# Detection of Passive Integrated Transponder (PIT) Tags on Piscivorous Bird Colonies in the Columbia River Basin, 2003-2005

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# EXECUTIVE SUMMARY

From 2003 to 2005, we detected the passive integrated transponder (PIT) tags of 200,000 juvenile Pacific salmonids *Oncorhynchus* spp. on abandoned piscivorous bird colonies in the Columbia River Basin. These tags had not been previously detected, and total detections of PIT tags on colonies accounted for as much as 4% of all PIT-tagged salmonids released into the Columbia River Basin in some migration years. The majority of tags were detected on colonies of the Caspian tern *Sterna caspia* and double-crested cormorant *Phalacrocorax auritas*. These species are the major avian piscivores in the Columbia River estuary and in Lake Wallula.

The primary tag detection location was on the East Sand Island tern colony in the Columbia River estuary. For PIT-tagged steelhead *O. mykiss* transported by barge combined with those detected at Bonneville Dam, detections on the East Sand Island tern colony averaged 10.9, 9.9, and 7.8% of all these fish released from the Snake, Upper Columbia, and Mid Columbia Basin respectively. In contrast, from the same respective subbasins, only 1.6, 1.6, and 1.3% of these steelhead were detected on the cormorant colony. However, detection efficiencies on cormorant colonies averaged only 40%, meaning predation impacts by cormorants were likely twice as high as indicated by PIT-tag detections. Impacts from avian predators in the estuary for other salmonid species were considerably lower than for steelhead.

The secondary tag detection location was Lake Wallula, where the majority of tags were detected on the Crescent Island tern colony. Of steelhead detected at Lower Monumental Dam and returned to migrate in the river, detection rates on bird colonies in Lake Wallula averaged 12.5%. Although detection rates of steelhead that migrated through Lake Wallula have been over 20% in some years, these impacts were lessened (<2%) when transported steelhead were included in the population. Again, the impacts from avian predators in Lake Wallula for other salmonid species were considerably lower than for steelhead.

There is evidence that juvenile salmonids which have been bypassed at multiple Snake River dams return as adults at lower rates than those that did not experience bypass. This difference has been partially attributed to differences in vulnerability to avian predation caused by the experience of multiple bypasses. However, we did not find significant differences between proportions of salmonids detected on bird colonies in the estuary based on the number of times they experienced a juvenile fish bypass system.

Lower Columbia River fall Chinook *O. tshawytscha* salmonid stocks rely on a longer estuary rearing period. Because of this life history characteristic, there was concern that the impact to these stocks by avian predators may be as great or greater than that of upriver stocks. These fish are not generally PIT-tagged, so to obtain data to address this concern, we tagged over 49,000 of these fish from 2003 through 2005. We found that predation rates of lower Columbia River fall Chinook *O. tshawytscha* were considerably higher than those of fall Chinook detected at or released directly downstream from Bonneville Dam. For other lower Columbia River salmonids, predation rates were closer to the levels of their upriver cohorts detected at or released immediately downstream from Bonneville Dam.

**CONTENTS**

# AVIAN PREDATOR COLONIES

## Introduction

Colonies of Caspian terns *Sterna caspia* along the north Pacific Coast have expanded rapidly, growing from 3,500 breeding pairs in 1960 to 12,500 in 2001 (USACE 2001). Since the mid-1960s, Caspian tern 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). In 2004, about 9,500 breeding pairs of Caspian terns were estimated near the mouth of the Columbia River on East Sand Island (Jessica Atkins, Oregon State University, personal communication). 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 12,400 breeding pairs in 2004 (Jessica Atkins, OSU, personal communication).

In addition to terns and cormorants nesting in the Columbia River estuary, there are at least nine islands in upstream areas of the Columbia River that host colonies of piscivorous birds. These colonies include the tern; cormorant; gull *Larus spp*.; American white pelican *Pelecanus erythrorhyncho*; and three heron species, *Ardea alba, A. herodias, and Nycticorax nycticorax.*

## Methods

PIT-tag detection efforts were conducted from 2003 through 2005 on Caspian tern, double-crested cormorant, and gull colonies identified as having the potential to impact PIT-tagged juvenile salmonids. In addition, we conducted PIT-tag detection efforts on an American White pelican colony in 2005. PIT-tag sampling was conducted using either a flat-plate or pole-mounted detector that was specially designed for detecting PIT tags on bird colonies (Ryan et al. 2001). In addition, PIT tags were physically removed from the Crescent Island and the Goose Island tern colonies by Real Time Research (CBR 2005) using magnets and rakes.

Sampling boundaries of each colony area were established during site visits to each colony late in the nesting season. During these visits, colony size was estimated based on ground counts of adult birds on colony, which we defined as a population index. Oregon State University and other research groups conducted more comprehensive population surveys, and we used their population estimates when they were available.

Colonies sampled from 2003 through 2005 ranged from East Sand Island at river kilometer (rkm) 8 in the Columbia River estuary to the convergence of the Okanogan and Columbia Rivers near rkm 858. Sampling locations from 2003 to 2005 are described below (Figure 1).

## Results

**Estuary**--In the estuary, a 1.6 ha area of open sand on the east end of East Sand Island has hosted a colony of over 8,000 breeding pairs of Caspian terns annually (CBR 2004). At the west end of the island, a rock jetty and adjacent sands hosted a double-crested cormorant colony of over 10,000 breeding pairs in 2003, which grew to over 12,000 in subsequent years (CBR 2005).

**Lake Celilo (The Dalles Reservoir)--**In Lake Celilo, small rock outcroppings of approximately 0.5 ha on Little Miller Island hosted a gull colony with a population index of 1,700 in both 2003 and 2004. This colony was not studied in 2005.

**Lake Wallula (John Day Dam Reservoir)--**In Lake Wallula, three islands hosted piscivorous birds: The first of these was Crescent Island, which hosted both a Caspian tern colony (ranging from 470 to 800 breeding pairs on 0.1 ha of open sand) and a gull colony, which encompassed the majority of the island (CBR 2005). The gull colony has not been censused, but is estimated to host several thousand breeding pairs. Foundation Island also hosted a double-crested cormorant colony of over 300 breeding pairs on 0.2 ha of deciduous trees from 2003 through 2005 (D. Lyons, Oregon State University, personal communication). Finally, Badger Island hosted an American White pelican colony on approximately 0.9 ha of open sand, trees, and shrubbery. The population index was approximately 1,000 individuals; however, we sampled Badger Island only in 2005.

**Potholes Reservoir--**In Potholes Reservoir, located 40 km from Wanapum Reservoir on the Columbia River (rkm 665), two small sand islands, Solstice and Goose Islands, hosted colonies of Caspian terns in 2003, but there were no confirmed colony counts. In 2004, terns began to nest on Solstice Island, but the colony quickly failed due to rising water levels and predation (Chris Thompson, University of Washington, personal communication). Most of the birds re-nested on Goose Island, which already hosted a population of terns with an index of 200 breeding pairs (Don Lyons, Oregon State University, personal communication). In 2005, terns nested solely on Goose Island, with a population of 330 nesting pairs. In the northern area of Potholes Reservoir, there is a grassy field with an ephemeral pool surrounded by deciduous trees, where evidence was found of 300-500 nesting pairs of double-crested cormorants in 2004 (CBR 2004) and 800-900 pairs in 2005 (D. Lyons, Oregon State University, personal communication).

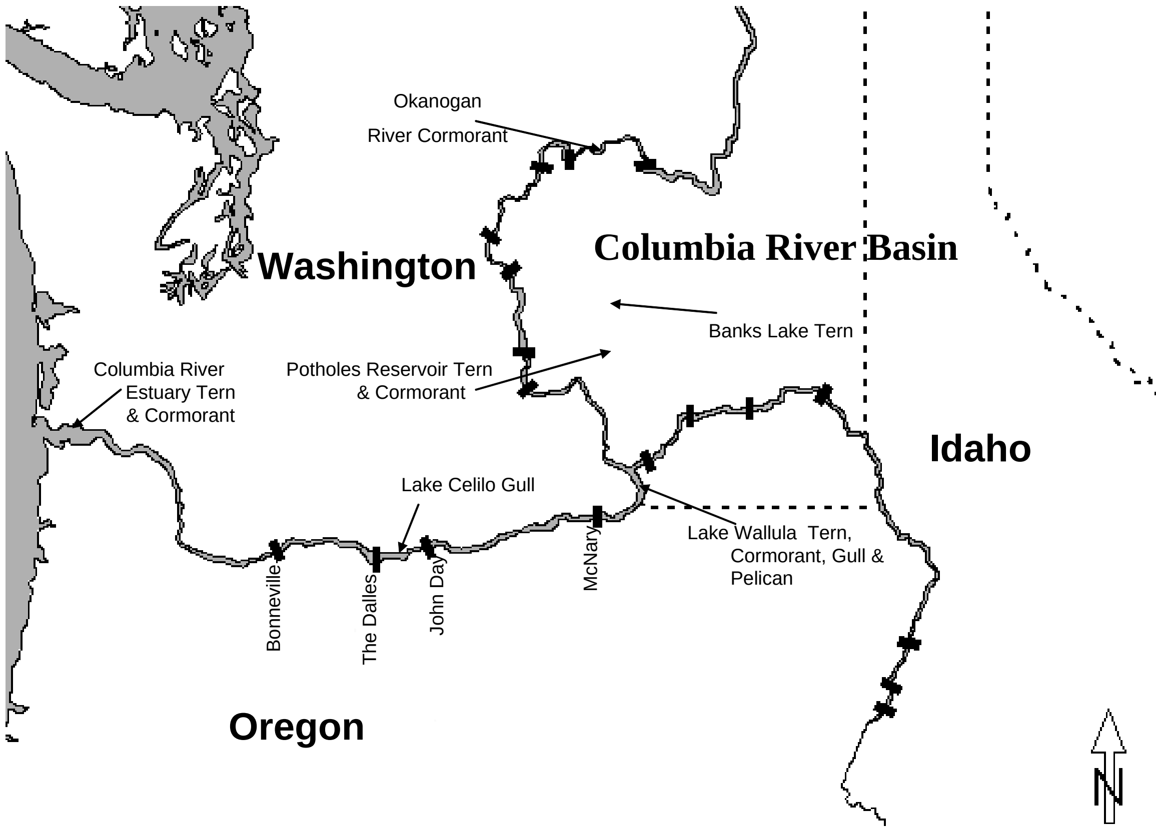


Figure 1. Locations and bird species of major colonies sampled from 2003 to 2005 in the Columbia River Basin (Tern indicates Caspian Tern colonies; Cormorant indicates Double-Crested Cormorant colonies).

