Alternative Barging Strategies to Improve Survival of Salmonids Transported from Lower Granite Dam

Final Report from the 2006-2008 Spring/Summer Chinook Salmon and Steelhead Juvenile Migrations

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Executive Summary

In 2011, the final year class of adult salmon *Oncorhynchus* spp. returned from smolt groups released for a multi-year study to evaluate an alternate release site for transported fish. Smolts were collected and tagged at Lower Granite Dam, transported, and released at the alternate site near Astoria, Oregon (river kilometer 10) or at the traditional release site near Skamania Landing (rkm 225) just downstream of Bonneville Dam.

Study fish were juvenile steelhead *O. mykiss* and yearling spring/summer Chinook salmon *O. tshawytscha*, and our evaluation was based on comparisons of smolt-to-adult return rates (SARs) between replicate paired groups. Our hypothesis was that moving the traditional barge-release site 215 km downstream could increase adult returns by decreasing smolt mortality due to predation by piscivorous fish and birds. Paired groups were released weekly over 6 weeks during the migration seasons of 2006, 2007, and 2008. The last adult steelhead from these releases returned in May 2011 (2-ocean), and the last adult Chinook salmon in August 2011 (3-ocean).

In each study year, we collected river-run yearling spring/summer Chinook salmon and steelhead at the Lower Granite Dam juvenile fish facility. All study fish were tagged with passive integrated transponder (PIT) tags. Both hatchery and wild fish were collected on six consecutive Sundays from mid-April to late May. In 2007, only five paired study groups were released because the first release of the migration season was blocked by a legal challenge from regional agencies and tribes.

Each week, paired groups were loaded to barges, with one group transported to Astoria and a second to Skamania. Between 2006 and 2008, total annual release numbers ranged 28,766-47,791 for yearling Chinook and 53,939-71,585 for steelhead.

Avian predation—To reduce predation from colonies of Caspian terns *Hydroprogne caspia* and double-crested cormorants *Phalacrocorax auritas* on East Sand Island, all Astoria groups were released after dark on an outgoing tide. After the nesting season, vacant bird colonies were scanned to detect PIT tags from fish released for this study and others. We used these data to estimate minimum predation rates.

For Chinook salmon, estimates of minimum predation ranged 3.1-7.1% for releases at Skamania Landing and 0.8-1.1% for releases at Astoria (Table E1). For steelhead, we found larger differences in estimated predation between study groups, with estimates ranging 16.7-26.1% for Skamania vs. 2.2-4.9% for Astoria releases (Table E1).

For Astoria and Skamania release groups, we converted estimates of mortality from predation (P_A and P_S) to express relative survival. For each paired group, we subtracted the rate of predation from 1 to obtain rates of predator avoidance $(1 - P_A)$ and $(1 - P_S)$. We then estimated relative survival of the two groups by calculating predator avoidance ratios: $(1 - P_A)/(1 - P_S)$.

Table E1. Summary of estimated minimum predation and mean predator avoidance ratio for traditional (Skamania) and alternate (Astoria) release sites, hatchery and wild fish combined.

	Hatchery and wild fish combined					
	Chinook salmon			Steelhead		
	Minimum predation (%)		Predator avoidance ratio	Minimum predation (%)		Predator avoidance ratio
	Astoria	Skamania		Astoria	Skamania	
2006	0.79	7.08	1.06	3.07	26.09	1.31
2007	0.99	3.07	1.02	2.18	17.43	1.21
2008	1.06	4.66	1.04	4.89	16.66	1.13
2006-2008	0.95	5.11	1.04	3.51	20.35	1.21

These results show that releasing fish farther downstream, at night, and on an outgoing tide had the predicted effect of substantially reducing avian predation, particularly for steelhead, the species most vulnerable to avian predation. However, these survival benefits were largely offset by impaired homing during the adult migration.

Effect of fish pathogens—To further investigate causes of mortality, we evaluated pathogen loads in individual study fish to determine whether levels of infection affected vulnerability to avian predators. We collected nearly 1,800 non-lethal gill clip samples over each season and evaluated them for *Renibacterium salmoninarum* and *Nucleospora salmonis*. We found no evidence from any study year that infection with one or both pathogens influenced rates of avian predation. However, infection levels of *R. salmoninarum* were low in the majority of test fish during all 3 years, and therefore statistical power to detect an effect was low.

Smolt-to-adult returns (SARs)—For pooled groups of hatchery and wild steelhead from releases over all years and at both locations, the number of adults returning to Lower Granite Dam ranged 1,015-1,787 (Table E2). Pooled hatchery and wild steelhead from all groups had annual SARs ranging 1.74-2.82% for releases at Astoria (T_A) and 1.32-2.25% for releases at Skamania Landing (T_S; Table E2).

We tested the null hypothesis that SARs were equal for Astoria and Skamania release groups, against the two-sided alternative hypothesis that SARs were not equal. For these tests, we first calculated the SAR ratio (T_A/T_S) for each paired release. We then calculated the geometric mean and corresponding variance of each estimate by year.

Table E2. Release numbers, adult returns to Lower Granite Dam (LGR), and smolt-to-adult return rates (SARs) for combined hatchery and wild study fish transported and released at alternate vs. traditional sites.

	Astoria and Skamania (N)		SARs (%)		Geometric mean
	Smolts released	Adult returns to LGR	Astoria (T_A)	Skamania (T_S)	T_A/T_S
	Combined hatchery and wild steelhead				
2006	70,968	1,062	1.75	1.32	1.19
2007	53,939	1,015	1.74	1.99	0.94
2008	71,585	1,787	2.82	2.25	1.18
	Combined hatchery and wild Chinook salmon				
2006	40,583	190	0.33	0.57	0.59
2007	28,766	231	0.77	0.82	1.03
2008	47,791	739	1.55	1.54	0.93

To compare SARs between paired study groups, we conducted a Student's *t*-test between mean SARs transformed on the logarithmic scale. We repeated these tests for all paired releases across the 3 study years with $\alpha = 0.05$.

For paired releases of wild steelhead, mean T_A/T_S across the 3 years was 1.04, and mean SARs did not differ significantly between release locations within or across years. For hatchery steelhead, we found a significant difference in 2006, with Astoria releases having a 22% higher mean SAR ($P = 0.02$). Across the 3 years, mean SAR for hatchery steelhead released at Astoria was 14% higher than for those released at Skamania, but the difference was not significant at the 0.05 level ($P = 0.14$). Relative SARs for the two release locations did not show temporal trends within years (seasons).

For pooled groups of hatchery and wild Chinook salmon from releases over all years and at both release locations, the number of adults returning to Lower Granite Dam ranged 190-739 (Table E2). Pooled hatchery and wild Chinook from all groups had annual SARs ranging 0.33-1.55% for releases at Astoria (T_A) and 0.57-1.54% for releases at Skamania Landing (T_S; Table E2).

For wild Chinook salmon, relative SARs varied widely across years, with mean T_A/T_S ratios ranging 0.48-1.80. Because adult return numbers were low, no differences between release groups were significant. For wild Chinook, mean SARs were similar between release locations over the 3 years, with a mean T_A/T_S ratio of 1.04 ($P = 0.92$).

For hatchery Chinook salmon, mean SAR ratios were less than 1.0 within all 3 years, meaning Astoria groups had lower survival than Skamania groups. However, none of the within-year differences was significant (P values were 0.41, 0.51, and 0.81). Across the 3 years, Astoria SARs averaged only 76% of Skamania SARs ($P = 0.25$).

Adult conversion rates—For Chinook salmon, average adult conversion rates from Bonneville to Lower Granite Dam were 10% lower for groups released at Astoria than for those released at Skamania over the 3 study years (Table E3). However, the difference was not statistically significant ($P = 0.12$). In contrast, for steelhead, the difference in average conversion rates between release sites was greater and was highly significant ($P < 0.01$), both across years and within each study year. The magnitude of the difference was consistent as well: the rate at which adult steelhead successfully completed migration from Bonneville to Lower Granite Dam was 20-22% lower for fish released at Astoria than for those released at Skamania Landing. This lower rate was a result of higher rates of straying and wandering, which likely increased exposure to fisheries, both sport and commercial.

Table E3. Relative conversion rates for Astoria/Skamania releases of combined hatchery and wild study fish.

Astoria/Skamania conversion rates, overall ratio 2006-2008		
Reach	Geometric mean (95% CI)	*P* value
	Combined hatchery and wild steelhead	
Bonneville to McNary	0.85 (0.83-0.88)	<0.001
McNary to Lower Granite	0.92 (0.90-0.95)	<0.001
Bonneville to Lower Granite	0.79 (0.75-0.82)	<0.001
	Combined hatchery and wild Chinook salmon	
Bonneville to McNary	0.91 (0.81-1.01)	0.065
McNary to Lower Granite	0.97 (0.90-1.03)	0.299
Bonneville to Lower Granite	0.90 (0.78-1.03)	0.120

Adult straying rates—To evaluate rates of straying, we examined numbers of returning adults detected at sites other than Bonneville, McNary, Ice Harbor, and Lower Granite Dams. For fish identified as strays in this way, we also distinguished between temporary and permanent straying. Fish that were eventually detected at Lower Granite Dam were considered temporary strays, or "wanderers." Those that were never detected at Lower Granite Dam were permanent strays, or "lost."

Very few adult spring/summer Chinook salmon from this study strayed (only 37 of 1,660 hatchery and wild adults from both release sites). Straying rates for pooled hatchery and wild adult Chinook from all study years were 2.6% for Astoria releases and 2.0% for Skamania releases ($P = 0.46$). Only one of the 37 Chinook salmon strays was later detected at Lower Granite Dam; all others were lost.

Rates of straying were higher for steelhead than for Chinook salmon and higher for fish released at Astoria than those released at Skamania. Across the 3 study years, straying was 28% greater for wild steelhead released at Astoria ($P = 0.16$) and 47% greater for hatchery steelhead released at Astoria ($P = 0.003$).

Wild steelhead released at Astoria had an average straying rate to the John Day and Deschutes Rivers that was 52% higher than that of their cohorts released at Skamania ($P = 0.06$). To these same rivers, hatchery steelhead released at Astoria had an average straying rate 54% higher than their cohorts released at Skamania ($P = 0.003$).

Release from Astoria was also associated with an increased probability of permanent straying. Averaged across the 3 study years, wild steelhead released at Astoria were 64% more likely to become permanent strays than their counterparts released at Skamania ($P = 0.03$). For hatchery steelhead, the increase in permanent straying for releases from Astoria averaged 51% ($P < 0.001$).

Conclusions—We found no evidence of a consistent difference in SARs for fish released at the two barge-release locations. Data were not sufficient to evaluate the effects of fish pathogens on avian predation. There was clear evidence that fish of both species released at Astoria were less vulnerable to avian predators than those released at the customary site at Skamania Landing. Unfortunately, this survival benefit did not translate to higher SARs, as it was offset by higher rates of straying by fish released from Astoria. This was likely a result of greater impairment to homing ability for fish released at Astoria.

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Introduction

At transport dams on the Snake and Columbia Rivers, salmonid smolts collected in the juvenile bypass systems are either routed back to the river to continue migration or transported by truck or barge to a release site below Bonneville Dam. The purpose of transporting fish is to avoid mortality associated with passage through additional dams and reservoirs. However, the benefit provided by transportation has varied for different fish stocks and with the timing of transport during the juvenile migration season (Williams et al. 2005; Muir et al. 2006; Smith et al. 2013).

Typically, about 50% of Snake River smolts survive the migration from Lower Granite Dam to the upper estuary downstream from Bonneville Dam (Williams et al. 2005). About 98% of smolts survive transport through this reach (Schreck et al. 2006; McMichael et al. 2011). Hence, if survival in subsequent life stages was equal for transported smolts and smolts that survived the migration inriver, then transported fish would return to Lower Granite Dam as adults at roughly double the rate of non-transported survivors. However, this degree of transportation benefit has not been realized consistently.

Transported fish have been assessed for condition and health prior to and after transport in previous studies (Pascho and Elliott 1989; Elliott and Pascho 1991, 1992, 1993, 1994; Elliott et al. 1997; Congleton et al. 2000, 2005; Kelsey et al. 2002; Schreck et al. 2005). In these studies, sources of transport stress and stressors were examined in detail and identified. Based on these findings, fish collection and transport systems have been modified to reduce or eliminate sources of stress (Williams and Matthews 1995). However, in spite of these improvements, transportation benefit has continued to fall short of the projected double return rate, particularly for wild Chinook salmon *Oncorhynchus tshawytscha* (Williams et al. 2005).

We can assume that at some stage(s) that occur after the release of transported fish downstream of Bonneville Dam, transported smolts experience higher mortality than do inriver migrants that survived to the same point. The ratio between observed and predicted relative return rates is termed *differential* post-Bonneville survival between transported and inriver migrants; this quantity is referred to as "*D.*"

Avian predation is known to impact migrating fish throughout the estuary downstream of Bonneville Dam. We hypothesized that transporting fish to a release site in the lower estuary, farther downstream than the conventional site, might reduce impacts of avian predation, increasing SARs for transported fish and reducing *D*.

The primary objective of this study was to determine whether barged yearling Chinook and steelhead released from an alternate site near Astoria, Oregon (river kilometer 10), would have higher SARs than fish released from the conventional location at Skamania Landing (rkm 225; Figure 1). Releasing from Astoria would minimize the time spent moving into and through the Columbia River estuary and thus reduce exposure to the large nesting colonies of avian predators located there.

Columbia River dams

a. Grand Coulee
b. Chief Joseph
c. Wells
d. Rocky Reach
e. Rock Island
f. Wanapum
g. Priest Rapids
h. John Day
i. The Dalles

Snake River dams

j. Ice Harbor
k. Lower Monumental
l. Little Goose
m. Hells Canyon
n. Oxbow
o. Brownlee

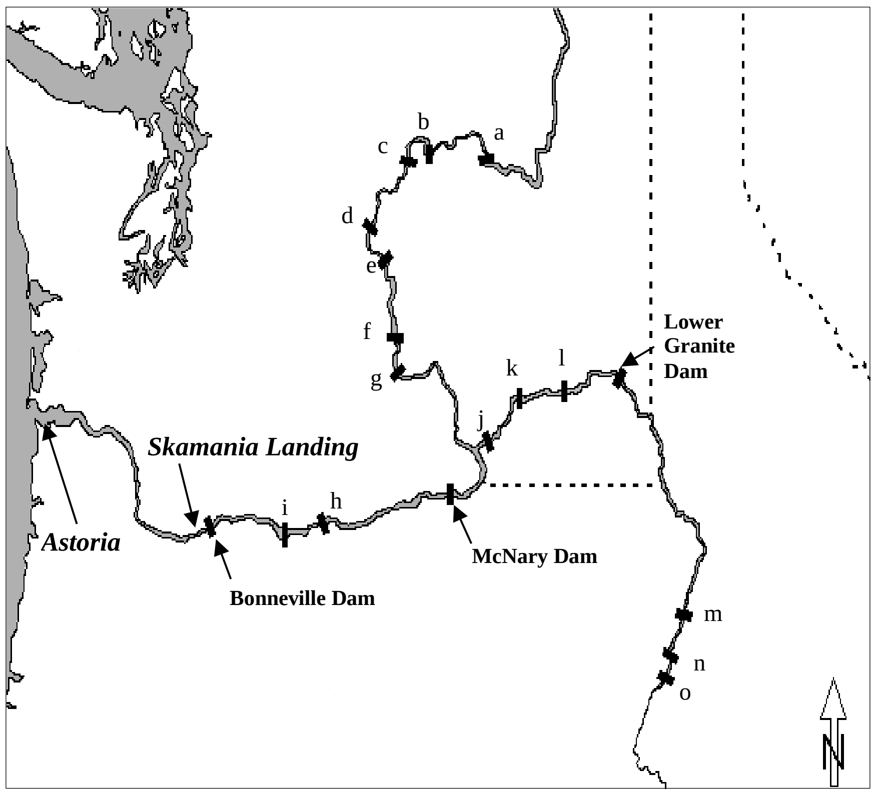

Figure 1. Study area showing collection and tagging site at Lower Granite Dam, release sites at Skamania Landing (rkm 225), and Astoria (rkm 10), and adult detection sites at McNary and Bonneville Dam for fish released as juveniles during 2006-2008.

In studies of coho salmon *O. kisutch*, Solazzi et al. (1991) found that smolts transported to a release point near Columbia River km 29 returned at a rate 1.6 times greater than those released upriver. Similarly, Gunnerod et al. (1988) found that Atlantic salmon *Salmo salar* released in salt water returned at a higher rate. Marsh et al. (1996, 1998, 2000) compared steelhead *O. mykiss* released at Columbia River km 225 with those released at rkm 29, but too few adults returned from either release point for a meaningful

evaluation. The present study contributes to an ongoing effort to improve post-release survival of fish transported by the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program.

To provide additional insight into the vulnerability of smolts to avian predators, we documented fish condition prior to release. Our approach was to tag smolts with passive integrated transponder (PIT) tags (Prentice et al. 1990), collect samples for pathogen analysis, and transport fish for release at either the traditional or alternate site. In addition to pathogen analysis, we evaluated avian predation for each juvenile release group. Study groups were released at both locations during the juvenile migration for 3 study years: 2006, 2007, and 2008 (Ryan et al. 2007; Marsh et al. 2008, 2010).

Original study objectives were:

1. Compare avian predation rates between fish groups released at Skamania Landing and those released at Astoria.
2. Determine prevalence and levels of the pathogens *Renibacterium salmoninarum* and *Nucleospora salmonis* within each release group and evaluate whether pathogen levels were correlated with avian predation rates.
3. Compare SARs between study groups released near Astoria, Oregon (rkm 10) and those released at Skamania Landing (rkm 225).

In the course of analyzing data from returning adults, we found important information regarding adult upstream migration performance. Therefore, we added the following objectives:

4. Compare upstream adult conversion rates between study groups released at Skamania Landing and those released at Astoria.
5. Compare adult straying rates between study groups released at Skamania Landing and those released at Astoria.
6. Compare adult upstream travel time between study groups released at Skamania Landing and those released at Astoria.

Adult returns from all smolt release years were complete in August 2011. In this report, we summarize juvenile data and adult returns from both release sites for all 3 study years (2006-2008). Based on these results, we evaluate the efficacy of using the Astoria release site as an alternative to the traditional release site at Skamania Landing.

Juvenile Release Groups

Sample Size Determination

For this study, as for all fish transportation studies, the single most important metric for evaluation was smolt-to-adult return (SAR) rate. We evaluated SARs based on adult fish returning to Lower Granite Dam from smolts released in 2006, 2007, and 2008. Our study design called for tagging sufficient numbers from each species to identify a difference in SARs of at least 30%.

For each paired replicate, we determined SAR ratios by dividing the SAR for fish released at Astoria (T_A) by that for fish released at Skamania Landing (T_S). A T_A/T_S ratio of 1.3 or higher would indicate SARs were at least 30% higher for fish released at the alternate site. This ratio was based on an expected SAR of 1.0% for the Astoria releases.

Based on these expected SARs and desired detectable difference, we set goals to tag 53,000 yearling Chinook salmon and 53,000 steelhead. However, for both species, we could select fish for tagging only from those that arrived at Lower Granite Dam and entered the juvenile bypass facility. Therefore, while 53,000 fish was our goal, the actual numbers tagged varied in accordance with numbers of fish arriving at the dam during the migration season each year. Because of this variation, we tagged fewer yearling Chinook but more steelhead than planned. For both species, hatchery and wild fish were tagged in proportion to numbers arriving at the dam.

Fish Collection and Tagging

Each spring from 2006 to 2008, we collected and PIT-tagged steelhead and yearling Chinook salmon smolts of both hatchery and wild origin. All tagged fish were assigned to an individual paired release group. Six paired replicates of each species were tagged, with one replicate released at each location. Tagging was conducted at the NOAA facility at Lower Granite Dam on six consecutive Sundays from mid-April through May (Table 1). We followed protocols in the *PIT Tag Marking Procedures Manual* (CBFWA 1999) for mass marking using simple PIT-tag injectors. Marsh et al. (2001) provided a complete description of tagging methods used at this facility.

Table 1. Release numbers of PIT-tagged hatchery and wild (H & W) juvenile steelhead and yearling Chinook salmon by date at the Astoria and Skamania Landing release sites during 2006-2008.

