewladt 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 (BRNW 2007). Both the tern and cormorant colonies are considered to be the largest of their respective species in North America.

Large-scale efforts to detect PIT tags on avian predator colonies in the CRB began in 1998 (Ryan et al. 2001). The 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). High levels of annual salmonid consumption related to these large breeding colonies of avian piscivores were indicated.

These initial findings prompted management agencies to relocate the Caspian tern colony from Rice Island (freshwater) downstream to East Sand Island (brackish water). 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 on these and other colonies throughout the CRB continued to focus on evaluating the relative vulnerability of salmonids to avian predation. Presently, these efforts primarily target the larger avian colonies responsible for the majority of predation on juvenile salmonids. This approach was intended to develop data for better evaluation of management alternatives for avian colonies.

We used modified detection equipment (Prentice et al. 1990a,b) to recover juvenile salmonid PIT tags from the nesting colonies in 2008. In previous years, biologists from Oregon State University (OSU) and Real Time Research, Inc. (RTR) assisted with PIT-tag recovery efforts of the National Marine Fisheries Service (NMFS). Beginning in 2007, we divided recovery efforts on colonies among research groups stationed within different geographic regions of the CRB. We then pooled detection information for our respective analyses. In this report, we summarize the PIT-tag recovery, methodology, and general vulnerabilities of juvenile salmonids to avian predators in 2009. Data obtained during this study contributed to additional analyses of the broader aspects of avian behavior, population dynamics, smolt consumption, and species-specific vulnerabilities of juvenile salmonids to avian predation. These data have also contributed to analyses of avian predation, including the relative vulnerability of juvenile salmonids to predation obtained by expanded PIT-tag recoveries.

METHODS

Study Sites

Our study sites consisted of 16 distinct avian breeding colonies on 12 islands (Table 1). All PIT-tag sampling occurred during summer and fall after the terminus of the breeding season when birds had completely vacated the nesting colonies. Locations of avian colonies ranged from East Sand Island, at river kilometer (rkm) 8 in the Columbia River estuary, to Banks Lake, a 43-km-long irrigation reservoir located south of the Columbia River near rkm 959 (Figure 1). The majority of PIT-tag recovery efforts were concentrated on the largest avian predator colonies located on islands in the Columbia River estuary (Figure 2) and on islands in the McNary Dam reservoir near the confluence of the Columbia and Snake Rivers.

Table 1. Location of avian breeding colonies and distance from Columbia River mouth.

River Reach and Island	Distance to Columbia River mouth (km)
Columbia River estuary	
East Sand Island	8
Rice Island	34
The Dalles Dam Reservoir	
Miller Rocks Island	331
John Day Dam Reservoir	
Three Mile Canyon Island	412
Rock Island	441
McNary Dam Reservoir	
Crescent Island	510
Badger Island	512
Foundation Island	518
Interior Columbia Plateau	
Potholes Reservoir	665*
Banks Lake	959*
Snake River	
Swallows Park	751
Lower Hog Island	759

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

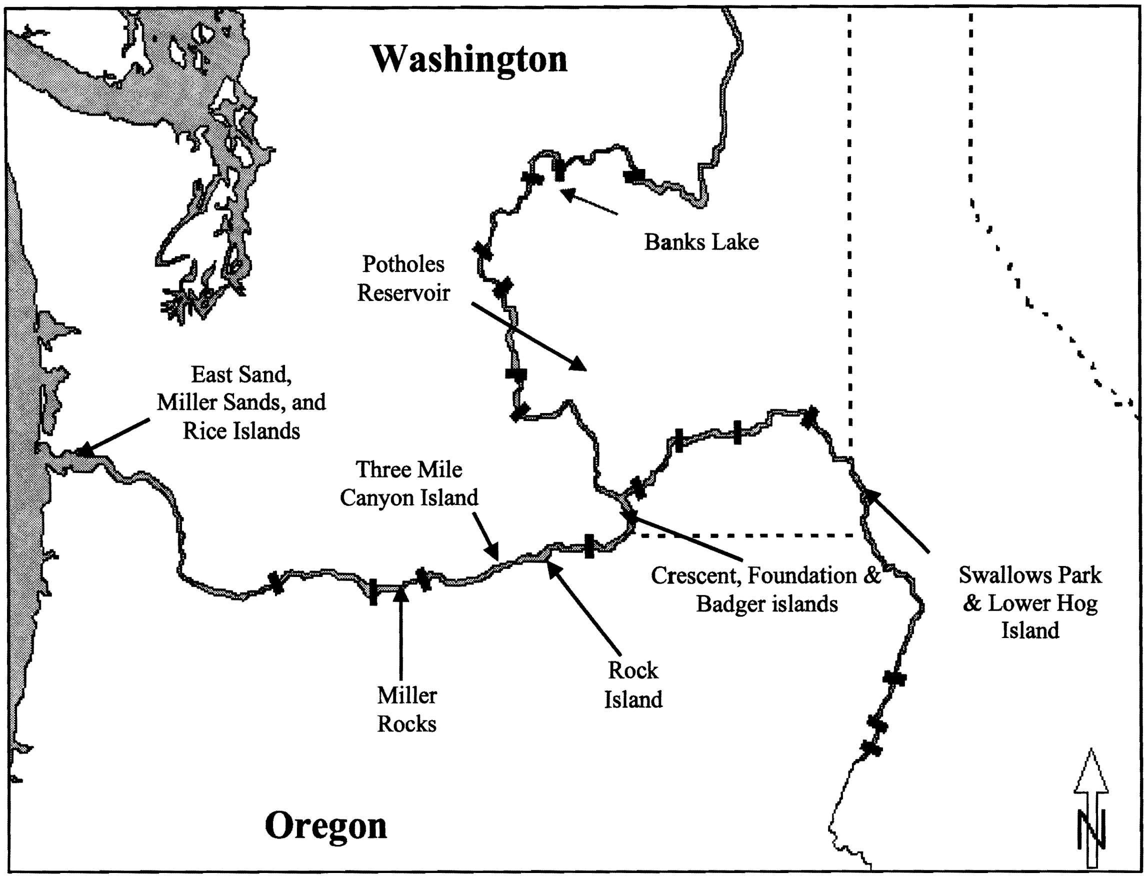

Figure 1. Location of avian predator colonies and post-breeding season PIT-tag collection efforts.

Recovery of PIT tags

In 2009, PIT-tag recovery efforts were conducted by NMFS, OSU, and RTR research staff at separate locations throughout the Columbia River Basin. Tags from East Sand Island were recovered by NMFS staff based at the Point Adams Research Station, located near the Columbia River estuary. We also provided tractor-towed, flat-plate antenna systems to assist in recovery of tags on Crescent Island tern and gull colonies. Tags from avian colonies in the mid- and upper Columbia River were recovered by OSU and RTR. These agencies focused primarily on avian colonies on Crescent Island, Foundation Island, and the Potholes Reservoir, but they also recovered tags from other colonies in that region.

Recovery data from previous years indicated that a large proportion of PIT tags would be located on Crescent, East Sand, and Foundation Islands (Ryan et al. 2003, 2006, 2007), and that several other colonies would have substantial numbers of PIT tags (Ryan et al. 2001, 2002). These secondary colonies were located on islands in the reservoirs of The Dalles and John Day Dams and on islands upstream from Priest Rapids Dam and in the Potholes Reservoir.

We used hand-held transceivers and flat-plate antenna systems for PIT-tag detection, as described by Ryan et al. (2001). Flat-plate antennas were used primarily on Crescent and East Sand Island tern colonies, where potential for tag-code collision was greatest due to higher densities of PIT tags. Collision of tag codes occurs when two or more PIT tags are present in the detection field simultaneously, resulting in interference between tag-code signals so that neither code is correctly read by the transceiver (Brännäs et al. 1994). Tern colonies are generally located on more level, unobstructed terrain, which allowed NMFS to operate a tractor to tow the flat-plate antennas. Individual passes were made with flat-plate antennas in different directions to vary orientation of antenna to tags, which improves detection of tag codes. Hand-held antennas were used as an alternative technique where rugged, obstructed terrain limited use of flat-plate antennas.

Detection Efficiency

As in previous years, we collaborated with OSU and RTR to evaluate detection efficiency. For these evaluations, we distributed known numbers of PIT tags, hereafter referred to as control tags, on avian colonies at various intervals throughout the breeding season. Colony-specific detection efficiencies were calculated by dividing the number of control tags electronically recovered by the total number of control tags planted on the colony. In previous years, we had observed temporal changes in detection rates of control tags at the Crescent Island and Potholes Reservoir tern colonies (Sebring 2010). Therefore, we used linear regression models to interpolate weekly detection efficiencies for avian colonies, where control tags were planted during at least four intervals throughout the breeding season. The final planting of control tags was conducted after the nesting season, when birds had left the colonies, and just prior to our electronic recovery efforts. Thus, we used detection efficiency rates from post-season control tags as the maximum weekly value, even if this value was less than that generated by the linear regression model.

Detection efficiencies were calculated differently on the East Sand Island cormorant colony, where a diversity of nesting substrates exist, because these colonies can yield variable PIT-tag recovery rates by habitat type. We calculated detection efficiencies for each habitat type where both pre- and post-season groups of control tags were planted (i.e., rip-rap, bare sand, etc.). In collaboration with RTR, the results were weighted by the proportion of birds nesting on each habitat type using geospatially referenced data. This method, which weighted for nesting habitat use, produced more accurate detection efficiency calculations for the East Sand Island cormorant colony.

Colony-Specific Predation

In addition to basin-wide avian predation rates, we also estimated predation rates of PIT-tagged salmonids known to be migrating within specific reaches of the Columbia River. We expected greater accuracy in estimates of predation using this method because after detection at the nearest index site, mortality unrelated to avian predation is likely negligible. The upper Columbia River, the McNary and The Dalles Dam reservoirs, and the Columbia River estuary were identified as reaches that either contained avian colonies where large numbers of PIT tags were detected annually or were in close proximity to such colonies. Detections of PIT-tags at the nearest colony were used as an index of vulnerability to avian predation.

For most avian colonies, PIT-tag detections from only one location were used to index predation rates within a reach. For example, detections at Bonneville Dam were used as an index of PIT-tagged fish potentially available to be consumed by avian predators nesting in the Columbia River estuary. Some breeding colonies (i.e., Miller Rocks gull and Crescent Island tern colonies) were located in areas where birds could forage upstream from the nearest index site. For example, predation in the forebays of John Day and Ice Harbor Dam precluded the use of these locations as index sites because of the likelihood that at these locations, PIT-tagged fish could be consumed in the forebay and thus excluded from the population of vulnerable prey.

