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Fish Ecology Division

Northwest Fisheries Science Center

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Seattle, Washington

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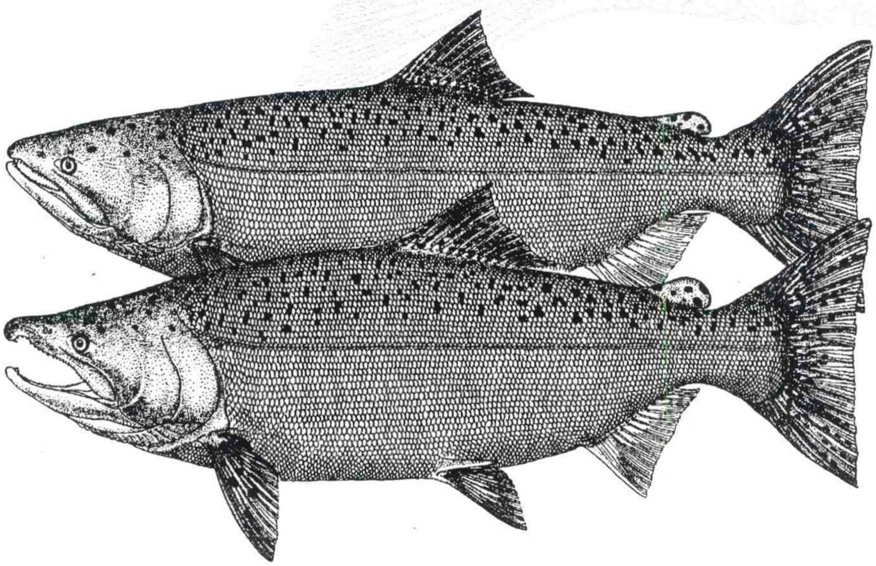

Detection of Passive Integrated Transponder (PIT) Tags on Piscivorous Avian Colonies in the Columbia River Basin, 2007

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Report of research by

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EXECUTIVE SUMMARY

In 2007, the National Marine Fisheries Service and Real Time Research, Inc. collaborated to recover passive integrated transponder (PIT) tags from juvenile Pacific salmonids *Oncorhynchus* spp. on avian colonies throughout the Columbia River Basin (CRB). Over 63,000 PIT tag codes with no previous detection on an avian colony were recovered. Of this total, over 42,000 were from fish migrating in 2007. Avian predators consumed a minimum of 3.0% of the 1.4 million PIT-tagged salmonids released into the CRB for migration during 2007. Approximately 90% of those fish were consumed either by Caspian terns *Sterna caspia* or double-crested cormorants *Phalacrocorax auritas*.

The primary PIT-tag recovery location was on East Sand Island in the Columbia River estuary, where we recovered 65% of PIT-tags from avian colonies throughout the CRB. Of PIT-tagged fish known to have survived downstream of Bonneville Dam and subsequently consumed by avian piscivores in the estuary, 9% originated from the mid-Columbia River, 24% originated from the upper Columbia River, and 61% originated from the Snake River. As in previous years, other important recovery locations were tern and gull colonies on Crescent Island and a cormorant colony on Foundation Island, both near the confluence of the Columbia and Snake Rivers. PIT tags recovered from these two mid-Columbia River islands accounted for approximately 21% of all recoveries in 2007. Sampling at other colonies in the CRB yielded an additional 14% of PIT tag codes collected.

As in previous years, we planted control PIT tags on avian colonies through the nesting season to evaluate the effectiveness of post-season PIT tag recovery. Detection of these control PIT tags in 2007 was equal to or greater than those reported in recent years. Recoveries on cormorant colonies were similar to those in previous years, ranging from 69 to 74%. Recoveries on tern colonies in 2007 were more than 20% higher than those in 2006, ranging from 69 to 90%. Operation of an improved flat-plate antenna system in 2007 likely increased detection efficiency and decreased collision of tag codes compared to 2006. It does not appear that removal of PIT tags from the East Sand Island tern colony using magnets significantly changed PIT tag density on that colony, but magnets were effective in removal of PIT tags from Crescent Island.

As in previous years, avian predators on colonies sampled for PIT-tags overall consumed a higher percentage of juvenile steelhead (11%) than any other species of PIT-tagged juvenile salmonid. In the estuary, only subyearling Chinook salmon originating in the lower Columbia River (LCR) were more vulnerable to avian piscivores than steelhead (9% and 6%, respectively) and were 3-fold higher than for non-transported subyearling

Chinook salmon originating upstream of Bonneville Dam (3%). In 2007, we PIT-tagged and released over 12,000 subyearling Chinook salmon to further document vulnerability of this stock in the estuary. Our tagging efforts for LCR fish represent 20% of the total PIT-tagged fish released in this river reach in 2007.

CONTENTS

INTRODUCTION

Since 1987, juvenile Pacific salmonids *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 the decline of salmonids 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 two million 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, Caspian tern *Sterna caspia* colonies have shifted northward from California, and by the 1980s, 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 over 14,000 breeding pairs in 2007 (Columbia Bird Research 2007). Both of these colonies are considered to be the largest for the respective species.

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 vulnerabilities of different salmonid species, run or rear types, and areas of origin (Collis et al. 2001a, Ryan et al. 2003). Initially high levels of annual salmonid consumption related to these large breeding colonies of avian piscivores were found.

These initial findings prompted management agencies to relocate the estuarine Caspian tern colony from Rice Island (freshwater reach) to East Sand Island (brackish water reach) to mitigate predation by terns (USACE 2001). PIT-tag detection efforts continued to focus on evaluating the relative vulnerability of salmonids to consumption by avian predators throughout the CRB. Presently, these efforts primarily target the larger avian colonies responsible for the majority of predation on juvenile salmonids. This approach is intended to develop data for better evaluation of management alternatives for avian colonies.

We used modified PIT-tag detection equipment (Prentice et al. 1990a,b) to recover juvenile salmonids tags from the nesting colonies in 2007. In previous years, NOAA was assisted with PIT-tag recovery efforts by Oregon State University and Real Time Research, Inc. (OSU/RTR) biologists. However, in 2007, all entities cooperated to divide recovery efforts among colonies to suit groups stationed within different geographic regions of the CRB.

In this report, we summarize the PIT-tag recovery, methodology, and general vulnerabilities of juvenile salmonids to avian predators in 2007. Data obtained during this study contributed to additional analyses of the broader aspects of avian behavior, population dynamics, bioenergetics, and species-specific vulnerabilities of juvenile salmonids to avian piscivory. These analyses of avian predation, including relative vulnerabilities of juvenile salmonids obtained by expanded PIT-tag recoveries, will be reported elsewhere.