Tagging date(s)	Astoria (rkm 10) Chinook salmon Hatchery	Astoria Chinook salmon Wild	Astoria Steelhead Hatchery	Astoria Steelhead Wild	Skamania Landing (rkm 225) Chinook salmon Hatchery	Skamania Landing Chinook salmon Wild	Skamania Landing Steelhead Hatchery	Skamania Landing Steelhead Wild	Total Chinook H & W	Total Steelhead H & W
2006										
23 Apr	2,852	902	6,696	456	2,192	953	5,657	527	6,899	13,336
30 Apr	3,567	747	3,240	439	5,929	1,331	4,915	807	11,574	9,401
7 May	3,309	262	3,893	553	5,569	495	5,362	912	9,635	10,720
14 May	3,309	184	4,295	290	5,456	288	6,500	609	9,237	11,694
22-23 May	703	329	5,502	1,227	1,448	561	9,701	1,978	3,041	19,408
30 May	15	32	2,091	479	46	103	4,064	775	196	7,409
Total	13,755	2,456	25,717	3,444	20,640	3,731	36,199	5,608	40,582	70,968
	Hatchery and wild combined				Hatchery and wild combined					
Total	16,211		29,161		24,371		41,807		111,550	
2007										
22 Apr	Collection and tagging planned but not carried out									
29 Apr	2,215	245	3,578	243	3,793	499	4,391	325	6,752	8,537
6 May	2,981	401	4,010	859	4,360	648	4,530	1,235	8,390	10,634
13 May	3,187	737	3,787	566	4,264	988	5,138	1,321	9,176	10,812
20 May	982	412	5,929	594	1,838	766	9,562	1,363	3,998	17,448
27 May	129	96	2,902	291	134	90	3,069	246	449	6,508
Total	9,494	1,891	20,206	2,553	14,389	2,991	26,690	4,490	28,765	53,939
	Hatchery and wild combined				Hatchery and wild combined					
Total	11,385		22,759		17,380		31,180		82,704	
2008										
19-20 Apr	1,560	388	4,549	921	2,926	474	6,212	1,365	5,348	13,047
26-27 Apr	1,337	576	8,075	869	2,395	954	9,554	1,236	5,262	19,734
4 May	3,118	844	3,753	869	3,000	1,234	3,549	928	8,196	9,099
11 May	4,648	500	2,459	738	6,014	692	2,563	846	11,854	6,606
18 May	4,088	405	2,059	767	6,383	682	4,031	899	11,558	7,756
24-25 May	1,767	323	4,522	1,537	2,996	484	6,948	2,339	5,570	15,346
Total	16,518	3,036	25,417	5,701	23,714	4,520	32,857	7,613	47,788	71,588
	Hatchery and wild combined				Hatchery and wild combined					
Total	19,554		31,118		28,234		40,470		119,376	

After each tagging session, fish were transferred to the east-bank transport raceways and held 24 h for recovery. This tagging schedule was followed in all years except 2007, when regional agencies and tribes refused permission for the first release planned for 23 April. Thus in 2007, the study began with the second planned release on 30 April. We were unable to tag a make-up replicate after the last planned release on 27 May because too few fish were available.

Transport and Release

For Skamania Landing fish, one group of each species was loaded to either an 8000-series or a 2000-series transport barge, depending on whether the release coincided with the general transport program schedule. Each year, the first one or two groups were transported before the start of the general program. These early groups were loaded to a 2000-series barge. Skamania study groups formed while the general program was in operation were loaded to an 8000-series barge and along with run-of-river fish collected for the general transport program. After loading, these fish were transported and released at rkm 225, the standard transportation release site.

For Astoria fish, one group of each species was loaded to a 2000-series barge, transported, and released at rkm 10, the alternate release site in the lower estuary. Astoria releases were timed to occur at night on an ebb tide to reduce predation by Caspian terns *Hydroprogne caspia* and double-crested cormorants *Phalacrocorax auritas* from the nearby nesting colonies on East Sand Island (Table 2).

For the first 1-2 paired releases, barges for both release sites were towed by the same vessel. For subsequent paired releases, the barge used for Astoria groups was towed with a separate vessel, mirroring the path of the Skamania barge until after it passed Bonneville Dam, and then continuing downstream to rkm 10. Dissolved oxygen levels, water temperatures, and mortalities were monitored using the same standard procedures on both the 2000- and 8000-series barges.

We attempted to keep barge loading densities as close to equal as possible between the Skamania Landing (8000 series) and Astoria (2000 series) barges. Loading density for each release group was measured as a percentage of hold capacity. This percentage was calculated by dividing the number of pounds of fish loaded into the barge hold by the total fish capacity of the hold.

Table 2. Release dates, times, and locations for groups of PIT-tagged juvenile steelhead and yearling Chinook salmon smolts released at Skamania Landing and near Astoria during 2006-2008. Times of high tide are noted for the Astoria releases.

Yearling Chinook and steelhead				
	Astoria releases (rkm 10)		Skamania Landing releases (rkm 225)	
Release date	Time (PDT)	Time of high tide at rkm 10 (PDT)	Release date	Time (PDT)
		2006		
27 Apr	0315	0018	26 Apr	0035
3 May	2115	1912	2 May	2115
11 May	0145	0009	9 May	1925
17 May	2115	1754	16 May	1955
26 May	0230	0018	25 May	1905
2 Jun	2100	1922	1 Jun	1910
		2007		
26-27 Apr	releases planned but not made			
3 May	0330	0158	2 May	0415
9 May	2215	2022	8 May	1900
17 May	0300	0131	16 May	0450
23 May	2200	2031	23 May	0830
31 May	0220	0051	29 May	1950
		2008		
24 Apr	0445	0252	23 Apr	0710
1 May	0010	2226	30 Apr	0515
8 May	0410	0223	6 May	1957
15 May	0012	2230	13 May	2300
22 May	0315	0151	20 May	1820
28 May	2230	2041	27 May	1915

Fish capacity of the hold is determined by the number of gallons the hold can contain and the water exchange rate in gallons per minute (gal/min). The 2000-series barge can hold 28,333 gal, or about 12% more than the 8000-series barge (25,000 gal). However, the water exchange rate of the 2000-series barge is only about 30% that of the 8000-series (4,600 gal/min vs. 15,000 gal/min). Therefore, fish capacity is 60% higher in the 8000-series (12,500 lb) than in the 2000-series barge (7,300 lb).

Non-tagged fish were added to the holds of both barges in an attempt to equalize fish density between the two barges (Table 3). However, in spite of these efforts, we did not always achieve equal loading densities between replicates. This goal proved difficult to achieve because the numbers of fish tagged and loaded were directly dependent upon numbers arriving at the dam, and arriving numbers varied unpredictably. However, while densities were sometimes farther from equal than planned, all loading densities were low, with only one barge in the entire study exceeding 50% capacity (Skamania group 4 in 2008).

Table 3. Numbers of PIT-tagged fish, and numbers of untagged fish added to equalize densities, for Skamania Landing and Astoria release barges, 2006-2008. All Astoria groups were transported by a 2000-series barge. Skamania groups were transported by 8000-series barge, except those marked with an asterisk (*), which were transported by 2000-series barge. Total pounds of fish and percent of barge hold capacity are given. Hold capacity depends on volume of the hold and exchange rate of water in the hold.

Yearling Chinook and Steelhead									
Astoria release (rkm 10)					Skamania Landing release (rkm 225)				
Release date	Tagged fish (N)	Non-tagged fish(N)	Total fish weight (lb)	Percent hold capacity (%)	Release date	Tagged fish (N)	Non-tagged fish (N)	Total fish weight (lb)	Percent hold capacity (%)
2006									
27 Apr	10,906	13,188	2,536	34.7	26 Apr	9,329	7,092	1,729	13.8
3 May	7,993	10,804	2,066	28.3	2 May	12,982	1,431	1,584	12.7
11 May	8,017	17,041	2,410	33.0	9 May	12,338	36,716	4,717	37.7
17 May	8,078	16,953	3,477	47.6	16 May	12,853	10,133	3,193	25.5
26 May	7,761	2,596	1,191	16.3	25 May	13,688	8,886	2,595	20.8
2 Jun	2,617	13,268	1,241	17.0	1 Jun	4,988	14,427	1,517	12.1
2007									
26 Apr	(no release)				25 Apr	(no release)			
3 May	6,281	5,841	1,707	23.4	2 May*	9,008	3,560	1,770	24.3*
9 May	8,251	7,081	1,783	24.4	8 May	10,773	6,328	1,989	15.9
17 May	8,277	5,328	1,790	24.5	16 May	11,711	2,844	1,915	15.3
23 May	7,917	13,233	3,065	42.0	23 May	13,529	8,626	3,211	25.7
31 May	3,418	1,052	784	10.7	29 May	3,539	1,704	920	7.4
2008									
24 Apr	7,418	9,731	2,382	32.6	23 Apr*	10,977	7,435	2,557	35.0*
1 May	10,857	11,017	3,170	43.4	30 Apr*	14,139	10,693	3,599	49.3*
8 May	8,584	6,325	2,378	32.6	6 May	8,711	7,440	2,568	20.5
15 May	8,345	19,106	3,265	44.7	13 May	10,115	77,388	10,421	83.4
22 May	7,319	19,706	3,554	48.7	20 May	11,995	34,401	6,107	48.9
28 May	8,149	16,272	3,489	47.8	27 May	12,767	23,929	5,242	41.9

Avian Predation on Transported Juveniles

Methods

During each study year after the nesting season, vacated nesting colonies in the Columbia River estuary were scanned for PIT-tags from juvenile salmonids consumed by avian predators (Ryan et al. 2007; Sebring et al. 2009, 2010). Detection data from the NOAA recovery project are used to evaluate the annual impact on juvenile salmon from major avian predators such as Caspian terns and double-crested cormorants (Ryan et al. 2001, 2003). From 2006 to 2008, a portion of the tags detected during these recovery efforts came from fish released for this study, and we used these data to estimate predation rates for each paired release.

To estimate the probability of tag detection on a specific colony, researchers dropped "control" tags on each colony each year. They estimated detection efficiency rates for that colony based on the proportion of control tags detected during recovery efforts that year (Table 4; Sebring et al. 2013). We used these detection efficiency rates to estimate minimum avian predation for each group, by adjusting the number of tags detected from that group by the detection efficiency rate on the colony where the tag was detected. These estimates represent minimum rates of predation because the proportion of tags from fish taken by birds and deposited away from the colonies is not known.

Table 4. Number of control tags dropped and percent recovered (detection efficiency) from tern and cormorant colonies on East Sand Island (Sebring et al. 2013). Detection efficiencies during our study years (2006-2008) are emphasized.

	Detection efficiency rates by colony			
	Cormorant colony		Tern colony	
Year	Control tags (N)	Detected (%)	Control tags (N)	Detected (%)
2002	300	35	300	95
2003	300	45	300	85
2004	600	36	1,100	92
2005	800	55	1,200	83
2006	**600**	**52**	**1,200**	**64**
2007	**200**	**58**	**600**	**89**
2008	**600**	**69**	**600**	**92**
2009	600	70	600	90
2010	400	76	400	84
Mean 2002-2010		55		86

We compared estimated minimum rates of predation between paired release groups to determine whether fish released at Skamania Landing were more susceptible to predation by piscivorous birds than fish released at Astoria. These estimates were also used to determine whether differences in predation rate might be related to infection with *R. salmoninarum* or *N. salmonis*.

Rates of avian predation are measures of mortality, whereas SARs and adult conversion rates are measures of survival. However, rates of relative mortality and survival are not directly comparable. For example, if mortality, *M* is 5% in group A and 10% in group B, then relative mortality (M_A/M_B) is 5/10% or 0.5, or a 50% difference between groups. However, in terms of survival, *S*, those mortality rates represent a difference between groups of only 5%, as relative survival (S_A/S_B) is 95/90% or 1.05

Ultimately, the purpose of our study was to evaluate the effect of avian predation on SARs, so we wanted to evaluate relative rates of survival. Therefore, we converted estimates of minimum predation (mortality) to estimates of predator avoidance (survival) to compare relative survival between experimental groups. For each paired release, we first calculated P_A and P_S, the respective rates of minimum predation on Astoria and Skamania groups. These rates were subtracted from 1 (representing 100% survival) to obtain rates of predator avoidance $(1 - P_A)$ and $(1 - P_S)$.

To evaluate differences between experimental groups, we calculated rates of relative predator avoidance using the ratio $(1 - P_A)/(1 - P_S)$ for each paired release. For these ratios, values of one indicate no difference in survival between groups, values greater than one indicate higher survival for Astoria groups, and values less than one indicate higher survival for Skamania groups.

We log-transformed Astoria-to-Skamania predator avoidance ratios to normalize their distribution and calculated the arithmetic mean and sample variance across replicates within each season. Using standard normal-theory methods, we constructed a 95% confidence interval around each mean and used a one-sample Student's *t*-test on the logarithmic scale to determine whether the mean of the transformed ratios was equal to zero. Because log (1) = 0, an arithmetic mean of 0 for the log-transformed ratios is equivalent to a geometric mean of 1 for the non-transformed ratios.

We then back-transformed the mean log-ratios and endpoints of their respective 95% CIs to return quantities to the original scale. We calculated statistics and conducted *t*-tests both within each study year and across all 3 years. We report *P* values for all tests.

Results

For both steelhead and yearling Chinook salmon, avian predator avoidance rates were significantly higher for fish released at Astoria during nighttime and on an ebb tide than for their cohorts released 215 km upstream at Skamania Landing using conventional transportation-program protocols (Tables 5-10; Appendix Tables A1-A2).

For combined hatchery and wild steelhead across the 3 study years, the geometric mean predator avoidance ratio was 1.21; an average survival advantage of 21% for fish released from the alternate site at Astoria (Table 5). For combined hatchery and wild Chinook salmon, the geometric mean predator avoidance ratio over the 3 study years was 1.04; an average survival advantage of 4% for fish released at Astoria (Table 8).

Hatchery and Wild Steelhead

For hatchery and wild steelhead juveniles released at Skamania Landing, estimated minimum predation by East Sand Island terns and cormorants was 26.1% in 2006, 17.4% in 2007, and 16.7% in 2008 (Table 5). For hatchery and wild steelhead released at Astoria, estimated minimum predation was 3.1% in 2006, 2.2% in 2007, and 4.9% in 2008 (Table 5).

Caspian terns had a greater predation impact on combined hatchery and wild steelhead than did double-crested cormorants (Table 6). For combined steelhead released at Skamania across the 3 years, average minimum predation rates were 16.5% for terns and 3.9% for cormorants. For Astoria releases of these fish, average minimum predation rates were 3.2% by terns and 0.3% by cormorants.

Caspian tern predation rates were higher for hatchery than for wild steelhead, regardless of release location (Table 6). For Skamania releases, the 3-year average minimum tern predation was 17.6% for hatchery and 10.2% for wild steelhead. For Astoria releases, respective tern predation rates were 3.4 for hatchery and 1.7% for wild steelhead.

In contrast, predation rates by double-crested cormorants were similar between hatchery and wild steelhead: for releases at Skamania Landing, 3-year average predation rates were 3.9% for both rearing types. For releases at Astoria, cormorant predation was minimal, but higher for hatchery than for wild steelhead (0.3 vs. 0.2%).

No consistent seasonal trends were seen in predation rates for steelhead in any release year (Table 7; Appendix Table A1).

Table 5. Release numbers of hatchery and wild steelhead smolts released with subsequent detections adjusted for detection efficiency on East Sand Island bird colonies, 2006-2008. Estimated minimum predation and predator avoidance rates are given, as are geometric means of estimated relative predator avoidance for replicate paired releases. *P* value is for *t*-test comparing mean predator avoidance rates between two release sites; shaded cells indicate significant difference at the $\alpha = 0.05$ level.

	East Sand Island avian predation on combined hatchery and wild steelhead										Relative predator avoidance $(1 - P_A)/(1 - P_S)$		
	Astoria (rkm 10)					**Skamania Landing (rkm 225)**							
	Released (n)	Detected (n)	Adjusted (n)	Min predation (P_A)	Predator avoidance ($1 - P_A$)	Released (n)	Detected (n)	Adjusted (n)	Min predation (P_S)	Predator avoidance ($1 - P_S$)	Geo mean ratio	95% CI	*P*
2006													
Wild	3,444	36	58.4	1.70	98.30	5,608	699	1,166.8	20.81	79.19	1.23	1.16-1.31	<0.001
Hatchery	25,717	523	835.6	3.25	96.75	36,199	5,963	9,741.6	26.91	73.09	1.32	1.21-1.44	<0.001
Combined	29,161	559	894.0	3.07	96.93	41,807	6,662	10,908.4	26.09	73.91	1.31	1.21-1.42	<0.001
2007													
Wild	2,553	26	29.8	1.17	98.83	4,490	398	493.4	10.99	89.01	1.16	1.05-1.27	0.012
Hatchery	20,206	400	465.7	2.30	97.70	26,690	4,140	4,941.7	18.52	81.48	1.22	1.11-1.33	0.004
Combined	22,759	426	495.5	2.18	97.82	31,180	4,538	5,435.2	17.43	82.57	1.21	1.10-1.33	0.006
2008													
Wild	5,701	122	134.4	2.36	97.64	7,613	741	845.7	11.11	88.89	1.10	1.05-1.14	0.003
Hatchery	25,417	1,256	1,387.3	5.46	94.54	32,857	5,288	5,894.9	17.94	82.06	1.14	1.08-1.19	<0.001
Combined	31,118	1,378	1,521.7	4.89	95.11	40,470	6,029	6,740.6	16.66	83.34	1.13	1.08-1.18	0.0011
2006-2008													
Wild	11,698	184	222.6	1.90	98.10	17,711	1,838	2,505.9	14.15	85.85	1.26	1.12-1.20	<0.001
Hatchery	71,340	2,179	2,688.5	3.77	96.23	95,746	15,391	20,578.3	21.49	78.51	1.22	1.17-1.28	<0.001
Combined	83,038	2,363	2,911.2	3.51	96.49	113,457	17,229	23,084.2	20.35	79.65	1.21	1.16-1.27	<0.001

Table 6. Minimum predation estimates by avian species for hatchery and wild steelhead smolts released at Astoria (P_A) and Skamania Landing (P_S), 2006-2008. Geometric mean relative predator avoidance $(1 - P_A)/(1 - P_S)$ across replicate paired groups shown with 95% CIs. Shading indicates significant difference ($\alpha = 0.05$).

	Hatchery and wild steelhead							
	Caspian tern				Double-crested cormorant			
	Predation (%)		$(1 - P_A)/(1 - P_S)$		Predation (%)		$(1 - P_A)/(1 - P_S)$	
	Astoria	Skamania	Geo mean	95% CI	Astoria	Skamania	Geo mean	95% CI
2006								
Wild	1.36	13.71	1.14	1.06-1.23	0.34	7.10	1.07	1.02-1.12
Hatchery	2.87	20.66	1.23	1.11-1.37	0.38	6.25	1.06	1.02-1.10
Combined	2.69	19.73	1.22	1.10-1.34	0.38	6.37	1.06	1.02-1.10
2007								
Wild	1.10	8.03	1.11	1.02-1.20	0.07	2.96	1.04	0.99-1.09
Hatchery	2.07	15.40	1.17	1.08-1.27	0.23	3.12	1.03	0.997-1.07
Combined	1.96	14.34	1.16	1.07-1.26	0.21	3.10	1.03	0.997-1.07
2008								
Wild	2.23	8.99	1.07	1.02-1.12	0.13	2.11	1.02	1.01-1.04
Hatchery	5.11	16.15	1.11	1.06-1.17	0.35	1.79	1.02	1.001-1.04
Combined	4.58	14.80	1.10	1.05-1.16	0.31	1.85	1.02	1.002-1.04
2006-2008								
Wild	1.73	10.24	1.11	1.06-1.15	0.18	3.91	1.04	1.02-1.06
Hatchery	3.44	17.64	1.17	1.11-1.23	0.33	3.85	1.04	1.02-1.06
Combined	3.20	16.49	1.16	1.10-1.22	0.31	3.86	1.04	1.02-1.06

Table 7. Minimum predation rates for paired release groups of steelhead smolts (hatchery and wild combined) by release date, 2006-2008, derived from percentage of PIT tags detected on tern and cormorant colonies expanded for detection efficiency. Also shown are annual rates of predation by each bird species for the combined groups from each release location.