**Banks Lake--**In Banks Lake, there were nesting colonies of Caspian terns on each of two unnamed silt and rock islands. Each colony was approximately 0.4 ha and was estimated to host fewer than 50 nesting pairs. At the confluence of the Columbia and Okanogan Rivers, in approximately 0.5 ha of deciduous trees, nesting pairs of double-crested cormorants were estimated at 20-30 in 2004 (CBR 2004) and 38 in 2005 (D. Lyons, Oregon State University, personal communication). These were termed the Okanogan colony.

## PREDATION IMPACTS AND RELATIVE VULNERABILITY

### Introduction

Since 1991, twelve evolutionarily significant units (ESUs) of Pacific salmon *Oncorhynchus* spp. in the Columbia River Basin have been listed as threatened or endangered under the U.S. Endangered Species Act (NMFS 2000). Under its congressional mandate to identify and protect depressed or endangered salmonid populations, the National Marine Fisheries Service (NMFS) has undertaken research on several fronts. Research has ranged from evaluating criteria to define distinct population segments (Waples 1991) to identifying the causes of mortality at different life history stages (NMFS 2000).

Recovery planning is also at the forefront of this research, and one important contribution to this area was a study of Chinook salmon *O. tshawytscha* by Kareiva et al. (2000). They examined the potential effects on population viability after variable mortality rates at different life history stages and found that reductions as low as 5% in early ocean and estuarine mortality could arrest population declines. Ironically, even as the habitats and life history stages central to recovery are being identified, growing populations of piscivorous birds now present additional risk to threatened salmonid populations in these same habitats and life history stages (Collis et al. 2001).

Information on at-risk populations during these critical life history stages is essential for recovery planning. This ongoing study provides information for continued evaluations of the relative vulnerability of juvenile salmonids to bird predation based on species, run, rear-type, and migration history. Here we report the results of PIT-tag detection efforts on piscivorous bird colonies in the Columbia River Basin and estuary from 2003 through 2005.

### Methods

To monitor and evaluate their survival through the Federal Columbia River Power System, juvenile salmonids have been tagged annually with passive integrated transponder (PIT) tags since 1987 (Prentice et al. 1990a,b). The total number of PIT-tagged juvenile salmonids released in the Columbia River Basin varies, but generally grows each year. This number is estimated to have increased from less than 50,000 in 1987 to over 2 million in 2003 (PSMFC 2006).

In 1998, we began detecting the PIT tags of juvenile salmonids on piscivorous bird colonies in the Columbia River Basin using detection equipment modified for use on land (Ryan et al. 2001). Tag codes from these detections have been used to analyze bird feeding behavior, prey selectivity, and the relative vulnerability of various groups of juvenile salmonids to avian predation (Collis et al. 2001; Ryan et al. 2003).

At the time of tagging, individual PIT-tag codes and other information, such as species type and origin, are recorded in a shared regional database, the Columbia Basin PIT Tag Information System (PTAGIS; PSMFC 2006). Codes in PTAGIS can be matched with records of subsequent detection and used to determine the migration history and often the ultimate fate of an individual fish.

Two types of PIT tags have been detected using these methods: the Standard Tag and the Super Tag. The Standard, or BE tag, which has been detected throughout this project, was modified to become the Super Tag and released in 2003 (Peterson 2002). This adapted tag is made more efficient by utilizing a larger ferrite, resulting in a better coupling coefficient between the tag and the antenna. This in turn allows the Super Tag to be read in a weaker magnetic field, which increases the read range and allows for improvements in RF noise immunity.

Data collected from this research were used to assess the relative impacts of avian predator populations on different stocks of PIT-tagged juvenile salmonids in the Columbia River Basin. Avian predation rates based on PIT tag detections on colonies represent minimum estimates of predation because 1) not all tags consumed by birds are deposited on the colony, 2) wind and water erosion remove an unknown number of tags from the colony each year, and 3) PIT-tag detection efficiency is not 100% (Collis et al. 2001; Ryan et al. 2003).

## Results

Piscivorous bird colonies in the Columbia River estuary yielded more than 330,000 juvenile salmonid PIT tags for migration years 1998 through 2005. Of the PIT-tagged juvenile salmon released to migrate in-river during migration years 2003 through 2005, over 225,000 were detected at Bonneville Dam (Table 1). Of these fish, detection rates on piscivorous bird colonies in the Columbia River estuary ranged from 1.2% for fall Chinook in 2003 to 12.8% for steelhead in 2004 (Table 1).

Table 1. PIT-tagged salmonids detected at Bonneville Dam, and the percentage of these tags subsequently detected on East Sand Island piscivorous bird colonies in the Columbia River estuary in from 2003 through 2005. Species with less than 100 detections at Bonneville are not reported.

| Species | Detected at Bonneville Dam (n) | East Sand Island detections: Tern (%) | East Sand Island detections: Cormorant (%) | **Total detections (%)** |
|---|---|---|---|---|
| **Migration year 2003** | | | | |
| Spring/Summer Chinook | 82,127 | 2.3 | 0.7 | 3.0 |
| Fall Chinook | 11,116 | 1.6 | 0.7 | 2.3 |
| Unknown Chinook | 10,479 | 0.7 | 0.6 | 1.2 |
| Steelhead | 48,464 | 11.9 | 0.7 | 12.7 |
| Coho | 3,463 | 5.6 | 0.7 | 6.3 |
| Sockeye | 268 | 3.0 | 0.7 | 3.7 |
| Total | 155,917 | 5.2 | 0.7 | 5.9 |
| **Migration year 2004** | | | | |
| Spring/Summer Chinook | 27,094 | 3.2 | 1.5 | 4.7 |
| Fall Chinook | 1,389 | 1.0 | 0.9 | 1.9 |
| Unknown Chinook | 1,832 | 2.2 | 1.5 | 3.7 |
| Steelhead | 7,256 | 10.4 | 2.4 | 12.8 |
| Coho | 1,197 | 10.4 | 1.1 | 11.4 |
| Total | 38,768 | 4.7 | 1.6 | 6.3 |
| **Migration year 2005** | | | | |
| Spring/Summer Chinook | 14,649 | 1.4 | 1.1 | 2.5 |
| Fall Chinook | 2,358 | 0.5 | 0.8 | 1.2 |
| Unknown Chinook | 5,350 | 1.9 | 1.0 | 2.9 |
| Steelhead | 7,362 | 9.1 | 1.6 | 10.7 |
| Coho | 909 | 4.6 | 2.1 | 6.7 |
| Total | 30,628 | 3.3 | 1.2 | 4.5 |

In addition to PIT-tagged salmonids migrating in-river, over 580,000 PIT-tagged salmonids were collected at Snake and Columbia River dams and transported to release sites below Bonneville Dam from 2003 through 2005 (Table 2). The proportions of transported salmonids subsequently detected on piscivorous bird colonies in the Columbia River estuary were generally lower than those of in-river migrants, ranging from 1.6% for fall Chinook in 2003 to 13.1% for steelhead in 2004 (Table 2).

For spring/summer Chinook, average predation rates were approximately 1.5% when tern and cormorant impacts were combined, while predation rates for fall Chinook were even lower. Not all of the juvenile detection facilities at Bonneville Dam were operative during the 2004 and 2005 migrations, resulting in a lower number of juvenile salmonids detected than in previous years.

## Discussion

Using our detection techniques basin-wide, PIT-tag-detection efforts on piscivorous bird colonies have suggested that avian predation has accounted for as high as a 4% overall mortality for PIT-tagged juvenile salmonids released into the Columbia River Basin. This is in spite of the fact that PIT-tag recoveries are minimum estimates due to a less than 100% detection efficiency, unknown deposition rates, and the lack of representation of all avian predators (Ryan et al. 2001). The high predation rates are even more concerning when one considers that hatchery and wild steelhead have been found to be equally vulnerable (Ryan et al. 2003; Ryan 2005).

Avian predation is a natural part of anadromous salmonids' life history. However, anthropogenic influences have likely created imbalances in the Columbia River Basin that may now allow piscivorous birds to exploit juvenile salmonids at higher rates than occurred historically. Reasons for the contemporary increases in predation may include the creation of islands from dredged material and of reservoirs above dams, as well as the annual production and release of millions of juvenile salmonids from hatcheries. The recent expansion of a previously non-existent Caspian tern colony on a dredge disposal island in the Columbia River estuary to become the world's largest breeding population is a prime example of what can happen in nature when predator/prey imbalances occur or are inadvertently created by man (Carter et al. 1995; Roby et al. 2002).

Table 2. PIT-tagged salmonids that were transported to release sites below Bonneville Dam and the percentage of tags from these fish detected on East Sand Island piscivorous bird colonies in the Columbia River estuary from 2003 through 2005. Species with less than 100 barged individuals are not reported.

| | | East Sand Island Detections | | |
|---|---|---|---|---|
| Species | Transported (n) | Tern (%) | Cormorant (%) | **Total (%)** |
| **Migration year 2003** | | | | |
| Spring/Summer Chinook | 133,537 | 2.4 | 0.6 | 3.1 |
| Fall Chinook | 39,603 | 1.0 | 0.6 | 1.6 |
| Unknown Chinook | 27,767 | 0.9 | 0.7 | 1.6 |
| Steelhead | 42,321 | 9.5 | 0.9 | 10.4 |
| Coho | 224 | 4.5 | 0.0 | 4.5 |
| Total | 243,452 | 3.3 | 0.7 | 3.9 |
| **Migration year 2004** | | | | |
| Spring/Summer Chinook | 113,580 | 2.1 | 1.7 | 3.8 |
| Fall Chinook | 29,187 | 1.1 | 0.8 | 1.9 |
| Unknown Chinook | 14,857 | 1.0 | 1.1 | 2.1 |
| Steelhead | 29,354 | 10.7 | 2.3 | 13.1 |
| Sockeye | 1,373 | 2.5 | 2.3 | 4.8 |
| Total | 188,351 | 3.2 | 1.6 | 4.8 |
| **Migration year 2005** | | | | |
| Spring/Summer Chinook | 82,694 | 1.4 | 1.1 | 2.5 |
| Fall Chinook | 14,488 | 1.3 | 2.6 | 3.9 |
| Unknown Chinook | 19,781 | 0.7 | 0.9 | 1.6 |
| Steelhead | 30,976 | 9.7 | 1.5 | 11.2 |
| Sockeye | 1,715 | 0.7 | 1.5 | 2.2 |
| Total | 149,654 | 3.0 | 1.3 | 4.3 |

At the beginning of this study in 1998, it was estimated that avian predation was responsible for the loss of millions of juvenile anadromous salmonids annually, and management actions were being discussed regarding how this impact could be substantially reduced (Roby et al. 2002). However, while it was clear that piscivorous birds, particularly those nesting in the Columbia River estuary, were preying upon large numbers of salmonids, it was unclear which species were at the greatest risk. These uncertainties left doubt about the impact avian predators were having on endangered wild salmonid stocks. There was considerable speculation that avian predators were primarily preying on hatchery fish and that impacts to endangered wild stocks were minimal. Many fisheries managers throughout the Columbia River Basin believed that if avian predators were preying only on hatchery salmonids, there was no need for concern; however, if there was a significant impact on wild salmonids, then management action would be needed.