To account for forebay predation, we included detections of PIT-tagged fish from two upstream locations when the nearest index site was within foraging range of a breeding colony. For example, gulls nesting at Miller Rocks Island can forage in the forebay of John Day Dam. Therefore we used detections of fish at both John Day and McNary Dams to index predation on fish by gulls nesting on Miller Rocks Island in the Columbia River Gorge.

PIT-tagged fish detected at Bonneville Dam were used as an index of fish available to avian predators in the Columbia River estuary. We also used detections of PIT-tagged fish at Ice Harbor and Lower Monumental Dams to provide an index of availability of Snake River fish to avian predators in the McNary Dam reservoir. PIT-tagged fish released from Rock Island Dam (rkm 730) were used as an index of fish originating in the upper Columbia River and available to avian predators nesting in Potholes reservoir and on islands within McNary Dam reservoir.

We evaluated the effects of migration history by comparing avian predation rates on groups of transported and in-river migrating fish in the Columbia River estuary. We compared weekly predation rates based on migration history (in-river vs. transport) between PIT-tagged fish detected at Bonneville Dam or released from a transport barge at

Skamania Landing (rkm 224) within the same week. Weeks with a minimum of 100 fish detected at Bonneville Dam or released from Skamania Landing were included in statistical comparisons because predation rates are known to vary throughout the migration season. All species (i.e., Chinook, coho, steelhead, etc.) and run codes (spring, summer, fall, winter, unknown) are designated in PTAGIS (2009).

Tagging of Lower Columbia River Chinook and Coho salmon

During 2009, we continued to PIT-tag subyearling fall Chinook salmon from the lower Columbia River (LCR) to evaluate avian predation on this evolutionary significant unit (ESU). The LCR Chinook salmon has a distinct life history type (Narum et al. 2004), but is typically represented by few PIT-tagged individuals. Using techniques described in Ryan et al. (2006), we PIT-tagged over 12,000 subyearling fall Chinook salmon during spring and early summer at four hatcheries located on rivers flowing into the LCR.

Tagging was conducted at the Big Creek (rkm 49), Deep River net pen (rkm 37), Kalama Falls (rkm 135), and Warrenton High School Hatcheries (rkm 14). Groups of fish released from these four hatcheries were used to examine whether predation rates of subyearling fall Chinook salmon released near the estuary were similar to those of stocks released further upstream. We also PIT-tagged 2,000 coho salmon (*Oncorhynchus kisutch*) at Blind Slough net pen (rkm 47), Deep River net pen, and Warrenton High School Hatcheries using identical methods. These groups were used to compare predation rates of Chinook and coho salmon released into the LCR to those of fish detected at Bonneville Dam during the same week. To avoid potential bias related to migration history, we included only non-transported fish in the analysis.

Comparative Predation of Acoustic-Tagged vs. PIT-Tagged Fish

In addition to our annual analyses of avian predation, we included a comparative analysis of predation on PIT-tagged fish versus those implanted with both PIT and acoustic tags during a single surgical procedure (hereafter referred to as double-tagged fish). We used daily numbers of PIT-tagged and double-tagged fish detected passing Bonneville Dam as an index of those vulnerable to predation by birds nesting on East Sand Island.

We analyzed relative vulnerability of double-tagged and PIT-tagged fish to predation by Caspian terns and double-crested cormorants in the Columbia River estuary. For this analysis, we used only fish consumed by Caspian Terns or double-crested cormorants nesting in the Columbia River estuary because these were the only colonies that had sufficient numbers of detections of both tag types over multiple weeks for reliable estimates of predation. We assumed equal probability that PIT tags from either group would be deposited on avian colonies and an equal probability of detection.

Statistical Comparisons

We made statistical comparisons using a two-tailed *t*-test ($\alpha < 0.05$) between treatment groups released from LCR hatcheries, released from transport barges, or detected at Bonneville Dam. Predation rates of double-crested cormorants and Caspian terns are known to vary throughout the season with changes in the availability of alternate prey and in the metabolic requirements of recently hatched young. Therefore, comparisons of predation were generally limited to fish entering a given reach within the same week.

Predation rates were compared between LCR-released vs. Bonneville-detected fish; Bonneville-detected (inriver migrant) vs. transported fish; and PIT-tagged vs. double-tagged fish. We also compared predation rates between tule and upriver bright subyearling fall Chinook salmon detected at Bonneville Dam during different weeks because these fish migrate at different times. Daily predation rates of PIT-tagged vs. double-tagged fish were compared, although data for double-tagged fish was pooled with adjacent days when necessary to provide sufficient sample sizes. Predation rates of all other groups of interest were compared on a weekly basis.

RESULTS

Recovery of PIT tags

Using physical and electronic recovery techniques, we collected over 117,000 PIT-tag codes with no previous detection history on avian breeding colonies (Appendix Table 1). More than 91,000 recoveries were from fish migrating during 2009 (Table 2). Total numbers of tag codes recovered from individual salmonid ESUs revealed long-ranging effects of predation from each avian colony. Predation rates from these recoveries were minimum estimates because we could not adjust for off-colony deposition of PIT tags. However, our results provide an overall, basin-wide measure of the numbers consumed by each colony for each ESU.

Table 2. Number of PIT-tag codes recovered on avian breeding colonies from salmonids migrating during 2009. The percentage of the total annual recovery is listed for each island and colony.

Recovery site	American White Pelican	Caspian tern	Double-crested cormorant	Gull species	Mixed avian species	Total (N)	Total (%)
Columbia River estuary							
East Sand Island		37,920	25,114	4		63,038	68.7
Rice Island				14		14	0.0
Lake Celilo (The Dalles Dam reservoir)							
Miller Rocks Isl				4,174		4,174	4.6
Lake Umatilla (John Day Dam reservoir)							
Three Mile Canyon Island				188		188	0.2
Rock Island		1,255				1,255	1.4
Lake Wallula (McNary Dam reservoir)							
Badger Island	1,729					1,729	1.9
Crescent Island		8,073		1,871	255	10,199	11.1
Foundation Island			7,215			7,215	7.9
Interior Columbia Plateau							
Potholes Reservoir		3,268	20			3,288	3.6
Banks Lake		62				62	0.1
Snake River/Clearwater River							
Lower Hog Island				5		5	<0.1
Swallows Park			535			535	0.6
Total (N)	1,729	50,578	32,884	6,256	255	**91,702**	
Percent (%)	1.9	55.2	35.9	6.8	0.3		

Interior Columbia Plateau—Predation rates by Caspian terns and double-crested cormorants nesting in the Potholes Reservoir of fish released at Rock Island Dam were generally less than 1% (Appendix Tables 2 and 3). Double-crested cormorants did not consume any fish detected at Rock Island Dam. However, for steelhead from the upper Columbia River ESU, consumption by Caspian terns ranged between 10 and 16%.

McNary Dam Reservoir—Farther downstream in the McNary Dam reservoir, predation rates were less than 5% at all colonies and for all salmonid species (Appendix Tables 4-7) with the exception of Caspian terns nesting on Crescent Island. Caspian terns generally preferred steelhead to other PIT-tagged salmonids, as did double-crested cormorants nesting on Foundation Island. In addition, steelhead from the Snake River ESU were preferred to those from the upper Columbia River.

The Dalles and John Day Dam Reservoirs—Avian colonies between McNary Dam reservoir and the Columbia River estuary made a negligible contribution to basin-wide predation. With the exception of steelhead, Caspian terns nesting on Rock Island and gulls nesting on Miller Rocks Island generally consumed less than 0.5% of all available fish regardless of ESU (Appendix Tables 8 and 9). Predation rates of steelhead by both colonies were approximately 1% for all run and rear types.

Columbia River estuary—Predation rates of Caspian terns and double-crested cormorants nesting on East Sand Island were highest for lower Columbia River ESUs of fall Chinook and coho salmon and steelhead (Appendix Tables 10 and 11). Combined predation rates by Caspian terns and double-crested cormorants on LCR hatchery steelhead (16%) were similar to those of fish released from transport barges (17%; Appendix Table 12).

Detection Efficiency

Mean detection efficiency using control tags planted by OSU and RTR on colonies where the majority of PIT tags were detected ranged from 46 to 91% (Table 3). Detection efficiencies measured at other avian colonies ranged from 20 to 77.5%. In general, these detection efficiencies were similar to those measured on the same colonies during the past 2 years, with one notable exception: on the East Sand Island double-crested cormorant colony, detection efficiency during was 70% during 2009, a considerable improvement from efficiencies of 28% in 2007 and 57% in 2008 (Sebring et al. 2009, 2010).

Table 3. Number of control PIT tags planted and number detected on colonies of various avian species throughout the Columbia River basin during 2009. Recoveries sites and avian colonies are listed in ascending order of distance from the Columbia River mouth.

		Control tags (N)		Detection efficiency
Recovery site	Avian colony	Detected	Planted	(%)
Columbia River estuary				
East Sand Island	Brandt's Cormorant	88	100	88.0
	Double-crested cormorant	759	1,000	75.9*
	Caspian tern	549	600	91.5
	Gull	40	200	20.0
Rice Island	Gull	65	200	32.5
Lake Celilo (The Dalles Dam reservoir)				
Miller Rocks Island	Gull	156	200	78.0
Lake Umatilla (John Day Dam reservoir)				
Rock Island	Caspian tern	84	100	84.0
Lake Wallula (McNary Dam reservoir)				
Badger Island	Am. White Pelican	170	200	85.0
Crescent Island	Caspian tern	285	400	71.5
	Gull	155	200	77.5
Foundation Island	Double-crested cormorant	291	400	72.8
Columbia Plateau				
Goose Island	Caspian tern	186	400	46.5
Banks Lake	Caspian tern	67	100	67.0

* A mean detection efficiency of 75.9% on the East Sand Island cormorant colony yielded a value adjusted for proportional recovery of PIT tags by nesting habitat type of 70.4%.

We found a significant temporal relationship between the percentage of control tags detected and date of planting for Caspian tern colonies on Crescent and Goose Island in the Potholes Reservoir, but not on East Sand Island (Appendix Figure 7). Therefore, we used linear regression models to interpolate weekly temporal changes in detection efficiency during the breeding season for Caspian tern colonies on Crescent Island and Potholes Reservoir.

