

**Alternative Barging Strategies to Improve Survival of Transported
Juvenile Salmonids, 2007**

Report of research by

Douglas M. Marsh and William D. Muir

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
2725 Montlake Boulevard East
Seattle, WA 98112

and

Diane Elliott, Tony Murray, LynnMarie Applegate, Connie McKibben,
and Sacha Mosterd

U.S. Geological Survey
Western Fisheries Research Center,
6506 NE 65th St
Seattle, WA 98115

to

Walla Walla District
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EXECUTIVE SUMMARY

During spring 2007, we conducted a study to test the hypothesis that releasing transported juvenile salmonids *Oncorhynchus* spp to the lower Columbia River estuary at river kilometer (rkm) 10 would produce higher smolt-to-adult return rates (SARs) than releasing them just below Bonneville Dam at rkm 225. We speculated that releasing transported fish an additional 215 km downstream from the location presently used could decrease smolt mortality due to predation by piscivorous fish and birds. Adults returning over the next several years will provide data to test this hypothesis.

In addition to evaluating a release location for transported fish, we used new, non-lethal techniques to collect fish pathogen data. We determined pathogen loads in study fish to evaluate whether pathogens in individual fish affect vulnerability to avian predators as well as SARs.

On five consecutive Sundays, starting in late April 2007 and running through May, run-of-the-river yearling Chinook salmon *O. tshawytscha* and steelhead *O. mykiss* were collected and tagged with passive integrated transponder (PIT) tags at the Lower Granite Dam juvenile fish facility. Following tagging, fish were transferred to raceways and held until the following day, when they were loaded on barges for transport. A total of 9,494 hatchery and 1,891 wild yearling Chinook salmon were tagged and released downstream from Astoria at rkm 10, while 14,390 hatchery and 2,991 wild yearling Chinook salmon were tagged and released at Skamania Landing (rkm 225). In total, we released 20,206 hatchery and 2,553 wild steelhead at rkm 10 and 26,692 hatchery and 4,490 wild steelhead at rkm 225. Fewer fish were tagged than planned, particularly Chinook salmon, because permission to begin the study was delayed for a week; thus we missed the opportunity to tag on an earlier Sunday in April.

All Astoria releases were made after dark on an outgoing tide to reduce avian predation by Caspian terns *Hydroprogne caspia* and double-crested cormorants *Phalacrocorax auritus* from the nearby nesting colonies on East Sand Island. In fall 2007, abandoned bird colonies were scanned to detect PIT tags from fish released from this and other studies, and these data were used to estimate the number of fish from each release group preyed upon by piscivorous birds.

During each tagging day, about 300 non-lethal gill clip samples were collected for pathogen analyses (*Renibacterium salmoninarum* and *Nucleospora salmonis*), for a total of 1,449 samples over the season. These data allowed us to determine whether infection with *R. salmoninarum*, *N. salmonis*, or both pathogens was correlated with predation

vulnerability. There was no evidence from the 2006 or 2007 study that infection of fish with one or both pathogens influenced rates of predation, but *R. salmoninarum* infection levels in the majority of tested fish were low, especially in the 2007 sample. Current methodologies for assaying *N. salmonis* can only provide numbers of fish infected, not infection levels, although a quantitative test should be in place for the 2008 study.

We will need to wait several years for complete adult returns to determine the efficacy of releasing transported salmonids at rkm 10 instead of the traditional release site at rkm 225. Based on preliminary returns from 2006 releases, transporting smolts to the estuary appeared to provide a modest improvement in SARs for steelhead, but not for yearling Chinook salmon. For steelhead, based on returns through 18 November 2008, 504 adults returned from the Skamania Landing releases with an estimated SAR of 1.21, while 445 adults returned from the Astoria releases with an estimated SAR of 1.52, resulting in a T_A/T_S of 1.26. For yearling Chinook salmon, with jacks and 2-ocean adult returns, the total thus far from the Skamania Landing releases is 124 with estimated SARs of 0.51, and from the Astoria releases, 49 with an estimated SAR of 0.30, resulting in a T_A/T_S of 0.59.