STUDY SITE

Our study sites consisted of 15 distinct avian breeding colonies on 10 islands (Table 1). All PIT-tag sampling occurred during late summer and fall, after the breeding season had ended and birds had abandoned the 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 at rkm 959 (Figure 1). PIT-tag recovery efforts were concentrated on the largest avian predator colonies located in the Columbia estuary (Figure 2) and 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	rkm
Columbia River estuary	
East Sand Island	8
Miller Sands Island	38
The Dalles Dam Reservoir	
Miller Rocks Island	331
John Day Dam Reservoir	
Rock Island	441
McNary Dam Reservoir	
Crescent Island	510
Badger Island	512
Foundation Island	518
Ice Harbor Tailrace Island	537
Potholes Reservoir	
Goose Island	665
Upper Columbia River	
Banks Lake	959

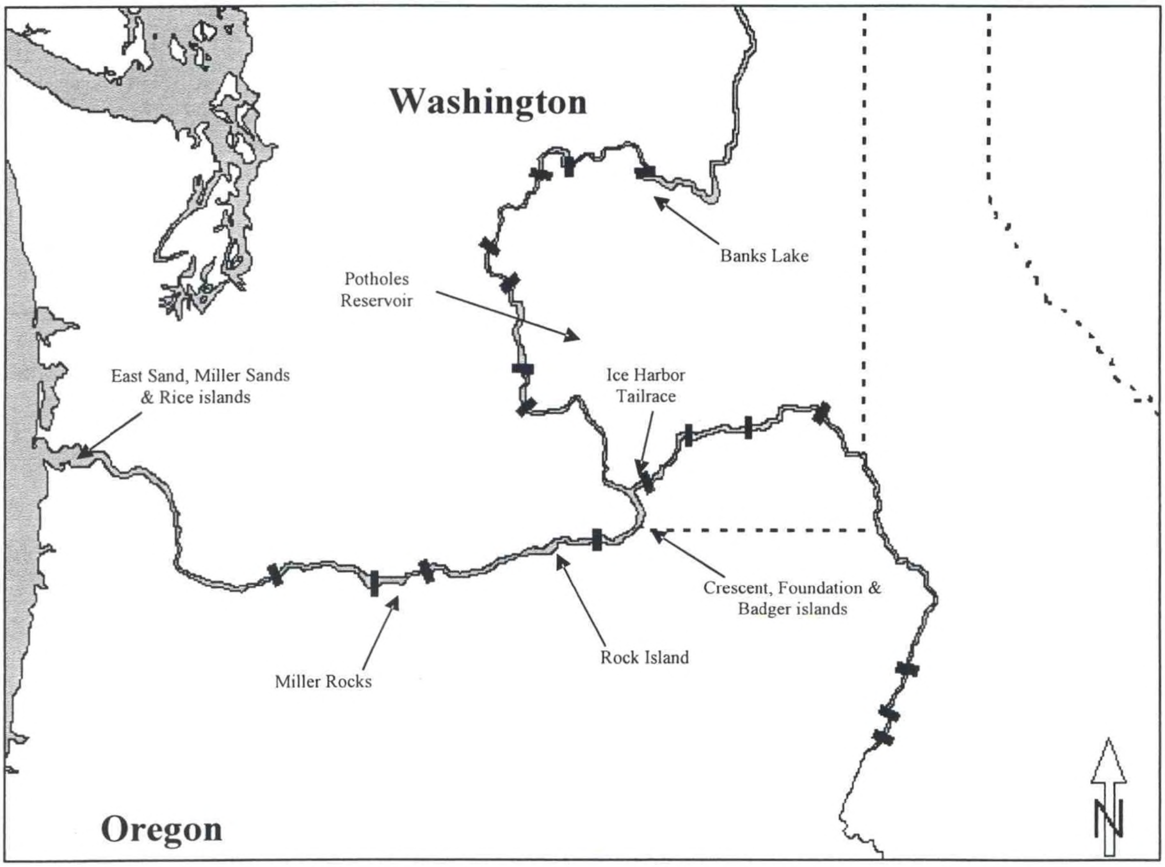

Figure 1. Location of avian predator nesting colonies and post-nesting season PIT tag collection efforts, 2007.

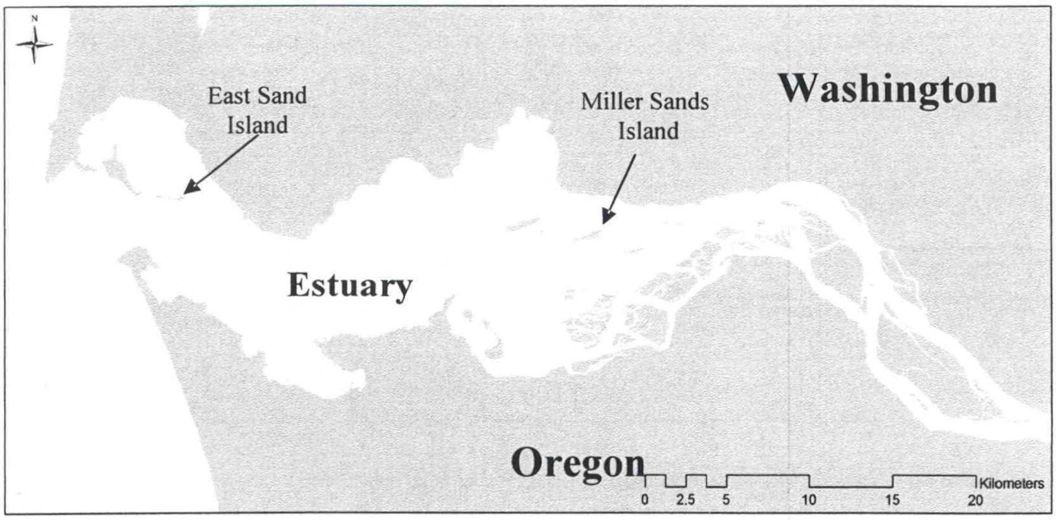

Figure 2. Islands in the Columbia River estuary where breeding colonies of avian predators were located. PIT tag recovery efforts were conducted on East Sand and Miller Sands Islands.

METHODS

PIT-Tag Recovery

In 2007, PIT-tag recovery efforts were conducted by the cooperating agencies at separate locations throughout the CRB. Tags from East Sand Island were recovered by National Marine Fisheries (NMFS) research staff based at the Point Adams Research Station located near the Columbia River estuary. NMFS staff also provided flat-plate antenna systems to assist in recovery of tags on the Crescent Island tern and gull colonies. OSU/RTR research staff focused their recovery efforts on the avian colonies in the mid- and upper Columbia River, primarily on Crescent and Foundation Islands, but also on other colonies in that region. Previous research indicated that a large proportion of PIT tags would be located on these three islands (Ryan et al. 2003, 2006, 2007), but also that several less-populated avian predator nesting colonies would have significant numbers of PIT tags (Ryan et al. 2001, 2002). These secondary colonies were located in The Dalles and John Day Dam reservoirs and near the upper Columbia River.

We used the hand-held transceivers and flat-plate antenna systems for PIT-tag detection, as described by Ryan et al. (2001). We continued to improve the design of flat-plate antenna equipment, which was used primarily on Caspian tern colonies. Design changes were needed to adjust for increased detection range of PIT tags. This increased detection range, however, can decrease detection efficiency by increasing tag collision rates in areas with high densities of PIT tags, such as Caspian tern colonies.