With this need for clarification in mind, we have been characterizing the individual salmonid stocks being preyed upon by piscivorous birds, using detections of juvenile salmonid PIT tags on piscivorous bird colonies (Ryan et al. 2001). It is important to remember, though, that these methods represent only PIT-tagged salmonids, and no effort is being made to PIT tag all stocks emigrating from the Columbia River Basin in a representative manner.

PIT-tags detected on piscivorous bird colonies throughout the Columbia River Basin continue to provide estimates of relative vulnerability to avian predation, as well as information useful to relocation efforts in the Columbia River estuary (Collis et al. 2001; Ryan et al. 2003). In addition, these data are stored on a central database which allows individual researchers to remove known mortalities from their data sets, thereby increasing accuracy.

## PREDATION IMPACT BY RIVER REACH, ESU LOCATION, AND BIRD COLONY

### Predation Impact by River Reach

Minimum predation rates, that is, the percent of tags released or interrogated in-river that were detected on bird colonies, were measured by river reach (Table 3). Reaches were designated as Columbia River estuary, Lake Celilo (The Dalles Reservoir), Lake Umatilla (John Day Reservoir), and Lake Wallula (McNary reservoir). To assess the spatial distribution of smolt loss to colonial waterbird predation, the combined predation impacts for all bird colonies identified within each reach were estimated and compared.

Reach-specific predation impacts were estimated by calculating the proportion of all PIT-tagged juvenile salmonids released and available, that is, inriver migrants, to the birds nesting within a reach that were subsequently detected on bird colonies within that reach.

PIT-tagged juvenile salmonids that were either transported through the reach and/or released downstream of the reach were determined to be unavailable to birds within a reach, and were therefore excluded from this analysis. These analyses did not attempt to correct for any inriver mortality of PIT-tagged juvenile salmonids that occurred prior to entering the reach.

Table 3. Numbers of PIT tags by river reach from juvenile salmonids detected on piscivorous waterbird colonies, 1998-2005. These data do not account for differences in recovery effort among locations (e.g., not all colonies were searched for tags in all years).

| Predator | Chinook | Coho | Steelhead | Sockeye | Total |
|---|---|---|---|---|---|
| **Columbia River estuary** | | | | | |
| Caspian tern | 110,445 | 12,568 | 133,180 | 399 | 256,592 |
| Double-crested cormorant | 48,071 | 3,647 | 21,927 | 324 | 73,969 |
| **Lake Wallula (McNary Reservoir)** | | | | | |
| Caspian tern | 31,363 | 3,799 | 63,994 | 327 | 99,483 |
| Gulls | 8,361 | 1,124 | 21,790 | 99 | 31,374 |
| Double-crested cormorant | 9,044 | 389 | 10,340 | 60 | 19,833 |
| American white pelican | 694 | 150 | 885 | 0 | 1,729 |
| Heron/Egret | 92 | 15 | 0 | 0 | 107 |
| **Lake Celilo (The Dalles Reservoir)** | | | | | |
| Gulls | 10,524 | 1,211 | 11,067 | 150 | 22,952 |
| **Lake Umatilla (John Day Reservoir)** | | | | | |
| Caspian tern | 4,609 | 278 | 5,482 | 44 | 10,413 |
| Gulls | 750 | 102 | 966 | 21 | 1,839 |
| **Potholes Reservoir** | | | | | |
| Caspian tern | 5,802 | 569 | 15,628 | 17 | 22,016 |
| Double-crested cormorant | 5 | 2 | 2 | 0 | 9 |
| **Okanogan River** | | | | | |
| Double-crested cormorant | 76 | 30 | 443 | 0 | 549 |
| **Totals** | 229,836 | 23,884 | 285,704 | 1,441 | 540,865 |

## Predation Impact by ESU Location

Proportions of tags released from barges or interrogated at dams and later detected on bird colonies were also measured by the ESU location where fish originated. Average proportions of steelhead by ESU location (Snake River Basin, Upper Columbia River, and Mid-Columbia River) that were detected on colonies ranged from 3.0 to 5.3%, and proportions of coho salmon ranged from 0.8 to 2.7% (Table 4). Proportions of sockeye salmon and fall and spring/summer Chinook from all locations were less than 2% (Table 4). Data shown are numbers of juvenile salmonids with a known origin that had the potential to migrate through the Columbia River estuary. Numbers were not adjusted to account for differing detection and survival probabilities.

Of the steelhead known to have survived to Bonneville Dam, in addition to those barged and released below Bonneville Dam, an average of 10.9% of the Snake River, 9.9% of the Upper Columbia River, and 7.8% of the Mid Columbia River Basin ESUs were detected on estuarine Caspian tern colonies: only 1.6, 1.6, and 1.3% of steelhead from the same respective locations were detected on cormorant colonies (Table 5).

For example, we looked at the proportion of salmonids detected at Bonneville Dam and subsequently detected on a bird colony in the Columbia River estuary to determine survival through the FCRPS. In evaluating these detections, we did not find any clear pattern showing higher vulnerability to avian predation for any particular ESU.

However, because the proportion of each stock tagged within each ESU differs annually, multi-year comparisons among these stocks are tenuous. In addition, using Bonneville Dam detections excluded the Lower Columbia River ESU and all of the Willamette River stocks from this analyses.

Table 4. Numbers of PIT-tagged juvenile salmonids by ESU location that were released into the Snake and Columbia River basins and the percentage of these tags that were subsequently detected on piscivorous bird colonies in the Columbia River estuary. This analysis does not include juvenile salmonids of unknown origin.

| Migration | Fall Chinook | | Spring/Summer Chinook | | Coho | | Steelhead | | Sockeye | |
|---|---|---|---|---|---|---|---|---|---|---|
| year | released | detected (%) | released | detected (%) | released | detected (%) | released | detected (%) | released | detected (%) |
| **Snake River basin ESUs** | | | | | | | | | | |
| 2003 | 156,287 | 1.0 | 578,340 | 1.5 | 7,000 | 0.6 | 129,978 | 6.2 | 11,305 | 0.3 |
| 2004 | 92,697 | 1.0 | 390,687 | 1.3 | 13,420 | 0.8 | 131,203 | 4.5 | 6,651 | 1.1 |
| 2005 | 215,951 | 0.5 | 402,706 | 0.9 | 8,606 | 1.1 | 137,970 | 5.1 | 8,052 | 0.5 |
| Average | | 0.8 | | 1.2 | | 0.8 | | 5.3 | | 0.6 |
| SE | | 0.2 | | 0.1 | | 0.1 | | 0.4 | | 0.2 |
| **Upper Columbia River basin ESUs** | | | | | | | | | | |
| 2003 | 84,235 | 0.9 | 589,917 | 1.6 | 17,037 | 2.1 | 485,633 | 4.7 | 0 | |
| 2004 | 9,316 | 0.7 | 606,287 | 2.3 | 38,630 | 4.1 | 486,279 | 3.9 | 1,083 | 0.6 |
| 2005 | 25,630 | 0.2 | 128,505 | 1.6 | 28,416 | 1.9 | 579,187 | 4.2 | 887 | 0.6 |
| Average | | 0.6 | | 1.8 | | 2.7 | | 4.3 | | 0.6 |
| SE | | 0.2 | | 0.2 | | 0.6 | | 0.2 | | 0.0 |
| **Mid-Columbia River basin ESUs** | | | | | | | | | | |
| 2003 | 3,522 | 0.8 | 26,666 | 1.4 | 10,056 | 1.9 | 8,874 | 2.7 | | |
| 2004 | 5,942 | 0.8 | 26,427 | 1.2 | 2,005 | 2.0 | 28,664 | 3.3 | | |
| 2005 | 10,350 | 0.6 | 37,959 | 1.6 | 1,706 | 0.7 | 40,470 | 2.9 | | |
| Average | | 0.8 | | 1.4 | | 1.5 | | 3.0 | | |
| SE | | 0.1 | | 0.1 | | 0.4 | | 0.2 | | |