As described above, detection efficiency estimates for the double-crested cormorant colonies on East Sand Island were calculated using a new technique in 2009.

Both prior to and after the nesting season, we calculated the percentage of control tags recovered by habitat type. Resulting detection efficiencies were then weighted by the proportion of cormorants nesting on that habitat type. Mean non-weighted detection efficiency on the East Sand Island double-crested cormorant colony was 75.9%, while mean weighted detection efficiency was 70.4%.

Colony-Specific Predation

We measured predation rates of avian colonies in Potholes Reservoir, Lake Wallula (McNary Dam reservoir), the Columbia River Gorge, and the Columbia River estuary using the nearest upstream detection site as an index of fish vulnerable to avian predation.

Predation by Caspian terns nesting on Goose Island in the Potholes Reservoir was less than 5% for spring/summer-run Chinook salmon from the upper Columbia ESUs throughout the entire migration season (Appendix Figure 1). Sockeye salmon was the least vulnerable species. However, predation rates by this avian colony exceeded 10% for steelhead during several weeks during late May and early June. For upper Columbia River steelhead detected at Rock Island Dam, weekly predation rates by avian predators nesting in McNary Dam reservoir were less than 5% during all weeks except in early June. In contrast, weekly predation of upper Columbia River sockeye salmon was less than 1% (Appendix Figure 2). The majority of avian predation on upper Columbia River fish was by terns, although gulls consumed significant proportions of fish in comparison to other avian predators nesting in this river reach during certain periods.

Weekly predation rates for fish detected at dams in the lower Snake River yielded results similar to those for upper Columbia River fish. Weekly predation rates were generally less than 5% for all salmon species throughout the migration season, yet predation rates of Snake River steelhead exceeded 10% during several weeks (Appendix Figure 3). Greater proportions of Snake River fish, particularly steelhead and fall Chinook salmon, were consumed by terns and cormorants relative to other avian predators. Weekly predation rates of fish detected passing McNary or John Day Dams and consumed by gulls nesting on Miller Rocks Island were 1% or less for all species of salmon, with the exception of steelhead (Appendix Figure 4). Predation rates of steelhead by gulls exceeded 1% during nearly all weeks and were approximately 5% late in the migration season.

Weekly predation rates by birds nesting on East Sand Island on all species of salmon and steelhead detected passing Bonneville Dam exceeded 5% throughout most of the migration season (Appendix Figure 5). Predation rates of steelhead detected passing Bonneville Dam exceeded 15% through mid-June, and was primarily the result of consumption by terns. Consumption of spring/summer and unknown run Chinook salmon was more equally distributed among terns and cormorants, although the majority of fall Chinook salmon were consumed by cormorants. Weekly predation rates on sockeye salmon were generally less than 5% during their short migration period. Weekly predation rates of transported fish were similar to those of inriver migrants with few notable exceptions (Appendix Figure 6).

For steelhead transported early in the migration season, predation rates were considerably lower than those of fish detected at Bonneville Dam (in-river migrants); however, for steelhead transported during the peak of the migration season, predation rates were similar to those of in-river migrants. Overall predation rates were not significantly different between transported and in-river migrant steelhead ($P = 0.29$). Likewise, we did not observe significantly different predation rates between transported and in-river migrant spring/summer Chinook ($P = 0.92$), fall Chinook ($P = 0.32$), unknown Chinook ($P = 0.27$), or sockeye salmon ($P = 0.68$). Higher predation rates on transported fall Chinook salmon were observed early during the migration season, when the majority of fish consumption was by cormorants.

Tagging of Lower Columbia River Salmon Stocks

We PIT-tagged a total of 12,116 subyearling fall Chinook salmon at four LCR hatcheries from early May through mid-June 2009 (Table 4). Records obtained from PTAGIS showed that a total of 26,120 PIT-tagged hatchery subyearling fall Chinook salmon from various upstream release sites were detected at Bonneville Dam from April through September 2009. For avian predators nesting on East Sand Island, mean adjusted predation on LCR-released subyearlings was 23.2%, similar to rates observed during previous years (Ryan et al. 2006, 2007; Sebring et al. 2009, 2010).

Weekly predation rates of subyearlings released into the LCR were significantly different ($P < 0.05$) than those of fish detected passing Bonneville Dam (mean 6.4%). A larger proportion of LCR-released fish were consumed by cormorants than terns (78% by cormorants and 22% by terns). This was also true for subyearlings detected passing Bonneville Dam (69% by cormorants, 31% by terns), although the difference was not significant ($P = 0.24$).

For subyearling Chinook salmon detected at Bonneville Dam, weekly predation rates of Spring Creek Hatchery tule detected early in the migration season were not significantly different than those of upriver brights detected later in the season ($P = 0.43$; Figure 2). A larger proportion of hatchery tule than upriver brights were consumed by double-crested cormorants, but the difference was not significant ($P = 0.05$).

Table 4. Numbers released and consumed of PIT-tagged subyearling fall Chinook and coho salmon. Fish were either released from hatcheries and net pens (np) in the LCR or detected at Bonneville Dam and subsequently consumed by terns and cormorants on East Sand Island. Groups are listed in chronological order of release date. Predation rates are adjusted for detection efficiency by colony.

		Releases	Predations (N)		Estimated predation rate (%)		
Species	Location of release or detection	Fish (N)	Caspian tern	Double-crested cormorant	Caspian Terns	Double-crested cormorant	LCR
Fall Chinook salmon	Big Creek	3,038	82	427	2.9	20.1	**23.0**
	Skipanon River	3,162	184	346	6.6	16.4	**23.0**
	Deep River (np)	2,902	169	434	5.8	19.6	**25.4**
	Kalama Falls	3,014	143	326	5.4	16.0	**21.4**
	Bonneville Dam	25,857	344	642	1.5	6.6	**8.1**
Coho salmon	Blind Slough (np)	2,018	77	262	4.1	15.8	**20.0**
	Deep River (np)	2,027	47	321	2.5	19.3	**21.8**
	Skipanon River	2,082	11	70	0.6	4.2	**4.7**
	Bonneville Dam	4,093	174	44	5.7	1.2	**6.9**

We also PIT-tagged a total of 6,127 coho salmon from three hatcheries during late April and early May 2009. Coho salmon were released into the LCR several weeks prior to the arrival of considerable numbers of fish at Bonneville Dam. Mean size of coho salmon released to the LCR was similar to that of coho salmon released from Blind Slough and Deep River net pens (151 and 148 mm, respectively), but greater than that of Warrenton Hatchery coho (80 mm). Mean avian predation was approximately 20% for coho salmon released from Blind Slough and Deep River net pens but was substantially less for those released from Warrenton Hatchery (5%).

Predation rates of coho salmon released in the LCR were significantly different ($P = 0.03$) than those of fish detected passing Bonneville Dam. A larger proportion of these coho were consumed by cormorants than terns (90% cormorants, 10% terns). However, for coho salmon detected at Bonneville Dam, a larger proportion was consumed by terns than cormorants (20% cormorants, 80% terns). Predation rates for coho salmon released into the LCR versus those detected passing Bonneville Dam were significantly different ($P < 0.05$).

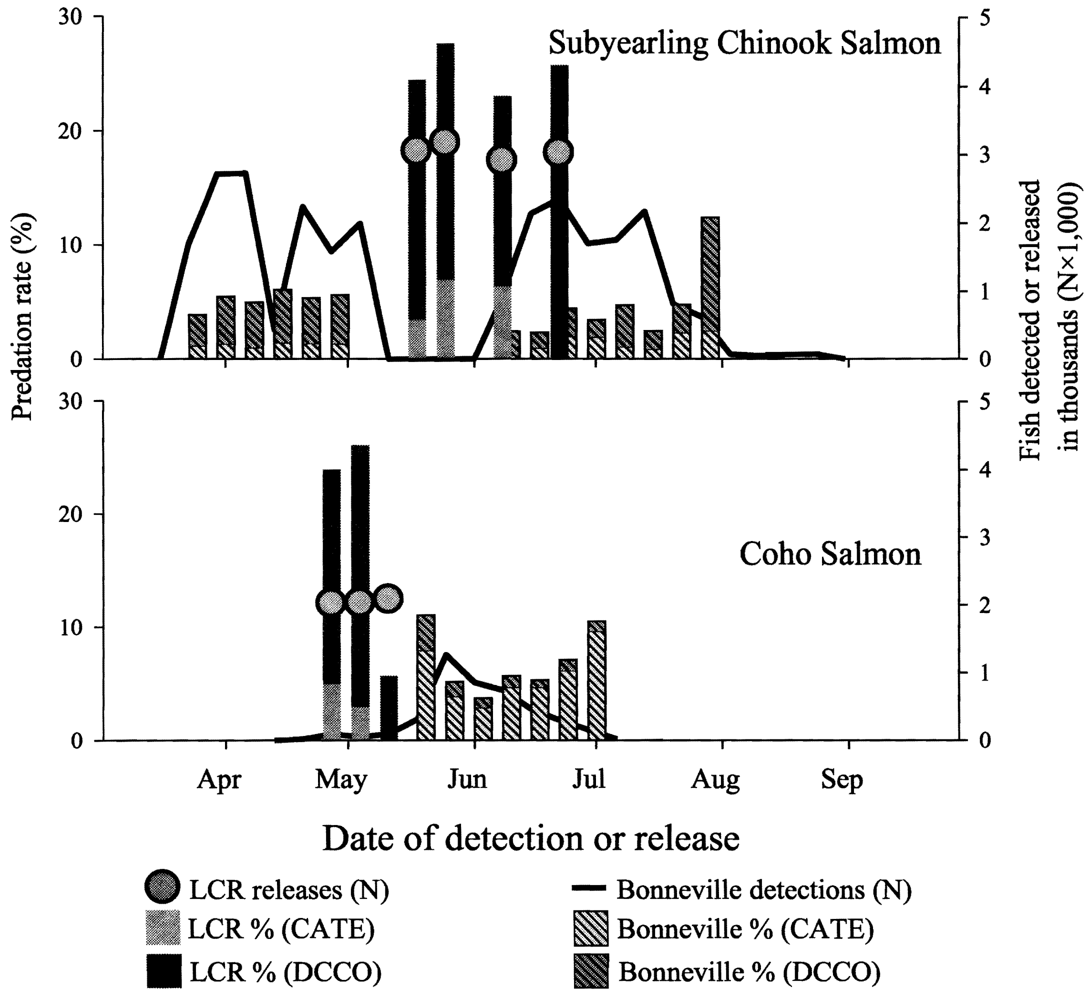

Figure 2. Seasonal predation rates by Caspian terns (CATE) and double-crested cormorants (DCCO) nesting on East Sand Island of subyearling fall Chinook and coho salmon released into the LCR or detected at Bonneville Dam during 2009.