	Minimum predation on combined hatchery and wild steelhead (%)			
	Caspian tern		Double-crested cormorant	
Release date	Astoria	Skamania	Astoria	Skamania
		2006		
26 and 27 Apr	2.36	20.57	0.05	5.57
2 and 3 May	0.59	8.55	1.10	10.69
9 and 11 May	0.88	16.76	0.30	9.10
16 and 17 May	4.33	15.63	0.42	4.03
25 and 26 May	2.79	22.74	0.43	6.85
1 and 2 Jun	6.57	34.45	0.15	0.99
Combined 2006 groups	**2.69**	**19.73**	**0.38**	**6.37**
		2007		
25 and 26 Apr	--	--	--	--
2 and 3 May	7.97	23.04	0.54	8.04
8 and 9 May	0.88	11.15	0.21	2.78
16 and 17 May	0.03	6.16	0.24	3.18
23 and 23 May	0.67	14.44	0.11	1.88
29 and 31 May	1.72	23.08	0.00	0.47
Combined 2007 groups	1.96	14.34	0.21	3.10
		2008		
23 and 24 Apr	11.96	20.83	0.37	0.77
30 Apr & 1 May	4.16	20.19	0.23	1.16
6 and 8 May	0.78	7.74	0.82	5.31
13 and 15 May	0.51	7.75	0.27	3.61
20 and 22 May	0.50	5.51	0.10	0.82
27 and 28 May	5.51	14.56	0.10	1.78
Combined 2008 groups	4.58	14.80	0.31	1.85

Hatchery and Wild Chinook Salmon

Proportions of PIT tags recovered on avian colonies were smaller for Chinook salmon than for steelhead. However, the proportions recovered still showed significantly higher rates of predation for Chinook released at Skamania Landing (Table 8). For Chinook salmon released at Skamania Landing, minimum annual predation for hatchery and wild releases combined was 7.1% in 2006, 3.1% in 2007, and 4.7% in 2008. For Chinook released at Astoria, estimated predation was 0.8% in 2006, 1.0% in 2007, and 1.1% in 2008.

For Chinook salmon released at Astoria (hatchery and wild combined), Caspian terns had a greater predation impact than double-crested cormorants in all 3 years (Table 9). However, both types of birds took small numbers of these fish, with an average predation rate across the 3 years of only 0.6% by terns and 0.4% by cormorants.

For Chinook salmon released at Skamania (hatchery and wild combined), cormorants and terns had similar predation impacts overall. Cormorants took more smolts than terns in 2006, the two species took similar numbers in 2007, and terns took more than cormorants in 2008. Average predation on these fish across the 3 years was 2.6% for terns and 2.5% for cormorants.

Terns had greater predation impacts on hatchery than on wild Chinook salmon regardless of release location, with respective hatchery and wild predation rates of 0.6 and 0.3% on Astoria releases and 2.7 and 2.0% on Skamania releases. Cormorant impacts on Chinook salmon were similar between fish of different origin, with respective hatchery and wild predation rates of 0.4 and 0.3% on Astoria releases and 2.5 and 2.8% on Skamania releases.

No consistent seasonal trends were seen in predation rates for Chinook salmon in any release year (Table 10; Appendix Table A2).

Table 8. Release numbers of hatchery and wild Chinook salmon smolts released with subsequent detections adjusted for detection efficiency on East Sand Island bird colonies, 2006-2008. Estimated minimum predation and predator avoidance rates are given, as are geometric means of estimated relative predator avoidance for replicate paired releases. *P* value is for *t*-test comparing mean predator avoidance rate between two release sites; shaded cells indicate significant difference at the $\alpha = 0.05$ level.

	East Sand Island avian predation on combined hatchery and wild Chinook salmon										Relative predator avoidance $(1 - P_A)/(1 - P_S)$		
	Astoria (rkm 10)					Skamania Landing (rkm 225)							
	Released (n)	Detected (n)	Adjusted (n)	Min predation (P_A)	Predator avoidance ($1 - P_A$)	Released (n)	Detected (n)	Adjusted (n)	Min predation (P_S)	Predator avoidance ($1 - P_S$)	Geo mean	95% CI	*P* value
2006													
Wild	2,456	4	7.0	0.28	99.72	3,731	145	261.5	7.01	92.99	1.06	1.03-1.09	0.003
Hatchery	13,755	73	121.3	0.88	99.12	20,640	830	1,463.8	7.09	92.91	1.06	1.04-1.08	<0.001
Combined	16,211	77	128.2	0.79	99.21	24,371	975	1,725.4	7.08	92.92	1.06	1.04-1.08	0.001
2007													
Wild	1,891	8	12.6	0.67	99.33	2,991	50	68.8	2.30	97.70	1.01	0.996-1.03	0.102
Hatchery	9,494	76	99.8	1.05	98.95	14,389	343	464.7	3.23	96.77	1.03	1.01-1.04	0.004
Combined	11,385	84	112.4	0.99	99.01	17,380	393	533.5	3.07	96.93	1.02	1.01-1.03	0.002
2008													
Wild	3,036	21	25.4	0.84	99.16	4,520	165	201.8	4.46	95.54	1.03	1.001-1.06	0.044
Hatchery	16,518	150	181.9	1.10	98.90	23,714	949	1,115.2	4.70	95.30	1.04	1.01-1.07	0.019
Combined	19,554	171	207.3	1.06	98.94	28,234	1,114	1,317.0	4.66	95.34	1.04	1.01-1.07	0.018
2006-2008													
Wild	7,383	33	44.9	0.61	99.39	12,242	360	523.1	4.73	95.27	1.04	1.02-1.05	<0.001
Hatchery	39,767	299	403.0	1.01	98.99	58,743	2,122	3,043.7	5.18	94.82	1.04	1.03-1.05	<0.001
Combined	47,150	332	447.9	0.95	99.05	69,985	2,482	3,575.8	5.11	94.89	1.04	1.03-1.05	<0.001

Table 9. Minimum predation estimates by avian species for hatchery and wild Chinook salmon smolts released at Astoria (P_A) and Skamania Landing (P_S), 2006-2008. Geometric mean relative predator avoidance $(1 - P_A)/(1 - P_S)$ across replicate paired groups shown with 95% CIs. Shading indicates significant difference ($\alpha = 0.05$).

Hatchery and wild yearling Chinook salmon								
	Caspian tern				Double-crested cormorant			
	Predation (%)		$(1-P_A)/(1-P_S)$		Predation (%)		$(1-P_A)/(1-P_S)$	
	Astoria	Skamania	Geo mean	95% CI	Astoria	Skamania	Geo mean	95% CI
2006								
Wild	0.13	2.01	1.02	1.01-1.03	0.16	5.00	1.04	1.01-1.07
Hatchery	0.60	2.78	1.03	1.02-1.04	0.28	4.31	1.03	1.01-1.05
Combined	0.53	2.66	1.02	1.01-1.03	0.26	4.42	1.03	1.01-1.05
2007								
Wild	0.12	1.09	1.01	1.00-1.02	0.55	1.21	1.004	0.99-1.02
Hatchery	0.62	1.65	1.01	1.00-1.03	0.44	1.58	1.01	1.0002-1.02
Combined	0.53	1.55	1.01	1.00-1.02	0.45	1.52	1.01	1.001-1.02
2008								
Wild	0.50	2.48	1.02	1.00-1.04	0.33	1.99	1.01	0.996-1.03
Hatchery	0.64	3.29	1.03	1.01-1.05	0.46	1.41	1.01	0.999-1.02
Combined	0.62	3.16	1.03	1.01-1.05	0.44	1.50	1.01	0.999-1.02
2006-2008								
Wild	0.28	1.95	1.01	1.01-1.02	0.33	2.78	1.02	1.01-1.03
Hatchery	0.62	2.71	1.02	1.01-1.03	0.39	2.47	1.02	1.01-1.03
Combined	0.57	2.59	1.02	1.01-1.03	0.38	2.52	1.02	1.01-1.03

Table 10. Minimum predation rates for paired release groups of Chinook salmon smolts (hatchery and wild combined) by release date, 2006-2008, derived from percentage of PIT tags detected on tern and cormorant colonies expanded for detection efficiency. Also shown are annual rates of predation by each bird species for the combined groups from each release location.

	Minimum predation on combined hatchery and wild Chinook salmon (%)			
	Caspian tern		Double-crested cormorant	
Release dates	Astoria	Skamania	Astoria	Skamania
		2006		
26 and 27 Apr	1.04	4.41	0.41	3.24
2 and 3 May	0.25	2.37	0.31	5.35
9 and 11 May	0.13	2.86	0.05	4.50
16 and 17 May	0.85	2.12	0.22	4.32
25 and 26 May	0.15	1.94	0.37	3.25
1 and 2 Jun	0.00	2.10	0.00	0.00
Combined 2006 groups	0.53	2.66	0.26	4.42
		2007		
25 and 26 Apr	--	--	--	--
2 and 3 May	1.28	2.02	0.70	1.57
8 and 9 May	0.66	1.50	0.46	0.93
16 and 17 May	0.11	1.39	0.09	1.71
23 and 23 May	0.16	1.17	1.11	2.23
29 and 31 May	0.00	2.01	0.00	0.00
Combined 2007 groups	0.53	1.55	0.45	1.52
		2008		
23 and 24 Apr	3.12	5.24	2.53	1.92
30 Apr & 1 May	1.42	5.52	0.76	2.34
6 and 8 May	0.22	4.95	0.26	2.84
13 and 15 May	0.27	3.08	0.20	1.47
20 and 22 May	0.07	1.09	0.03	0.45
27 and 28 May	0.36	1.03	0.00	0.87
Combined 2008 groups	0.62	3.16	0.44	1.50

Juvenile Fish Pathogen Levels

Juvenile fish were analyzed for the presence of two common salmonid pathogens known to occur in the Snake and Columbia River Basins. These were *Renibacteria salmoninarum*, the causative agent of bacterial kidney disease (BKD), and *Nucleospora salmonis*, an intranuclear microsporidian parasite. *N. salmonis* primarily infects lymphoblast cells and can cause a chronic, severe lymphoblastosis and a leukemic-like condition.

Methods of pathogen sampling and analysis were similar among study years and were detailed by Ryan et al. (2007) and Marsh et al. (2008, 2010) in previous reports of this study. During each tagging day, we collected about 300 non-lethal gill clip samples for pathogen analyses for a total of about 1,800 samples over each season.

We did not find evidence from studies in 2006, 2007, or 2008 that rates of avian predation were influenced by infection with *R. salmoninarum*, *N. salmonis*, or both. However, statistical power to detect the influence of pathogens was low because infection levels of *R. salmoninarum* were low in the majority fish tested during all 3 years. Furthermore, few tags from fish sampled for pathogens were recovered on bird colonies. Because they were ultimately inconclusive, we do not reiterate the details from each analysis here. Complete accounts of the pathogen evaluations conducted for each release group and year were reported by Ryan et al. (2007) and Marsh et al. (2008, 2010).

Smolt-to-Adult Return Rates

Methods

Lower Granite Dam was the adult recovery site used for analyses of SARs from paired releases in all 3 years. For each release group, we tabulated the number of adults detected at Lower Granite Dam. When adult return numbers were low for one or both groups of a pair, we pooled consecutive groups until the sum was at least 2 for each release site. For steelhead, pooling was required only for the second and third paired releases from 2006. Chinook salmon had lower return rates, so that pooling was necessary more often.

To calculate SARs, we divided the number of adults from a given group that were detected at Lower Granite Dam by the number of juveniles released from that group. Smolt-to-adult return rates were denoted T_A for Astoria and T_S for Skamania Landing release groups. We then calculated the relative SAR, or T_A/T_S ratio, for each paired release group (or pooled release groups).

We log-transformed T_A/T_S ratios to normalize their distribution and calculated the arithmetic mean and sample variance of the log-transformed data across replicates within each year. With the transformed ratios, we used standard normal-theory methods to construct a 95% confidence interval around each mean and conducted a one-sample Student's *t*-test to determine whether the mean of the ratios was different from zero. When SARs are equal for the two groups, the T_A/T_S ratio is equal to 1.0, and the log-transformed ratio is equal to 0.0. Thus, a mean log-ratio equal to zero indicates that SARs of the two groups were equal on average (i.e., the geometric mean of the ratios was equal to one).

We back-transformed the mean log-ratio and the endpoints of the 95% confidence interval to return the quantities to the original ratio scale. We also calculated the statistics and conducted the test using estimates from all paired releases across the 3 years of the study. We report significant differences based on $\alpha = 0.05$; however, *P* values are provided for all tests.

Results

Hatchery and Wild Steelhead

Estimated mean T_A/T_S ratios varied considerably across years (Table 11); however, the only significant difference was for hatchery steelhead released in 2006 (P = 0.02). For these fish, the mean SAR for groups released at Astoria was 19% higher than that of groups released at Skamania. For wild steelhead, the mean SAR ratio across 2006-2008 was 1.04; that is, estimated SARs were nearly equal between the two release sites. For hatchery steelhead, the 3-year geometric mean SAR ratio was 1.14, but this 14% difference in survival for hatchery steelhead was not significant (P = 0.14). No consistent seasonal patterns were observed for paired release groups of hatchery or wild steelhead (Figure 2).

Table 11. Annual total numbers of steelhead transported and released at Astoria or Skamania Landing, 2006-2008. Total adult returns to Lower Granite Dam are given with the corresponding smolt-to-adult return rates (SARs). Relative SAR ratios (T_A/T_S) were calculated for each paired release; geometric means across paired releases within each year are shown, along with 95% CIs. *P* value is for *t*-test for equality of SARs between the two release sites. Shading indicates a significant difference for α = 0.05.

	Steelhead smolts and adults						Astoria/Skamania SAR ratio (T_A/T_S)		
	Astoria (rkm 10)			Skamania Landing (rkm 225)					
	Juveniles released	Adults at LGR	SAR (%)	Juveniles released	Adults at LGR	SAR (%)	Geometric mean	95% CI	*P* value
2006									
Wild	3,444	43	1.25	5,608	62	1.11	1.09	0.70-1.71	0.62
Hatchery	25,717	467	1.82	36,199	490	1.35	1.22	1.04-1.43	0.02
Combined	29,161	510	1.75	41,807	552	1.32	1.19	1.01-1.41	0.04
2007									
Wild	2,553	82	3.21	4,490	131	2.92	1.12	0.80-1.57	0.40
Hatchery	20,206	314	1.55	26,690	488	1.83	0.92	0.67-1.25	0.48
Combined	22,759	396	1.74	31,180	619	1.99	0.94	0.70-1.25	0.57
2008									
Wild	5,701	191	3.35	7,613	248	3.26	0.93	0.56-1.55	0.73
Hatchery	25,417	687	2.70	32,857	661	2.01	1.28	0.75-2.18	0.29
Combined	31,118	878	2.82	40,470	909	2.25	1.18	0.73-1.90	0.41
2006-2008									
Wild							1.04	0.85-1.27	0.71
Hatchery							1.14	0.95-1.37	0.14
Combined							1.11	0.94-1.30	0.19

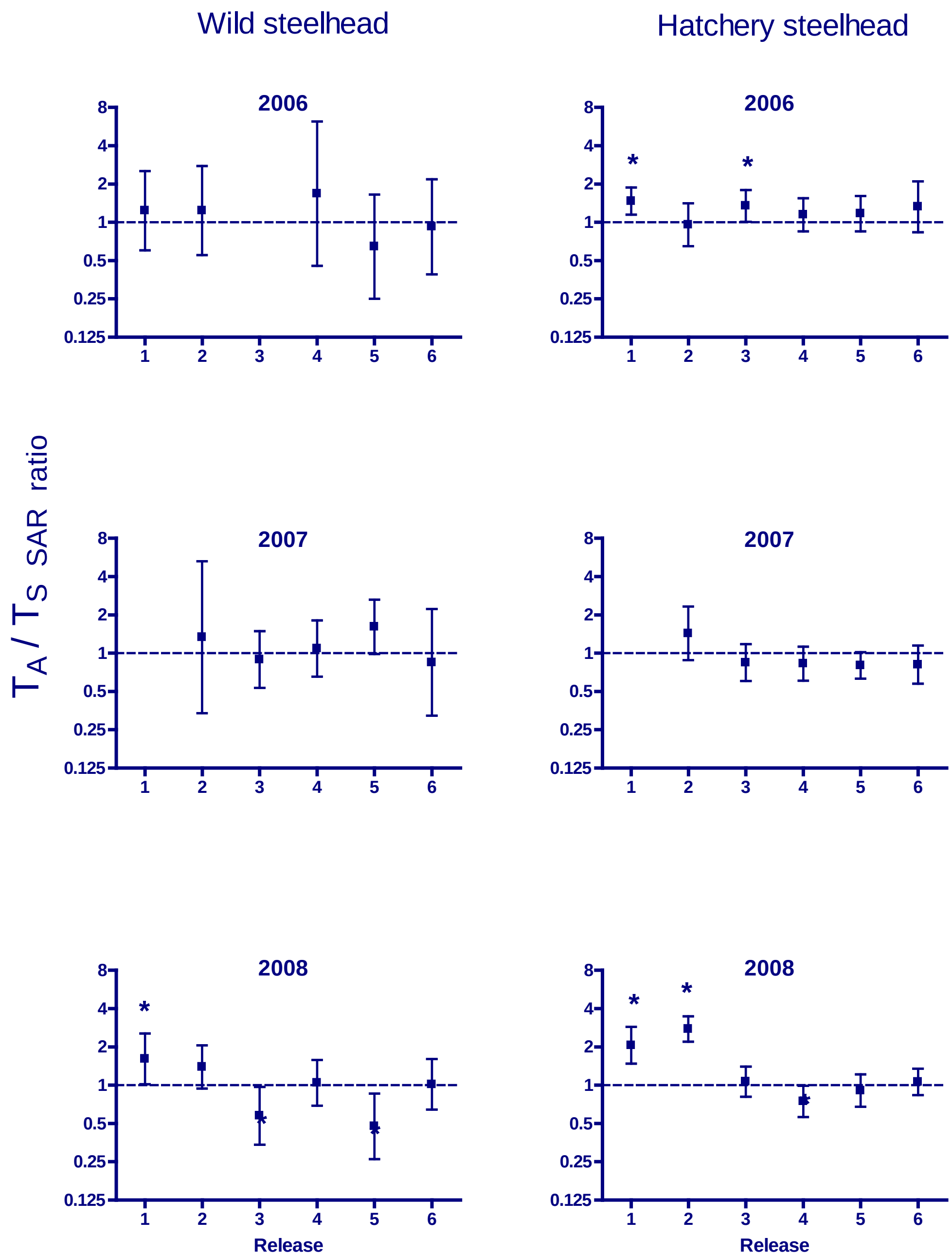

Figure 2. Relative SARs (T_A/T_S) for paired groups of transported hatchery and wild steelhead released at Astoria or Skamania, 2006-2008. Ratios greater than 1.0 indicate higher returns of fish released at Astoria; ratios less than 1.0 indicate higher returns of fish released at Skamania Landing. Whiskers show 95% confidence intervals. Asterisks indicate a significant difference between release sites ($\alpha = 0.05$).

Hatchery and Wild Chinook Salmon

For hatchery and wild Chinook salmon, estimated mean T_A/T_S ratios varied considerably across years. We observed no significant differences between release sites in within-year mean SARs (α = 0.05; Table 12). For wild Chinook, the geometric mean T_A/T_S ratio across 2006-2008 was 1.04; that is, estimated SARs were nearly equal between the two release sites. Hatchery Chinook salmon released at Astoria had lower SARs than their counterparts released at Skamania in all 3 years, and the 3-year geometric mean was 0.75. In other words, the overall average SAR for Astoria groups was only 75% of the average for Skamania groups, though the difference was not significant (P = 0.25). No consistent seasonal patterns were observed for paired release groups of hatchery or wild Chinook salmon (Figure 3).

Table 12. Annual total numbers of Chinook salmon smolts transported and released at Astoria or Skamania Landing, 2006-2008. Total adult returns to Lower Granite Dam are given, with the corresponding smolt-to-adult return rates (SARs). Relative SAR ratios (T_A/T_S) were calculated for each paired release; geometric means across paired releases within each year are shown, along with 95% CIs. *P* value is for *t*-test for equality of SARs between the two release sites. Shading indicates a significant difference for α = 0.05.