Table 5. Numbers of PIT-tagged juvenile salmonids available to Caspian terns and double-crested cormorants nesting in the Columbia River estuary by ESU location, with proportions of tags from these fish subsequently detected on tern or cormorant colonies in the estuary. Available PIT-tagged fish are those detected at Bonneville Dam or released from barges or trucks below Bonneville Dam. Minimum samples of 300 were required to calculate percentages by bird species

| | Fall Chinook | | | Spring/Summer Chinook | | | Steelhead | | |
|---|---|---|---|---|---|---|---|---|---|
| Migration year | Available | Tern (%) | Cormorant (%) | Available | Tern (%) | Cormorant (%) | Available | Tern (%) | Cormorant (%) |
| **Snake River basin ESUs** | | | | | | | | | |
| 2003 | 45,203 | 1.1 | 0.6 | 126,905 | 2.6 | 0.6 | 35,325 | 11.5 | 1.0 |
| 2004 | 33,531 | 1.0 | 0.7 | 92,724 | 2.1 | 1.6 | 17,458 | 12.2 | 2.2 |
| 2005 | 16,301 | 1.1 | 2.4 | 94,074 | 1.4 | 1.1 | 26,472 | 8.9 | 1.6 |
| Average | | 1.1 | 1.2 | | 2.1 | 1.1 | | 10.9 | 1.6 |
| SE | | 0.0 | 0.4 | | 0.3 | 0.2 | | 0.7 | 0.3 |
| **Upper Columbia River basin ESUs** | | | | | | | | | |
| 2003 | 4,513 | 1.6 | 0.5 | 79,960 | 2.0 | 0.7 | 53,626 | 10.6 | 0.7 |
| 2004 | 245 | 1.2 | 1.2 | 44,386 | 2.7 | 1.8 | 18,775 | 9.1 | 2.5 |
| 2005 | 293 | 0.7 | 1.7 | 5,331 | 1.1 | 1.1 | 23,936 | 10.1 | 1.6 |
| Average | | 1.2 | 1.2 | | 2.0 | 1.2 | | 9.9 | 1.6 |
| SE | | 0.2 | 0.2 | | 0.3 | 0.2 | | 0.3 | 0.4 |
| **Mid Columbia River basin ESUs** | | | | | | | | | |
| 2003 | 395 | 2.0 | 1.3 | 3,573 | 1.4 | 0.6 | 963 | 7.2 | 0.3 |
| 2004 | 155 | -- | -- | 2,075 | 1.1 | 0.7 | 393 | 10.7 | 2.0 |
| 2005 | 711 | 0.1 | 0.3 | 2,735 | 1.4 | 0.5 | 880 | 5.5 | 1.6 |
| Average | | 1.1 | 0.8 | | 1.3 | 0.6 | | 7.8 | 1.3 |
| SE | | 0.5 | 0.3 | | 0.1 | 0.1 | | 1.1 | 0.4 |

## Impact of Specific Bird Colonies

Previous detection efforts have indicated that terns and cormorants are the major predators affecting salmonid species (Ryan et al. 2002, 2003). Colony-specific predation impacts were estimated for avian predator populations that posed the greatest risk to salmon survival, namely, the Caspian tern and double-crested cormorant colonies in the Columbia River estuary and Lake Wallula.

To assess predation impacts of terns and cormorants in the estuary, PIT-tag detections of in-river migrating and barge-released fish at Bonneville Dam, the furthest downstream dam (and lowest fixed PIT-tag detection point on the Columbia River), were used as measures of those PIT-tagged fish available to birds nesting in the estuary. Proportions of these fish that were subsequently interrogated on the estuary tern and cormorant colonies provided minimum estimates of avian predation rates on different groups of juvenile salmonids.

Similarly, PIT-tagged juvenile salmonids detected at Rock Island and Lower Monumental Dams were used as a measure of the numbers of PIT-tagged fish originating from the upper Columbia and Snake River, respectively, which were available to Caspian terns and double-crested cormorants nesting in Lake Wallula. Again, proportions of PIT-tagged fish subsequently detected on the Crescent Island Caspian tern colony provided minimum estimates of predation.

For migration years 2003 through 2005, we detected over 220,000 PIT tags on piscivorous bird colonies in the Columbia River Basin utilizing electronic techniques. In addition, approximately 20,000 previously-detected PIT tags were physically recovered by Real Time Research in migration years 2003 through 2005. The approximate 240,000 juvenile salmonid PIT tags detected on piscivorous bird colonies accounted for varying proportions of salmonids released into the Columbia River Basin ranging from 0.8 to 8.5%, depending on migration year and species (Appendix Table 1). The majority of tags were detected on colonies in the Columbia River estuary followed by colonies on Lake Wallula (Table 3).

Consistent with previous years, the largest areas of impact coincided with the largest populations of Caspian terns and cormorants in the Columbia River estuary and Lake Wallula, respectively. Other reaches contained primarily gull and heron colonies, and impacts were relatively low. However, there are two gull colonies on Richland Island and Island 18 which are of concern due simply to the sheer number of nesting gulls. Together, these colonies are home to tens of thousands of these birds. Although previous efforts have shown proportionally low tag recoveries, we feel it is time to revisit these islands (Ryan et al. 2002; Glabek et al. 2003). Our concern stems from the underrepresentation of PIT-tagged salmonids originating near islands in the Upper Columbia River Basin during the time they were surveyed.

**Lake Wallula**

Piscivorous bird colonies in Lake Wallula yielded over 76,000 juvenile salmonid PIT tags for migration years 2003 through 2005. Of the steelhead that potentially migrated though Lake Wallula, proportions detected on these colonies were 6.0% of fish from the from the Snake River, 2.3% from the Upper Columbia River, and 1.9% from the Mid Columbia River ESU (Table 6). Proportions of coho detected ranged from 0.9% for both the Upper and Mid Columbia River Basin ESUs to 1.1% for the Snake River Basin ESU (Table 6). The proportions of sockeye, fall Chinook, and spring/summer Chinook were less the 1.5% for all three ESUs (Table 6). We note that these predation rates were for salmonids with the potential to migrate through Lake Wallula; therefore, the release numbers excluded salmonids transported through the lake or released at downstream sites.

Concerning salmonids migrating from the Snake River Basin, the Lower Monumental Dam PIT-tag detection facility provides a large sample of PIT-tagged salmonids known to have survived within 67 km of Lake Wallula. From 2003 through 2005, over 126,000 PIT-tagged fall and spring/summer Chinook and steelhead were detected at Lower Monumental Dam and returned to the river to continue their migration (Table 7). PIT-tag detection efforts on piscivorous bird colonies in Lake Wallula accounted for 6.0 to 20.5% of the steelhead and 1.6 to 2.3% of the spring/summer Chinook detected at lower Monumental Dam that were allowed to continue their migration in-river to Lake Wallula (Table 7). The majority of this impact was due to terns nesting on Crescent Island. However, when transported salmonids were included in calculations of the impacts of Lake Wallula avian predators, the average predation rates were was much lower (Ryan 2005).

For salmonids migrating from the Upper Columbia River Basin, detections and releases of PIT-tagged salmonids at Rock Island Dam provided a sample of salmonids known to have survived to within 200 km of Lake Wallula. From 2003 through 2005, over 224,000 PIT-tagged Chinook and steelhead were detected or released from Rock Island Dam to continue their migration (Table 7). PIT-tag detection efforts on

Table 6. Porportions of detectctions on Lake Wallula (McNary Reservior) piscivorous bird colonies by ESU location for PIT-tagged juvenile salmonids released into the Snake and Columbia River basins (not including juvenile salmonids transported through Lake Wallula in barges). Analysis does not include salmonids of unknown origin.

| Migration | Fall Chinook | | Spring/summer Chinook | | Coho | | Steelhead | | Sockeye | |
|---|---|---|---|---|---|---|---|---|---|---|
| year | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) |
| **Snake River Basin ESUs** | | | | | | | | | | |
| 2003 | 119,375 | 0.9 | 481,078 | 0.6 | 6,977 | 0.5 | 103,671 | 3.6 | 11,239 | 0.6 |
| 2004 | 66,193 | 1.0 | 303,351 | 0.4 | 13,365 | 1.3 | 114,706 | 8.9 | 5,282 | 0.0 |
| 2005 | 201,588 | 0.4 | 314,871 | 0.4 | 8,541 | 1.5 | 112,464 | 5.5 | 6,364 | 0.3 |
| Average | | 0.8 | | 0.4 | | 1.1 | | 6.0 | | 0.3 |
| SE | | 0.2 | | 0.1 | | 0.3 | | 1.3 | | 0.1 |
| **Upper Columbia River Basin ESUs** | | | | | | | | | | |
| 2003 | 84,235 | 0.5 | 589,917 | 0.3 | 17,037 | 1.0 | 485,633 | 2.0 | 0 | 0.0 |
| 2004 | 9,316 | 1.4 | 606,287 | 0.4 | 38,630 | 0.9 | 486,279 | 2.6 | 1,083 | 0.6 |
| 2005 | 25,630 | 2.5 | 128,505 | 0.3 | 28,416 | 0.8 | 579,187 | 2.3 | 887 | 0.2 |
| Average | | 1.5 | | 0.3 | | 0.9 | | 2.3 | | 0.3 |
| SE | | 0.5 | | 0.0 | | 0.1 | | 0.1 | | 0.2 |
| **Mid Columbia River Basin ESUs** | | | | | | | | | | |
| 2003 | 3,522 | 0.5 | 26,666 | 0.2 | 10,056 | 1.4 | 8,874 | 0.8 | | |
| 2004 | 5,942 | 0.5 | 26,427 | 0.5 | 2,005 | 0.8 | 28,664 | 3.0 | | |
| 2005 | 10,350 | 0.3 | 37,959 | 0.9 | 1,706 | 0.5 | 40,470 | 1.9 | | |
| Average | | 0.4 | | 0.5 | | 0.9 | | 1.9 | | |
| SE | | 0.1 | | 0.2 | | 0.2 | | 0.5 | | |

Table 7. Number of PIT-tagged juvenile salmonids available to piscivorous birds nesting in Lake Wallula (McNary Reservior) and the number and proportion of tags from these fish subsequently detected on the Caspian tern colony on Crescent Island. PIT-tagged fish interrogated at Lower Monumental Dam on the Snake River and at Rock Island Dam on the Columbia River were determined to be available. A minimum sample size of 300 PIT-tagged fish was required in order to calculate the proportion on tern colonies.