In 2006, detection efficiencies evaluated using control PIT tags on Crescent and East Sand Island tern colonies were significantly lower in relation to previous years due to collision of tag codes (Brännäs et al. 1994). 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 tag code is correctly read by the transceiver. Decreased detection efficiency could indicate that PIT tag density on these colonies was approaching a threshold at which the effectiveness of electronic recovery would decrease due to tag collision.

In 2006, we used a multiple-port model FS 1001M multiplex transceiver system for the first time with a six-coil flat-plate antenna (Ryan et al. 2007). In 2007, we used the multiplex transceiver with a different six-coil flat-plate. The two flat-plate antennas differed only in diameter of the antenna coil wire: in 2006, diameter of the wire was 15.2 cm, whereas in 2007, it was 7.6 cm.

The multiplexing transceiver operated by alternating power between adjacent wire coils to avoid signal interference, with power activated and deactivated to each coil in sequence (i.e., 1-6). Although the cycle was repeated with a frequency of less than one second, a brief period occurred when power was deactivated from one wire coil and not yet activated on the adjacent coil. Although this period is a fraction of a second, it could result in an otherwise functioning PIT tag signal being missed. Therefore, we advanced the tractor-mounted flat-plate antennas over avian colonies at a slow rate of speed (approximately 1 m/s) to decrease the probability of missing functioning PIT tags.

To further decrease the possibility of missed tags, we also used four single-port model FS 1001A transceivers simultaneously connected to a four-coil flat-plate antenna system. This system was designed to correct for the gap in the activation/deactivation cycle operating the six-coil multiplexing transceiver system. The four-coil system operated with continuous power (no deactivation cycle) to all four transceivers. In addition, the four-coil antenna system was constructed with lead shielding around each wire coil, which prevented signal interference between coils.

It is possible that simultaneous operation of wire coils would decrease the potential for tag-code collision and result in fewer missed PIT tag codes. We compared performance of both flat-plate systems on Crescent Island and East Sand Island tern colonies to evaluate any potential difference in performance of multiplexing and single-port system transceiver systems.

Detection Efficiency

As in previous years, we collaborated with OSU/RTR to distribute known numbers of control PIT tags at various intervals throughout the breeding season. We estimated detection efficiency by dividing the number of control PIT tags recovered by the number of control PIT tags placed on the colony. Control tags used for detection efficiency estimates on the East Sand Island cormorant colony could only be spread over limited areas. These areas did not represent the diversity of nesting substrates or the large size of the colony. Thus, parts of this cormorant colony where few PIT tags were dispersed could potentially bias detection efficiency estimates.

We corrected for this possible bias of detection efficiency on the East Sand Island cormorant colony by calculating the number of PIT tags deposited by birds nesting on experimental nesting platforms of standard dimension and known number of nests. We assumed utilization of experimental nesting platforms made no difference in likelihood of cormorants to consume PIT-tagged salmonids or deposit PIT-tags on the nesting area. We extrapolated the number of PIT tags consumed by cormorants utilizing the experimental nesting platforms to the entire population of cormorants nesting on East Sand Island. This produced an estimate of PIT tag consumption not subject to the biases of nesting substrate and colony size.

Colony-Specific Predation

We estimated predation effects from avian predators nesting on colonies in the CRB where the greatest numbers of salmonids were consumed. These included the Caspian tern and double-crested cormorant colonies on East Sand Island, as well as Caspian tern colonies on Crescent Island and double-crested cormorant colonies on Foundation Island. Detections of PIT-tags at the nearest location upstream from the colonies studied were used as an index of the numbers of PIT-tagged fish available to avian piscivores. For example, PIT-tagged fish detected at Bonneville Dam were used to evaluate the number available to avian piscivores in the Columbia estuary, whereas detections of fish at Ice Harbor (rkm 538) and Lower Monumental Dams (rkm 589) were used to evaluate numbers available in the Snake River Basin. To index the number of Columbia River fish available to avian predators in McNary Dam Reservoir, we evaluated records of fish PIT-tagged and released at Rock Island Dam (rkm 730). Release numbers were used because juvenile fish detection facilities at this location were not operated in 2007.

PIT-Tagging of Lower Columbia River Stocks

We continued PIT-tagging fish from the Lower Columbia River to evaluate avian predation by evolutionary significant unit (ESU) and distinct life history type (Narum et al. 2004). Using techniques described in Ryan et al. 2006, we PIT-tagged over 12,000 subyearling Chinook salmon in the spring and early summer at four hatcheries located on rivers flowing into the LCR. Tagging was conducted at Big Creek (rkm 49), Kalama Falls (rkm 135), North Toutle (rkm 190), and Washougal Hatcheries (rkm 225; Figure 3). Detections of these tags were used to examine whether predation rates of subyearling Chinook salmon released in or near the estuary were similar to those of stocks released further upstream. We limited comparisons of subyearling Chinook salmon to those not subjected to transportation. Predation rate comparisons were made by summarizing fish detected at Bonneville Dam during the same week when subyearling Chinook salmon from each LCR hatchery were released.