	Chinook salmon smolts and adults						Astoria/Skamania SAR ratio (T_A/T_S)		
	Astoria (rkm 10)			Skamania Landing (rkm 225)					
	Juveniles released	Adults at LGR	SAR (%)	Juveniles released	Adults at LGR	SAR (%)	Geometric mean	95% CI	*P* value
2006									
Wild	2,456	7	0.29	3,731	22	0.59	0.48	0.21-1.13	0.09
Hatchery	13,755	45	0.33	20,640	116	0.56	0.66	0.17-2.62	0.41
Combined	16,211	52	0.32	24,371	138	0.57	0.59	0.17-2.01	0.26
2007									
Wild	1,891	24	1.27	2,991	24	0.80	1.80	0.64-5.06	0.14
Hatchery	9,494	64	0.67	14,389	119	0.83	0.88	0.52-1.49	0.51
Combined	11,385	88	0.77	17,380	143	0.82	1.03	0.57-1.85	0.88
2008									
Wild	3,036	56	1.84	4,520	91	2.01	0.89	0.62-1.29	0.44
Hatchery	16,518	248	1.50	23,714	344	1.45	0.95	0.60-1.53	0.81
Combined	19,554	304	1.55	28,234	435	1.54	0.93	0.65-1.32	0.61
2006-2008									
Wild							1.04	0.44-2.44	0.92
Hatchery							0.76	0.47-1.23	0.25
Combined							0.88	0.72-1.07	0.17

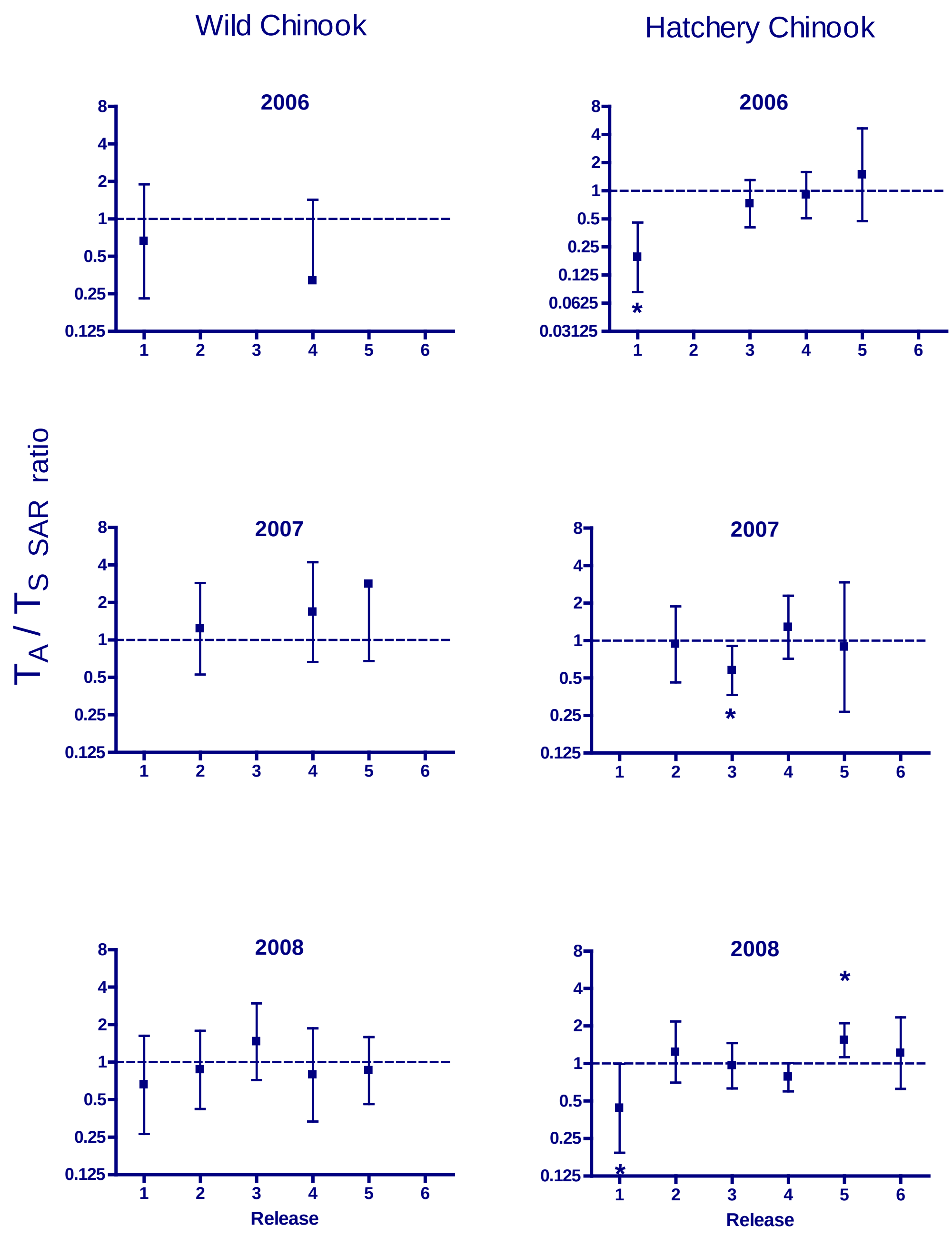

Figure 3. Relative SARs (T_A/T_S) for paired groups of transported hatchery and wild Chinook salmon released at Astoria or Skamania, 2006-2008. Ratios greater than 1.0 indicate higher returns of fish released at Astoria; ratios less than 1.0 indicate higher returns of fish released at Skamania Landing. Whiskers show 95% confidence intervals. Asterisks indicate a significant difference between release sites ($\alpha = 0.05$).

Adult Conversion Rates

Methods

For migrating adult salmonids in the Columbia River Basin, *conversion rate* is typically defined as the percent of adult migrants surviving to a given point that also survive to a second point farther upstream. Conversion rates are affected by natural mortality during the adult migration; by commercial, recreational, and tribal fisheries; and by straying.

For each tagged release group, we calculated conversion rates by tallying the number of fish detected at Bonneville Dam and determining the percentage of those fish subsequently detected at McNary and/or Lower Granite Dam. All counts were for hatchery and wild fish combined. Using these count data, we calculated conversion rates from Bonneville to McNary, from McNary to Lower Granite, and from Bonneville to Lower Granite Dam.

When adult return numbers were low, we pooled consecutive paired release groups by release site until the sum for the downstream dam was at least two. For steelhead, pooling was not required. For Chinook salmon, which had lower return rates, pooling was necessary in several cases. For each paired release group (or pooled group), we calculated the ratio of conversion rates between Astoria and Skamania release groups.

We log-transformed the ratios to normalize their distribution and calculated the arithmetic mean and sample variance of the log-transformed data across replicates within each year. Using standard normal-theory methods, we constructed a 95% confidence interval around each mean of log-ratios and conducted a one-sample Student's *t*-test to determine whether each mean was different from zero. When conversion rates are equal, the ratio of conversion rates is equal to 1.0, and the log-transformed ratio of conversion rates is equal to 0.0. Thus, the *t*-test of whether the mean log-ratio was equal to zero was equivalent to a test of whether conversion rates between the two groups were equal on average (i.e., the geometric mean of the ratios was equal to one).

We back-transformed the mean log-ratio and endpoints of the 95% CI to return quantities back to their original scale. We calculated statistics and conducted tests using estimates from all paired releases across the 3 years of the study. We set $\alpha = 0.05$ for statistical significance; however, *P* values for all tests are reported.

Results

Combined Hatchery and Wild Steelhead

Annual conversion rates for steelhead were fairly consistent across the 3 years. Conversion rates from Bonneville to McNary were lower than those from McNary to Lower Granite Dam for groups from both release sites. This lower rate between Bonneville and McNary Dam was likely due to take from the Zone 6 fishery, which is located in this reach and which is reserved by treaty exclusively for Native American commercial fishing.

For adult steelhead, all within- and across-year geometric mean ratios indicated that conversion rates were significantly lower for fish released as smolts at Astoria than for those released at Skamania Landing (Table 13). This relative difference was also greater in the lower river reach. Conversion rates for Astoria release groups averaged 85% those of Skamania groups in the reach from Bonneville to McNary, and 92% in the reach from McNary to Lower Granite Dam.

For wild and hatchery steelhead combined, annual conversion rates in the reach from Bonneville to Lower Granite Dam ranged 48-53% for fish released at Astoria and 60-64% for fish released at Skamania Landing. Across the 3 years, steelhead groups released at Astoria had a mean conversion rate just 79% that of groups released at Skamania Landing ($P < 0.001$).

Combined Hatchery and Wild Chinook Salmon

As with steelhead, conversion rates between Bonneville and McNary Dam were lower than those between McNary and Lower Granite Dam for combined Chinook salmon groups from both release sites (Table 14). Again, the lower conversion rate from Bonneville to McNary Dam was likely due to take from the Zone 6 fisheries.

For Chinook salmon released in 2007 and 2008, all conversion rates were similar between groups from Astoria and Skamania. In 2006, conversion rates for Astoria groups were lower than those of Skamania groups. Only two within-year differences between release sites were statistically significant ($\alpha = 0.05$). The first was for hatchery Chinook in 2006, when Astoria groups had lower conversion rates between McNary and Lower Granite Dam. The second was for hatchery Chinook in the same reach in 2007, when Astoria groups had higher conversion rates.

For wild and hatchery Chinook salmon combined, annual conversion rates in the reach from Bonneville to Lower Granite Dam ranged 51-78% for fish released at Astoria and 67-77% for fish released at Skamania Landing. Across the 3 years, the mean conversion rate for combined Chinook groups released at Astoria was 90% of that for their cohorts released at Skamania Landing ($P = 0.120$).

Table 13. Annual conversion rates for combined hatchery and wild adult steelhead by location of juvenile release at Astoria or Skamania Landing in 2006-2008. Relative conversion rate (Astoria/Skamania ratio) was calculated for each paired release. Geometric means across paired releases within each year are shown along with 95% CIs. Abbreviations: BON, Bonneville; MCN, McNary, and LGR Lower Granite Dam. *P* values are for *t*-test comparing mean conversion rates between the two release sites. Shaded cells indicate significant difference at α = 0.05.

				Combined hatchery and wild steelhead Conversion rates (%)			Astoria/Skamania ratios		
Release location	Bonneville detection	Subsequent McNary detection	Subsequent Lower Granite detection	Bonneville to McNary	McNary to Lower Granite	Bonneville to Lower Granite	Reach	Geometric mean (95% CI)	*P* value
2006									
Astoria	1,037	644	500	62	78	48	BON to MCN	0.84 (0.73-0.98)	0.032
Skamania	917	667	546	73	82	60	MCN to LGR	0.93 (0.89-0.97)	0.004
							BON to LGR	0.78 (0.68-0.90)	0.006
2007									
Astoria	736	470	391	64	83	53	BON to MCN	0.89 (0.85-0.93)	0.003
Skamania	956	673	609	70	91	64	MCN to LGR	0.89 (0.83-0.96)	0.014
							BON to LGR	0.80 (0.72-0.89)	0.004
2008									
Astoria	1,738	1,075	865	62	81	50	BON to MCN	0.86 (0.80-0.91)	0.002
Skamania	1,448	1,042	895	72	86	62	MCN to LGR	0.92 (0.88-0.97)	0.010
							BON to LGR	0.79 (0.72-0.87)	0.002
2006-2008							BON to MCN	0.85 (0.83-0.88)	<0.001
							MCN to LGR	0.92 (0.90-0.95)	<0.001
							BON to LGR	0.79 (0.75-0.82)	<0.001

Table 14. Annual conversion rates for combined hatchery and wild adult Chinook salmon by location of juvenile release at Astoria or Skamania Landing in 2006-2008. Relative conversion rate (Astoria/Skamania ratio) was calculated for each paired release. Geometric means across paired releases within each year are shown along with 95% CIs. Abbreviations: BON, Bonneville; MCN, McNary, and LGR Lower Granite Dam. *P* values are for *t*-test comparing conversion rates between the two release sites. Shading indicates significant difference ($\alpha = 0.05$).

Combined hatchery and wild Chinook salmon									
				Conversion rates (%)			Astoria/Skamania ratios		
Release location	Bonneville detection	Subsequent McNary detection	Subsequent Lower Granite detection	Bonneville to McNary	McNary to Lower Granite	Bonneville to Lower Granite	Reach	Geometric mean (95% CI)	*P* value
2006									
Astoria	103	65	52	63	80	51	BON to MCN	0.79 (0.55-1.13)	0.140
Skamania	190	152	138	80	91	73	MCN to LGR	0.83 (0.71-0.98)	0.035
							BON to LGR	0.70 (0.42-1.17)	0.112
2007									
Astoria	111	89	86	80	97	78	BON to MCN	1.00 (0.89-1.13)	0.928
Skamania	177	147	137	83	93	77	MCN to LGR	1.06 (1.003-1.12)	0.043
							BON to LGR	1.06 (0.90-1.26)	0.325
2008									
Astoria	450	339	297	75	88	66	BON to MCN	0.95 (0.89-1.01)	0.088
Skamania	627	484	422	77	87	67	MCN to LGR	1.00 (0.94-1.07)	0.929
							BON to LGR	0.95 (0.88-1.02)	0.122
2006-2008							BON to MCN	0.91 (0.81-1.01)	0.065
							MCN to LGR	0.97 (0.90-1.03)	0.299
							BON to LGR	0.90 (0.78-1.03)	0.120

Adult Straying Rates

Methods

Because all study fish were collected as smolts at Lower Granite Dam, any adult detected outside the lower Columbia or Snake River was considered to have strayed from the expected migration route. To evaluate rates of straying, we first tallied adults detected at Bonneville Dam for each release group. Then, for those fish detected at Bonneville Dam, we tallied detections at any site other than McNary, Ice Harbor, or Lower Granite Dam.

We categorized strays according to three areas of detection: John Day or Deschutes River; other tributaries; and Upper Columbia River dams. We also tallied whether strays were eventually detected at Lower Granite, the "correct" uppermost dam. Fish not detected at Lower Granite Dam were considered permanent or "lost" strays. Those that were eventually detected at the correct uppermost dam were considered temporary strays, or "wanderers."

Results

Combined Hatchery and Wild Steelhead

Straying rates of steelhead were much higher than those of Chinook salmon in all 3 years (Table 15 and Appendix Table B5). Wild and hatchery steelhead had similar straying rates (Tables 16 and 17). Of the 564 combined wild and hatchery steelhead strays to all areas, 84.8% were detected in either the John Day or Deschutes River. Of steelhead detected in Columbia River tributaries or in the upper Columbia River, 24.1% eventually crossed Lower Granite Dam (18.3% of wild and 25.5% of hatchery steelhead). The incidence of wandering was much higher for steelhead than for stray Chinook salmon, almost all of which were lost (never detected at Lower Granite Dam).

In all 3 study years, the straying rate was higher for adult steelhead that had been released as smolts at Astoria than for their counterparts released at Skamania, likely because of greater impairment of homing ability. Across the 3 years of releases, the average straying rate was 28% greater for wild steelhead released at Astoria (P = 0.16) and 47% greater for hatchery steelhead released at Astoria (P = 0.003).

Table 15. Straying data by area of straying for adult steelhead and Chinook salmon (hatchery and wild combined) released as smolts at Astoria or Skamania Landing in 2006-2008. Also shown are the number of temporary strays ("wanderer"), the total stray rate, the permanent stray rate ("lost"), and the percentage of total strays that were lost.

		Location of stray detection (n)				Stray proportions (%)		
Juvenile release location	Detected at Bonneville (n)	John Day or Deschutes R	Other tributary	Upper Columbia R dams	Wanderer (n)	Total	Lost	Lost from total
		Combined hatchery and wild steelhead						
2006								
Astoria	1,037	74	4	8	20	8.3	6.4	76.7
Skamania	917	49	1	11	21	6.7	4.4	65.6
Total	1,954	123	5	19	41	7.5	5.4	72.1
2007								
Astoria	736	52	0	6	11	7.9	6.4	81.0
Skamania	956	49	1	6	9	5.9	4.9	83.9
Total	1,692	101	1	12	20	6.7	5.6	82.5
2008								
Astoria	1,738	169	3	15	38	10.8	8.6	79.7
Skamania	1,448	85	2	29	37	8.0	5.5	68.1
Total	3,186	254	5	44	75	9.5	7.2	75.2
		Combined hatchery and wild Chinook salmon						
2006								
Astoria	103	0	0	0	--	--	--	--
Skamania	190	0	0	1	0	0.5	0.5	100.0
Total	293	0	0	1	0	0.3	0.3	100.0
2007								
Astoria	111	0	0	0	--	--	--	--
Skamania	177	0	0	0	--	--	--	--
Total	288	0	0	0	--	--	--	--
2008								
Astoria	450	4	4	9	1	3.8	3.6	94.1
Skamania	627	6	1	11	0	2.9	2.9	100.0
Total	1,077	10	5	20	1	3.2	3.2	97.1

Table 16. Summary of stray data for adult wild steelhead by smolt release location and release group, 2006-2008. Shown are total number of strays and total stray rate, and total number of permanent strays ("lost") and permanent stray rate.

	Wild steelhead									
	Astoria releases					Skamania Landing releases				
Paired release number	Bonneville Dam detections (n)	Total strays (n)	Total strays %	Lost strays (n)	Lost strays %	Bonneville Dam detections (n)	Total strays (n)	Total strays %	Lost strays (n)	Lost strays %
					2006					
1	27	3	11.1	3	11.1	22	0	0.0	0	0.0
2	7	1	14.3	1	14.3	8	0	0.0	0	0.0
3	16	1	6.3	0	0.0	17	0	0.0	0	0.0
4	6	0	0.0	0	0.0	7	1	14.3	1	14.3
5	22	2	9.1	2	9.1	30	4	13.3	4	13.3
6	13	2	15.4	2	15.4	16	1	6.3	1	6.3
Total	91	9	9.9	8	8.8	100	6	6.0	6	6.0
					2007					
1										
2	8	0	0.0	0	0.0	5	0	0.0	0	0.0
3	47	6	12.8	6	12.8	63	4	6.3	4	6.3
4	41	5	12.2	5	12.2	67	3	4.5	2	3.0
5	37	1	2.7	1	2.7	73	7	9.6	7	9.6
6	14	0	0.0	0	0.0	10	0	0.0	0	0.0
Total	147	12	8.2	12	8.2	218	14	6.4	13	6.0
					2008					
1	68	7	10.3	7	10.3	56	10	17.9	9	16.1
2	90	5	5.6	5	5.6	78	6	7.7	3	3.8
3	55	6	10.9	5	9.1	64	6	9.4	3	4.7
4	70	6	8.6	5	7.1	64	4	6.3	2	3.1
5	40	5	12.5	5	12.5	59	3	5.1	1	1.7
6	56	6	10.7	3	5.4	70	4	5.7	2	2.9
Total	379	35	9.2	30	7.9	391	33	8.4	20	5.1

Table 17. Summary of stray data for adult hatchery steelhead by smolt release location and release group, 2006-2008. Shown are total number of strays and total stray rate, and total number of permanent strays ("lost") and permanent stray rate.

	Hatchery steelhead									
	Astoria releases					Skamania Landing releases				
Paired release number	Bonneville Dam detections (n)	Total strays (n)	Total strays %	Lost strays (n)	Lost strays %	Bonneville Dam detections (n)	Total strays (n)	Total strays %	Lost strays (n)	Lost strays %
					2006					
1	335	21	6.3	16	4.8	158	2	1.3	0	0.0
2	79	10	12.7	8	10.1	102	12	11.8	9	8.8
3	166	13	7.9	10	6.0	156	11	7.1	7	4.5
4	133	7	5.3	4	3.0	156	10	6.4	5	3.2
5	154	15	9.7	10	6.5	171	13	7.6	8	4.7
6	79	11	13.9	10	12.7	74	7	9.5	5	6.8
Total	946	77	8.2	58	6.1	817	55	6.7	34	4.2
					2007					
1										
2	62	1	1.6	0	0.0	37	1	2.7	0	0.0
3	108	13	12.0	10	9.3	110	5	4.5	30	2.7
4	128	9	7.0	8	6.3	183	12	6.6	11	6.0
5	194	19	9.8	14	7.2	306	22	7.2	18	5.9
6	97	4	4.1	3	3.1	102	2	2.0	2	2.0
Total	589	46	7.8	35	5.9	738	42	5.7	34	4.6
					2008					
1	179	38	21.2	30	16.8	97	14	14.4	11	11.3
2	442	41	9.3	30	6.8	171	8	4.7	6	3.5
3	224	19	8.5	17	7.6	144	15	10.4	9	6.3
4	168	16	9.5	10	6.0	170	8	4.7	6	3.5
5	134	12	9.0	12	9.0	219	16	7.3	11	5.0
6	212	26	12.3	20	9.4	256	22	8.6	16	6.3
Total	1,359	152	11.2	119	8.8	1,057	83	7.9	59	5.6

Differential straying rates for steelhead were greater when we considered only straying into the John Day and Deschutes Rivers. In just these two tributaries, the average straying rate was 52% greater for wild fish released at Astoria (P = 0.06) and 54% greater for hatchery fish released at Astoria (P = 0.003).