Comparative Predation of Acoustic-Tagged vs. PIT-Tagged Fish

A total of 7,240 yearling Chinook salmon, 6,442 subyearling fall Chinook salmon, and 8,219 steelhead were released into the CRB with both an acoustic and PIT tag during spring 2009 (PTAGIS 2009). Of double-tagged fish, a total of 650 yearling Chinook salmon, 329 subyearling Chinook salmon, and 743 steelhead were detected passing Bonneville Dam. In every comparison, mean predation rates for double-tagged fish were greater than those of fish with only a PIT tag (Table 5). However, the differences in predation rates were not statistically significant.

Table 5. Predation rates of double-tagged fish (implanted with both acoustic and PIT tags) and those fish implanted with only a PIT tag that were detected passing Bonneville Dam and recovered on East Sand Island, 2009. *P*-values and degrees of freedom are listed for the mean difference in daily predation rates.

	Subyearling Chinook salmon (16 Jun-30 Jul)	Yearling Chinook salmon (26 Apr-15 Jun)	Steelhead (26 Apr-15 Jun)
Double-tagged fish			
Bonneville Dam (N)	330	650	757
East Sand Island (N)	16	35	122
Predation rate (%)	4.8	5.4	16.1
PIT-tagged only fish			
Bonneville Dam (N)	23,356	62,029	32,089
East Sand Island (N)	788	2,877	4,575
Predation rate (%)	3.4	4.6	14.3
P-value	0.22	0.41	0.18
Degrees of freedom	41	52	52

DISCUSSION

Since 1998, NMFS has provided juvenile salmonid PIT-tag recovery data for annual assessments of vulnerability to avian predation throughout the CRB (Ryan et al. 2001, 2002, 2003, 2007; Glabek et al. 2003; Sebring et al. 2009, 2010). We continue to provide recovery data and to summarize basin-wide avian predation. While we report any relevant changes from the previous year, our focus in recovery effort is now on the specific avian colonies with potential management implications. In 2009, these colonies were the primary PIT-tag detection sites on islands in the Columbia River estuary and in the McNary Dam reservoir. Annual collation of deposited PIT tags on these colonies provides an index to help determine the success or failure of management strategies for reducing the impact of avian predators on juvenile salmonids in the CRB.

Our recovery of control tags placed on avian breeding colonies in 2009 yielded detection efficiency estimates consistent with those measured during 2007 and 2008. Our efforts to reduce collision of tag codes on avian breeding colonies with large densities of PIT tags using shielding and a modified coil design were successful. Detection efficiency measurements for the cormorant colonies on East Sand Island in particular were the highest reported to date. Detection efficiency measurements on Caspian tern colonies on Crescent and East Sand Islands remained high and consistent with results from previous years, although they were less than 50% on Goose Island in the Potholes Reservoir. Additional effort may be necessary at Goose Island due to increasing numbers of terns nesting at this location.

In general, predation rates for LCR subyearling fall Chinook and coho salmon were considerably greater than for those detected at Bonneville Dam. In addition, greater proportions of both LCR subyearling Chinook and LCR coho salmon were consumed by double-crested cormorants than by other bird species. For two of the three groups of PIT-tagged LCR coho salmon, we observed generally high predation rates that were similar to those of subyearling Chinook salmon. Proportional consumption of LCR-released and Bonneville-detected coho salmon by avian predators was significantly different. These differences in vulnerability to predation may reflect differences in behavior, release timing, and duration of estuary residency. These data indicate critical disparities in relative vulnerability of LCR-released salmonids to avian predation.

As in previous years, our results indicated that for subyearling fall Chinook salmon, predation rates for LCR stocks were much greater than those for upriver bright stocks originating upstream of Bonneville Dam (Ryan et al. 2006; Sebring et al. 2008, 2009). We found that for subyearling fall Chinook salmon migrating through the estuary during the same period, stocks originating in the LCR were nearly three times more likely to be consumed by avian predators than stocks originating upstream from Bonneville Dam. However, predation rates on subyearling Chinook salmon originating from Spring Creek National Fish Hatchery, located approximately 40 rkm upstream of Bonneville Dam, were generally lower and less variable than those measured during 2008. Spring Creek Hatchery subyearlings are known to rear in the estuary for extended periods prior to ocean entry (Teel et al. 2009). One possible explanation for the lower predation on this release group during 2009 is that different conditions in the estuary may have resulted in decreased usage of habitats within the foraging range of avian predators.

For LCR and upriver bright stocks of PIT-tagged subyearling Chinook salmon, we theorized that different migration and residence timing in the estuary may have resulted in different vulnerabilities to avian predators. In 2009, for the second year, large numbers of tule stock subyearling Chinook salmon were reared at Spring Creek Hatchery. Similar releases are scheduled annually through 2010 and will provide additional fish to compare with those released into the LCR. Because of their high vulnerability to avian predation, tule subyearling fall Chinook salmon can provide an effective indicator of success in evaluating abatement actions intended to protect threatened and endangered salmonid populations.

During the early 2000s, the combined catch of adult fall Chinook salmon in Oregon coastal waters and Columbia River inland waters was estimated at 41% of the annual North American catch and was valued at 22 million dollars (Mann et. al 2005). Though management decisions frequently focus on threatened salmonid stocks in the upper Columbia and Snake River basins, it is also important to consider lower river stocks, which are acutely vulnerable to avian predation. Management action to relocate avian colonies outside the estuary may benefit all salmonid migrants in the CRB.

The use of surgically implanted acoustic tags as a method to investigate spatially explicit migration behavior of juvenile fish has increased in recent years. This has also led to greater scrutiny of the effects of acoustic tags on fish behavior (Adams et al. 1998b; Martinelli et al. 1998; Hockersmith et al. 2003) and survival (Lacroix et al. 2004; Hall et al. 2009; Rub et al. 2009), either due to the presence of tags or associated implantation procedures. Studies to evaluate tag effects have included some comparisons of predation rates between Chinook salmon implanted with both acoustic and PIT tags versus those with only a PIT tag. Cohorts were released at Lower Granite Dam, but the numbers of these fish found on avian colonies provided small sample sizes for evaluation and did not reveal significant differences in rates of avian predation between tag types (Rub et al. 2009).

In contrast, our recoveries in 2008 of PIT tags from fish detected passing or released from Bonneville Dam suggested that fish implanted with both acoustic and PIT tags were significantly more vulnerable to avian predators nesting on East Sand Island than fish tagged with only the PIT tag (Sebring et al. 2010). We simplified our comparisons during 2009 by using only fish detected passing Bonneville Dam to reduce differences in tag effects of recently tagged fish versus those tagged weeks before.

In evaluations of predation rates between double-tagged and PIT-tagged fish, data from both 2008 and 2009 were compared on a daily basis throughout the migration season. Comparing differences on a daily basis provided greater statistical power to resolve subtle differences in predation rates. Our predation rate comparisons of double-tagged and PIT-tagged fish during 2008 blocked by week did not reveal significant differences (Sebring et al. 2010). Tests of predation rates blocked by week had less statistical power because fewer comparison groups were incorporated into the analysis. In 2009, we found no significant differences in predation rates between tag types for any species, although the overall avian predation rates of double-tagged fish were consistently greater than those of fish implanted with only a PIT tag.

It is possible that a delayed post-tagging effect on acoustic-tagged fish may result in slightly greater vulnerability to avian predators immediately after surgery. For fish released farther upstream (i.e., Lower Granite Dam), the effects of surgical implantation of acoustic tags may also result in tag-related mortality prior to fish entering the foraging range of birds nesting on East Sand Island. We recommend paired comparisons of PIT-tagged and double-tagged fish to be released throughout the migration season near large avian colonies such as those nesting on East Sand Island. Such comparisons will be necessary to conclusively evaluate the effect of surgical implantation of acoustic tags on vulnerability of fish to avian predation.

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APPENDIX

Detection Data Tables and Figures

Appendix Table 1. Number of PIT tag codes recovered on avian predator breeding colonies in 2009 that were not detected in previous years. The percentage of the total annual recovery is listed for each island and colony.

Recovery site	American White Pelican	Caspian tern	Double-crested Cormorant	Gull species	Mixed species	Total (N)	Percent (%)
Columbia estuary							
East Sand Island		44,655	33,938	9		78,602	66.7
Rice Island				58		58	0.0
Lake Celilo (The Dalles Dam reservoir)							
Miller Rocks Island				6,187		6,187	5.2
Lake Umatilla (John Day Dam reservoir)							
Three Mile Canyon Island				746		746	0.6
Rock Island		2,213				2,213	1.9
Lake Wallula (McNary Dam reservoir)							
Badger Island	2,924					2,924	2.5
Crescent Island		8,685		2,582	376	11,643	9.9
Foundation Island			10,141			10,141	8.6
Columbia Plateau							
Potholes Island		3,815	51			3,866	3.3
Banks Lake		68				68	0.1
Lower Granite Lake							
Lower Hog Island			1,389			1,389	1.2
Swallows Park				23		23	0.0
Total (N)	2,924	59,436	45,519	9,605	376	**117,860**	
Percent (%)	2.5	50.4	38.6	8.1	0.3		

Appendix Table 2. Actual numbers of PIT tags recovered and estimated predation rates on inriver migrant salmonids from the 2009 migration year. Recoveries were from the Caspian tern colony on Goose Island in the Potholes Reservoir. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 detections at Rock Island Dam (RIS).

		Upper Columbia River		
Species/Run	Rear type	Number recovered	RIS detections	Est. predation rate (%)
Spring/Summer Chinook salmon	Hatchery			
	Wild			
	Unknown	12	2,576	1.0
Fall Chinook salmon	Hatchery			
	Wild			
	Unknown			
Unknown Chinook salmon	Hatchery			
	Wild			
	Unknown			
Coho salmon	Hatchery			
	Wild			
	Unknown			
Steelhead	Hatchery	230	3,413	15.0
	Wild	92	1,891	10.8
	Unknown	167	2,217	16.7
Sockeye salmon	Hatchery			
	Wild			
	Unknown	2	2,059	0.2

Appendix Table 3. Actual numbers of PIT tags recovered and estimated predation rates on inriver migrant salmonids from the 2009 migration year. Recoveries were from the double-crested cormorant colony in the Potholes Reservoir. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 detections at Rock Island Dam (RIS).