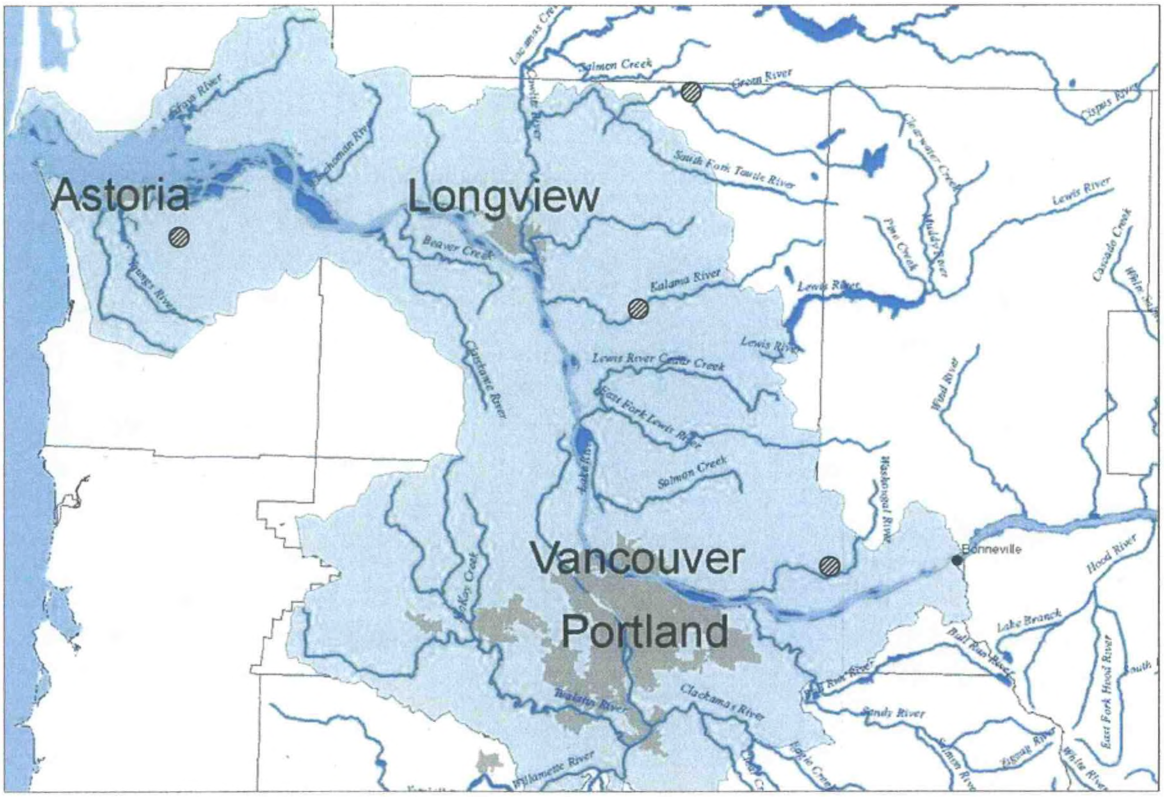

Figure 3. Approximate locations of Lower Columbia River Hatcheries (◍) where subyearling Chinook salmon were PIT-tagged.

RESULTS

PIT-Tag Recovery

Using physical and electronic recovery techniques, we collected codes for over 63,000 PIT tags that had not been previously detected on avian breeding colonies (Appendix Table 1). Over 43,000 of these tag codes were from fish listed in PTAGIS under migration year 2007 (Table 2). This total represented 3.1% of all fish released for migration in 2007, and was a minimum estimate of predation by colonial nesting avian piscivores in the CRB. When we expanded this observed total based on control tags planted on the colonies through the nesting season, we estimated that approximately 53,000 PIT-tagged fish, or about 3.6% of those released for migration in 2007, were consumed by avian predators at the primary detection locations. As in previous years, the greatest effect of avian predators occurred in the Columbia River estuary, where avian predators consumed 2% of juvenile salmonids migrating to the ocean in 2007 (Table 3).

Table 2. Numbers of 2007 migration year PIT tags recovered from breeding colonies of avian piscivores in the Columbia River Basin (42,332 total).

	Avian Colony				
River Reach and Island	Cormorant	Gull	Mixed	Pelican	Tern
Columbia estuary					
East Sand Island	4,482				22,902
Miller Sands Island	352				
The Dalles Dam Reservoir					
Miller Rock Islands		2,295			
The John Day Dam Reservoir					
Rock Island					597
The McNary Dam Reservoir					
Crescent Island		1,203	49		3,677
Badger Island				750	
Foundation Island	5,133		19		
Ice Harbor Tailrace Island			6		
Potholes Reservoir					
Goose Island	4				1,177
Upper Columbia River					
Banks Lake					31

Table 3. Numbers of PIT-tagged salmonids released in 2007 by species and percentage of those consumed by avian predators nesting at different locations throughout the CRB.

		PIT-tagged salmonids consumed				
Species	Released for migration year 2007	Estuary (%)	The Dalles and John Day Reservoirs (%)	McNary Dam Reservoir (%)	Potholes Reservoir (%)	Total (%)
Spring/Summer Chinook salmon	625,859	1.5	0.2	0.6	0	*2.3*
Fall Chinook salmon	150,395	2.0	0.4	1.4	0	*3.8*
Unknown Chinook salmon	212,661	1.7	0.2	0.7	0.0	*2.6*
Coho salmon	64,720	1.6	0.5	0.8	0.2	*3.1*
Steelhead	294,538	6.4	1.1	3.1	0.4	*11.0*
Sockeye salmon	22,576	0.6	0.1	0.3	0.1	*1.1*
Total	*1,370,749*	*2.0*	*0.04*	*0.8*	*0.09*	2.9

We detected similar numbers of unique PIT tag codes with each flat-plate antenna system, regardless of detection location (Appendix Table 2). The four-coil antenna system required continual modification of input parameters for optimal operation. However, when treated independently, each antenna system recovered about 4,150 PIT-tag codes from the Crescent Island tern colony. Of these, 81% were detected by both systems. Conversely, each antenna system recovered about an additional 780 PIT tags, or 19%, that were not recovered by the other antenna.

Neither antenna consistently recovered greater numbers of PIT tags based on year of tag deposition (Appendix Table 3). However, significantly greater numbers of PIT-tagged fish migrating during 2003 were detected by the six-coil flat-plate ($P = 0.03$). Greater numbers of SST-type PIT tags ($P = 0.05$) were recovered by the four-coil flat-plate than the six-coil flat-plate (Appendix Table 4). About 40% of PIT-tagged fish released into the CRB in 2007 were implanted with SST-type tags. However, about 79% (n = 1,414) of SST-type PIT tags recovered from the Crescent Island tern colony were collected using magnets. Therefore, these tags were not available to be detected by any of our electronic recovery techniques.

Detection Efficiency

Detection efficiency ranged from 68 to 90% in evaluations using control PIT tags placed on bird colonies by OSU/RTR at primary detection locations (Appendix Table 5). Similar detection efficiencies were measured during 2006 at most colonies, with the exception of tern colonies on Crescent and East Sand Islands. At these recovery sites, flat-plate antennas were used, and detection efficiencies increased by at least 20% over the previous year. Mean detection efficiency on the East Sand Island cormorant colony was 75% for all habitat types (colony-wide, rip-rap, and experiment nesting plot). The adjusted detection efficiency estimate for the entire cormorant colony was 28%.

Depending on colony location, the results of using magnets as a means to decrease annual accumulation of PIT tags on tern colonies were variable. Physical recovery using magnets followed by hand scanning was the first technique used on the Crescent Island tern colony, where about 50% of all PIT tag codes were recovered by magnets. In contrast, the use of magnets on the East Sand Island tern colony resulted in less than 2% of the total number of PIT tags detected on this colony.

Colony-Specific Predation

Of the total number of PIT tags collected on avian colonies in the CRB during 2007, about 65% were recovered from the tern and cormorant colonies on East Sand Island. Of those, about 84% were recovered from the tern colony. The actual number of PIT tags recovered from East Sand Island avian colonies was about 29,000, or 2.0% of all PIT-tagged fish released into the CRB for migration in 2007. Based on detection efficiency of tags recovered on East Sand Island colonies, we estimated over 41,000 PIT-tagged fish released for migration in 2007 were consumed by birds nesting on this island.

Avian predators nesting on East Sand Island consumed about 4.3% of the nearly 72,000 PIT-tagged fish detected at Bonneville Dam. As in all previous years, when combining both hatchery and wild rearing types, juvenile steelhead was the most frequently consumed species. This was the case for steelhead whether they migrated in-river and were detected at Bonneville Dam (Table 4) or were released from transportation barges just downstream of the dam (Table 5). After adjusting for detection efficiency and combining hatchery and wild rearing types, transported steelhead were 37% less likely to be consumed by avian predators nesting in the Columbia River estuary than non-transported steelhead. Lower rates of avian predation for transported juveniles of other species were less significant, i.e., predation rates for in-river vs. transported fish differed less than 0.5% for combined spring and summer Chinook salmon.