Release from Astoria was also associated with an increased probability of permanent straying. Averaged across the 3 years of the study, wild steelhead released at Astoria were 64% more likely to be "lost" than their counterparts released at Skamania (P = 0.03). For hatchery steelhead, rates of lost straying averaged 51% higher for Astoria releases (P < 0.001).

Combined Hatchery and Wild Chinook Salmon

No stray adult Chinook salmon were observed from groups released at either site in 2007 (Table 15 and Appendix Table B6). For fish released in 2006, there was only one stray Chinook. It had been released at Skamania Landing and was detected as an adult in the upper Columbia River (above the Snake River confluence).

For Chinook released in 2008, rates of straying were higher: 17 adults from Astoria and 19 from Skamania releases were detected as strays. These strays were detected in the Columbia River and its tributaries both above and below the Snake River confluence, and most were of hatchery origin. Of the 37 Chinook salmon strays, only 10 (27%) were detected in the John Day or Deschutes River. Twice as many (20) were detected at upper Columbia River dams. Only 1 of the 37 was later detected at Lower Granite Dam; all others were lost.

For pooled adult returns of Chinook salmon from all 3 release years, straying rates were 2.6% for Astoria groups and 2.0% for Skamania groups (P = 0.46). Because rates of straying were too low to provide data for any specific conclusions, we did not look for temporal differences among years.

Adult Travel Time

Methods

We calculated travel time for each adult that was detected at Bonneville Dam and also detected at McNary and/or Lower Granite Dam. For each individual fish, travel time was calculated as the elapsed time (d) between first detection at Bonneville Dam and first detection at McNary or Lower Granite Dam.

We grouped individual travel times by species, rearing type, release year, release site, and adult age class and calculated the median travel time for each such group. To test for effects of smolt release site on adult travel time, we compared median travel times using the nonparametric two-sample Mann-Whitney test (Hollander and Wolfe 1999). Median travel time was compared between Astoria and Skamania release groups by sub-group (e.g., 1-ocean hatchery steelhead adults that were released as smolts in 2006). We conducted these tests for hatchery and wild rearing types both separately and combined.

Results

Combined Hatchery and Wild Steelhead

Median adult travel time from Bonneville to Lower Granite Dam was considerably longer for steelhead than for Chinook salmon (Figure 4 and Appendix Table B7). For combined hatchery and wild steelhead, we observed a significant difference in median travel time between Astoria and Skamania release locations only for 1-ocean adults released in 2006. Median travel time for these adults was 56.0 d for Astoria releases vs. 49.7 d for Skamania releases.

For combined hatchery and wild steelhead, median adult travel time ranged 38.8-49.7 d for groups released at Skamania Landing and 35.4-56.0 d for those released at Astoria. Overall, a wide variety of patterns was observed (Appendix Table B7), and there were no pronounced trends in the differences between subgroups; for example, between hatchery vs. wild rear types or between different adult age classes.

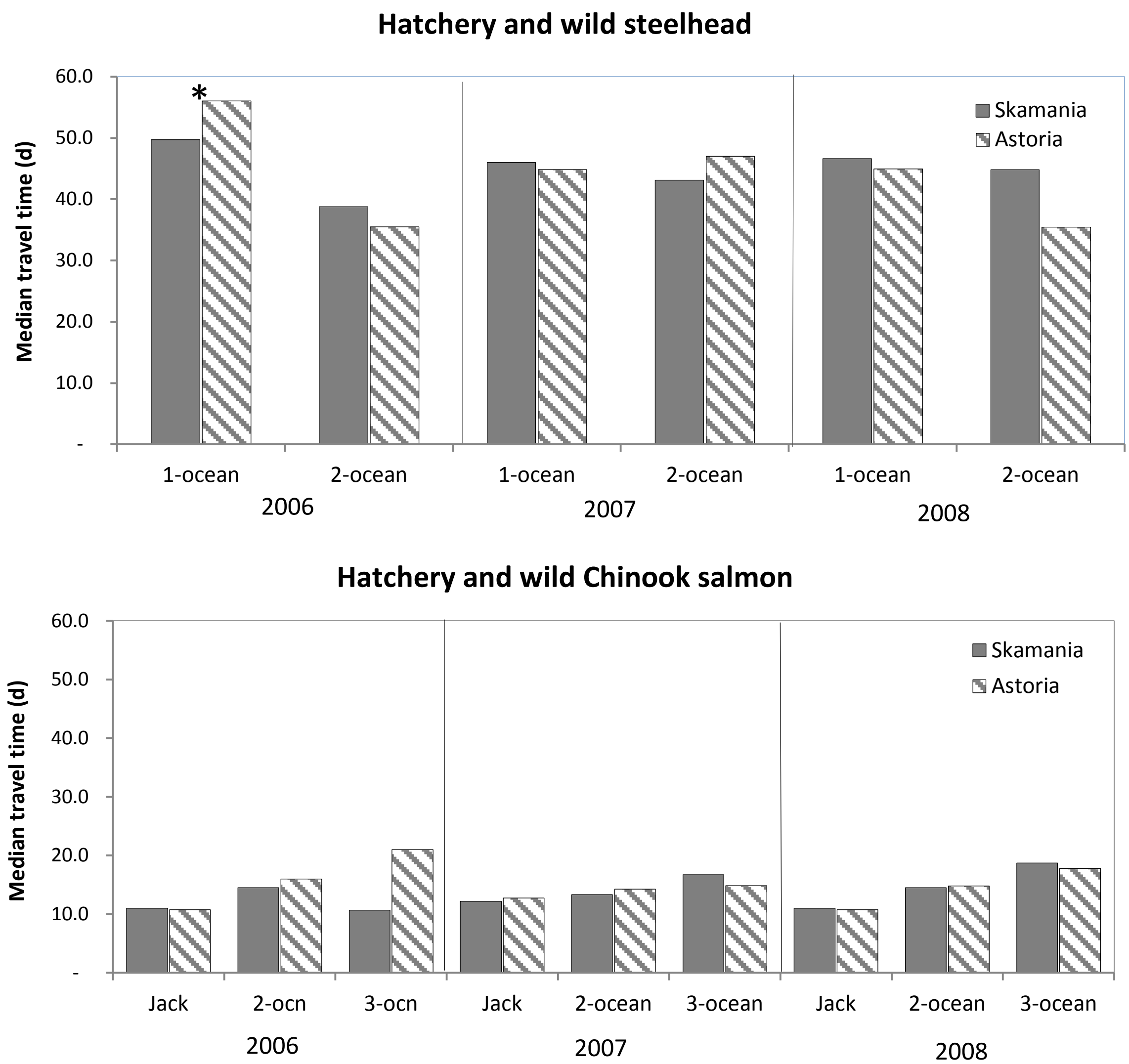

Figure 4. Median travel time from Bonneville Dam to Lower Granite Dam for adult steelhead and Chinook salmon released as smolts at Skamania Landing vs. Astoria. Asterisk above paired bars indicate significant difference ($\alpha = 0.05$).

Combined Hatchery and Wild Chinook Salmon

Chinook salmon adults showed no significant differences in median travel time from Bonneville to either McNary or Lower Granite Dam (Figure 4 and Appendix Table B8). For combined hatchery and wild Chinook salmon, median adult travel time from Bonneville to Lower Granite Dam ranged 10.7-18.7 d for fish released at Skamania Landing and 10.8-21.0 d for fish released at Astoria over the 3 study years (Figure 4). In general, jacks had the shortest median travel time, while 3-ocean adults had the longest.

Discussion

A primary goal in this study was to evaluate whether survival from release to ocean entry could be increased by using an alternate release site for transported fish. The experimental release site was below the Astoria Bridge, 215 km farther downstream than the customary release site at Skamania Landing. We hypothesized that fish released at this site would survive to the ocean at higher rates as a result of reduced avian predation in the Columbia River estuary.

Steelhead smolts are particularly vulnerable to predation by piscivorous birds: Collis et al. (2001) reported that over 15% of the PIT tags from steelhead detected at Bonneville Dam in 1998 were later found on estuarine bird colonies. In contrast, they found only 2% of the tags from yearling Chinook detected at Bonneville Dam on colonies that year.

In 1998 the greatest number of PIT tags was recovered on Rice Island, which hosted the largest Caspian tern colony in North America (Collis et al. 2002). The USACE relocated the tern colony further downstream, from Rice to East Sand Island during 1999-2000. The relocation was intended to encourage terns to select alternate prey, such as baitfish, rather than feeding primarily on salmon. However, in the years following relocation, Ryan et al. (2002, 2003) and Glabek et al. (2003) reported levels of tern predation on East Sand Island similar to those seen on Rice Island.

In an attempt to maximize avoidance of avian predators in the estuary, we released Astoria groups during nighttime hours on an ebb tide. Based on previous evaluations of estuary travel time (Ledgerwood et al. 2001), we expected that most study fish would reach the ocean during one tidal cycle. Thus, the majority of fish released at Astoria would pass colonies during nighttime hours, when foraging by avian predators was not likely. Our results supported this hypothesis: avian predation rates for smolts released at Astoria were lower than those for smolts released at Skamania Landing.

In addition to conferring a survival advantage through avian predator avoidance, use of the alternate release site near Astoria could improve survival by facilitating avoidance of piscivorous fishes. Ward et al. (1995) sampled multiple locations in the lower Snake and middle and lower Columbia Rivers to develop an index of predation by northern pikeminnow *Ptychocheilus oregonensis*. They found the highest rates of predation in the Columbia River below Bonneville Dam, an area located near the Skamania Landing release site. By releasing transported smolts farther downstream, this source of potential mortality could also be avoided.

Release in the lower estuary could confer an additional advantage to trasnported fish that would otherwise migrate in the Columbia River near its confluence with the Willamette, where high levels of toxic chemicals have been found (Spromberg et al. 2008). Although fish traversing this area by barge would still be exposed to recirculating river water, the duration of exposure to any toxic chemicals would be shorter.

Finally, releasing transported fish from an alternate release site in the lower estuary could increase SARs for late-season steelhead by discouraging cessation of migration. During years with low flows and high water temperatures, late-season steelhead migrants often cease migration. These fish revert to the parr stage and overwinter in freshwater; however, few of them survive to resume migration the following spring (Williams et al. 2005). If these late-season steelhead were released near the mouth of the river, in a strong current and on an ebb tide, more of them might be encouraged to continue rather than to cease migration, even at higher water temperatures.

Another study goal was to monitor prevalence and levels of *R. salmoninarum* and *N. salmonis* to evaluate whether these fish pathogens influenced rates of avian predation in the estuary. Both of these pathogens can cause chronic infection, and both have immunosuppressive properties (Wongtavatchai et al. 1995; Alcorn et al. 2005). Although infection with either pathogen can be directly fatal, both increase vulnerability to opportunistic infection by other pathogens.

Unfortunately, the numbers of PIT tags recovered on East Sand Island from pathogen study groups were too small to form sufficient sample sizes for evaluation. However, among fish with tags that were recovered, the presence of *R. salmoninarum*, *N. salmonis*, or both pathogens was not observed to influence susceptibility to avian predation in either steelhead or Chinook salmon. This finding was not surprising, considering the relatively low levels of *R. salmoninarum* we found in fish subsampled during the 3 study years.

In the end, the most important question is not whether use of an alternate release site increases juvenile survival to the ocean, but whether it produces greater SARs. It is conceivable that fish released at Astoria could have higher rates of survival to ocean entry but could still have adult returns rates the same or lower than those of fish released at Skamania Landing. For example, fish released at Astoria might experience higher mortality in the ocean because they were less physiologically prepared to enter seawater than fish released further upstream at the traditional release site.

On the other hand, fish released at Astoria could survive at higher rates in the ocean if they were more fit upon ocean entry than their counterparts released at Skamania. This might be the case if Astoria releases obtained a fitness advantage from

conserving energy they would otherwise have expended during migration through the lower river and estuary. Ultimately, we based our evaluation of the alternate release site on comparisons of SAR among study groups, augmented with an understanding of the different rates of straying rates between these groups.

Studies of coho and Atlantic salmon have found that transported smolts released to the estuary or ocean returned as adults at higher rates than those released to freshwater (Solazzi et al. 1991; Gunnerod et al. 1988). Between 1992 and 1994, we conducted a 3-year study to evaluate an alternate release site for transported steelhead (Marsh et al. 1996, 1998, 2000). We released groups of transported smolts to the estuary at Tongue Point (rkm 29) for comparison with releases at Skamania Landing.

This study employed methods similar to those in the present study, using SARs from paired releases to evaluate an alternate transport release site. For adults returning from releases in 1994, the ratio of SARs for Tongue Point to Skamania Landing was 3.0, indicating a large survival advantage for fish released at the alternate site. However, SAR ratios from releases in the other 2 years were near 1.0. More importantly, overall results were statistically inconclusive because too few adults returned from any of the 3 release years (Marsh et al. 1996, 1998, 2000).

In the present study, releasing transported smolts at the alternate site (rkm 10) instead of the customary release site (rkm 225) had no significant effect on SARs for Chinook salmon. This result may have been related to lack of statistical power because of the lower number of Chinook tagged than planned for each year.

For wild Chinook salmon released as smolts in 2006, the average estimated SAR for groups released at Astoria was about half that of groups released at Skamania (based on a total of only 29 adults). In contrast, for wild Chinook released in 2007, the average SAR for Astoria groups was nearly double that of Skamania groups. Across the 3 years of the study, average SARs were essentially equal between the two release sites.

For hatchery Chinook salmon, Astoria releases had lower average SARs than Skamania releases in all 3 years. However, high variability among replicate paired release groups led to none of the differences being statistically significant. The difference between 3-year averages was also not statistically significant.

For Chinook salmon released in all 3 study years, predation by Caspian terns and double-crested cormorants in the estuary was generally lower for Astoria releases than for Skamania releases, and the differences were significant. We converted predation rates to rates of predator avoidance to evaluate predation effects in terms of survival. These evaluations showed that Chinook salmon released at Skamania survived migration past

the avian colonies at high rates to begin with (96-98%). Therefore, while avian predation rates between Astoria and Skamania releases were significantly different, the lower rates of predation for Astoria releases likely had only a small effect on SARs.

For hatchery steelhead in 2006, the alternate release site at Astoria produced significantly higher SARs, but this outcome was not repeated in any other comparison. Across all study years, average SARs of Astoria groups were 4% higher than those of Skamania groups for wild steelhead and 14% higher than Skamania groups for hatchery steelhead. However, neither of these 3-year comparisons was significant.

We were surprised by the lack of evidence for a consistent benefit in SARs to steelhead released from Astoria. We had expected higher SARs for Astoria releases because of the strong evidence that these fish were considerably more likely to avoid avian predation in the estuary. Pooling data across the 3 years of releases at Skamania, our estimates of minimum predation were 14.1% for wild and 21.5% for hatchery steelhead. Estimates of minimum predation for Astoria releases were far lower, at 1.9% for wild and 3.8% for hatchery steelhead.

These predation estimates correspond to considerably higher predator avoidance rates for steelhead released at Astoria. In terms of avian predator avoidance, Astoria groups of wild steelhead averaged 26% higher survival than Skamania groups, and the benefit for hatchery steelhead was 22%. However, based on the SAR results, these survival advantages appear to have been largely offset by higher mortality rates later in the life cycle.

In part, the lower-than-expected SARs for steelhead released at Astoria could be related to a reduction in homing or an increase in mortality during adult migration in the Columbia River. Without exception, average within-year adult conversion rates for Astoria groups (hatchery and wild combined) were significantly lower than those of Skamania groups. Across the 3 years, the average steelhead conversion rate between Bonneville and Lower Granite Dam for Astoria releases was only 79% of that for Skamania releases. This lower conversion rate at least partly explains why the survival advantage from predator avoidance did not translate to higher SARs.

Conversion rates are affected by harvest, adult mortality, and straying. While it is difficult to measure the effects of harvest and adult mortality on a study group of PIT-tagged fish, we can estimate straying effects. Since the early 2000s, PIT-tag detection systems have been operated in the adult fish ladders of several Columbia and Snake River dams. In addition, several tributaries in the basin have in-stream PIT-tag detection systems and/or weirs where adults are trapped and scanned for tags. The

largest increase in tributary detection occurred in fall 2007 when an in-stream detector became operational in the John Day River (PTAGIS site code JD1).

Based on detections of steelhead in these tributaries and in the adult ladders of dams upstream from the Columbia/Snake River confluence, straying rates were higher for Astoria than for Skamania release groups. This finding was consistent for both "permanent" strays (fish that never passed Lower Granite Dam) and the total straying rate, which includes "wanderers" or "temporary strays" (fish detected straying, but eventually passed Lower Granite Dam).

The cause of greater homing impairment for steelhead released at Astoria is unknown. Olfactory homing cues may have been missed because they spent less time in the river and migrated over a shorter distance as juveniles. Another possible cause of increased straying was the lower water exchange rate on the 2000-series barge used for Astoria releases.

Results from this study provide some new information on post-Bonneville Dam mortality of transported fish. Anderson et al. (2011) and Muir et al. (2006) hypothesized that Chinook salmon smolts transported early in the migration season would experience poor post-release survival as a result of entering the ocean too early and at too small a size. If this hypothesis is correct, then Chinook smolts transported early in the season would survive at even lower rates if they were also released farther downstream, since ocean entry would be still earlier.

Our results provide some support for this hypothesis. Seasonal trends in our estimated SAR ratios for Chinook salmon were not particularly strong. However, in both 2006 and 2008, the earliest paired releases of hatchery Chinook had significantly lower SARs in the Astoria group. Unfortunately, no early season releases were possible in 2007 because of a legal challenge.

In summary, use of an alternate barge release site was successful insofar as it reduced avian predation in the estuary for both yearling Chinook salmon and steelhead. However, significant improvements in SARs were not observed except for hatchery steelhead released in 2006. For Chinook salmon, losses to avian predators were relatively low in groups from both release sites. Therefore, while releasing transported fish at Astoria did reduce losses of juvenile fish to avian predation, the survival benefit was not large enough to result in corresponding differences in SAR data. For juvenile steelhead released at Astoria, losses to avian predation were substantially reduced. However in terms of SARs, any benefit from higher juvenile survival was likely offset by lower adult conversion rates due to homing impairment.

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References

Alcorn, S., A. L. Murray, R. J. Pascho, and J. Varney. 2005. A cohabitation challenge to compare the efficacies of vaccines for bacterial kidney disease (BKD) in Chinook salmon *Oncorhynchus tshawytscha.* Diseases of Aquatic Organisms 63:151-160.

Anderson, J. J., K. D. Ham, and J. L. Gosselin. 2011. Snake River Basin differential delayed mortality synthesis. Report to the U.S. Army Corps of Engineers, PNWD-4283, 438.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5:1-437.

CBFWA (Columbia Basin Fish and Wildlife Authority). 1999. PIT Tag Marking Procedures Manual. Version 2.0. Available www.psmfc.org/pittag/Software_and_Documentation/ (August 2007).

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

Collis, K. D., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D. E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537-550.

Congleton, J. L., J. Evavold, D. Jones, M. Santora, B. Sun, and T. Wagner. 2005. Evaluation of physiological condition of transported and inriver migrating juvenile salmonids and effects on survival (DACW68-00-C-0030). Annual Report, 2003. Report of Idaho Cooperative Fish and Wildlife Research Unit to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA.

Congleton, J. L., W. J. LaVoie, C. B. Schreck, and L. E. Davis. 2000. Stress indices in migrating juvenile Chinook salmon and steelhead of wild and hatchery origin before and after barge transportation. Transactions of the American Fisheries Society 129:946-961.

Elliott, D. G., and C. L. McKibben. 1997. Comparison of two fluorescent antibody techniques (FATs) for detection and quantification of *Renibacterium salmoninarum* in coelomic fluid of spawning Chinook salmon *Oncorhynchus tshawytscha.* Diseases of Aquatic Organisms 30:37-43.

Elliott, D. G., and R.J. Pascho. 1991. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1989 (Contract E86880047) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA.

Elliott, D. G., and R.J. Pascho. 1992. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1990 (Contract E86890043) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA.