		Upper Columbia River		
Species/Run	Rear type	Number recovered	RIS detections	Est. predation rate (%)
Spring/Summer Chinook salmon	Hatchery			
	Wild			
	Unknown	0	2,576	0
Fall Chinook salmon	Hatchery			
	Wild			
	Unknown			
Unknown Chinook salmon	Hatchery			
	Wild			
	Unknown			
Steelhead	Hatchery	0	3,413	0
	Wild	0	1,891	0
	Unknown	0	2,217	0
Sockeye salmon	Hatchery			
	Wild			
	Unknown	0	2,059	0

Appendix Table 4. Actual numbers of PIT tags recovered and estimated predation rates on inriver migrant salmonids from the 2009 migration year. Recoveries were from the double-crested cormorant colony on Foundation Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 detections at Rock Island Dam (RIS) or Ice Harbor (ICH) and Lower Monumental Dams (LMN).

		Upper Columbia River			Snake River		
Species/Run	Rear type	Number recovered	RIS detections	Est. predation rate (%)	Number recovered	ICH and LMN detections	Est. predation rate (%)
Spr/Sum Chinook salmon	Hatchery				181	30,775	0.7
	Wild				34	8,133	0.7
	Unknown	0	2,576	0			
Fall Chinook salmon	Hatchery				170	46,587	0.6
	Wild						
	Unknown				8	1,806	0.9
Unknown Chinook salmon	Hatchery				144	17,738	0.9
	Wild				37	5,969	0.7
	Unknown				6	306	2.9
Coho salmon	Hatchery				1	321	1.1
	Wild						
	Unknown						
Steelhead	Hatchery	5	3,413	0.2	756	56,620	1.9
	Wild	0	1,891	0	142	10,825	1.9
	Unknown	1	2,217	0.1			
Sockeye salmon	Hatchery				59	5,651	1.1
	Wild						
	Unknown	0	2,059	0			

Appendix Table 5. Actual numbers recovered and estimated rates of predation on in-river migrating PIT-tagged salmonids from the 2009 migration year. Recoveries were from the Caspian tern colony located on Crescent Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 detections at Rock Island Dam (RIS) or Ice Harbor (ICH) and Lower Monumental Dams (LMN).

		Upper Columbia River			Snake River		
Species/Run	Rear type	Number recovered	RIS detections	Est. predation rate (%)	Number recovered	ICH and LMN detections	Est. predation rate (%)
Spr/Sum Chinook salmon	Hatchery				170	30,775	1.0
	Wild				56	8,133	1.3
	Unknown	0	2,576	0			
Fall Chinook salmon	Hatchery				219	46,587	0.7
	Wild						
	Unknown				48	1,806	2.8
Unknown Chinook salmon	Hatchery				141	17,738	1.4
	Wild				42	5,969	1.3
	Unknown				3	306	2.3
Coho salmon	Hatchery				4	321	1.7
	Wild						
	Unknown						
Steelhead	Hatchery	37	3,413	1.5	795	56,620	4.4
	Wild	25	1,891	1.9	357	10,825	6.2
	Unknown	27	2,217	1.7			
Sockeye salmon	Hatchery				13	5,651	0.5
	Wild						
	Unknown	2	2,059	0.1			

Appendix Table 6. Actual and estimated percentages of migration year 2009 in-river migrating PIT-tagged salmonids recovered from the California gull colony located on Crescent Island. Numbers of PIT tags recovered and predation rates are separated by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 detections at Rock Island Dam (RIS) or Ice Harbor (ICH) and Lower Monumental Dams (LMN).

		Upper Columbia River			Snake River		
Species/Run	Rear type	Number recovered	RIS detections	Est. predation rate (%)	Number recovered	ICH and LMN detections	Est. predation rate (%)
Spr/Sum Chinook salmon	Hatchery				19	30,775	0.1
	Wild				4	8,133	0.2
	Unknown	0	2,576	0			
Fall Chinook salmon	Hatchery				25	46,587	0.1
	Wild						
	Unknown				1	1,806	0.1
Unknown Chinook salmon	Hatchery				22	17,738	0.1
	Wild				2	5,969	<0.01
	Unknown				0	306	0
Coho salmon	Hatchery				0	321	0
	Wild						
	Unknown						
Steelhead	Hatchery	30	3,413	1.1	243	56,620	0.6
	Wild	5	1,891	0.3	46	10,825	0.5
	Unknown	27	2,217	1.6			
Sockeye salmon	Hatchery				7	5,651	0.1
	Wild						
	Unknown	1	2,059	0.1			

Appendix Table 7. Actual numbers recovered and estimated rates of predation on in-river migrating PIT-tagged salmonids from the 2009 migration year. Recoveries were from the American white pelican colony located on Badger Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 detections at Rock Island Dam (RIS) or Ice Harbor (ICH) and Lower Monumental Dams (LMN).

		Upper Columbia River			Snake River		
Species/run type	Rear type	Number recovered	RIS detections	Est. predation rate (%)	Number recovered	ICH and LMN detections	Est. predation rate (%)
Spring/Summer Chinook salmon	Hatchery				29	30,775	0.1
	Wild				5	8,133	0.1
	Unknown	0	2,576	0			
Fall Chinook salmon	Hatchery				14	46,587	0.1
	Wild						
	Unknown				6	1,806	0.3
Unknown Chinook salmon	Hatchery				19	17,738	0.1
	Wild				2	5,969	<0.01
	Unknown				3	306	1.1
Coho salmon	Hatchery				0	321	0
	Wild						
	Unknown						
Steelhead	Hatchery	10	3,413	0.3	133	56,620	0.3
	Wild	2	1,891	0.1	17	10,825	0.2
	Unknown	6	2,217	0.3			
Sockeye salmon	Hatchery				2	5,651	0.2
	Wild						
	Unknown	0	2,059	0			

Appendix Table 8. Actual numbers recovered and estimated rates of predation on in-river migrating PIT-tagged salmonids from the 2009 migration year. Recoveries were from the Caspian tern colony located on Rock Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 detections at McNary Dam (MCN).

		Mid-Columbia River			Upper Columbia River			Snake River		
Salmon species/run type	Rear type	Number recovered	MCN detections	Est. predation rate (%)	Number recovered	MCN detections	Est. predation rate (%)	Number recovered	MCN detections	Est. predation rate (%)
Spr/Sum Chinook	H	5	4,076	0.1	0	3,185	0	65	26,650	0.3
	W	0	304	0	0	814	0	4	4,724	0.1
	U				0	3,185	0			
Fall Chinook	H	2	1,483	0.2				4	19,517	<0.1
	W									
	U									
Unknown Chinook	H							31	13,375	0.3
	W							3	3,998	0.1
	U									
Coho	H	1	1,299	0.1	1	1,109	0.1			
	W									
	U									
Steelhead	H	3	747	0.5	2	1,443	0.2	55	12,891	0.5
	W	2	344	0.7	2	564	0.4	21	3,654	0.7
	U				3	304	1.2	1	147	0.8

Appendix Table 9. Actual numbers recovered and estimated rates of predation on in-river migrating PIT-tagged salmonids from the 2009 migration year. Recoveries were from the gull colony located on Miller Rocks Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 fish detected at John Day Dam (JDA) and McNary Dam (MCN).

		Mid-Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	Number recovered	JDA and MCN detections	Est. predation rate (%)	Number recovered	JDA and MCN detections	Est. predation rate (%)	Number recovered	JDA and MCN detections	Est. predation rate (%)
Spr/Sum Chinook salmon	H	20	6,757	0.4	10	5,509	0.2	87	34,094	0.3
	W	3	1,703	0.2	3	1,508	0.3	12	6,884	0.2
	U	1	1,273	0.1						
Fall Chinook salmon	H	10	3,076	0.4				109	34,467	0.4
	W									
	U	1	625	0.2				6	926	0.8
Unknown Chinook salmon	H							63	19,909	0.4
	W							9	5,570	0.2
	U									
Coho salmon	H	26	2,857	1.2	31	3,189	1.2			
	W									
	U									
Steelhead	H	17	2,573	0.8	23	3,670	0.8	261	26,949	1.2
	W	10	1,874	0.7	5	930	0.7	61	5,928	1.3
	U	7	706	1.3	5	599	1.1	3	322	1.2
Sockeye salmon	H				3	1,196	0.3	15	1,768	1.1
	W				1	790	0.2			
	U				1	379	0.3			

Appendix Table 10. Actual numbers recovered and estimated rates of predation on in-river migrating PIT-tagged salmonids from the 2009 migration year. Recoveries are from the Caspian tern colony located on East Sand Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 fish detected at Bonneville Dam (BON).