| | Fall Chinook | | | | Spring/summer Chinook | | | | Steelhead | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | All | | | | All | | | | All |
| Migration | Available | Tern colony | | detections | Available | Tern colony | | detections | Available | Tern colony | | detections |
| year | (n) | (n) | (%) | (%) | (n) | (n) | (%) | (%) | (n) | (n) | (%) | (%) |
| **Snake River basin (from tags interrogated at Lower Monumental Dam)** | | | | | | | | | | | | |
| 2003 | 7,749 | 89 | 1.1 | 1.3 | 9,183 | 109 | 1.2 | 1.6 | 16,620 | 676 | 4.1 | 6.0 |
| 2004 | 9,600 | 141 | 1.5 | 1.8 | 14,463 | 263 | 1.8 | 2.3 | 23,658 | 4,326 | 18.3 | 20.5 |
| 2005 | 4,764 | 98 | 2.1 | 2.2 | 17,534 | 139 | 0.8 | 1.7 | 23,207 | 2,002 | 8.6 | 11.1 |
| Average | | | 1.6 | 1.8 | | | 1.3 | 1.9 | | | 10.3 | 12.5 |
| SE | | | 0.2 | 0.2 | | | 0.2 | 0.2 | | | 3.0 | 3.0 |
| **Upper Columbia River basin (from tags interrogated at Rock Island Dam)** | | | | | | | | | | | | |
| 2003 | 0 | 0 | -- | -- | 90,877 | 324 | 0.4 | 0.5 | 0 | 0 | -- | -- |
| 2004 | 0 | 0 | -- | -- | 87,535 | 361 | 0.4 | 0.5 | 2,627 | 78 | 3.0 | 3.5 |
| 2005 | 0 | 0 | -- | -- | 43,417 | 55 | 0.1 | 0.2 | 0 | 0 | -- | -- |
| Average | | | -- | -- | | | 0.3 | 0.4 | | | 3.0 | 3.5 |
| SE | | | -- | -- | | | 0.1 | 0.1 | | | -- | -- |

piscivorous bird colonies in Lake Wallula accounted for an average of 3.5% of the steelhead and 0.4% of the spring/summer Chinook that were released or detected at Rock Island Dam (Table 7). While these impacts are fairly low, the majority could once again be attributed to Caspian terns nesting on Crescent Island. There is no transportation from the Upper Columbia River, so there was no recalculation of minimum predation impacts that accounted for transported fish.

**Lake Celilo, Potholes Reservoir, Banks Lake, and Okanogan River**

Piscivorous bird colonies in Lake Celilo yielded approximately 7,000 juvenile salmonid PIT tags for migration years 2003 and 2004. These tags accounted on average for less than 0.6% of the steelhead and spring/summer and fall Chinook that had the potential to migrate through the lake for all three ESUs (Appendix Table 2).

Piscivorous bird colonies in the Potholes Reservoir area yielded less than 17,000 juvenile salmonid PIT tags from migration years 2003 through 2005. These tags accounted for approximately 0.6% of steelhead and less then 0.1% for all other PIT tagged salmonid stocks released into the Snake or Columbia River Basins (Appendix Table 3).

However, despite low predation numbers in Potholes reservoir, it is important to note that the proportion of steelhead tags recovered doubled from 2004 to 2005, and therefore monitoring should continue in this area. Piscivorous bird colonies along the Okanogan River and the Banks Lake areas yielded only 518 and 103 juvenile salmonid PIT tags, respectively, from migration years 2003 through 2005. These tags accounted for less than 0.05% of the steelhead, fall Chinook, spring/summer Chinook, coho, and sockeye that were tagged and released into the Snake and Columbia River Basins.

# DETECTION EFFICIENCY EVALUATIONS

## Introduction

Although large numbers of tags have been detected annually since land-based detection efforts began, a major concern has been PIT-tag detection efficiency. To examine this issue, we distributed known PIT tags on colonies prior to the nesting season, and subsequently calculated the percentage of these tags detected at the end of the nesting seasons. Prior to 2005, PIT tags were not distributed on Banks Lake Island, the Okanogan River area, North Potholes Reservoir area, or on Goose Island due to the uncertainty of the nesting locations prior to the nesting season.

In addition to overall detection efficiencies on the islands, we also addressed the issue of low detection efficiency on the Crescent Island tern colony measured in previous years in a cooperative effort with Real Time Research, Inc. and Oregon State University (OSU) in 2004 and 2005. We investigated the hypothesis that numbers of tags detected were not equally distributed temporally by examining detection efficiencies throughout the nesting season on the islands that produced the largest number of overall detections, the tern colonies on East Sand and Crescent Islands.

## Methods

We planted a known number of tags during four discrete periods: 1) before the nesting season, 2) during chick emergence, 3) at fledging, and 4) after the birds vacated the island. On Crescent Island, tags were planted in four plots representative of the tern colony at the discretion of Real Time Research and NOAA Fisheries. On East Sand Island, tags were planted in areas representative of the tern colony at the discretion of colony monitors working for OSU.

Once the birds abandoned the nesting colony, we conducted our normal tag detection effort. We then calculated detection efficiencies using the planted tag codes that we recovered. In addition, researchers from Real Time Research and OSU used manual sifting techniques to recover PIT tags from Crescent Island and East Sand Island after we had completed our detection efforts in 2004 (Collis et al. 2005). We used the recovery efforts as an additional evaluation of detection efficiency by calculating the percentage of tags they recovered that were missed during our detection effort.

Because of concern regarding tag collision[†], an additional pass was made in 2004 using electronic detection on the Crescent Island tern colony following hand removal of PIT tags by Real Time Research and OSU.

We felt that the physical tag removal by Real Time Research/OSU would reduce the frequency of tag collision, possibly allowing us to detect tags whose signals had been obscured during previous detection efforts. In 2005, hand removal preceded our detection efforts in order to observe any disparities in tag recovery caused by our detection equipment, and to reduce tag collision prior to electronic detection.

## Results and Discussion

Detection efficiencies, based on previously distributed tags, ranged from 44 to 85% in 2003, 36 to 94% in 2004, and 21 to 83% in 2005, depending on colony and detection method (Table 8). Of the test tags intentionally spread on the Crescent Island tern colony during four discrete time periods in 2004, 82.3% were recovered on-colony using all detection and collection efforts combined (Table 9). Of the lower read-range (BE) tags, 79.0% were recovered, whereas 81.5 % of the higher read-range Super Tags were recovered.

Detection efficiencies for all tag types ranged from a low of 0.3% during the pre-season release (first day or day 0 of the 2004 nesting season) to a high of 99.0% during the post-season wrap up (last day or day 125 of the 2004 nesting season) (Allen Evans, Real Time Research, personal communication). On the East Sand Island tern colony, we intentionally spread 1,018 test tags (499 BE tags and 519 Super tags) during 3 periods in 2004. We subsequently detected 92.1% of these tags (Table 9). We detected 94.8% of the lower read-range BE tags and 93.1 % of the higher read-range Super Tags. Detection efficiency for all tag types combined ranged from 86.3% during chick emergence to 97.0% during the pre-season nesting period.

In 2005, we planted only Super Tags on colonies in the Columbia River Basin. During this migration season, our detection efficiencies on the Crescent Island tern colony ranged from 29.4% in the pre-season to 95% in the post-season. On the East Sand Island tern colony, detection efficiencies ranged from 75.3% during late incubation to 89.0% during chick banding.

† Tag collision occurs when one tag is in close proximity to another under the detecting coil, which results in the antenna not being able to read either code.

Table 8. Detection efficiency of PIT tags distributed on colonies prior to the nesting season. Exception is Crescent Island and East Sand Island Caspian tern colonies, where PIT tags were planted throughout the nesting season in 2004.

| | Detection efficiency (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Mean |
| **Tern** | | | | | | | |
| East Sand Island | 94 | 95 | 95 | 85 | 94 | 83 | 91 |
| Crescent Island | | 45 | 15 | 45 | 80 | 71 | 51 |
| Goose Island | | | | | | 21 | 21 |
| Solstice Island | | | 29 | 44 | 45 | | 39 |
| **Cormorant** | | | | | | | |
| East Sand Island | | 45 | 35 | 45 | 36 | | 40 |
| Foundation Island | | | 67 | | 63 | 68 | 66 |
| **Gull** | | | | | | | |
| Littler Miller Island | | 49 | 36 | | | | 43 |
| Memaloose Island | | 77 | | | | | 77 |
| Little Miller Island | | | | | 55 | | 55 |
| Richland Island | | 37 | 54 | | | | 46 |
| Island 18 | | 37 | 43 | | | | 40 |
| **Pelican** | | | | | | | |
| Badger Island | | 65 | 68 | | | 58 | 64 |

Table 9. Detection efficiency of test tags intentionally released on the Crescent and East Sand Island tern colonies during discrete time periods, 2004 and 2005.

| | Detection efficiency (%) | | | |
|---|---|---|---|---|
| | Crescent Island | | East Sand Island | |
| | 2004 | 2005 | 2004 | 2005 |
| Before nesting | 58.3 | 29.4 | 97.0 | 86.3 |
| Chick emergence | 81.8 | 74.1 | 86.3 | 75.3 |
| Fledging | 90.0 | 84.5 | 93.0 | 89.0 |
| After nesting | 99.0 | 95.0 | -- | 82.3 |
| Mean | 82.3 | 70.7 | 92.1 | 83.3 |

Of the 400 test tags planted on the Foundation Island cormorant colony in 2005, we subsequently detected 67.8%. Our detection efficiencies ranged from 58% during mid-season to 79% in the pre-season. During the pre-season, 100 test tags were planted on the Badger Island pelican colony and 500 on the Goose Island tern colony. We subsequently detected 58% of the Badger Island tags and 21% of the Goose Island tags (Table 8).

While we have not developed a method to evaluate the rates that tags are deposited on our sample sites, we have evaluated detection efficiency for tags known to have been deposited on them. Evaluations of detection efficiency on East Sand Island indicated that over 90% of all tags on the tern colony over the past 4 years were detected, with the exception of 2003 when only 85% were detected. Manual recovery of several thousand tags for migration year 2003 by researchers from Real Time Research and OSU on Crescent Island resulted in an overall increase in detection efficiency of only 1.5%.

Overall, detection efficiency averaged approximately 56% for all colonies combined in 2004. In addition, Real Time Research and OSU added 6,976 migration year 2004 tag codes to the 14,463 tags we had already detected, an increase of 48.2%. Detection efficiency increased through the season on the Crescent Island tern colony in 2004, suggesting that salmonids preyed upon in the early part of the nesting season may have been under-represented relative to salmonids taken late in the nesting season.

Furthermore, the additional 1,761 detections after tag removal in 2004 suggested that tag collision was occurring and that by removing the tags, we were able to improved detection efficiency.  The removal resulted in an 8.0% increase of detected tags.  Future efforts will involve removing tags before normal electronic detection occurs to help alleviate some of the problems associated with tag collision.  The overall detection efficiency of 80.2% on the Crescent Island tern colony for migration year 2004 was the highest ever recorded.  However, even a detection efficiency of 100% would still represent only a partial estimate of total predation, as not all tags are deposited on colonies after the tagged fish is consumed.