Elliott, D. G., and R.J. Pascho. 1993. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1991 (Contract E86910058) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA.

Elliott, D. G., and R.J. Pascho. 1994. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1992 (Contract E86920048) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA.

Glabek, J. H., B. A. Ryan, E. P. Nunnallee, and J. W. Ferguson. 2003. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River Basin, 2001. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington

Gunnerod, T. B., N. A. Hvidsten, and T. G. Heggberget. 1988. Open sea releases of Atlantic salmon smolts, *Salmo salar*, in central Norway, 1973-1983. Canadian Journal of Fisheries and Aquatic Sciences 45:1340-1345.

Hollander, M. and D. A. Wolfe (1999), *Nonparametric Statistical Methods, 2nd ed.* New York: John Wiley & Sons.

Kelsey, D. A., C. B. Schreck, J. L. Congleton, and L. E. Davis. 2002. Effects of juvenile steelhead on juvenile Chinook salmon behavior and physiology. Transactions of the American Fisheries Society 131:676-689.

Ledgerwood, R. D., B. Ryan, and R. N. Iwamoto. 2001. Estuarine and nearshore-ocean acoustic tracking of juvenile spring chinook salmon from the Columbia River. Pages 245-255 *in* Moore, A., I. Russell. (Eds.). Advances in fish telemetry: proceedings of the 3rd conference on fish telemetry in Europe, June 20-25, 1999, Norwich, UK. Centre for Environment, Fisheries, and Aquaculture Science, Lowestoft, UK.

Marsh, D. M., J. R. Harmon, K. W. McIntyre, K. L. Thomas, N. N. Paasch, B. P. Sandford, D. J. Kamikawa, and G. M. Matthews. 1996. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1995. Report of the U.S. National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Mathews. 1998. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1997. Report of the U.S. National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Mathews. 2000. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1998. Report of the U.S. National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2001. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M. W. D. Muir, D. Elliott, T. Murray, L. Applegate, C. McKibben, and S. Mosterd. 2008. Alternative barging strategies to improve survival of transported juvenile salmonids, 2007. Report of the U.S. National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District.

Marsh, D. M. W. D. Muir, B. P. Sandford, D. Elliott, L. Applegate, C. McKibben, S. Mosterd, S. Badil, and J. Woodson. 2010. Alternative barging strategies to improve survival of transported juvenile salmonids, 2008. Report of the U.S. National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District.

McMichael, G. A., J. R. Skalski, and K. A. Deters. 2011. Survival of juvenile Chinook salmon during barge transport. North American Journal of Fisheries Management, 31:6, 1187-1196.

Muir, W. D., D. M. Marsh, B. P. Sandford, S. G. Smith, and J. G. Williams. 2006. Post-hydropower system delayed mortality of transported Snake River stream-type Chinook salmon: Unraveling the mystery. Transactions of the American Fisheries Society 135:1523–1534.

Pascho, R. J., and D. G. Elliott. 1989. Juvenile fish transportation: impact of bacterial kidney disease on survival of spring/summer chinook salmon stocks. Annual Report, 1988 (Contract E86880047) prepared by the U.S. Fish and Wildlife Service, Seattle, WA, for the U.S. Army Corps of Engineers, Walla Walla, WA. 319 p.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Ryan, B. A., M. C. Carper, B. P. Sandford, and G. M. Matthews. 2007. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River Basin, 2006. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

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

Ryan, B. A., J. H. Glabek, J. W. Ferguson, E. P. Nunnallee, and R. D. Ledgerwood. 2002. Detection of passive integrated transponder (PIT) tags on piscivorous bird colonies in the Columbia River Basin, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

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

Ryan, B. A., M. Carper, D. M. Marsh, D. Elliott, T. Murray, L. Applegate, C. McKibben, and S. Mosterd. 2007. Alternative barging strategies to improve survival of transported juvenile salmonids, 2006. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District.

Schreck C. B., M. D. Karnowski, B. J. Clemens. 2005. Evaluation of post release losses and barging strategies that minimize post release mortality. Report of the Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon to the U.S. Army Corps of Engineers, Walla Walla District.

Schreck C. B., Stahla, T. P., Davis, L. E., Roby, D. D. and Clemensa, B. J. 2006. Mortality estimates of juvenile spring–summer Chinook salmon in the lower Columbia River and estuary, 1992–1998: evidence for delayed mortality? Transactions of the American Fisheries Society 135(2):457-475.

Sebring, S. H., R. D. Ledgerwood, B. P. Sandford, A. F. Evans, and G. M. Matthews. 2009. Detection of Passive Integrated Transponder (PIT) Tags on Piscivorous Bird Colonies in the Columbia River Basin, 2007. Report to U.S. Army Corps of Engineers, Walla Walla District. Delivery Order 2RL4SPTP00. 31 pages (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA. 98112 2097.)

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

Sebring, S. H., M. C. Carper, R. D. Ledgerwood, B. P. Sandford, G. M. Matthews, and A. F. Evans. 2013. Relative vulnerability of PIT-tagged subyearling fall Chinook salmon to predation by Caspian terns and double-crested cormorants in the Columbia River estuary. Transactions of the American Fisheries Society 142:1321-1334.

Smith, S. G., D. M. Marsh, R. L. Emmett, W. D. Muir, and R. W. Zabel. 2013. Study to Determine Seasonal Effects of Transporting Fish from the Snake River to Optimize a Transportation Strategy. Report to U.S. Army Corps of Engineers, Walla Walla District. Delivery Order W68SBV10698480. 74 pages + appendices (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA. 98112 2097.)

Solazzi, M. F., T. E. Nickelson, and S. L. Johnson. 1991. Survival, contribution, and return of hatchery coho Salmon (*Oncorhynchus kisutch*) released into freshwater, estuarine, and marine environments. Canadian Journal of Fisheries and Aquatic Sciences 48:248-253.

Spromberg, J. A., and L. L. Johnson. 2008. Potential effects of freshwater and estuarine contaminant exposure on Lower Columbia River Chinook Salmon (*Oncorhynchus tshawytscha*) populations. Population-level Ecotoxicological Risk Assessment.

Ward, D. L., J. H. Petersen, and J. J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River and Lower Snake River. Transactions of the American Fisheries Society 124:321-334.

Williams, J. G., and G. M. Matthews. 1995. A Review of Flow and Survival Relationships for Spring and Summer Chinook Salmon, *Oncorhynchus-tshawytscha*, from the Snake-River Basin. Fishery Bulletin 93(4):732-740.

Williams, J. G., S. G. Smith, R. W. Zabel, W. D. Muir, M. D. Scheuerell, B. P. Sandford, D. M. Marsh, R. McNatt, and S. Achord. 2005. Effects of the federal Columbia River Power system on salmon populations. NOAA Technical Memorandum NMFS-NWFSC-63.

Wongtavatchai, J., P. A. Conrad, and R. P. Hedrick. 1995. Effect of the microsporidian *Enterocytozoon salmonis* on the immune response of Chinook salmon. Veterinary Immunology and Immunopathology 48:367-374.

Appendix A: Juvenile Release Data

Appendix Table A1. Number of juvenile steelhead released and the number of PIT tags detected on the East Sand Island Caspian tern and double-crested cormorant colonies from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225).

Steelhead released in 2006

	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		PIT tags detected					PIT tags detected			
	Juveniles	Tern		Double-crested cormorant		Juveniles	Tern		Double-crested cormorant	
Release days	released	Det.	Exp.	Det.	Exp.	released	Det.	Exp.	Det.	Exp.
Wild steelhead										
26 and 27 Apr	456	2	3.1	0	0.0	527	45	70.3	14	26.9
2 and 3 May	439	0	0.0	2	3.8	807	38	59.4	59	113.5
9 and 11 May	553	1	1.6	2	3.8	912	74	115.6	40	76.9
16 and 17 May	290	7	10.9	0	0.0	609	32	50.0	15	28.8
25 and 26 May	1,227	10	15.6	2	3.8	1,978	178	278.1	77	148.1
1 and 2 Jun	479	10	15.6	0	0.0	775	125	195.3	2	3.8
Total	3,444	30	46.9	6	11.5	5,608	492	768.8	207	398.1
Hatchery steelhead										
26 and 27 Apr	6,696	106	165.6	2	3.8	5,657	769	1201.6	165	317.3
2 and 3 May	3,240	14	21.9	19	36.5	4,915	275	429.7	259	498.1
9 and 11 May	3,893	24	37.5	5	9.6	5,362	599	935.9	257	494.2
16 and 17 May	4,295	120	187.5	10	19.2	6,500	679	1060.9	134	257.7
25 and 26 May	5,502	110	171.9	13	25.0	9,701	1,522	2378.1	339	651.9
1 and 2 Jun	2,091	98	153.1	2	3.8	4,064	942	1471.9	23	44.2
Total	25,717	472	737.5	51	98.1	36,199	4,786	7478.1	1,177	2263.5
Hatchery and wild steelhead combined										
26 and 27 Apr	7,152	108	168.8	2	3.8	6,184	814	1271.9	179	344.2
2 and 3 May	3,679	14	21.9	21	40.4	5,722	313	489.1	318	611.5
9 and 11 May	4,446	25	39.1	7	13.5	6,274	673	1051.6	297	571.2
16 and 17 May	4,585	127	198.4	10	19.2	7,109	711	1110.9	149	286.5
25 and 26 May	6,729	120	187.5	15	28.8	11,679	1,700	2656.3	416	800.0
1 and 2 Jun	2,570	108	168.8	2	3.8	4,839	1,067	1667.2	25	48.1
Total	29,161	502	784.4	57	109.6	41,807	5,278	8246.9	1,384	2661.5

Appendix Table A1. Continued.

	Steelhead released in 2007									
	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		PIT tags detected					PIT tags detected			
	Juveniles released	Tern		Double-crested cormorant		Juveniles released	Tern		Double-crested cormorant	
Release days		Det.	Exp.	Det.	Exp.		Det.	Exp.	Det.	Exp.
Wild steelhead										
25 and 26 Apr										
2 and 3 May	243	11	12.4	0	0.0	325	44	49.4	19	32.8
8 and 9 May	859	5	5.6	1	1.7	1,235	87	97.8	11	19.0
16 and 17 May	566	1	1.1	0	0.0	1,321	34	38.2	32	55.2
23 and 23 May	594	1	1.1	0	0.0	1,363	112	125.8	14	24.1
29 and 31 May	291	7	7.9	0	0.0	246	44	49.4	1	1.7
Total	2,553	25	28.1	1	1.7	4,490	321	360.7	77	132.8
Hatchery steelhead										
25 and 26 Apr										
2 and 3 May	3,578	260	292.1	12	20.7	4,391	923	1037.1	201	346.6
8 and 9 May	4,010	33	37.1	5	8.6	4,530	485	544.9	82	141.4
16 and 17 May	3,787	0	0.0	6	10.3	5,138	320	359.6	887	150.0
23 and 23 May	5,929	38	42.7	4	6.9	9,562	1,292	1451.7	105	181.0
29 and 31 May	2,902	42	47.2	0	0.0	3,069	637	715.7	8	13.8
Total	20,206	373	419.1	27	46.6	26,690	3,657	4109.0	483	832.8
Hatchery and wild steelhead combined										
25 and 26 Apr										
2 and 3 May	3,821	271	304.5	12	20.7	4,716	967	1086.5	220	379.3
8 and 9 May	4,869	38	42.7	6	10.3	5,765	572	642.7	93	160.3
16 and 17 May	4,353	1	1.1	6	10.3	6,459	354	397.8	119	205.2
23 and 23 May	6,523	39	43.8	4	6.9	10,925	1,404	1577.5	119	205.2
29 and 31 May	3,193	49	55.1	0	0.0	3,315	681	765.2	9	15.5
Total	22,759	398	447.2	28	48.3	31,180	3,978	4469.7	560	965.5

Appendix Table A1. Continued.

	Steelhead released in 2008									
	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		PIT tags detected					PIT tags detected			
	Juveniles	Tern		Double-crested cormorant		Juveniles	Tern		Double-crested cormorant	
Release days	released	Det.	Exp.	Det.	Exp.	released	Det.	Exp.	Det.	Exp.
Wild steelhead										
23 and 24 Apr	921	63	68.5	0	0.0	1,365	214	232.6	6	8.7
30 Apr & 1 May	869	9	9.8	0	0.0	1,236	152	165.2	12	17.4
6 and 8 May	869	4	4.3	3	4.3	928	26	28.3	29	42.0
13 and 15 May	738	4	4.3	1	1.4	846	52	56.5	23	44.4
20 and 22 May	767	1	1.1	0	0.0	899	19	20.7	6	8.7
27 and 28 May	1,537	36	39.1	1	1.4	2,339	167	181.5	35	50.7
Total	5,701	117	127.2	5	7.2	7,613	630	684.8	111	160.9
Hatchery steelhead										
23 and 24 Apr	4,549	539	585.9	14	20.3	6,212	1,238	1345.7	34	49.3
30 Apr & 1 May	8,075	333	362.0	14	20.3	9,554	1,852	2013.0	74	107.2
6 and 8 May	3,753	29	31.5	23	33.3	3,549	293	318.5	135	195.7
13 and 15 May	2,459	11	12.0	5	7.2	2,563	191	207.6	62	89.9
20 and 22 May	2,059	12	13.0	2	2.9	4,031	231	251.1	22	31.9
27 and 28 May	4,522	271	294.6	3	4.3	6,948	1,077	1170.7	79	114.5
Total	25,417	1,195	1298.9	61	88.4	32,857	4,882	5306.5	406	588.4
Hatchery and wild steelhead combined										
23 and 24 Apr	5,470	602	654.3	14	20.3	7,577	1,452	1578.3	40	58.0
30 Apr & 1 May	8,944	342	371.7	14	20.3	10,790	2,004	2178.3	86	124.6
6 and 8 May	4,622	33	35.9	26	37.7	4,477	319	346.7	164	237.7
13 and 15 May	3,197	15	16.3	6	8.7	3,409	243	264.1	85	123.2
20 and 22 May	2,826	13	14.1	2	2.9	4,930	250	271.7	28	40.6
27 and 28 May	6,059	307	333.7	4	5.8	9,287	1,244	1352.2	114	165.2
Total	31,118	1,312	1426.1	66	95.7	40,470	5,512	5991.3	517	749.3

Appendix Table A2. Number of yearling Chinook salmon released and number of PIT tags detected by year on East Sand Island Caspian tern and double-crested cormorant colonies from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225).

Yearling Chinook released in 2006

	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		PIT tags detected					PIT tags detected			
	Juveniles	Tern		Double-crested cormorant		Juveniles	Tern		Double-crested cormorant	
Release days	released	Det.	Exp.	Det.	Exp.	released	Det.	Exp.	Det.	Exp.
Wild Chinook salmon										
26 and 27 Apr	902	2	3.1	0	0.0	953	19	29.7	20	38.5
2 and 3 May	747	0	0.0	0	0.0	1,331	14	21.9	48	92.3
9 and 11 May	262	0	0.0	0	0.0	495	6	9.4	10	19.2
16 and 17 May	184	0	0.0	0	0.0	288	0	0.0	9	17.3
25 and 26 May	329	0	0.0	2	3.8	561	8	12.5	10	19.2
1 and 2 Jun	32	0	0.0	0	0.0	103	1	1.6	0	0.0
Total	2,456	2	3.1	2	3.8	3,731	48	75.0	97	186.5
Hatchery Chinook salmon										
26 and 27 Apr	2,852	23	35.9	8	15.4	2,192	70	109.4	33	63.5
2 and 3 May	3,567	7	10.9	7	13.5	5,929	96	150.0	154	296.2
9 and 11 May	3,309	3	4.7	1	1.9	5,569	105	164.1	132	253.8
16 and 17 May	3,309	19	29.7	4	7.7	5,456	78	121.9	120	230.8
25 and 26 May	703	1	1.6	0	0.0	1,448	17	26.6	24	46.2
1 and 2 Jun	15	0	0.0	0	0.0	46	1	1.6	0	0.0
Total	13,755	53	82.8	20	38.5	20,640	367	573.4	463	890.4
Hatchery and wild Chinook salmon combined										
26 and 27 Apr	3,754	25	39.1	8	15.4	3,145	89	139.1	53	101.9
2 and 3 May	4,314	7	10.9	7	13.5	7,260	110	171.9	202	388.5
9 and 11 May	3,571	3	4.7	1	1.9	6,064	111	173.4	142	273.1
16 and 17 May	3,493	19	29.7	4	7.7	5,744	78	121.9	129	248.1
25 and 26 May	1,032	1	1.6	2	3.8	2,009	25	39.1	34	65.4
1 and 2 Jun	47	0	0.0	0	0.0	149	2	3.1	0	0.0
Total	16,211	55	85.9	22	42.3	24,371	415	648.4	560	1076.9

Appendix Table A2. Continued.

	Yearling Chinook released in 2007									
	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		PIT tags detected					PIT tags detected			
	Juveniles	Tern		Double-crested cormorant		Juveniles	Tern		Double-crested cormorant	
Release days	released	Det.	Exp.	Det.	Exp.	released	Det.	Exp.	Det.	Exp.
Wild Chinook salmon										
25 and 26 Apr										
2 and 3 May	245	0	0.0	0	0.0	499	11	12.4	2	3.4
8 and 9 May	401	1	1.1	2	3.4	648	4	4.5	3	5.2
16 and 17 May	737	0	0.0	0	0.0	988	4	4.5	11	19.0
23 and 23 May	412	1	1.1	4	6.9	766	10	11.2	5	8.6
29 and 31 May	96	0	0.0	0	0.0	90	0	0.0	0	0.0
Total	1,891	2	2.2	6	10.3	2,991	29	32.6	32	36.2
Hatchery Chinook salmon										
25 and 26 Apr										
2 and 3 May	2,215	28	31.5	10	17.2	3,793	66	74.2	37	63.8
8 and 9 May	2,981	19	21.3	7	12.1	4,360	63	70.8	24	41.4
16 and 17 May	3,187	4	4.5	2	3.4	4,264	61	68.5	41	70.7
23 and 23 May	982	1	1.1	5	8.6	1,838	17	19.1	30	51.7
29 and 31 May	129	0	0.0	0	0.0	134	4	4.5	0	0.0
Total	9,494	52	58.4	24	41.4	14,389	211	237.1	132	227.6
Hatchery and wild Chinook salmon combined										
25 and 26 Apr										
2 and 3 May	2,460	28	31.5	10	17.2	4,292	77	86.5	39	67.2
8 and 9 May	3,382	20	22.5	9	15.5	5,008	67	75.3	27	46.6
16 and 17 May	3,924	4	4.5	2	3.4	5,252	65	73.0	52	89.7
23 and 23 May	1,394	2	2.2	9	15.5	2,604	27	30.3	35	60.3
29 and 31 May	225	0	0.0	0	0.0	224	4	4.5	0	0.0
Total	11,385	54	60.7	30	51.7	17,380	240	269.7	153	263.8

Appendix Table A2. Continued.

	Yearling Chinook released in 2008									
	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		PIT tags detected					PIT tags detected			
	Juveniles	Tern		Double-crested cormorant		Juveniles	Tern		Double-crested cormorant	
Release days	released	Det.	Exp.	Det.	Exp.	released	Det.	Exp.	Det.	Exp.
Wild Chinook salmon										
23 and 24 Apr	388	9	9.8	3	4.3	474	15	16.3	2	2.9
30 Apr & 1 May	576	3	3.3	3	4.3	954	48	52.2	14	20.3
6 and 8 May	844	1	1.1	1	1.4	1,234	25	27.2	34	49.3
13 and 15 May	500	0	0.0	0	0.0	692	8	8.7	9	13.0
20 and 22 May	405	0	0.0	0	0.0	682	3	3.3	2	2.9
27 and 28 May	323	1	1.1	0	0.0	484	4	4.3	1	1.4
Total	3,036	14	15.2	7	10.1	4,520	103	112.0	62	89.9
Hatchery Chinook salmon										
23 and 24 Apr	1,560	47	51.1	31	44.9	2,926	149	162.0	43	62.3
30 Apr & 1 May	1,337	22	23.9	7	10.1	2,395	122	132.6	40	58.0
6 and 8 May	3,118	7	7.6	6	8.7	3,000	168	182.6	49	71.0
13 and 15 May	4,648	13	14.1	7	10.1	6,014	182	197.8	59	85.5
20 and 22 May	4,088	3	3.3	1	1.4	6,383	68	73.9	20	29.0
27 and 28 May	1,767	6	6.5	0	0.0	2,996	29	31.5	20	29.0
Total	16,518	98	106.5	52	75.4	23,714	718	780.4	231	334.8
Hatchery and wild Chinook salmon combined										
23 and 24 Apr	1,948	56	60.9	34	49.3	3,400	164	178.3	45	65.2
30 Apr & 1 May	1,913	25	27.2	10	14.5	3,349	170	184.8	54	78.3
6 and 8 May	3,962	8	8.7	7	10.1	4,234	193	209.8	83	120.3
13 and 15 May	5,148	13	14.1	7	10.1	6,706	190	206.5	68	98.6
20 and 22 May	4,493	3	3.3	1	1.4	7,065	71	77.2	22	31.9
27 and 28 May	2,090	7	7.6	0	0.0	3,480	33	35.9	21	30.4
Total	19,554	112	121.7	59	85.5	28,234	821	892.4	293	424.6

Appendix B: Adult Return Data

Appendix Table B1. Number of juvenile steelhead released and number of returning adults by age class from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225).