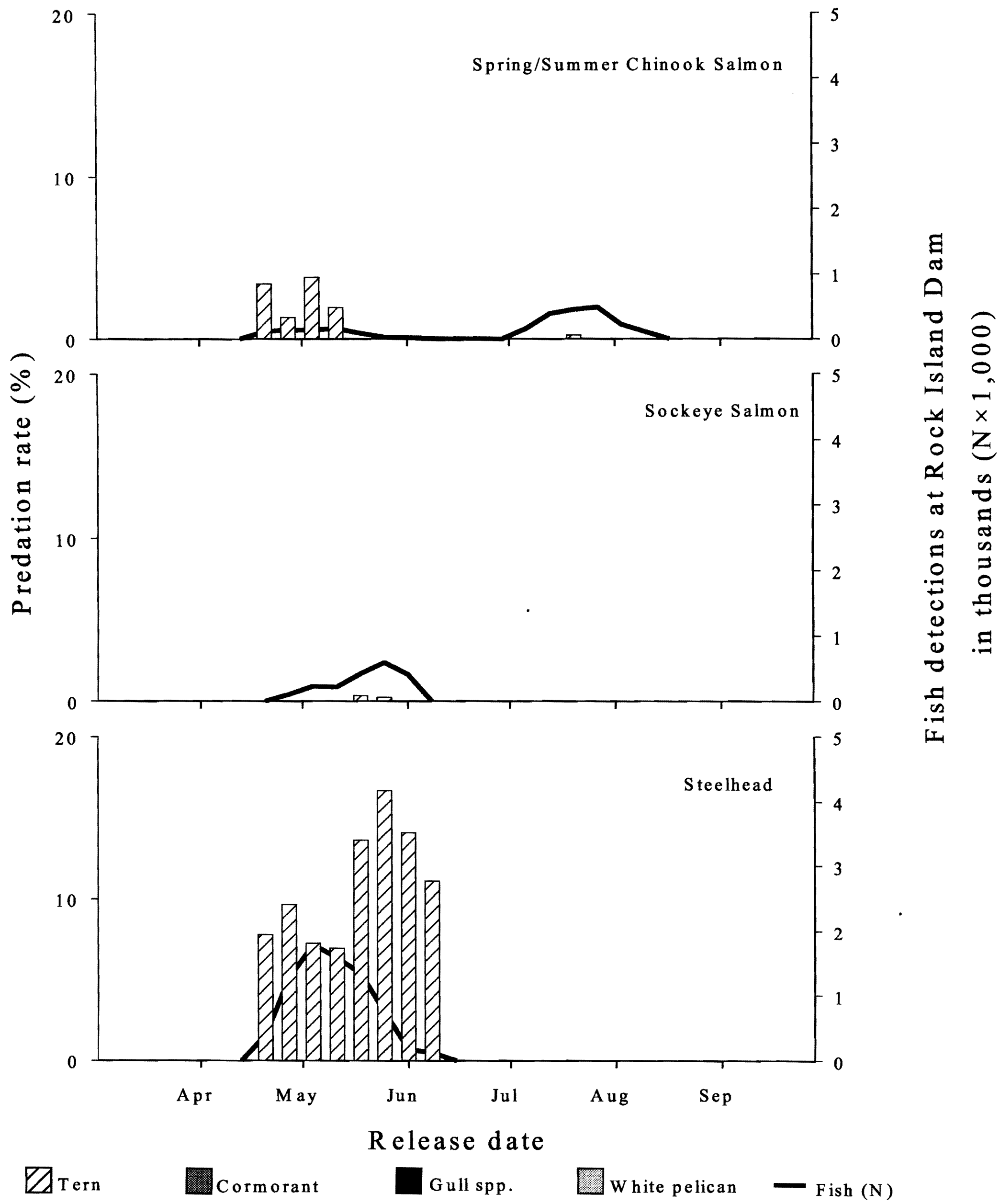
		Lower Columbia River			Mid-Columbia River			Upper Columbia River			Snake River		
Salmon species/ run type	Rear type	Number recovered	BON detections	Est predation rate (%)	Number recovered	BON detections	Est predation rate (%)	Number recovered	BON detections	Est predation rate (%)	Number recovered	BON detections	Est predation rate (%)
Spr/Sum Chinook	H	63	10,971	0.6	204	8,790	2.5	65	2,781	2.6	500	15,796	3.5
	W	12	5,830	0.2	11	750	1.6	3	618	0.5	26	2,153	1.3
	U				14	657	2.3						
Fall Chinook	H	592	13,722	4.7	224	17,251	1.4				208	16,516	1.4
	W							5	183	3.0			
	U				10	329	3.3	4	213	2.1	8	157	5.6
Unknown Chinook	H				263	11,022	2.6				477	13,114	4.0
	W	12	4,237	0.3							16	1,858	0.9
	U				112	5,733	2.1				5	144	3.8
Coho	H	135	6,127	2.4	89	1,588	6.1	94	2,582	4.0			
	W												
	U												
Steelhead	H	155	3,204	9.1	372	3,632	11.2	246	1,930	13.9	1,873	20,884	9.8
	W	117	162	3.5	152	1,894	8.8	41	458	9.8	305	2,664	12.5
	U				67	501	14.6	16	178	9.8	19	178	11.7
Sockeye	H												
	W							5	255	1.0	14	1,843	0.8
	U												

Appendix Table 11. Actual numbers recovered and estimated rates of predation on in-river migrating PIT-tagged salmonids from the 2009 migration year. Recoveries are from the double-crested cormorant colony located on East Sand Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with at least 100 fish detected at Bonneville Dam (BON).

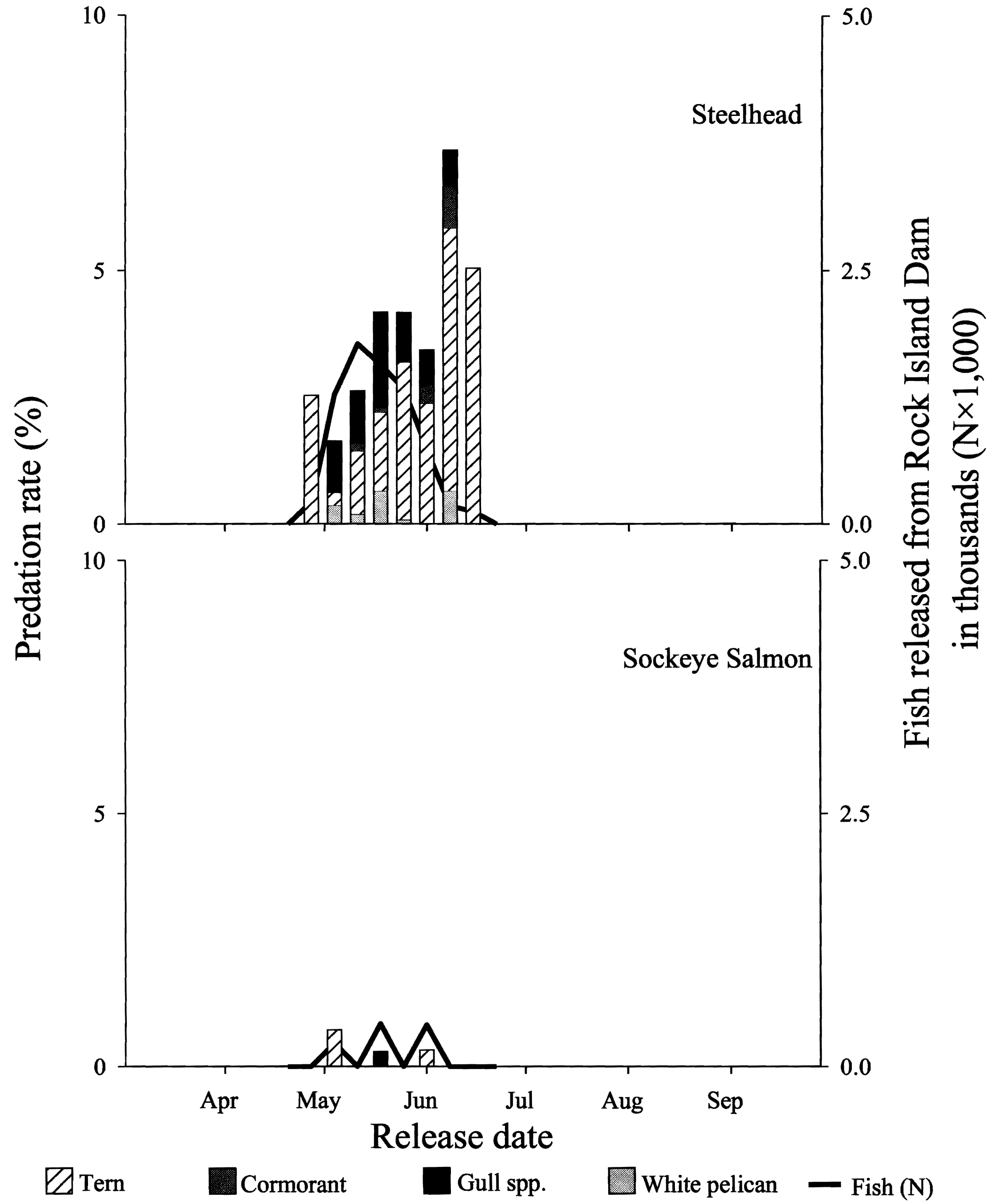
		Lower Columbia River			Mid-Columbia River			Upper Columbia River			Snake River		
Salmon species/ run type	Rear type	Number recovered	BON detections	Est predation rate (%)	Number recovered	BON detections	Est predation rate (%)	Number recovered	BON detections	Est predation rate (%)	Number recovered	BON detections	Est predation rate (%)
Spr/Sum Chinook	H	22	10,971	0.3	127	8,790	2.1	21	2,781	1.1	342	15,796	3.1
	W	12	5,830	0.2	15	750	2.8	3	618	0.7	49	2,153	3.2
	U				9	657	1.9						
Fall Chinook	H	1,701	13,722	17.6	570	17,251	4.7				236	16,516	2.0
	W							1	213	0.7			
	U				6	329	2.6				2	157	1.8
Unknown Chinook	H				197	11,022	2.5				312	13,114	3.4
	W	21	4,237	0.7							39	1,858	3.0
	U				97	5,733	2.4				1	144	1.0
Coho	H	670	6,127	15.5	25	1,588	2.2	14	2,582	0.8			
	W												
	U												
Steelhead	H	134	3,204	5.9	136	3,632	5.3	41	1,930	3.0	1097	20,884	7.5
	W	4	162	0.0	69	1,894	5.2	18	458	5.6	134	2,664	7.1
	U				28	501	7.9	2	178	1.6	6	178	4.8
Sockeye	H												
	W							7	255	3.9			
	U							3	206	2.1			

Appendix Table 12. Actual numbers recovered and estimated predation rates for transported PIT-tagged salmonids from the 2009 migration year. Recoveries were from the Caspian tern and double-crested cormorant colonies located on East Sand Island. Data are shown by ESU and only presented for species and rear types (hatchery, wild, unknown) with more than 100 fish released from transport barges.