Table 4. Numbers of PIT-tagged salmonids interrogated at the Bonneville Dam juvenile bypass systems in 2007. Included are the actual percentage of those tags recovered on colonies of avian piscivores in the estuary and estimated percentage of PIT tags deposited on these colonies based on detection efficiencies (DE). Species with less than 300 detections are not reported.

Species/run	Rear type	Detections (n)	Consumed (n)	Actual %	Estimated %
		East Sand Island Tern colony (DE = 90%)			
Spring/summer Chinook salmon	Hatchery	32,666	609	1.86	2.06
	Wild	2,541	27	1.06	1.18
Fall Chinook salmon	Hatchery	2,942	62	2.11	2.33
	Wild	478	3	0.63	0.70
Unknown Chinook salmon	Hatchery	8,994	177	1.97	2.18
	Wild	1,979	11	0.56	0.62
Coho salmon	Hatchery	3,070	162	5.28	5.84
Steelhead	Hatchery	9,845	1,178	11.97	13.25
	Wild	3,339	450	13.48	14.92
Sockeye salmon	Hatchery	905	11	1.22	1.35
		East Sand Island Cormorant colony (DE = 28%)			
Spring/summer Chinook salmon	Hatchery	32,666	135	0.41	1.49
	Wild	2,541	17	0.67	2.41
Fall Chinook salmon	Hatchery	2,942	15	0.51	1.83
	Wild	478	3	0.63	2.26
Unknown Chinook salmon	Hatchery	8,994	44	0.49	1.76
	Wild	1,979	13	0.66	2.36
Coho salmon	Hatchery	3,070	16	0.52	1.87
Steelhead	Hatchery	9,845	72	0.73	2.63
	Wild	3,339	38	1.14	4.09
Sockeye salmon	Hatchery	905	8	0.88	3.18

Table 5. PIT-tagged salmonids released from transport barges in 2007. Included are the actual percentage of those tags recovered on colonies of avian piscivores nesting in the estuary and the estimated percentage PIT tags deposited on those colonies based on detection efficiencies (DE). Species with less than 300 detections are not reported.

Species/Run	Rear type	Transported(n)	Consumed (n)	Actual %	Estimated %
	East Sand Island Tern colony (DE = 90%)				
Spring/summer Chinook salmon	Hatchery	38,482	631	1.64	1.82
	Wild	2,823	9	0.32	0.35
Fall Chinook salmon	Hatchery	569	8	1.41	1.56
	Wild				
Unknown Chinook salmon	Hatchery	24,724	252	1.02	1.13
	Wild	17,540	140	0.80	0.88
Steelhead	Hatchery	50,435	3,973	7.88	8.72
	Wild	20,258	1,403	6.93	7.67
	East Sand Island Cormorant colony (DE = 28%)				
Spring/summer Chinook salmon	Hatchery	38,482	210	0.55	1.96
	Wild	2,823	10	0.35	1.27
Fall Chinook Salmon	Hatchery	569	8	1.41	5.06
	Wild				
Unknown Chinook salmon	Hatchery	24,724	99	0.40	1.44
	Wild	17,540	88	0.50	1.80
Steelhead	Hatchery	50,435	324	0.64	2.31
	Wild	20,258	173	0.85	3.07

Of all PIT-tagged fish consumed by avian predators during the 2007 migration year, 11.6% were recovered from Crescent Island and 12.2% were recovered from Foundation Island. A total of 10,817 PIT-tagged non-transported juvenile salmonids, or 1% of those released from the Snake and upper Columbia Rivers, were recovered on avian colonies in McNary Dam reservoir. We estimated terns and cormorants nesting in McNary Dam reservoir consumed over 1,000 (1.8%) of non-transported salmonids detected at either Ice Harbor or Lower Monumental Dams (Table 6). Predation rates of PIT-tagged salmonids interrogated in the lower Snake River were greater when compared to PIT-tagged salmonids released from Rock Island Dam in the upper Columbia River (Table 7). California Gulls *Larus californicus* and American white pelicans *Pelecanus erythrorhynchos* nesting on Crescent and Badger Islands in Lake Wallula each consumed less than 100 salmonids detected at Ice Harbor or Lower Monumental Dams. These birds consumed a total of 1,953 juvenile salmonids, which represented less than 0.2% of upper Columbia River or Snake River migrants.

Table 6. PIT-tagged salmonids interrogated at juvenile bypass systems of Lower Monumental and Ice Harbor Dams in 2007. Included are actual percentages of those tags recovered on avian colonies in Lake Wallula. Also shown are estimated percentages of PIT tags deposited on those colonies based on detection efficiencies (DE). Species with less than 300 detections are not reported.

Species/Run	Rear type	Detections (n)	Consumed (n)	Actual %	Estimated %
	Crescent Island Tern colony (DE = 69%)				
Spring/summer Chinook salmon	Hatchery	33,427	55	0.16	0.24
	Wild	1,566	1	0.06	0.09
Fall Chinook salmon	Hatchery	3,078	11	0.36	0.52
	Wild				
Unknown Chinook salmon	Hatchery	12,718	17	0.13	0.19
	Wild	2,956	5	0.17	0.25
Steelhead	Hatchery	12,239	172	1.41	2.04
	Wild	3,215	45	1.40	2.03
	Foundation Island Cormorant colony (DE = 68%)				
Spring/summer Chinook salmon	Hatchery	33,427	145	0.45	0.67
	Wild	1,566	8	0.51	0.75
Fall Chinook salmon	Hatchery	3,078	13	0.42	0.62
	Wild				
Unknown Chinook salmon	Hatchery	12,718	70	0.55	0.81
	Wild	2,956	17	0.58	0.85
Steelhead	Hatchery	12,239	190	1.55	2.28
	Wild	3,215	50	1.56	2.29

Table 7. PIT-tagged salmonids tagged and released from Rock Island Dam in 2007. Included are the actual percentages of those tags recovered on colonies of avian piscivores nesting in the Lake Wallula, and the estimated percentage PIT tags deposited on those colonies based on detection efficiencies (DE). Species with less than 300 detections are not reported.