	Steelhead released in 2006							
	Astoria (rkm 10)				Skamania Landing (rkm 225)			
	Juveniles	Adult age class			Juveniles	Adult age class		
Release days	released	1-ocean	2-ocean	3-ocean	released	1-ocean	2-ocean	3-ocean
Wild steelhead								
26 and 27 Apr	456	8	7	-	527	7	7	-
2 and 3 May	439	1	-	-	807	2	3	-
9 and 11 May	553	4	5	-	912	4	5	-
16 and 17 May	290	2	2	-	609	3	2	-
25 and 26 May	1,227	4	2	-	1,978	7	8	-
1 and 2 Jun	479	5	3	-	775	3	11	-
Total	3,444	24	19	-	5,608	26	36	-
Hatchery steelhead								
26 and 27 Apr	6,696	44	126	-	5,657	25	73	-
2 and 3 May	3,240	30	11	-	4,915	48	17	-
9 and 11 May	3,893	48	42	-	5,362	58	34	-
16 and 17 May	4,295	46	28	1	6,500	67	32	-
25 and 26 May	5,502	31	30	-	9,701	53	39	-
1 and 2 Jun	2,091	17	13	-	4,064	26	18	-
Total	25,717	216	250	1	36,199	277	213	-
Hatchery and wild steelhead combined								
26 and 27 Apr	7,152	52	133	-	6,184	32	80	-
2 and 3 May	3,679	31	11	-	5,722	50	20	-
9 and 11 May	4,446	52	47	-	6,274	62	39	-
16 and 17 May	4,585	48	30	1	7,109	70	34	-
25 and 26 May	6,729	35	32	-	11,679	60	47	-
1 and 2 Jun	2,570	22	16	-	4,839	29	29	-
Total	29,161	240	269	1	41,807	303	249	-

Appendix Table B1. Continued.

	Steelhead released in 2007							
	Astoria (rkm 10)				Skamania Landing (rkm 225)			
	Juveniles	Adult age class			Juveniles	Adult age class		
Release days	released	1-ocean	2-ocean	3-ocean	released	1-ocean	2-ocean	3-ocean
Wild steelhead								
25 and 26 Apr								
2 and 3 May	243	3	1	-	325	2	2	-
8 and 9 May	859	8	15	-	1235	18	19	-
16 and 17 May	566	6	15	-	1321	25	20	-
23 and 23 May	594	13	13	-	1363	14	23	-
29 and 31 May	291	3	5	-	246	4	3	1
Total	2,553	33	49	-	4,490	63	67	1
Hatchery steelhead								
25 and 26 Apr								
2 and 3 May	3578	15	20	-	4391	10	20	-
8 and 9 May	4010	29	30	-	4530	36	43	-
16 and 17 May	3787	37	27	-	5138	56	49	-
23 and 23 May	5929	67	33	-	9562	125	76	-
29 and 31 May	2902	32	24	-	3069	44	29	-
Total	20,206	180	134	-	26,690	271	217	-
Hatchery and wild steelhead combined								
25 and 26 Apr								
2 and 3 May	3,821	18	21	-	4,716	12	22	-
8 and 9 May	4,869	37	45	-	5,765	54	62	-
16 and 17 May	4,353	43	42	-	6,459	81	69	-
23 and 23 May	6,523	80	46	-	10,925	139	99	-
29 and 31 May	3,193	35	29	-	3,315	48	32	1
Total	22,759	213	183	-	31,180	334	284	1

Appendix Table B1. Continued.

	Steelhead released in 2008							
	Astoria (rkm 10)				Skamania Landing (rkm 225)			
	Juveniles	Adult age class			Juveniles	Adult age class		
Release days	released	1-ocean	2-ocean	3-ocean	released	1-ocean	2-ocean	3-ocean
Wild steelhead								
23 and 24 Apr	921	20	17	-	1,365	24	10	-
30 Apr & 1 May	869	29	18	-	1,236	31	17	-
6 and 8 May	869	9	12	-	928	21	18	-
13 and 15 May	738	17	24	-	846	20	25	-
20 and 22 May	767	5	10	-	899	17	20	-
27 and 28 May	1,537	10	20	-	2,339	21	24	-
Total	5,701	90	101	-	7,613	134	114	-
Hatchery steelhead								
23 and 24 Apr	4,549	66	20	-	6,212	43	14	-
30 Apr & 1 May	8,075	142	101	-	9,554	59	45	-
6 and 8 May	3,753	76	30	-	3,549	71	23	-
13 and 15 May	2,459	65	13	-	2,563	85	24	-
20 and 22 May	2,059	45	19	-	4,031	96	42	-
27 and 28 May	4,522	87	23	-	6,948	113	46	-
Total	25,417	481	206	-	32,857	467	194	-
Hatchery and wild steelhead combined								
23 and 24 Apr	5,470	86	37	-	7,577	67	24	-
30 Apr & 1 May	8,944	171	119	-	10,790	90	62	-
6 and 8 May	4,622	85	42	-	4,477	92	41	-
13 and 15 May	3,197	82	37	-	3,409	105	49	-
20 and 22 May	2,826	50	29	-	4,930	113	62	-
27 and 28 May	6,059	97	43	-	9,287	134	70	-
Total	31,118	571	307	-	40,470	601	308	-

Appendix Table B2. Number of yearling Chinook salmon released and number of returning adults by age class from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225).

	Chinook salmon released in 2006							
	Astoria (rkm 10)				Skamania Landing (rkm 225)			
	Juveniles	Adult age class			Juveniles	Adult age class		
Release days	released	1-ocean	2-ocean	3-ocean	released	1-ocean	2-ocean	3-ocean
Wild Chinook salmon								
26 and 27 Apr	902	-	-	-	953	-	2	-
2 and 3 May	747	-	1	-	1,331	-	6	2
9 and 11 May	262	-	4	-	495	-	1	-
16 and 17 May	184	-	1	-	288	-	4	-
25 and 26 May	329	-	1	-	561	1	3	2
1 and 2 Jun	32	-	-	-	103	-	-	1
Total	2,456	-	7	-	3,731	1	16	5
Hatchery Chinook salmon								
26 and 27 Apr	2,852	1	-	-	2,192	4	3	-
2 and 3 May	3,567	1	3	1	5,929	10	22	-
9 and 11 May	3,309	3	13	-	5,569	8	27	2
16 and 17 May	3,309	3	15	-	5,456	5	27	1
25 and 26 May	703	1	3	1	1,448	1	6	-
1 and 2 Jun	15	-	-	-	46	-	-	-
Total	13,755	9	34	2	20,640	28	85	3
Hatchery and wild Chinook salmon combined								
26 and 27 Apr	3,754	1	-	-	3,145	4	5	-
2 and 3 May	4,314	1	4	1	7,260	10	28	2
9 and 11 May	3,571	3	17	-	6,064	8	28	2
16 and 17 May	3,493	3	16	-	5,744	5	31	1
25 and 26 May	1,032	1	4	1	2,009	2	9	2
1 and 2 Jun	47	-	-	-	149	-	-	1
Total	16,211	9	41	2	24,371	29	101	8

Appendix Table B2. Continued.

	Chinook salmon released in 2007							
	Astoria (rkm 10)				Skamania Landing (rkm 225)			
	Juveniles	Adult age class			Juveniles	Adult age class		
Release days	released	1-ocean	2-ocean	3-ocean	released	1-ocean	2-ocean	3-ocean
Wild Chinook salmon								
25 and 26 Apr								
2 and 3 May	245	-	-	-	499	1	2	-
8 and 9 May	401	-	8	1	648	2	7	1
16 and 17 May	737	-	10	-	988	1	4	3
23 and 23 May	412	-	3	1	766	-	3	-
29 and 31 May	96	-	1	-	90	-	-	-
Total	1,891	-	22	2	2,991	4	16	4
Hatchery Chinook salmon								
25 and 26 Apr								
2 and 3 May	2,215	7	5	-	3,793	5	16	1
8 and 9 May	2,981	6	20	-	4,360	17	48	1
16 and 17 May	3,187	6	16	-	4,264	2	21	-
23 and 23 May	982	1	2	-	1,838	1	6	-
29 and 31 May	129	-	-	1	134	-	1	-
Total	9,494	20	43	1	14,389	25	92	2
Hatchery and wild Chinook salmon combined								
25 and 26 Apr								
2 and 3 May	2,460	7	5	-	4,292	6	18	1
8 and 9 May	3,382	6	28	1	5,008	19	55	2
16 and 17 May	3,924	6	26	-	5,252	3	25	3
23 and 23 May	1,394	1	5	1	2,604	1	9	-
29 and 31 May	225	-	1	1	224	-	1	-
Total	11,385	20	65	3	17,380	29	108	6

Appendix Table B2. Continued.

	Chinook salmon released in 2008							
	Astoria (rkm 10)				Skamania Landing (rkm 225)			
	Juveniles	Adult age class			Juveniles	Adult age class		
Release days	released	1-ocean	2-ocean	3-ocean	released	1-ocean	2-ocean	3-ocean
Wild Chinook salmon								
23 and 24 Apr	388	4	3	-	474	3	8	2
30 Apr & 1 May	576	2	8	1	954	4	17	-
6 and 8 May	844	2	10	3	1,234	-	11	4
13 and 15 May	500	-	6	2	692	1	10	3
20 and 22 May	405	1	12	2	682	1	13	5
27 and 28 May	323	-	-	-	484	-	5	4
Total	3,036	9	39	8	4,520	9	64	18
Hatchery Chinook salmon								
23 and 24 Apr	1,560	4	3	-	2,926	14	14	2
30 Apr & 1 May	1,337	7	13	-	2,395	9	19	1
6 and 8 May	3,118	13	30	-	3,000	15	26	2
13 and 15 May	4,648	21	63	2	6,014	35	98	10
20 and 22 May	4,088	15	53	9	6,383	8	64	6
27 and 28 May	1,767	4	10	1	2,996	2	17	2
Total	16,518	64	172	12	23,714	83	238	23
Hatchery and wild Chinook salmon combined								
23 and 24 Apr	1,948	8	6	-	3,400	17	22	4
30 Apr & 1 May	1,913	9	21	1	3,349	13	36	1
6 and 8 May	3,962	15	40	3	4,234	15	37	6
13 and 15 May	5,148	21	69	4	6,706	36	108	13
20 and 22 May	4,493	16	65	11	7,065	9	77	11
27 and 28 May	2,090	4	10	1	3,480	2	22	6
Total	19,554	73	211	20	28,234	92	302	41

Appendix Table B3. Number of steelhead adults detected at Bonneville Dam (BON) and the number of those subsequently detected at either McNary (MCN) or Lower Granite (LGR) Dams by age class from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225). The only 3-ocean adults were hatchery steelhead from releases in 2006.

Steelhead released in 2006

	Astoria (rkm 10)			Skamania Landing (rkm 225)		
	BON	Subsequent detections		BON	Subsequent detections	
Release days	detections	MCN	LGR	detections	MCN	LGR
Wild steelhead 1-ocean adults						
26 and 27 Apr	16	9	8	11	9	7
2 and 3 May	4	3	1	2	2	2
9 and 11 May	9	5	4	9	6	4
16 and 17 May	2	2	2	5	3	3
25 and 26 May	13	7	4	20	12	7
1 and 2 Jun	8	6	5	3	3	3
Wild steelhead 2-ocean adults						
26 and 27 Apr	11	8	7	11	8	7
2 and 3 May	3	3	0	6	4	3
9 and 11 May	7	5	5	8	5	5
16 and 17 May	4	2	2	2	2	2
25 and 26 May	9	4	2	10	8	8
1 and 2 Jun	5	3	3	13	11	11
Hatchery steelhead 1-ocean adults						
26 and 27 Apr	90	58	44	45	30	25
2 and 3 May	58	40	29	77	58	47
9 and 11 May	90	66	46	98	75	58
16 and 17 May	91	61	44	102	79	64
25 and 26 May	76	45	31	99	72	53
1 and 2 Jun	45	26	17	45	34	26
Hatchery steelhead 2-ocean adults						
26 and 27 Apr	245	144	122	112	76	73
2 and 3 May	21	12	11	25	20	16
9 and 11 May	75	49	42	57	38	34
16 and 17 May	41	32	28	54	35	32
25 and 26 May	78	39	29	72	52	39
1 and 2 Jun	34	14	13	29	23	17
Hatchery steelhead 3-ocean adults						
26 and 27 Apr	0	0	0	1	1	0
2 and 3 May	0	0	0	0	0	0
9 and 11 May	1	0	0	1	1	0
16 and 17 May	1	1	1	0	0	0
25 and 26 May	0	0	0	0	0	0
1 and 2 Jun	0	0	0	0	0	0

Appendix Table B3. Continued.

	Steelhead released in 2007					
	Astoria (rkm 10)			Skamania Landing (rkm 225)		
	BON	Subsequent detections		BON	Subsequent detections	
Release days	detections	MCN	LGR	detections	MCN	LGR
	Wild steelhead 1-ocean adults					
25 and 26 Apr						
2 and 3 May	5	4	3	2	2	2
8 and 9 May	21	13	8	26	21	18
16 and 17 May	20	9	6	37	27	25
23 and 23 May	18	14	13	30	18	14
29 and 31 May	4	4	3	5	3	4
	Wild steelhead 2-ocean adults					
25 and 26 Apr						
2 and 3 May	3	2	1	3	2	2
8 and 9 May	26	16	15	37	24	19
16 and 17 May	21	15	15	30	23	20
23 and 23 May	19	15	13	43	26	23
29 and 31 May	10	6	5	5	3	3
	Hatchery steelhead 1-ocean adults					
25 and 26 Apr						
2 and 3 May	24	17	15	13	10	10
8 and 9 May	56	31	29	46	34	32
16 and 17 May	72	45	35	100	65	56
23 and 23 May	117	81	67	183	137	123
29 and 31 May	54	34	31	60	44	44
	Hatchery steelhead 2-ocean adults					
25 and 26 Apr						
2 and 3 May	38	25	20	24	20	20
8 and 9 May	52	37	29	64	45	42
16 and 17 May	56	31	27	83	51	48
23 and 23 May	77	43	32	123	89	76
29 and 31 May	43	28	24	42	29	28

Appendix Table B3. Continued.

	Steelhead released in 2008					
	Astoria (rkm 10)			Skamania Landing (rkm 225)		
	BON	Subsequent detections		BON	Subsequent detections	
Release days	detections	MCN	LGR	detections	MCN	LGR
	Wild steelhead 1-ocean adults					
23 and 24 Apr	48	26	20	39	32	23
30 Apr & 1 May	58	35	28	45	35	30
6 and 8 May	28	15	9	31	23	20
13 and 15 May	32	23	17	27	22	19
20 and 22 May	19	9	5	27	22	17
27 and 28 May	23	13	10	34	24	21
	Wild steelhead 2-ocean adults					
23 and 24 Apr	20	16	16	17	10	10
30 Apr & 1 May	32	19	18	33	20	17
6 and 8 May	27	15	12	33	21	18
13 and 15 May	38	26	24	37	29	25
20 and 22 May	21	14	10	32	25	20
27 and 28 May	33	21	20	36	28	24
	Hatchery steelhead 1-ocean adults					
23 and 24 Apr	136	84	66	73	49	43
30 Apr & 1 May	270	176	141	105	68	58
6 and 8 May	162	103	75	111	85	70
13 and 15 May	140	91	63	134	102	83
20 and 22 May	89	52	44	156	110	94
27 and 28 May	166	114	85	189	138	112
	Hatchery steelhead 2-ocean adults					
23 and 24 Apr	43	23	19	24	13	13
30 Apr & 1 May	172	102	99	66	45	44
6 and 8 May	62	36	29	33	23	23
13 and 15 May	28	16	13	36	25	24
20 and 22 May	45	22	19	63	43	42
27 and 28 May	46	24	23	67	50	45

Appendix Table B4. Number of Chinook salmon adults detected at Bonneville Dam (BON) and number of those subsequently detected at either McNary (MCN) or Lower Granite (LGR) Dam by age class from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225).

	Chinook salmon released in 2006					
	Astoria (rkm 10)			Skamania Landing (rkm 225)		
	BON	Subsequent detections		Bonneville	Subsequent detections	
Release days	detections	MCN	LGR	detections	MCN	LGR
	Wild Chinook salmon 1-ocean adults					
26 and 27 Apr	0	0	0	0	0	0
2 and 3 May	0	0	0	0	0	0
9 and 11 May	1	0	0	0	0	0
16 and 17 May	0	0	0	0	0	0
25 and 26 May	0	0	0	1	1	1
1 and 2 Jun	1	1	0	0	0	0
	Wild Chinook salmon 2-ocean adults					
26 and 27 Apr	0	0	0	2	2	2
2 and 3 May	2	2	1	9	8	6
9 and 11 May	4	4	4	1	1	1
16 and 17 May	2	1	1	5	4	4
25 and 26 May	1	1	1	11	3	3
1 and 2 Jun	0	0	0	0	0	0
	Wild Chinook salmon 3-ocean adults					
26 and 27 Apr	0	0	0	0	0	0
2 and 3 May	0	0	0	2	2	2
9 and 11 May	0	0	0	0	0	0
16 and 17 May	0	0	0	0	0	0
25 and 26 May	0	0	0	3	2	2
1 and 2 Jun	0	0	0	1	1	1
	Hatchery Chinook salmon 1-ocean adults					
26 and 27 Apr	1	1	1	7	6	4
2 and 3 May	8	3	1	13	12	10
9 and 11 May	4	4	3	10	8	8
16 and 17 May	4	3	3	9	6	5
25 and 26 May	2	2	1	2	1	1
1 and 2 Jun	0	0	0	0	0	0
	Hatchery Chinook salmon 2-ocean adults					
26 and 27 Apr	1	0	0	5	3	3
2 and 3 May	7	4	3	27	24	22
9 and 11 May	26	15	13	34	28	27
16 and 17 May	29	19	15	35	29	27
25 and 26 May	5	3	3	8	7	6
1 and 2 Jun	0	0	0	0	0	0
	Hatchery Chinook salmon 3-ocean adults					
26 and 27 Apr	0	0	0	0	0	0
2 and 3 May	1	1	1	0	0	0
9 and 11 May	1	0	0	2	2	2
16 and 17 May	1	0	0	3	2	1
25 and 26 May	2	1	1	3	2	2
1 and 2 Jun	0	0	0	1	1	1

Appendix Table B4. Continued.

	Chinook salmon released in 2007					
	Astoria (rkm 10)			Skamania Landing (rkm 225)		
	BON	Subsequent detections		BON	Subsequent detections	
Release days	detections	MCN	LGR	detections	MCN	LGR
	Wild Chinook salmon 1-ocean adults					
25 and 26 Apr						
2 and 3 May	0	0	0	1	1	1
8 and 9 May	0	0	0	2	2	2
16 and 17 May	0	0	0	1	1	1
23 and 23 May	0	0	0	0	0	0
29 and 31 May	0	0	0	0	0	0
	Wild Chinook salmon 2-ocean adults					
25 and 26 Apr						
2 and 3 May	0	0	0	2	2	2
8 and 9 May	9	7	7	8	7	7
16 and 17 May	10	9	9	4	4	4
23 and 23 May	4	3	3	4	4	3
29 and 31 May	1	1	1	0	0	0
	Wild Chinook salmon 3-ocean adults					
25 and 26 Apr						
2 and 3 May	0	0	0	0	0	0
8 and 9 May	1	1	1	1	1	1
16 and 17 May	0	0	0	3	3	3
23 and 23 May	1	1	1	0	0	0
29 and 31 May	0	0	0	0	0	0
	Hatchery Chinook salmon 1-ocean adults					
25 and 26 Apr						
2 and 3 May	7	7	7	5	5	5
8 and 9 May	7	6	6	19	17	17
16 and 17 May	7	7	6	2	2	2
23 and 23 May	2	4	4	3	1	1
29 and 31 May	1	0	0	0	0	0
	Hatchery Chinook salmon 2-ocean adults					
25 and 26 Apr						
2 and 3 May	6	5	5	17	15	13
8 and 9 May	29	21	20	60	50	46
16 and 17 May	23	17	16	31	23	20
23 and 23 May	2	2	2	9	6	6
29 and 31 May	0	0	0	1	1	1
	Hatchery Chinook salmon 3-ocean adults					
25 and 26 Apr						
2 and 3 May	0	0	0	2	1	1
8 and 9 May	0	0	0	2	1	1
16 and 17 May	0	0	0	0	0	0
23 and 23 May	0	0	0	0	0	0
29 and 31 May	1	1	1	0	0	0

Appendix Table B4. Continued.