## EVALUATION OF A MULTIPLE BYPASS EFFECT

It has been hypothesized that the experience of bypassing multiple hydroelectric facilities may increase the risk of avian predation to juvenile salmonids. To assess this potential impact, we summarized data on salmonids from the Snake River using hydrologic unit codes (Seaber 1987) as a means to separate the fish and removed all barged fish. We next segregated the remaining fish by the number of times they had been bypassed, always including Bonneville Dam (bypass = 1) as a means to determine survival to the last facility in the Columbia River hydropower system. Finally, we compared the proportion of salmonids detected on the East Sand Island tern colony to observe any trends in increased risk from increased bypass.

Six dams with the capability to bypass and detect juvenile salmonids (Lower Granite, Little Goose, Lower Monumental, McNary, John Day and Bonneville Dams) were included in migration years 2003, 2004, and 2005. For migration year 2005, we also included Ice Harbor Dam in the analyses.

Only spring/summer Chinook and steelhead provided adequate numbers of multiple-bypassed fish to compare with other groups. For fall Chinook, coho, and sockeye salmon, there were not sufficient numbers of multiple-bypassed fish. Numbers of all anadromous salmonids bypassed more than five times were also too few for analysis.

For spring/summer Chinook and steelhead, we did not find any consistent trend in the rate of predation resulting from passage through multiple bypasses (Figure 2). The highest rate of predation found was for spring/summer Chinook salmon bypassed twice in 2004 (3.6%); however, this value was nearly identical to the predation rate for salmonids bypassed five times in the same year. While steelhead were detected at much higher rates, averaging 16.8% compared to 2.5% for spring/summer Chinook, only those migrating in 2004 showed a possible increase in predation rate as the number of times bypassed increased.

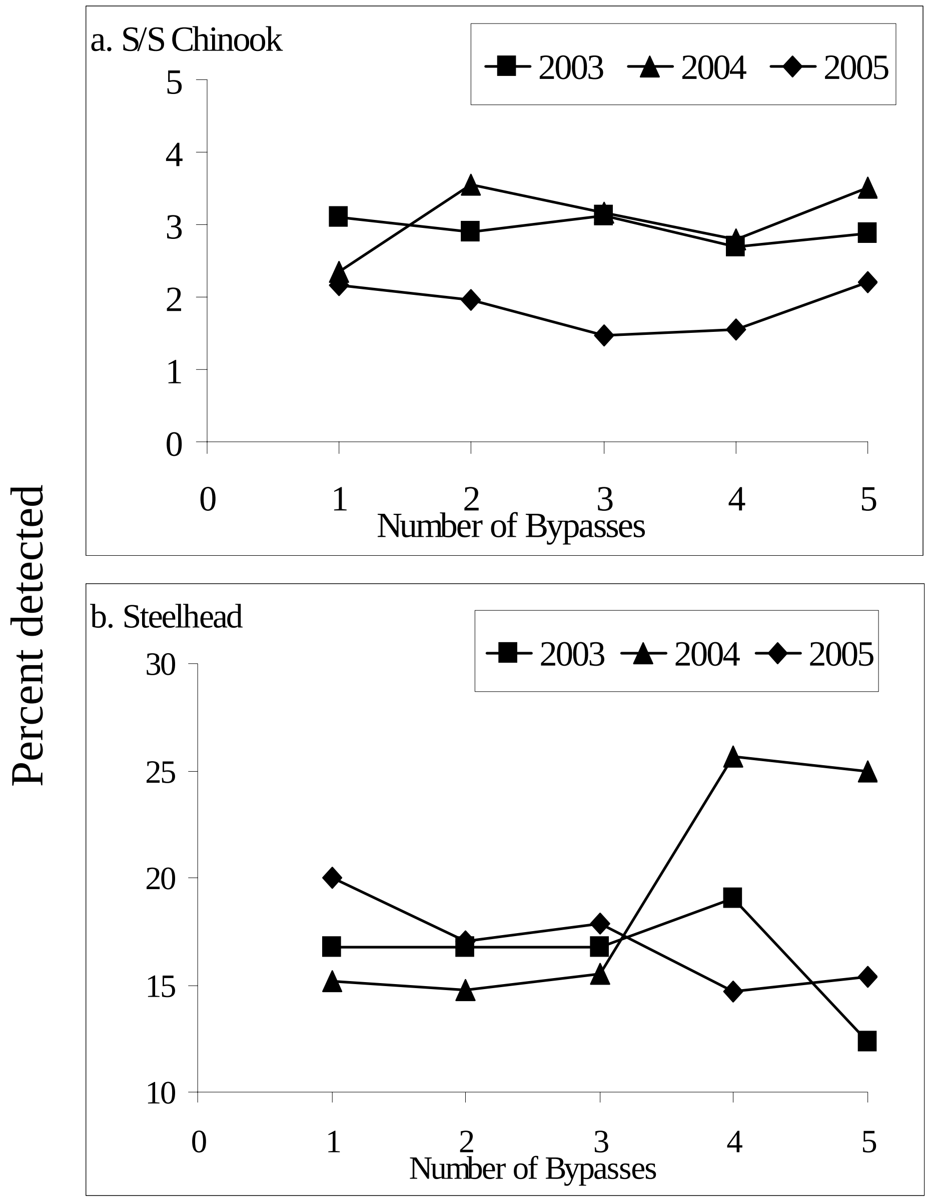


Figure 2. PIT-tagged Snake River spring/summer Chinook (a) and steelhead (b) bypassed through Bonneville Dam (Bypass: 1) and up to four additional bypass facilities, and the percentage detected on the East Sand Island tern colony.

There is evidence that juvenile salmonids that have been bypassed at multiple Snake River dams returned as adults at lower rates than those that never experienced bypass.  We did not find that there were significantly different proportions of salmonids detected on bird colonies in the estuary based on the number of times they had experienced a juvenile fish bypass system.

Evidently, the experience of fish passing through bypass systems did not influence vulnerability to avian predation.  However, this was only for fish that survived to be detected at Bonneville Dam.  It is also possible, therefore, that fish detected at bypass systems further upstream were less likely to survive to Bonneville Dam.  We also did not estimate the proportion of salmonids that did not experience a bypass that were detected on a bird colony.  While we could make this comparison, it would be from point of release and would not account for differences in inriver survival.

## TAGGING OF LOWER RIVER STOCKS

### Introduction

Because of major variations in its life history characteristics, Chinook salmon has been categorized into two separate types: "stream-type" and "ocean-type" (Narum et al. 2004). Life history disparities between the types include differences in the timing of adult spawning migrations, utilization of freshwater habitat, and juvenile morphology and behavior traits (Narum et al 2004). Stream-type Chinook spends at least one year in its natal river before migrating to sea, and is typically found in higher-elevation, headwater streams. It is typically referred to as spring Chinook. Ocean-type Chinook migrates from the natal stream more rapidly, frequently less than 3 months after hatching. Subsequently, this type may spend more time rearing in estuaries before moving into the ocean. This type is typically found in lower-elevation streams in the Columbia River Basin, and is generally referred to as fall Chinook salmon.

While PIT tagged salmonids have been released throughout the Columbia River Basin from sites upstream of Bonneville Dam since 1987, prior to 2001, no significant numbers of PIT-tagged salmonids had been released from populations residing in streams and rivers that discharge directly into the Columbia River estuary (PSMFC 2006). These stocks may be more vulnerable to avian predators nesting in the estuary than their upriver counterparts, as their life history strategies may rely more heavily on the estuarine habitat.

We were interested in comparing the potential effect of longer estuarine residency by fall Chinook salmon in terms of avian predation. Vulnerability to predation is of special concern for these stocks, considering the large colonies of piscivorous birds nesting in the estuary. To evaluate whether or not estuarine-rearing ocean-type salmonids were more vulnerable to avian predation, we began tagging samples of these fish to compare with upriver stocks in 2002. We continued these efforts from 2003 to 2005, and these evaluations constituted the only major tagging effort for these stocks.

## Methods

Each spring from 2003 through 2005, we PIT tagged hatchery spring Chinook, fall Chinook, steelhead *O. mykiss,* and coho *O. kisutch* and released them to rivers that discharged directly into the Columbia River estuary. Juveniles were tagged according to protocols outlined in the *PIT Tag Marking Procedures Manual* (CBFWA 1999) using mass marking and simple PIT-tag injectors. Following tagging, fish were held at the hatcheries for a minimum of 7 days to remove any tagging mortalities and rejected tags.

To examine the data for trends in differential predation rates between upriver and lower river fall Chinook and steelhead stocks, we summarized release and detection numbers both monthly and yearly where there were corresponding lower river release dates. Monthly summaries included data from both PIT-tag detections at Bonneville Dam and from barged fish released below Bonneville using release date as a substitute for detection date.

We included only Snake River salmonids in these comparisons, and only release or detection sums which included greater than 300 fish. By comparing predation rates for both fall Chinook and steelhead, we hoped to determine if disparities in predation rates were a result of behavioral variation between estuarine and upriver salmonids, particularly in fall Chinook, or of survival from Bonneville Dam for upriver stocks.

For avian predation comparisons, we used data from both tern and cormorant colonies on East Sand Island as they had access to all groups of salmonids migrating through that area to the ocean. Although the cormorant and tern colonies preyed more heavily on fall Chinook and steelhead, respectively, we summarized data for both species from both colonies to observe the entire impact of avian predators in the estuary.

In addition to monthly comparisons, we also examined weekly and biweekly data summaries, using the lower river releases as midpoints for the range of dates. The dates were adjusted to account for 3 days of travel time required to the estuary for fish detected at Bonneville Dam and those released from barge. Sufficient data were lacking for all weekly summaries, although they did support the trends observed in the monthly data. Daily comparisons similarly lacked adequate numbers to make useful comparisons.

Due to lack of tagging in the estuary in 2004, no comparisons were made between detection rates of lower and upper river releases for that year. All data used for comparisons fell within the migratory months of April through June. We used data from transported fish and those detected at Bonneville Dam only if the barge release or Bonneville detection timing corresponded with the timing of lower river releases.