Species/Run	Rear type	Released (n)	Consumed (n)	Actual %	Estimated %
		Crescent Island Tern colony (DE = 69%)			
Unk. Chinook salmon	Unknown	4,467	2	0.04	0.06
Steelhead	Hatchery	2,518	30	1.19	1.73
	Wild	1,103	16	1.45	2.10
Sockeye salmon	Unknown	2,084	6	0.19	0.28
		Foundation Island Cormorant colony (DE = 68%)			
Unk. Chinook salmon	Unknown	4,467	0	0.00	0.00
Steelhead	Hatchery	2,518	1	0.04	0.06
	Wild	1,103	0	0.00	0.00
Sockeye salmon	Unknown	2,084	2	0.10	0.14

PIT-Tagging of Lower Columbia River Stocks

We PIT-tagged a total of 12,330 subyearling Chinook salmon that were released into the LCR from early May to early July (Table 8). Avian predators consumed an average of 9% of these fish. Predation rates of fish released from three of the four hatcheries averaged 11.5%. Fish released from the North Toutle Hatchery had a predation rate of 1%, significantly less than those of fish released from other hatcheries. Fish from the North Toutle Hatchery were the final group PIT-tagged and were released 18 days later than the previous group.

At Bonneville Dam, there were 3,051 detections of subyearling Chinook salmon from various upstream release sites from late May through July 2007 (Figure 4; PSMFC 1996). Predation rates of these fish groups were consistent and did not exceed 5%. The majority of subyearling Chinook salmon originating upstream of Bonneville Dam were consumed by Caspian terns until July, when consumption was equally distributed between terns and cormorants. In contrast, the majority of subyearling Chinook released from LCR hatcheries was consumed by cormorants (Figure 5). Of the PIT-tagged LCR subyearling Chinook salmon consumed by avian predators, the percent consumed by cormorants nesting on East Sand Island was never less than 67%.

Table 8. Percentages of LCR PIT-tagged subyearling Chinook salmon consumed by avian piscivores on East Sand and Miller Sands Islands in 2007 compared to subyearling Chinook salmon detected at Bonneville Dam.

Release location	Release date	Distance from Columbia River mouth (rkm)	Number of fish released	Cormorant (%)	Tern (%)	Total (%)
Big Creek	5/4/07	49	3,028	8.3	2.8	11.7
Kalama Falls	6/21/07	135	3,013	8.9	4.4	14.0
North Toutle	7/9/07	190	3,278	0.7	0.3	1.1
Washougal	6/18/07	225	3,011	8.1	2.9	11.5
Bonneville Dam	-	234	3,051	1.1	2.2	3.3
LCR	-	-	12,330	6.5	2.6	9.4

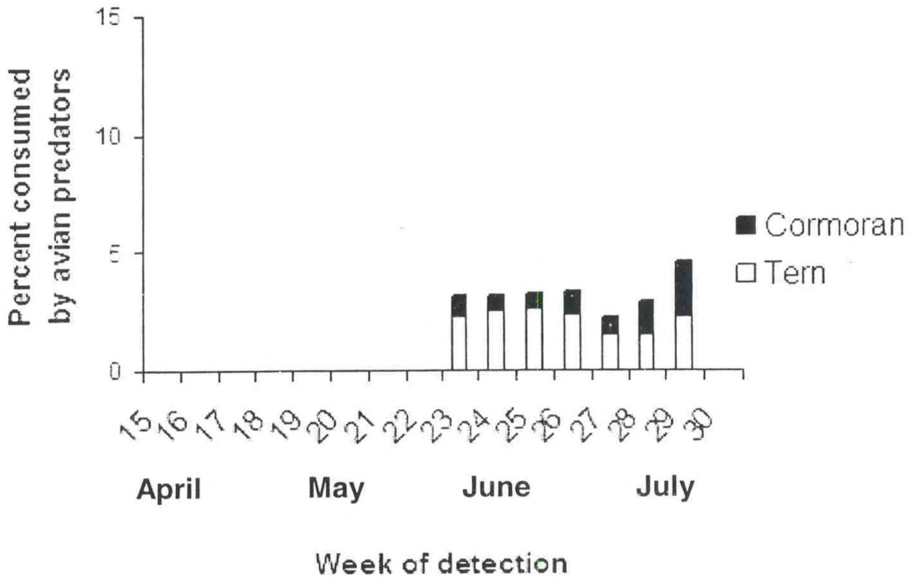

Figure 4. Percentages of subyearling Chinook salmon detected at Bonneville Dam that were consumed by avian predators in the Columbia River estuary. Predation rates were calculated for weeks in which a minimum of 100 fish were detected.

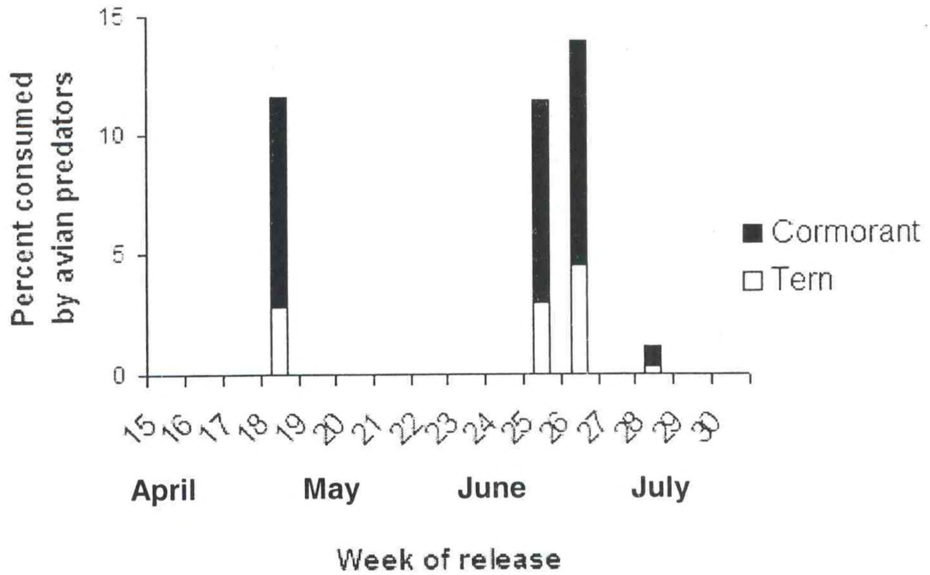

Figure 5. Percentages of subyearling Chinook salmon released from hatcheries located in the LCR that were consumed by avian predators in the Columbia River estuary.

DISCUSSION

PIT tag recovery efforts since 1998 have provided extensive documentation on the relative vulnerability of juvenile salmonids to avian predators throughout the CRB (Ryan et al. 2001-2003, 2007; Glabek et al. 2003). Although we will continue to present a basin-wide summary of avian predation and report any relevant changes from the previous year, we shifted PIT-tag recovery efforts to focus on specific avian colonies where potential management actions are possible. These colonies are on primary PIT tag detection sites in the Columbia River estuary and McNary Dam reservoir.

Management actions became possible after approval of the USACE 2001, 2007, and 2008 environmental impact statements, which recommended relocation of Caspian terns to Fern Lake Ridge Reservoir, Crump Lake, and Summer Lake in southern Oregon, and several sites within San Francisco Bay. These recommendations support the ongoing relocation efforts. If successful, relocations could reduce the number of terns nesting on East Sand Island, thereby reducing impacts on juvenile salmonids and aiding basin-wide recovery efforts of ESA-listed stocks (USACE 2007, 2008).