	Chinook salmon released in 2008					
	Astoria (rkm 10)			Skamania Landing (rkm 225)		
	BON	Subsequent detections		BON	Subsequent detections	
Release days	detections	MCN	LGR	detections	MCN	LGR
	Wild Chinook salmon 1-ocean adults					
23 and 24 Apr	6	6	4	4	2	2
30 Apr & 1 May	3	3	2	6	5	4
6 and 8 May	4	2	2	3	0	0
13 and 15 May	1	0	0	1	1	1
20 and 22 May	1	1	1	1	1	1
27 and 28 May	0	0	0	0	0	0
	Wild Chinook salmon 2-ocean adults					
23 and 24 Apr	6	3	3	17	14	8
30 Apr & 1 May	13	8	8	26	21	17
6 and 8 May	11	10	10	14	12	11
13 and 15 May	10	8	6	15	10	10
20 and 22 May	16	13	12	17	14	13
27 and 28 May	1	0	0	5	5	5
	Wild Chinook salmon 3-ocean adults					
23 and 24 Apr	0	0	0	1	1	1
30 Apr & 1 May	3	3	1	2	1	0
6 and 8 May	7	5	3	5	4	3
13 and 15 May	3	2	2	5	4	3
20 and 22 May	2	2	2	6	5	5
27 and 28 May	0	0	0	8	6	4
	Hatchery Chinook salmon 1-ocean adults					
23 and 24 Apr	8	7	4	22	19	14
30 Apr & 1 May	9	8	7	9	9	8
6 and 8 May	22	16	13	18	16	15
13 and 15 May	28	23	20	46	35	34
20 and 22 May	19	15	13	11	9	8
27 and 28 May	6	5	4	8	4	2
	Hatchery Chinook salmon 2-ocean adults					
23 and 24 Apr	13	6	3	33	19	13
30 Apr & 1 May	18	13	12	23	18	16
6 and 8 May	34	30	29	35	30	24
13 and 15 May	81	64	61	128	104	98
20 and 22 May	83	60	53	88	66	63
27 and 28 May	19	12	10	25	21	17
	Hatchery Chinook salmon 3-ocean adults					
23 and 24 Apr	0	0	0	4	3	1
30 Apr & 1 May	3	1	0	3	1	1
6 and 8 May	1	0	0	7	4	2
13 and 15 May	4	2	2	12	10	10
20 and 22 May	14	10	9	15	7	6
27 and 28 May	1	1	1	4	3	2

Appendix Table B5. Number of steelhead adults detected at Bonneville Dam (BON) and the number of those subsequently detected at either the John Day or Deschutes Rivers (JD/D Rivers), other tributaries (Tribs), or upper Columbia River dams (above the confluence of the Snake River; UCR dams) by age class from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225). Also shown is the number of strays that eventually crossed Lower Granite Dam (LGR).

Steelhead released in 2006

	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		Stray sites					Stray sites			
Release days	BON	JD/D Rivers	Tribs	UCR dams	LGR	BON	JD/D Rivers	Tribs	UCR dams	LGR
Wild steelhead 1-ocean adults										
26 and 27 Apr	16	2	-	-	-	11	-	-	-	-
2 and 3 May	4	1	-	-	-	2	-	-	-	-
9 and 11 May	9	1	-	-	1	9	-	-	-	-
16 and 17 May	2	-	-	-	-	5	1	-	-	-
25 and 26 May	13	2	-	-	-	20	3	-	1	-
1 and 2 Jun	8	1	1	-	-	3	-	-	-	-
Wild steelhead 2-ocean adults										
26 and 27 Apr	11	1	-	-	-	11	-	-	-	-
2 and 3 May	3	-	-	-	-	6	-	-	-	-
9 and 11 May	7	-	-	-	-	8	-	-	-	-
16 and 17 May	4	-	-	-	-	2	-	-	-	-
25 and 26 May	9	-	-	-	-	10	-	-	-	-
1 and 2 Jun	5	-	-	-	-	13	1	-	-	-
Hatchery steelhead 1-ocean adults										
26 and 27 Apr	90	15	-	-	4	45	1	-	-	1
2 and 3 May	58	8	-	1	1	77	7	-	4	3
9 and 11 May	90	10	-	1	3	98	10	-	-	3
16 and 17 May	91	6	-	-	2	102	6	1	2	5
25 and 26 May	76	8	-	2	4	99	8	-	3	5
1 and 2 Jun	45	6	1	1	1	45	5	-	1	2
Hatchery steelhead 2-ocean adults										
26 and 27 Apr	245	5	1	-	1	112	1	-	-	1
2 and 3 May	21	1	-	-	1	25	1	-	-	-
9 and 11 May	75	2	-	-	-	57	1	-	-	1
16 and 17 May	41	-	-	1	1	54	1	-	-	-
25 and 26 May	78	3	-	2	1	72	2	-	-	-
1 and 2 Jun	34	2	1	-	-	29	1	-	-	-
Hatchery steelhead 3-ocean adults										
26 and 27 Apr	-	-	-	-	-	1	-	-	-	-
2 and 3 May	-	-	-	-	-	-	-	-	-	-
9 and 11 May	1	-	-	-	-	1	-	-	-	-
16 and 17 May	1	-	-	-	-	-	-	-	-	-
25 and 26 May	-	-	-	-	-	-	-	-	-	-
1 and 2 Jun	-	-	-	-	-	-	-	-	-	-

Appendix Table B5. Continued.

Release days	Astoria (rkm 10) BON	Astoria Stray sites JD/D Rivers	Astoria Stray sites Tribs	Astoria Stray sites UCR dams	Astoria LGR	Skamania Landing (rkm 225) BON	Skamania Stray sites JD/D Rivers	Skamania Stray sites Tribs	Skamania Stray sites UCR dams	Skamania LGR
Steelhead released in 2007										
Wild steelhead 1-ocean adults										
25 and 26 Apr										
2 and 3 May	5	-	-	-	-	2	-	-	-	-
8 and 9 May	21	4	-	-	-	26	1	1	-	-
16 and 17 May	20	3	-	-	-	37	3	-	-	1
23 and 23 May	18	1	-	-	-	30	4	-	-	-
29 and 31 May	4	-	-	-	-	5	-	-	-	-
Wild steelhead 2-ocean adults										
25 and 26 Apr										
2 and 3 May	3	-	-	-	-	3	-	-	-	-
8 and 9 May	26	2	-	-	-	37	2	-	-	-
16 and 17 May	21	2	-	-	-	30	-	-	-	-
23 and 23 May	19	-	-	-	-	43	3	-	-	-
29 and 31 May	10	-	-	-	-	5	-	-	-	-
Hatchery steelhead 1-ocean adults										
25 and 26 Apr										
2 and 3 May	24	1	-	-	1	13	1	-	-	1
8 and 9 May	56	10	-	-	2	46	3	-	-	1
16 and 17 May	72	6	-	1	-	100	9	-	-	1
23 and 23 May	117	6	-	1	2	183	14	-	2	3
29 and 31 May	54	-	-	-	-	60	-	-	-	-
Hatchery steelhead 2-ocean adults										
25 and 26 Apr										
2 and 3 May	38	-	-	-	-	24	-	-	-	-
8 and 9 May	52	2	-	1	1	64	1	-	1	1
16 and 17 May	56	1	-	1	1	83	2	-	1	-
23 and 23 May	77	10	-	2	3	123	5	-	1	1
29 and 31 May	43	4	-	-	1	42	1	-	1	-

Appendix Table B5. Continued.

	Steelhead released in 2008									
	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		Stray sites					Stray sites			
Release days	BON	JD/D Rivers	Tribs	UCR dams	LGR	BON	JD/D Rivers	Tribs	UCR dams	LGR
	Wild steelhead 1-ocean adults									
23 and 24 Apr	48	7	-	-	-	39	6	2	1	1
30 Apr & 1 May	58	5	-	-	-	45	5	-	1	3
6 and 8 May	28	4	-	-	-	31	4	-	1	2
13 and 15 May	32	3	-	1	-	27	3	-	-	1
20 and 22 May	19	3	-	-	-	27	1	-	-	-
27 and 28 May	23	1	-	1	1	34	2	-	2	2
	Wild steelhead 2-ocean adults									
23 and 24 Apr	20	-	-	-	-	17	1	-	-	-
30 Apr & 1 May	32	-	-	-	-	33	-	-	-	-
6 and 8 May	27	2	-	-	1	33	-	-	1	1
13 and 15 May	38	2	-	-	1	37	-	-	1	1
20 and 22 May	21	1	-	1	-	32	-	-	2	2
27 and 28 May	33	3	-	1	2	36	-	-	-	-
	Hatchery steelhead 1-ocean adults									
23 and 24 Apr	136	32	-	-	7	73	12	-	-	3
30 Apr & 1 May	270	31	1	3	10	105	7	-	-	2
6 and 8 May	162	12	1	-	2	111	13	-	2	6
13 and 15 May	140	13	-	-	6	134	7	-	1	2
20 and 22 May	89	8	-	1	-	156	12	-	3	5
27 and 28 May	166	17	1	5	5	189	7	-	9	4
	Hatchery steelhead 2-ocean adults									
23 and 24 Apr	43	6	-	-	1	24	2	-	-	-
30 Apr & 1 May	172	6	-	-	1	66	1	-	-	-
6 and 8 May	62	5	-	1	-	33	-	-	-	-
13 and 15 May	28	3	-	-	-	36	-	-	-	-
20 and 22 May	45	3	-	-	-	63	1	-	-	-
27 and 28 May	46	2	-	1	1	67	1	-	5	2

Appendix Table B6. Number of Chinook salmon adults detected at Bonneville Dam (BON) and the number of those subsequently detected at either the John Day or Deschutes Rivers (JD/D Rivers), other tributaries (Tribs), or upper Columbia River (UCR) dams (above the confluence of the Snake River by age class from 2006-2008 releases at Astoria and Skamania Landing. None of these fish strayed from releases in 2006. From releases in 2007, one fish strayed over a UCR dam, but this fish had not previously been detected at Bonneville Dam.

Wild Chinook salmon released in 2008

	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		Stray sites					Stray sites			
Release days	BON	JD/D Rivers	Tribs	UCR dams	LGR	BON	JD/D Rivers	Tribs	UCR dams	LGR
				1-ocean adults						
23 and 24 Apr	6	-	-	1	-	4	1	-	-	-
30 Apr & 1 May	3	1	-	-	-	6	-	-	-	-
6 and 8 May	4	-	-	-	-	3	-	-	-	-
13 and 15 May	1	-	-	-	-	1	-	-	-	-
20 and 22 May	1	-	-	-	-	1	-	-	-	-
27 and 28 May	-	-	-	-	-	-	-	-	-	-
				2-ocean adults						
23 and 24 Apr	6	-	-	-	-	17	-	-	1	-
30 Apr & 1 May	13	-	-	-	-	26	-	-	-	-
6 and 8 May	11	-	-	-	-	14	-	-	-	-
13 and 15 May	10	-	-	-	-	15	-	-	-	-
20 and 22 May	16	-	-	-	-	17	1	-	-	-
27 and 28 May	1	-	-	-	-	5	-	-	-	-
				3-ocean adults						
23 and 24 Apr	-	-	-	-	-	1	-	-	-	-
30 Apr & 1 May	3	-	-	-	-	2	-	-	-	-
6 and 8 May	7	-	-	-	-	5	-	-	-	-
13 and 15 May	3	-	-	-	-	5	-	-	-	-
20 and 22 May	2	-	-	-	-	6	-	-	-	-
27 and 28 May	-	-	-	-	-	8	-	-	-	-

Appendix Table B6. Continued.

	Astoria (rkm 10)					Skamania Landing (rkm 225)				
		Stray sites					Stray sites			
Release days	BON	JD/D Rivers	Tribs	UCR dams	LGR	BON	JD/D Rivers	Tribs	UCR dams	LGR
Hatchery Chinook salmon released in 2008										
1-ocean adults										
26 and 27 Apr	8	-	-	3	-	22	-	-	2	-
2 and 3 May	9	-	-	-	-	9	-	-	1	-
9 and 11 May	22	1	-	1	-	18	-	-	-	-
16 and 17 May	28	1	-	-	-	46	-	-	1	-
25 and 26 May	19	-	-	1	-	11	1	-	1	-
1 and 2 Jun	6	-	-	1	-	8	-	1	2	-
2-ocean adults										
26 and 27 Apr	13	-	1	-	-	33	-	-	2	-
2 and 3 May	18	-	-	-	-	23	-	-	-	-
9 and 11 May	34	-	-	1	-	35	1	-	-	-
16 and 17 May	81	-	-	1	-	128	-	-	-	-
25 and 26 May	83	1	-	-	-	88	2	-	-	-
1 and 2 Jun	19	-	1	-	-	25	-	-	-	-
3-ocean adults										
26 and 27 Apr	-	-	-	-	-	4	-	-	-	-
2 and 3 May	3	-	1	-	-	3	-	-	-	-
9 and 11 May	1	-	-	-	-	7	-	-	1	-
16 and 17 May	4	-	-	-	-	12	-	-	-	-
25 and 26 May	14	-	-	-	-	15	-	-	-	-
1 and 2 Jun	1	-	1	-	1	4	-	-	-	-

Appendix Table B7. Number of steelhead adults and the median travel times (d) between Bonneville and McNary Dam and between Bonneville and Lower Granite Dam by age class from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225).

	Travel time (d) Bonneville to McNary					Travel time (d) Bonneville to L Granite				
	Astoria (rkm 10)		Skamania Landing (rkm 225)		Astoria vs Skamania	Astoria (rkm 10)		Skamania Landing (rkm 225)		Astoria vs Skamania
	Adults	Median	Adults	Median	*P*-value	Adults	Median	Adults	Median	*P*-value
2006										
Wild steelhead										
1-ocean	32	39.7	35	32.1	0.702	24	57.8	26	49.2	0.519
2-ocean	25	18.9	38	17.3	0.897	19	26.7	36	46.4	0.256
3-ocean	0	NA	0	NA	NA	0	NA	0	NA	NA
Hatchery steelhead										
1-ocean	296	39.8	348	36.1	0.074	211	55.7	273	49.8	0.023
2-ocean	290	26.3	244	25.2	0.191	245	36.0	211	38.4	0.635
3-ocean	1	7.4	2	23.8	0.667	1	11.6	0	NA	NA
Hatchery and Wild steelhead combined										
1-ocean	328	39.8	383	35.9	0.067	235	56.0	299	49.7	0.019
2-ocean	315	25.1	282	25.0	0.197	264	35.5	247	38.8	0.964
3-ocean	1	7.4	2	23.8	0.667	1	11.6	0	NA	NA
2007										
Wild steelhead										
1-ocean	44	38.9	71	28.7	0.517	33	51.8	63	50.8	0.512
2-ocean	54	21.0	78	30.0	0.564	49	56.3	67	44.7	0.124
3-ocean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hatchery steelhead										
1-ocean	208	28.2	290	28.0	0.955	177	44.8	265	45.9	0.857
2-ocean	164	34.0	234	23.9	0.240	132	44.9	214	43.0	0.319
3-ocean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hatchery and Wild steelhead combined										
1-ocean	252	29.1	361	28.0	0.732	210	44.8	328	46.0	0.571
2-ocean	218	29.7	312	26.6	0.478	181	47.0	281	43.1	0.096
3-ocean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2008										
Wild steelhead										
1-ocean	121	29.7	158	34.0	0.647	89	44.9	130	51.0	0.460
2-ocean	111	26.2	133	15.1	0.064	100	61.7	114	40.9	0.021
3-ocean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hatchery steelhead										
1-ocean	620	30.9	552	31.1	0.438	474	44.8	460	45.0	0.833
2-ocean	223	12.9	199	18.5	0.131	202	28.8	191	47.3	0.013
3-ocean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hatchery and Wild steelhead combined										
1-ocean	741	30.9	710	31.9	0.747	563	44.9	590	46.6	0.695
2-ocean	334	15.0	332	18.0	0.919	302	35.4	305	44.8	0.507
3-ocean	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Appendix Table B8. Number of Chinook salmon adults and the median travel times between Bonneville and McNary Dams and between Bonneville and Lower Granite Dams by age class from 2006-2008 releases at Astoria (rkm 10) and Skamania Landing (rkm 225).

	Travel time (d) Bonneville to McNary					Travel time (d) Bonneville to L Granite				
	Astoria (rkm 10)		Skamania Landing (rkm 225)		Astoria vs Skamania	Astoria (rkm 10)		Skamania Landing (rkm 225)		Astoria vs Skamania
	Adults	Median	Adults	Median	*P*-value	Adults	Median	Adults	Median	*P*-value
2006										
Wild Chinook salmon										
Jacks	1	16.1	1	16.2	1.000	0	NA	1	24.0	NA
2-ocean	8	8.6	18	7.2	0.397	7	18.0	16	15.5	0.579
3-ocean	0	NA	5	4.8	NA	0	NA	5	10.2	NA
Hatchery Chinook salmon										
Jacks	13	4.8	33	4.9	0.108	9	10.8	28	10.9	0.302
2-ocean	41	7.8	91	6.2	0.238	34	15.4	85	14.3	0.142
3-ocean	2	8.8	4	6.2	0.133	2	21.0	3	15.8	0.800
Hatchery and Wild Chinook salmon combined										
Jacks	14	4.9	34	5.0	0.187	9	10.8	29	11.0	0.248
2-ocean	49	8.1	109	6.3	0.149	41	16.0	101	14.5	0.115
3-ocean	2	8.8	9	5.2	0.145	2	21.0	8	10.7	0.400
2007										
Wild Chinook salmon										
Jacks	0	NA	4	7.3	NA	0	NA	4	12.4	NA
2-ocean	20	6.7	17	6.2	0.892	20	14.8	16	13.6	0.694
3-ocean	2	5.7	4	9.1	0.800	2	14.4	4	19.8	0.533
Hatchery Chinook salmon										
Jacks	21	5.9	25	5.4	0.570	20	12.8	25	12.2	0.692
2-ocean	45	5.7	95	6.0	0.701	43	14.3	86	13.1	0.637
3-ocean	1	7.0	2	4.5	0.667	1	15.8	2	13.6	0.667
Hatchery and Wild Chinook salmon combined										
Jacks	21	5.9	29	5.8	0.953	20	12.8	29	12.2	0.709
2-ocean	65	6.2	112	6.1	0.837	63	14.3	102	13.3	0.418
3-ocean	3	6.7	6	5.4	0.905	3	14.9	6	16.7	0.905
2008										
Wild Chinook salmon										
Jacks	12	4.9	9	5.0	0.508	9	12.1	8	11.0	0.815
2-ocean	42	5.1	76	5.5	0.450	39	14.2	64	15.7	0.225
3-ocean	12	9.7	21	7.9	0.385	8	17.8	16	16.1	0.569
Hatchery Chinook salmon										
Jacks	74	5.1	92	5.1	0.566	61	10.8	81	11.0	0.250
2-ocean	185	5.3	258	5.6	0.796	168	15.0	231	14.2	0.150
3-ocean	14	6.1	28	7.0	0.644	12	18.6	22	23.6	0.557
Hatchery and Wild Chinook salmon combined										
Jacks	86	5.1	101	5.1	0.607	70	10.8	89	11.0	0.330
2-ocean	227	5.3	334	5.6	0.924	207	14.8	295	14.5	0.484
3-ocean	26	7.2	49	7.2	0.864	20	17.8	38	18.7	0.968