## Results and Discussion

From 2003 through 2005, we PIT tagged 49,100 lower Columbia River salmonids each spring and released them into rivers and streams that discharge into the Columbia River downstream of Bonneville Dam (Table 10). These releases allowed a comparison of predation rates between estuarine and upriver salmonids. Piscivorous bird colonies on East Sand Island in the Columbia River estuary yielded nearly 2,900 fall Chinook tags for migration years 2003 and 2005 combined. Of these, 1,505 detected tags had been released from estuarine hatcheries (20.3 and 12.0% of the tagged fish released from Sea Resources and Big Creek Hatchery, respectively). Bonneville Hatchery, however, accounted for only 121 of the tags (1.8%) recovered on East Sand Island during the 3-year period. In addition, only 2.2% (1,151 recovered tags) of fall Chinook released from barges during this period were recovered on the island.

Finally, only 2.0% (113 tags) of Bonneville Dam detections were recovered from the island. This pattern of higher predation rates for lower river fall Chinook remained consistent among years (Table 10). Monthly comparisons (Figure 3) also showed consistently higher predation rates for lower-river than for upper-river fall Chinook. Upriver steelhead, on the other hand, was preyed upon at higher rates than were lower river fish.

A distinct trend was observed for differences in predation rates between upriver and downriver fall Chinook. This trend remained consistent when observed both monthly and annually. Downriver stocks were preyed upon at appreciably higher rates than were their counterparts that originated further upstream. Steelhead, on the other hand, showed similar or higher predation rates for upriver stocks.

If predation rates for fall Chinook were not related to behavior (lower river stocks spend more time developing physically in the estuary), we would expect to observe similar patterns as with upriver and downriver steelhead stocks. The differences in predation rates also seem to be too large to be explained by differences in survival between Bonneville Dam and the estuary for the upriver stocks.

Table 10. PIT-tagged salmonids released into estuarine rivers downstream from Bonneville Dam and the percentage of these fish detected on piscivorous bird colonies in the estuary.

| Species | Release site | Release date | Total released (n) | East Sand Island Detection: Tern (%) | East Sand Island Detection: Cormorant (%) | Total detection (%) |
|---|---|---|---|---|---|---|
| **Migration year 2003** | | | | | | |
| Fall Chinook | Sea Resources H* | 18 June | 2,873 | 7.2 | 14.4 | 21.6 |
| Fall Chinook | Big Cr Hatchery | 1 May | 2,974 | 3.3 | 7.4 | 10.8 |
| Fall | Bonneville H | 17 June | 2,996 | 0.5 | 0.4 | 0.9 |
| Spring Chinook | Deep River | 1 May | 2,986 | 2.4 | 0.9 | 3.3 |
| Spring Chinook | Blind Slough | 9 April-27 May | 10,158 | 5.8 | 1.5 | 7.4 |
| Steelhead | Elochoman River | 22 April | 2,775 | 9.5 | 0.4 | 9.9 |
| Coho | Sea Resources H | 13 May | 651 | 4.8 | 2.8 | 7.5 |
| Total | | | 25,413 | | | 8.4 |
| **Migration year 2004** | | | | | | |
| Spring Chinook | Blind Slough | 7 April-20 May | 11,677 | 3.9 | 0.9 | 4.8 |
| **Migration year 2005** | | | | | | |
| Fall Chinook | Big Creek H | 1 June | 2,999 | 2.7 | 10.4 | 13.1 |
| Fall Chinook | Bonneville H | 15 June | 3,004 | 0.5 | 2.6 | 3.1 |
| Steelhead | Elochoman H | 15 April | 3,000 | 8.6 | 1.1 | 9.7 |
| Steelhead | Lewis River H | 1 June | 3,007 | 8.6 | 1.0 | 9.7 |
| Total | | | 12,010 | | | 8.9 |

* H = Hatchery

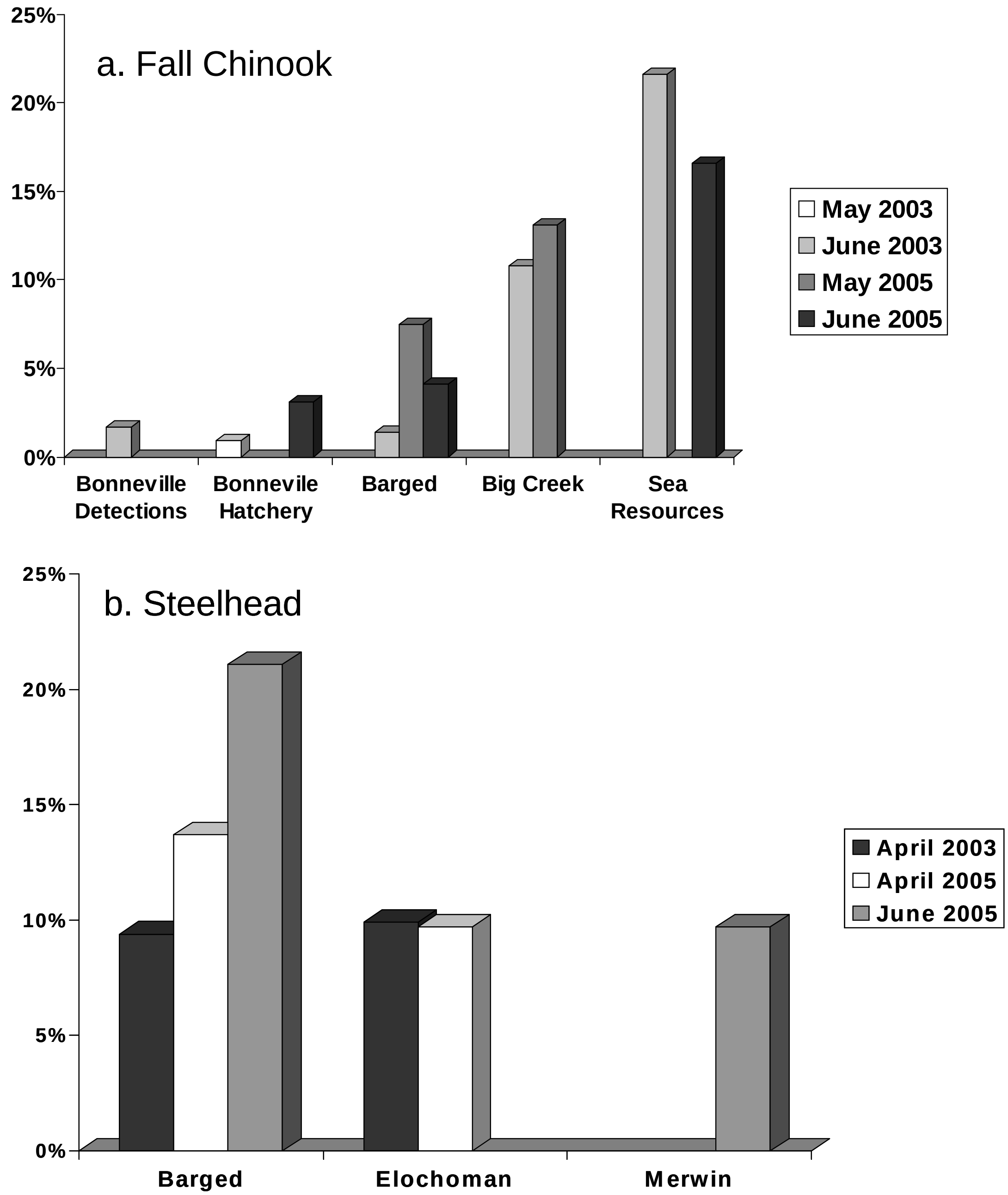


Figure 3. Percentage of subyearling fall Chinook (a) and steelhead (b) detected on East Sand Island (tern and cormorant colonies) by release location and date.

The low predation rates seen for both fall Chinook released from Bonneville Hatchery and in the Snake River support the notion that fall Chinook originating in lower river areas are more heavily preyed upon than their upriver counterparts. The location of Sea Resources Hatchery on the Chinook River may have played a part in artificially inflating the predation rate of lower river fall Chinook. Fish released from this hatchery are forced to pass through a narrow channel adjacent to the East Sand Island cormorant colony. However, downriver fish released from Big Creek Hatchery are also subject to increased predation as well, with predation rates for both hatcheries consistently and substantially higher than for upriver fall Chinook.

While we have attempted to address the lack of tagging in the Lower Columbia River area, which has been limited due to lack of resources, we have not been able to address the issue of the Willamette River stocks at all. In the future, a concerted PIT-tagging effort in the Willamette would not only help evaluate the impacts that avian predators have on these stocks, but the tagged fish would also be useful to researchers evaluating estuarine usage near the mouth of the Columbia River.

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**APPENDIX: Data Summary Tables**

Appendix Table 1. Number of PIT-tagged juvenile salmonids released into the Columbia River basin by migration year and percentages of their tags detected on piscivorous bird colonies. Colony-based PIT tag detections occurred following the breeding seasons in 1998 - 2005, although not all colonies were searched for tags in 1998 and 2005. An additional 25,671 tags from juvenile salmonids of unknown species were detected.