Consistent evaluation of PIT tags deposited by avian predators is necessary to determine the success or failure of this and other management strategies for avian predators. Additional management actions are proposed for double-crested cormorants nesting in the CRB and for Caspian terns nesting in Lake Wallula.

Recovery of control PIT tags placed on avian breeding colonies in 2007 yielded greater detection efficiency estimates compared to 2006. In particular, efficiency estimates on Crescent and East Sand Island tern colonies were substantially improved. NMFS electronic engineering staff determined that the larger-diameter wire coils in the six-coil flat-plate detector used in 2006 likely increased the potential for tag-code collision (B. Jonasson, NMFS personal communication). Improved weather conditions may also have played a role in greater detection efficiency of control PIT tags. However, concerns about diminishing detection efficiency due to annual accumulation of PIT tags remain.

Although there were differences in the number and type of PIT tags recovered by the six-coil and four-coil flat-plate systems tested on tern colonies, the results do not warrant continued use of both systems. We plan to continue the use of the four-coil flat-plate system on a limited and experimental basis in 2008 to evaluate possible tag collision and tag-type differences.

We demonstrated the use of magnets as an effective means to decrease the annual accumulation of PIT tags on certain avian colonies. Small-sized avian colonies with hard-packed fine-grain sand and silt substrate, as is present on the Crescent Island tern colony, were ideal for use of magnets to collect PIT tags. Large avian colonies with soft, sandy substrate, as is present on the 1.4-hectare East Sand Island tern colony, were marginally suited for use of magnets to collect PIT tags. Frequent rainfall in the Columbia River estuary also limited the utility of magnets for collection of PIT tags on East Sand Island.

An additional new focus of PIT-tag recovery is subyearling Chinook salmon in the Lower Columbia River, a reach where few fish are PIT-tagged. As in previous years, results in 2007 indicated that predation rates of LCR subyearling Chinook salmon were significantly greater than those of subyearling Chinook salmon originating upstream from Bonneville Dam (Ryan et al. 2006). We found that subyearling Chinook salmon originating in the LCR were at least three times more likely to be consumed by avian predators than subyearling Chinook salmon migrating through the Columbia River estuary during the same period.

Of the LCR subyearling Chinook salmon consumed, a consistent majority were preyed upon by cormorants. The mean predation rate by avian predators in the Columbia estuary on LCR subyearling Chinook salmon from the three earliest release groups was 11.8%. This predation rate was comparable to those estimated for LCR subyearling Chinook salmon in previous years (Ryan et. al 2005, 2006). Fish released from the North Toutle Hatchery had a lower avian predation rate in the Columbia River estuary than fish from the other three release sites, which we attributed to their later release date. We did not observe a consistent relationship between predation rate and distance of migration to the Columbia River estuary.

Adult Fall Chinook salmon catches in Oregon coastal waters and Columbia River inland waters have accounted for 41% of the annual North American catch and are valued at 22 million dollars (Mann et. al 2005). With 58% of salmonids in the CRB originating from the LCR (Mann et al. 2005), subyearling Chinook salmon in this river reach should be considered an important stock. Though management decisions frequently focus on threatened salmonid stocks in the upper Columbia and Snake River basins, it is critical to consider lower river stocks that are acutely vulnerable to avian predation. Management action to relocate avian colonies outside the estuary can benefit all salmonid migrants in the CRB.

Our short, focused PIT-tagging effort in the LCR accounted for about 20% of the PIT-tagged fish released within this portion of the CRB. With additional avian colony relocation projects scheduled to begin in spring 2008, PIT-tagged LCR subyearling Chinook salmon will serve as an effective indicator of success in evaluating changes in avian piscivory for these fish stocks.

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APPENDIX

Data Tables

Appendix Table 1. Numbers of PIT tags not previously recovered from breeding colonies of avian piscivores in the CRB, 2007.

	Avian Colony					
River Reach and Island	Cormorant	Gull	Mixed	Pelican	Tern	Total
Columbia estuary						
East Sand Island	10,986				25,637	36,623
Miller Sands Island	370					370
Lake Celilo						
Miller Rocks Island		5,702				5,702
Lake Umatilla						
Rock Island					1,379	1,379
Lake Wallula						
Crescent Island		1,635	694		6,768	9,097
Badger Island				1,222		1,222
Foundation Island	7,050		116			7,166
Ice Harbor Tailrace Isl			35			35
Potholes Reservoir						
Goose Island	32				1,456	1,488
Upper Columbia River						
Banks Lake					60	60
Total	18,438	7,337	845	1,222	35,300	63,142

Appendix Table 2. Numbers of unique PIT tags, excluding duplicate records, recovered by four-coil and six-coil flat-plate antennas on the Crescent Island tern colony during 2007.

Antenna	Total PIT tags	PIT tags detected by both antennas	PIT tags detected by only one antenna
FP4	4,149	3,369	779
FP6	4,164	3,369	794

Appendix Table 3. Numbers of unique PIT tags recovered by four-coil and six-coil flat-plate antennas on the Crescent Island tern colony during 2007. The numbers of unique PIT tag codes recovered by each antenna within each pass are categorized by year of deposition.

Migration	FP4 n = 779 PIT tags			FP6 n = 794 PIT tags			*t*-test
Year	Pass 1	Pass 2	Pass 3	Pass 1	Pass 2	Pass 3	(*P*-value)
2000	19	8	12	23	24	17	0.10
2001	65	47	56	77	89	66	0.06
2002	52	35	46	48	43	42	1.0
2003	54	39	58	71	68	79	0.03
2004	75	42	61	73	47	67	0.82
2005	64	33	42	77	39	51	0.56
2006	31	20	28	34	21	24	1.0
2007	30	19	33	24	19	18	0.21

Appendix Table 4. Numbers of unique PIT tags recovered by four-coil and six-coil flat-plate antennas on the Crescent Island tern colony during 2007. The numbers of unique PIT tag codes recovered by each antenna within each pass are categorized by PIT-tag types.

Tag	FP4 = 779 PIT tags			FP6 = 794 PIT tags			*t*-test
type	Pass 1	Pass 2	Pass 3	Pass 1	Pass 2	Pass 3	(*P*-value)
SGL	2	1	1	4	2	2	0.15
ST	384	235	334	410	339	354	0.36
SST	14	11	20	8	6	8	0.05

Appendix Table 5. Percentages of control tags recovered on the Crescent Island and East Sand Island tern colonies, 2000 - 2007.

	Control tags detected (%)	
Year	Crescent Island	East Sand Island
2000	-	96
2001	-	
2002	-	
2003	45	85
2004	80	94
2005	71	83
2006	45	69
2007	69	90

Appendix Table 6. Numbers of in-river migrating salmonids by ESU that were released for the 2007 migration year with actual and estimated percentages of those recovered from the Caspian tern colony located on East Sand Island. Estimates were not made for species with less than 300 fish released.