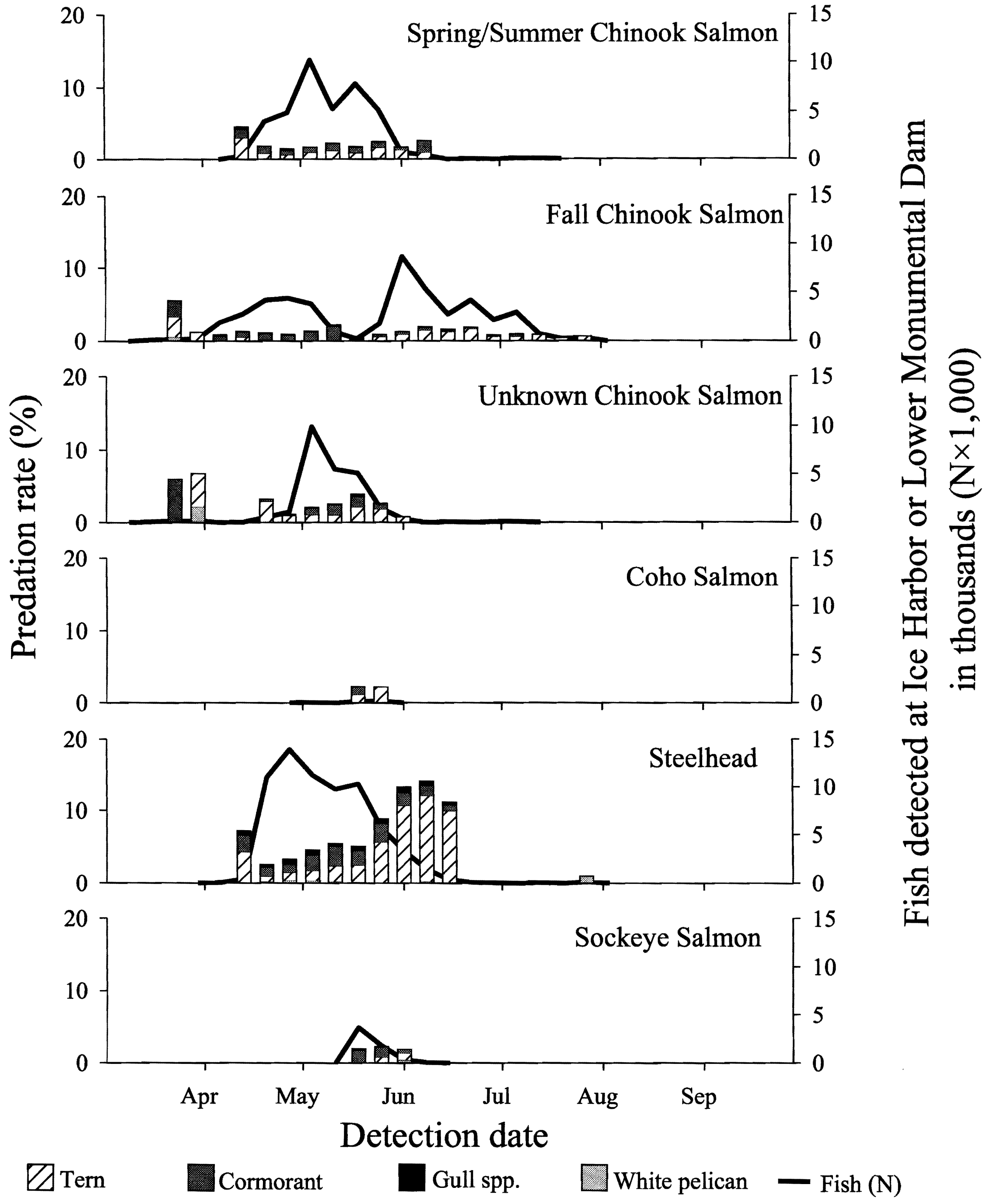
		PIT tags recovered (N)			Estimated predation rate (%)		
Species/Run	Rear type	Caspian Tern	Double-crested cormorant	Transport barge releases	Caspian Tern	Double-crested cormorant	Total
Spr/Sum Chinook salmon	Hatchery	1,406	1,035	46,957	3.3	3.1	6.4
	Wild	41	76	4,937	0.9	2.2	3.1
	Unknown						
Fall Chinook salmon	Hatchery	440	799	41,443	1.2	2.7	3.9
	Wild						
	Unknown						
Unknown Chinook salmon	Hatchery	47	31	1,045	4.9	4.2	9.1
	Wild	157	287	15,545	1.1	2.6	3.7
	Unknown						
Steelhead	Hatchery	4,390	1,708	43,202	11.0	5.6	16.7
	Wild	1,260	411	14,485	9.5	4.0	13.5
	Unknown						
Sockeye salmon	Hatchery	68	293	10,367	0.7	4.0	4.7
	Wild						
	Unknown						



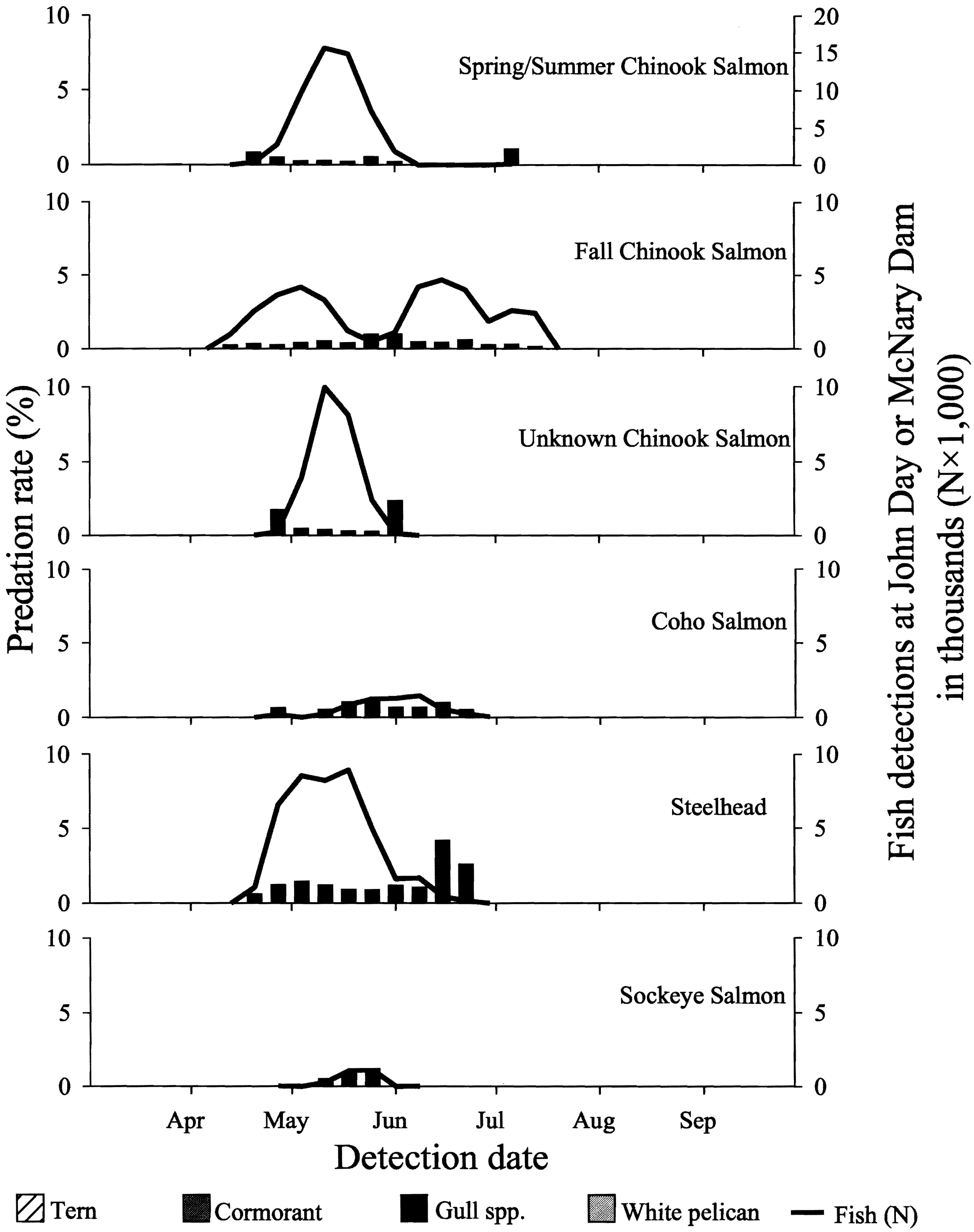
Appendix Figure 1. Weekly predation rate estimates adjusted for detection efficiency of PIT-tagged salmonids previously detected at Rock Island Dam and recovered from the Caspian tern colony on Goose Island located in the Potholes Reservoir.



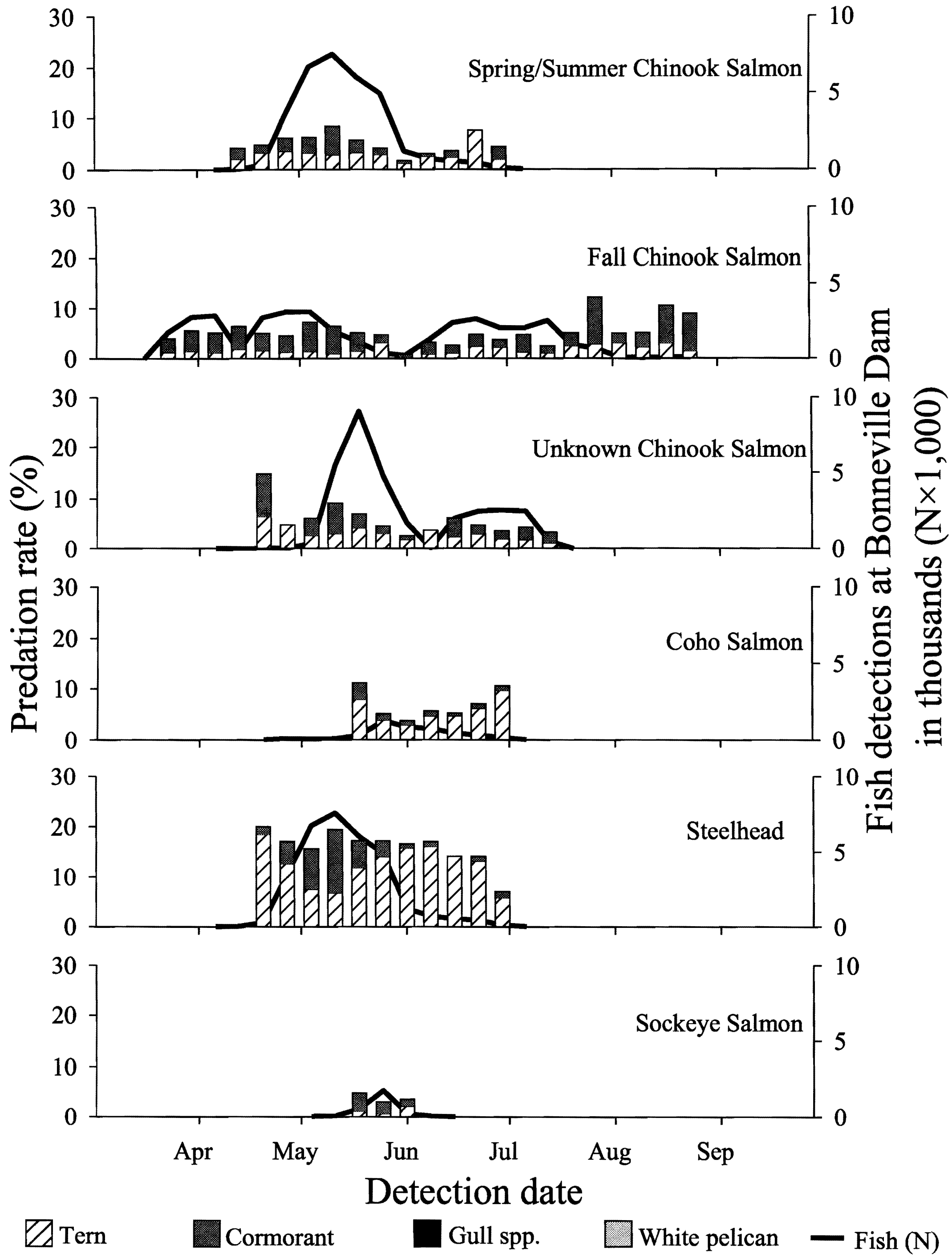
Appendix Figure 2. Weekly predation rate estimates adjusted for detection efficiency of PIT-tagged salmonids previously detected at Rock Island Dam and recovered from avian colonies located on Badger Island, Crescent Island, and Foundation Island.