| Migration | Fall Chinook | | Spring/Summer Chinook | | Coho | | Steelhead | | Sockeye | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| year | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) |
| 1987 | 654 | 0.2 | 1,991 | 0.1 | 0 | 0.0 | 5,166 | 0.4 | 1,934 | 0.1 | 9,745 | 0.3 |
| 1988 | 3,290 | 0.0 | 16,812 | 0.2 | 0 | 0.0 | 17,975 | 0.8 | 145 | 0.0 | 38,222 | 0.5 |
| 1989 | 494 | 0.2 | 64,937 | 0.1 | 0 | 0.0 | 31,581 | 0.9 | 3,979 | 0.1 | 100,991 | 0.4 |
| 1990 | 4,977 | 0.0 | 53,905 | 0.1 | 3 | 0.0 | 23,344 | 0.9 | 7,441 | 0.1 | 89,670 | 0.3 |
| 1991 | 4,355 | 0.1 | 50,122 | 0.1 | 6,040 | 0.6 | 23,280 | 0.7 | 8,578 | 0.1 | 92,375 | 0.3 |
| 1992 | 9,390 | 0.3 | 45,035 | 0.2 | 4,455 | 1.1 | 29,338 | 1.0 | 12,401 | 0.1 | 100,619 | 0.4 |
| 1993 | 6,050 | 0.2 | 103,493 | 0.4 | 5 | 20.0 | 34,633 | 2.3 | 33,440 | 0.1 | 177,621 | 0.7 |
| 1994 | 7,455 | 0.2 | 202,956 | 1.1 | 0 | 0.0 | 143,186 | 2.7 | 3,884 | 0.3 | 357,481 | 1.7 |
| 1995 | 34,414 | 0.3 | 152,311 | 0.6 | 0 | 0.0 | 80,489 | 3.5 | 8,134 | 0.4 | 275,348 | 1.4 |
| 1996 | 54,864 | 0.7 | 145,430 | 1.5 | 5,338 | 1.1 | 80,396 | 4.3 | 16,348 | 0.6 | 302,376 | 2.1 |
| 1997 | 178,072 | 1.2 | 249,913 | 1.7 | 47,359 | 4.2 | 125,962 | 6.9 | 4,267 | 0.8 | 605,573 | 2.8 |
| 1998 | 282,159 | 1.4 | 322,044 | 1.9 | 76,009 | 4.7 | 85,138 | 11.5 | 21,108 | 1.0 | 786,458 | 3.0 |
| 1999 | 322,121 | 1.5 | 539,487 | 2.2 | 60,960 | 4.5 | 353,891 | 9.5 | 13,243 | 1.4 | 1,289,702 | 4.1 |
| 2000 | 316,646 | 3.3 | 514,534 | 2.8 | 95,272 | 4.6 | 242,462 | 11.5 | 8,707 | 2.0 | 1,177,621 | 4.9 |
| 2001 | 265,649 | 1.7 | 597,061 | 4.6 | 49,500 | 5.7 | 132,791 | 10.5 | 5,893 | 3.0 | 1,050,894 | 4.7 |
| 2002 | 361,503 | 1.5 | 1,089,349 | 2.2 | 56,685 | 4.5 | 168,491 | 11.1 | 8,205 | 2.2 | 1,684,233 | 3.0 |
| 2003 | 258,097 | 1.8 | 1,272,381 | 2.1 | 58,143 | 2.6 | 631,899 | 7.8 | 11,305 | 1.0 | 2,231,825 | 3.7 |
| 2004 | 121,303 | 1.7 | 1,094,499 | 2.4 | 67,379 | 4.1 | 653,466 | 8.5 | 7,930 | 1.1 | 1,944,577 | 4.4 |
| 2005 | 280,106 | 1.2 | 631,664 | 1.4 | 83,529 | 1.8 | 768,770 | 7.5 | 8,939 | 0.8 | 1,773,008 | 4.0 |
| Total | 2,511,599 | 1.7 | 7,147,924 | 2.2 | 610,677 | 3.9 | 3,632,258 | 7.9 | 185,881 | 0.8 | 14,088,339 | 3.6 |
| Average | | 0.9 | | 1.4 | | 3.1 | | 5.4 | | 0.8 | | 2.2 |
| SE | | 0.3 | | 0.3 | | 1.4 | | 1.1 | | 0.2 | | 0.4 |

Appendix Table 2. PIT-tagged juvenile salmonids released into the Snake and the Columbia River basins and the percentage of these tags subsequently detected on piscivorous bird colonies in Lake Celilo (The Dalles Reservoir). Transported fish were excluded, as were juvenile salmonids of unknown origin. No islands were sampled in Lake Celilo in 2005.

| | Fall Chinook | | Spring/summer Chinook | | Coho | | Steelhead | | Sockeye | |
|---|---|---|---|---|---|---|---|---|---|---|
| Migration year | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) |
| **Snake River basin** | | | | | | | | | | |
| 1999 | 73,763 | 0.08 | 278,806 | 0.09 | 8,926 | 0.09 | 123,055 | 0.61 | 8,249 | 0.10 |
| 2000 | 64,706 | 0.30 | 208,466 | 0.17 | 8,346 | 0.19 | 139,359 | 1.26 | 6,290 | 0.54 |
| 2001 | 110,675 | 0.06 | 206,997 | 0.23 | 6,093 | 0.00 | 86,501 | 0.74 | 3,253 | 0.03 |
| 2002 | 177,409 | 0.06 | 409,441 | 0.16 | 5,102 | 0.27 | 117,804 | 0.77 | 4,568 | 0.13 |
| 2003 | 117,077 | 0.09 | 478,791 | 0.08 | 6,964 | 0.07 | 103,197 | 0.51 | 11,221 | 0.04 |
| 2004 | 63,539 | 0.13 | 302,275 | 0.05 | 13,363 | 0.10 | 114,487 | 0.53 | 5,280 | 0.00 |
| Average | | 0.12 | | 0.13 | | 0.12 | | 0.74 | | 0.14 |
| SE | | 0.05 | | 0.03 | | 0.05 | | 0.14 | | 0.10 |
| **Upper Columbia River Basin** | | | | | | | | | | |
| 1999 | 6,713 | 0.09 | 20,875 | 0.09 | 7,072 | 0.47 | 135,999 | 0.46 | 4,844 | 0.23 |
| 2000 | 6,103 | 0.20 | 66,950 | 0.34 | 16,879 | 0.62 | 38,686 | 1.26 | 1,389 | 0.43 |
| 2001 | 5,953 | 0.05 | 108,142 | 0.41 | 17,050 | 0.29 | 5,208 | 2.04 | 2,591 | 0.39 |
| 2002 | 5,977 | 0.10 | 451,515 | 0.20 | 24,752 | 0.42 | 5,632 | 1.01 | 3,590 | 0.61 |
| 2003 | 83,893 | 0.03 | 556,362 | 0.13 | 16,933 | 0.18 | 470,093 | 0.25 | 0 | 0.00 |
| 2004 | 9,290 | 0.09 | 581,209 | 0.18 | 38,606 | 0.32 | 473,555 | 0.34 | 1,081 | 0.19 |
| Average | | 0.09 | | 0.23 | | 0.38 | | 0.89 | | 0.31 |
| SE | | 0.03 | | 0.06 | | 0.08 | | 0.34 | | 0.11 |
| **Mid Columbia River Basin** | | | | | | | | | | |
| 1999 | 220,926 | 0.06 | 136,882 | 0.09 | 22,165 | 0.10 | 8,397 | 0.29 | | |
| 2000 | 222,980 | 0.16 | 112,796 | 0.13 | 46,080 | 0.18 | 9,045 | 0.36 | | |
| 2001 | 44,688 | 0.04 | 26,145 | 0.08 | 2,240 | 0.58 | 19,644 | 1.59 | | |
| 2002 | 66,544 | 0.05 | 40,046 | 0.17 | 4,003 | 0.20 | 10,101 | 0.29 | | |
| 2003 | 3,522 | 0.20 | 26,666 | 0.08 | 10,056 | 0.17 | 8,874 | 0.05 | | |
| 2004 | 5,942 | 0.13 | 26,427 | 0.11 | 2,005 | 0.35 | 28,664 | 0.35 | | |
| Average | | 0.11 | | 0.11 | | 0.26 | | 0.49 | | |
| SE | | 0.03 | | 0.02 | | 0.09 | | 0.28 | | |

Appendix Table 3. PIT-tagged juvenile salmonids released into the Snake and the Columbia River basins and the percentage these tags subsequently detected on piscivorous bird colonies in Potholes Reservoir and along the Okanogan River. Analysis does not include juvenile salmonids of unknown origin.

| | Fall Chinook | | Spring/summer Chinook | | Coho | | Steelhead | | Sockeye | |
|---|---|---|---|---|---|---|---|---|---|---|
| Migration year | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) | Released (n) | Colony (%) |
| Potholes Reservoir | | | | | | | | | | |
| 1999 | 322,121 | 0.00 | 539,487 | 0.00 | 60,960 | 0.00 | 353,891 | 0.00 | 13,243 | 0.00 |
| 2000 | 316,646 | 0.00 | 514,534 | 0.03 | 95,272 | 0.15 | 242,462 | 0.65 | 8,707 | 0.03 |
| 2001 | 265,649 | 0.03 | 597,061 | 0.23 | 49,500 | 0.32 | 132,791 | 0.19 | 5,893 | 0.12 |
| 2002 | 361,503 | 0.01 | 1,089,349 | 0.11 | 56,685 | 0.13 | 168,491 | 0.05 | 8,205 | 0.05 |
| 2003 | 258,097 | 0.01 | 1,272,381 | 0.09 | 58,143 | 0.04 | 631,899 | 0.33 | 11,305 | 0.01 |
| 2004 | 121,303 | 0.00 | 1,094,499 | 0.13 | 67,379 | 0.14 | 653,466 | 0.52 | 7,930 | 0.00 |
| 2005 | 280,106 | 0.00 | 631,664 | 0.06 | 83,529 | 0.09 | 768,770 | 1.05 | 8,939 | 0.03 |
| Average | | 0.01 | | 0.09 | | 0.12 | | 0.40 | | 0.03 |
| SE | | 0.00 | | 0.04 | | 0.06 | | 0.13 | | 0.02 |
| Okanogan River | | | | | | | | | | |
| 1999 | 322,121 | -- | 539,487 | -- | 60,960 | -- | 353,891 | -- | 13,243 | -- |
| 2000 | 316,646 | -- | 514,534 | 0.00 | 95,272 | 0.01 | 242,462 | 0.00 | 8,707 | -- |
| 2001 | 265,649 | 0.00 | 597,061 | 0.00 | 49,500 | 0.03 | 132,791 | -- | 5,893 | -- |
| 2002 | 361,503 | -- | 1,089,349 | 0.00 | 56,685 | -- | 168,491 | -- | 8,205 | -- |
| 2003 | 258,097 | -- | 1,272,381 | 0.00 | 58,143 | -- | 631,899 | 0.02 | 11,305 | -- |
| 2004 | 121,303 | -- | 1,094,499 | 0.00 | 67,379 | 0.02 | 653,466 | 0.02 | 7,930 | -- |
| 2005 | 280,106 | -- | 631,664 | 0.00 | 83,529 | -- | 768,770 | 0.03 | 8,939 | -- |
| Average | | 0.00 | | 0.00 | | 0.02 | | 0.02 | | -- |
| SE | | -- | | -- | | 0.01 | | 0.01 | | -- |