		ESU											
		Lower Columbia River			Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spr/Sum Chinook salmon	Hatchery	2,730	0.59	0.65	91,789	0.68	0.76	43,998	0.82	0.91	381,801	2.08	2.31
	Wild	6,093	0.03	0.04	7,336	0.33	0.36	21,758	0.06	0.07	85,941	0.38	0.42
	Unknown												
Fall Chinook salmon	Hatchery	12,330	2.60	2.89	35,315	0.27	0.30	3,064	0.59	0.65	47,560	0.64	0.71
	Wild				748	0.00	0.00	21,007	0.23	0.25	2,010	0.05	0.06
	Unknown				9,846	2.09	2.32				17,871	0.22	0.25
Unk. Chinook salmon	Hatchery				2,584	1.55	1.72	4,436	0.00	0.00	97,454	1.45	1.61
	Wild	7,271	0.08	0.09				482	0.00	0.00	24,211	0.97	1.08
	Unknown	300	0.00	0.00	695	0.00	0.00	4,436	0.41	0.45	29,188	0.47	0.53
Coho Salmon	Hatchery				32,264	0.77	0.85	29,936	1.21	1.34			
	Unknown				2,347	1.53	1.70						
Steelhead	Hatchery	1,582	11.19	12.43	38,034	3.44	3.82	50,903	2.60	2.89	66,744	36.63	40.71
	Wild				15,052	4.54	5.04	8,106	1.32	1.47	60,834	11.95	13.28
	Unknown							1,491	0.00	0.00	1,193	5.45	6.05
Sockeye salmon	Hatchery							14,859	0.29	0.32	7,342	0.19	0.21
	Wild							2,052	0.29	0.32			

Appendix Table 7. Numbers of migration year 2007 in-river migrating salmonids released by ESU and the actual and estimated percentages of those recovered from the double-crested cormorant colony located on East Sand Island. Estimates were not made for species with less than 300 fish released.

		ESU											
		Lower Columbia River			Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spr/Sum Chinook salmon	Hatchery	2,730	0.07	0.26	91,789	0.21	0.74	43,998	0.34	1.22	381,801	0.54	1.92
	Wild	6,093	0.03	0.12	7,336	0.10	1.03						
	Unknown				996	0.29	0.36	21,758	0.11	0.39	85,941	0.17	0.62
Fall Chinook salmon	Hatchery	12,330	6.38	22.80	35,315	0.14	0.51	3,064	0.10	0.35	47,560	0.19	0.66
	Wild				748	0.70	2.52	21,007	0.14	0.49	2,010	0.05	0.18
	Unknown				9,846	0.00	0.00				17,871	0.06	0.20
Unk. Chinook salmon	Hatchery				2,584	0.50	1.81	3,385	0.00	0.00	97,454	0.49	1.75
	Wild	7,271	0.04	0.15				482	0.00	0.00	24,211	0.62	2.23
	Unknown	300	0.00	0.00	695	0.00	0.00	4,436	0.20	0.72	29,188	0.08	0.28
Coho Salmon	Hatchery				32,264	0.19	0.67	29,936	0.12	0.43			
	Unknown				2,347	0.38	1.38						
Steelhead	Hatchery	1,582	0.36	1.28	38,034	0.23	0.81	50,903	0.22	0.78	66,744	0.82	2.92
	Wild				14,637	3.26	1.70	8,106	0.17	0.62	60,834	5.35	19.09
	Unknown							1,491	0.00	0.00	1,193	1.99	7.12
Sockeye salmon	Hatchery							14,859	0.17	0.62	7,342	0.11	0.39
	Wild							2,052	0.10	0.35			

Appendix Table 8. Numbers of migration year 2007 in-river migrating salmonids released by ESU and the actual and estimated percentages of those recovered from the Caspian tern colony located on Crescent Island. Estimates were not made for species with less than 300 fish released.

		ESU								
		Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
	Hatchery	56,737	0.12	0.17	43,998	0.11	0.16	381,801	0.20	0.28
Spr/Sum Chinook	Wild	3,125	0.16	0.23	21,758	0.02	0.03	85,941	0.14	0.21
salmon	Unknown	995	0.40	0.58						
	Hatchery	35,083	0.15	0.21	3,064	0.62	0.90	47,560	0.21	0.31
Fall Chinook	Wild	748	0.00	0.00	21,007	0.35	0.51	2,010	0.05	0.07
salmon	Unknown	5,853	0.00	0.00				17,871	0.68	0.99
	Hatchery				3,385	0.00	0.00	97,454	0.11	0.16
Unk. Chinook	Wild				482	0.00	0.00	24,211	0.18	0.26
salmon	Unknown				4,436	0.05	0.07	29,188	0.30	0.44
	Hatchery	32,264	0.19	0.27	29,936	0.17	0.25			
Coho Salmon	Unknown	2,346	0.38	0.56						
	Hatchery	29,998	0.94	1.36	50,903	0.50	0.72	66,744	1.70	2.46
	Wild	1,892	0.90	1.30	8,087	0.31	0.45	60,793	0.96	1.39
Steelhead	Unknown				1,491	0.00	0.00	1,138	5.54	8.02
Sockeye	Hatchery				14,859	0.02	0.03	7,342	0.07	0.10
salmon	Wild							917	0.33	0.47

Appendix Table 9. Numbers of migration year 2007 in-river migrating salmonids released by ESU and the actual and estimated percentages of those recovered from the double-crested cormorant colony located on Foundation Island. Estimates were not made for species with less than 300 fish released.

		ESU								
		Mid Columbia River			Upper Columbia River			Snake River		
Species/Run	Rear type	n	(%)	Est (%)	n	(%)	Est (%)	n	(%)	Est (%)
Spr/Sum Chinook salmon	Hatchery	56,737	0.75	1.11	43,998	0.06	0.09	381,801	0.55	0.80
	Wild	3,125	0.74	1.08	21,758	0.08	0.11	85,941	0.22	0.33
	Unknown	995	1.81	2.66						
Fall Chinook salmon	Hatchery	35,083	0.31	0.45	3,064	0.46	0.67	47,560	0.39	0.58
	Wild	748	0.00	0.00	21,007	1.03	1.51	2,010	0.00	0.00
	Unknown	5,853	0.02	0.03				17,871	0.28	0.41
Unk. Chinook salmon	Hatchery				3,385	0.00	0.00	97,454	0.47	0.69
	Wild				482	0.00	0.00	24,211	0.38	0.56
	Unknown				4,436	0.00	0.00	29,188	0.22	0.32
Coho Salmon	Hatchery	32,264	0.17	0.25	29,936	0.03	0.04			
	Unknown	2,346	0.26	0.38						
Steelhead	Hatchery	28,875	2.72	4.00	50,903	0.04	0.06	66,709	1.30	1.91
	Wild	1,892	2.27	3.34	8,087	0.01	0.02	60,793	0.55	0.82
	Unknown				1,491	0.00	0.00	1,193	5.57	8.19
Sockeye salmon	Hatchery				14,859	0.00	0.00	7,342	0.35	0.52
	Wild							917	0.44	0.64