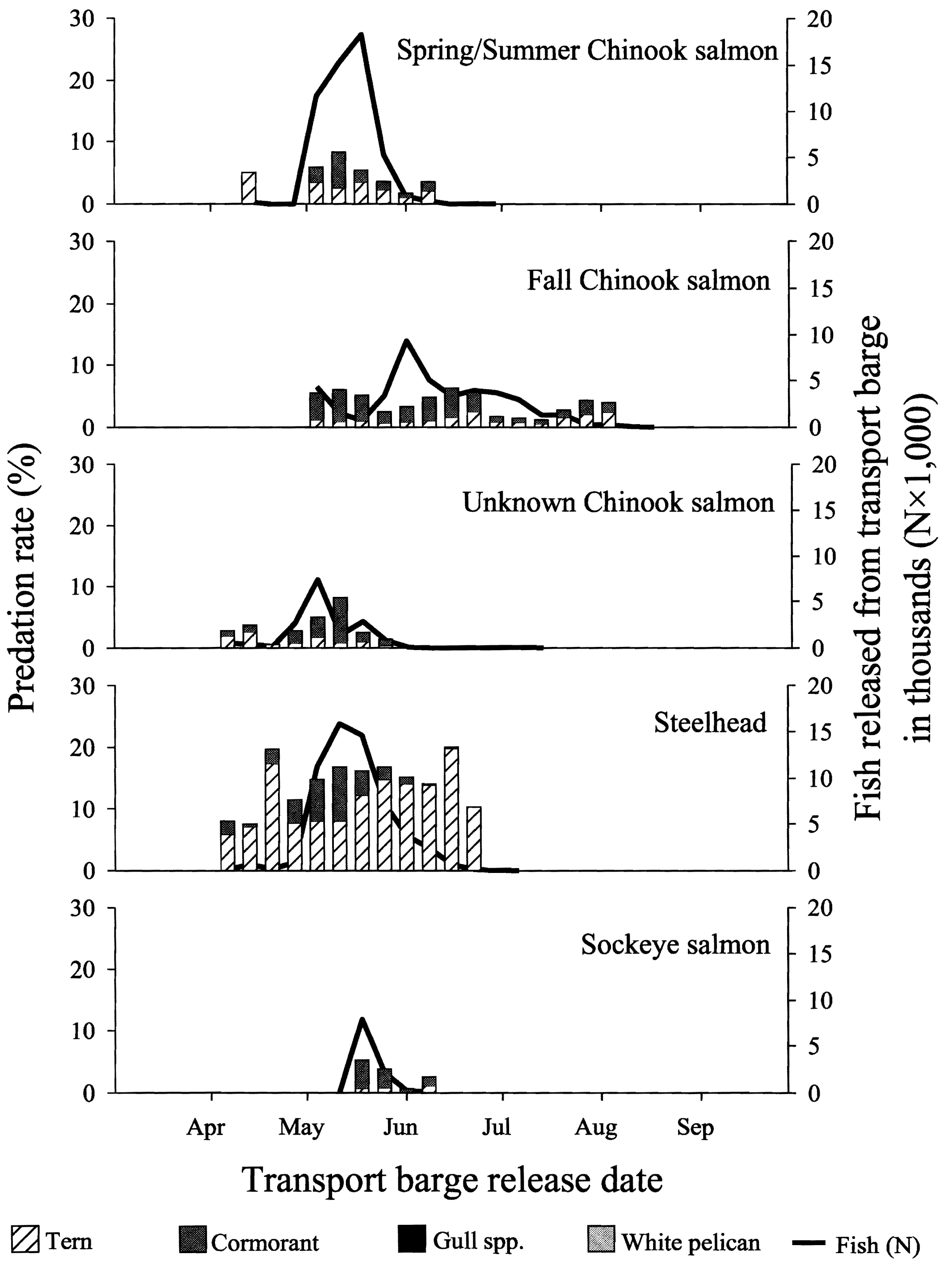
Appendix Figure 3. Weekly predation rate estimates adjusted for detection efficiency of PIT-tagged salmonids previously detected at Ice Harbor Dam and/or Lower Monumental Dam and recovered from the avian colonies located on Badger Island, Crescent Island, and Foundation Island.



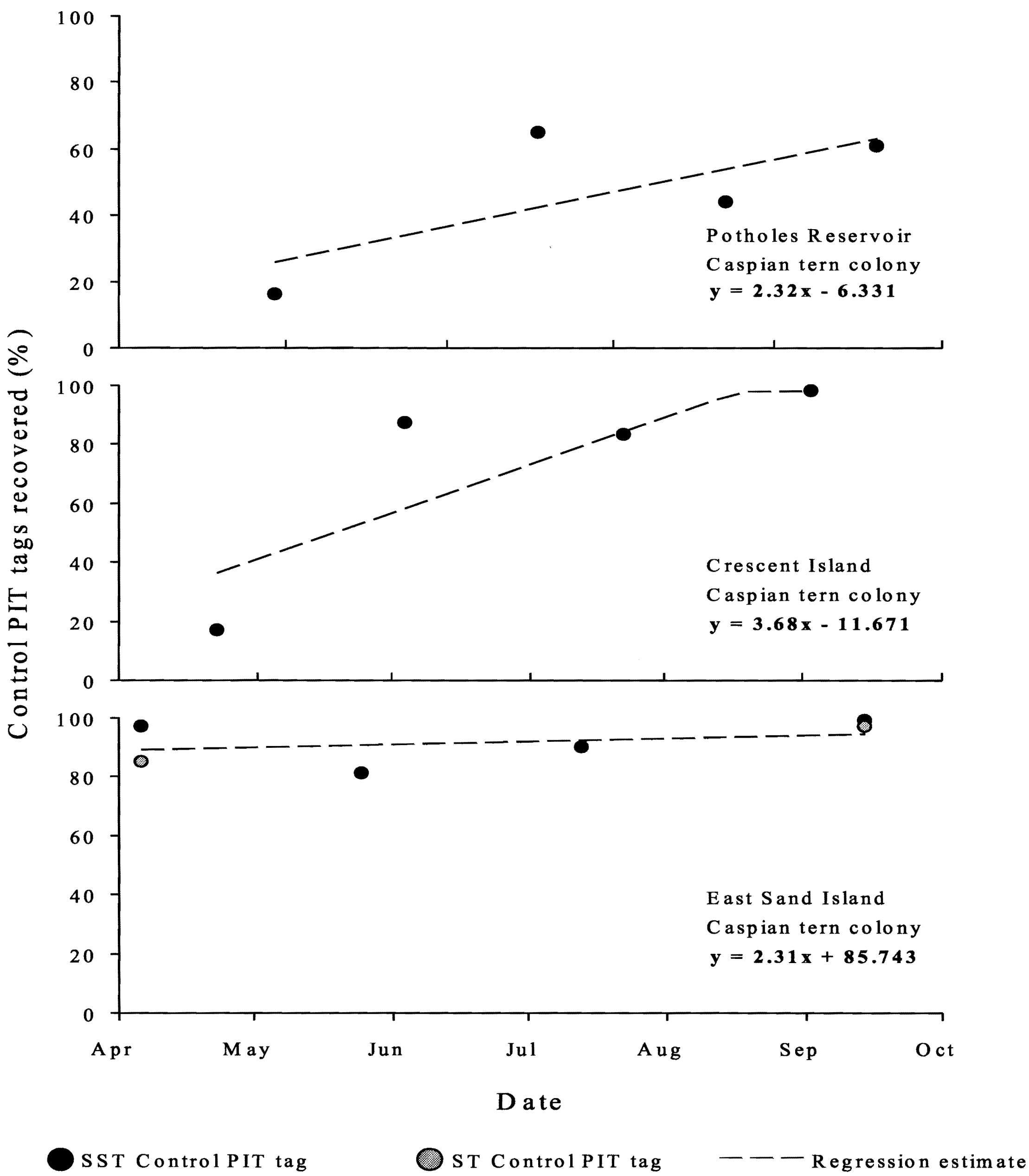
Appendix Figure 4. Weekly predation rate estimates adjusted for detection efficiency of PIT-tagged salmonids previously detected at John Day Dam and/or McNary Dam and recovered from the Miller Rocks gull colony.



Appendix Figure 5. Weekly predation rate estimates adjusted for detection efficiency of PIT-tagged salmonids previously detected at Bonneville Dam and recovered from the East Sand Island Caspian tern and double-crested cormorant colonies.



Appendix Figure 6. Weekly predation rate estimates adjusted for detection efficiency of PIT-tagged salmonids previously released from transport barges and recovered from the East Sand Island Caspian tern and double-crested cormorant colonies.



Appendix Figure 7. Linear regression equations were used to adjust weekly predation rate estimates not exceeding actual proportion of control tags recovered for Caspian tern colonies where a significant seasonal effect on PIT-tag recoveries was demonstrated (i.e., Crescent Island and Potholes Reservoir). Each point represents the percentage of control PIT tags detected out of 100 released.