After two years of releases at the two sites, we do know that the new release location affected vulnerability to avian predators: mean avian predation rates (minimum estimates as not all tags are detected) in 2007 were 1.9% for yearling Chinook salmon released at Skamania Landing, but only 0.6% for those released near Astoria. Avian predation rates were 12.8% for steelhead released at Skamania Landing, but only 1.7% for their cohort released at Astoria. These results are nearly identical to those from 2006 releases. These results show that releasing fish farther downstream, at night, and on an outgoing tide will reduce avian predation substantially, particularly for steelhead, the species most vulnerable to avian predation. This finding is relevant for management actions related to recovery of juvenile salmonids that pass the world's largest Caspian tern and double-crested cormorant colonies during their downstream migration.

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INTRODUCTION

At collector dams on the Snake and Columbia Rivers, migrating salmonid smolts are guided away from turbine intakes and collected for transport by truck or barge to a release site below Bonneville Dam. The purpose of transporting fish is to avoid mortality caused by dam passage, but the benefit provided by transportation has varied for different fish stocks and with the timing of transport within the migration season (Muir et al. 2006; Williams et al. 2005).

Typically, about 50% of Snake River migrant smolts survive downstream migration to below Bonneville Dam (Williams et al. 2005), while about 98% of transported smolts survive (Budy et al. 2002). Therefore, one would expect about twice as many adults would return from transported smolts than from migrant smolts. Nevertheless, on an annual basis, the ratio of transported to inriver migrant smolt adult returns is usually lower than expected. This indicates that higher mortality is experienced for transported smolts after release than for inriver migrants that survived migration. The difference in survival between inriver migrant and transported smolts has been termed “differential delayed mortality” or “*D*.” The purpose of this study is to determine if transporting juvenile fish farther downstream will increase smolt-to-adult return (SARs) and reduce *D* of transported fish.

Fish condition and health have been assessed prior to and after transport in previous studies (Pascho and Elliott 1989; Elliott and Pascho 1991-1994; Elliott et al., 1997; Congleton et al. 2000, 2005; Kelsey et al. 2002; Schreck et al. 2005). Although stress and stressors have been examined in detail in these studies, and modification to the collection and transportation system have been made to reduce stress (Williams and Matthews 1995), transportation has not provided the benefit expected, particularly for wild Chinook salmon *Oncorhynchus tshawytscha* (Williams et al. 2005). This research continues an ongoing effort by the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program to evaluate modifications to the existing fish transportation program to improve post-release survival for fish transported and released below Bonneville Dam.

Studies conducted with Coho salmon *O. kisutch* found that smolts transported to a release point near Tongue Point in the Columbia River returned at 1.6 times greater rate than those released upriver (Solazzi et al. 1991). Similarly, Gunnerod et al. (1988) found that Atlantic salmon *Salmo salar* released in seawater returned at a higher rate. Marsh et al. (1996, 1998, 2000) compared the Skamania Landing release site with a Tongue Point (rkm 29) release site in the Columbia River estuary, but too few adult steelhead *O. mykiss* returned from either release point for a meaningful evaluation.

The primary objective of the 2007 alternate barge release-site study was to determine whether releasing barged fish further downstream near Astoria at rkm 10 (approximately 10 km downstream from the Astoria Bridge) would improve the SAR rate of spring Chinook salmon and steelhead (Figure 1). The strategy was to minimize the time that fish spent moving into and through the estuary, while documenting fish

condition to provide insight into the vulnerability of smolts to predators. Our approach was to tag transported smolts with passive integrated transponder (PIT) tags (Prentice et al. 1990), collect samples for pathogen analysis, and release fish at the current barge release site downstream from Bonneville Dam near Skamania Landing (rkm 224) and at Astoria. Similar releases were made during 2006 at these two release locations (Ryan et al. 2007). When the adults return, we will compare SARs between the two release sites to determine the benefit (if any) of transporting smolts further downstream. Since SARs are reliant upon adult returns (PTAGIS 2008), we will not be able to complete this objective for several years.

Our second objective was to determine *Renibacterium salmoninarum* prevalence and severity, along with the presence of *Nucleospora salmonis*, within each release group. The infection profiles of *R. salmoninarum* and *N. salmonis* reported here can then be correlated with avian predation rates and SARs, although the latter correlation will have to wait several years for adult returns. Our third and final objective was to compare avian predation rates between Skamania Landing releases and Astoria releases.

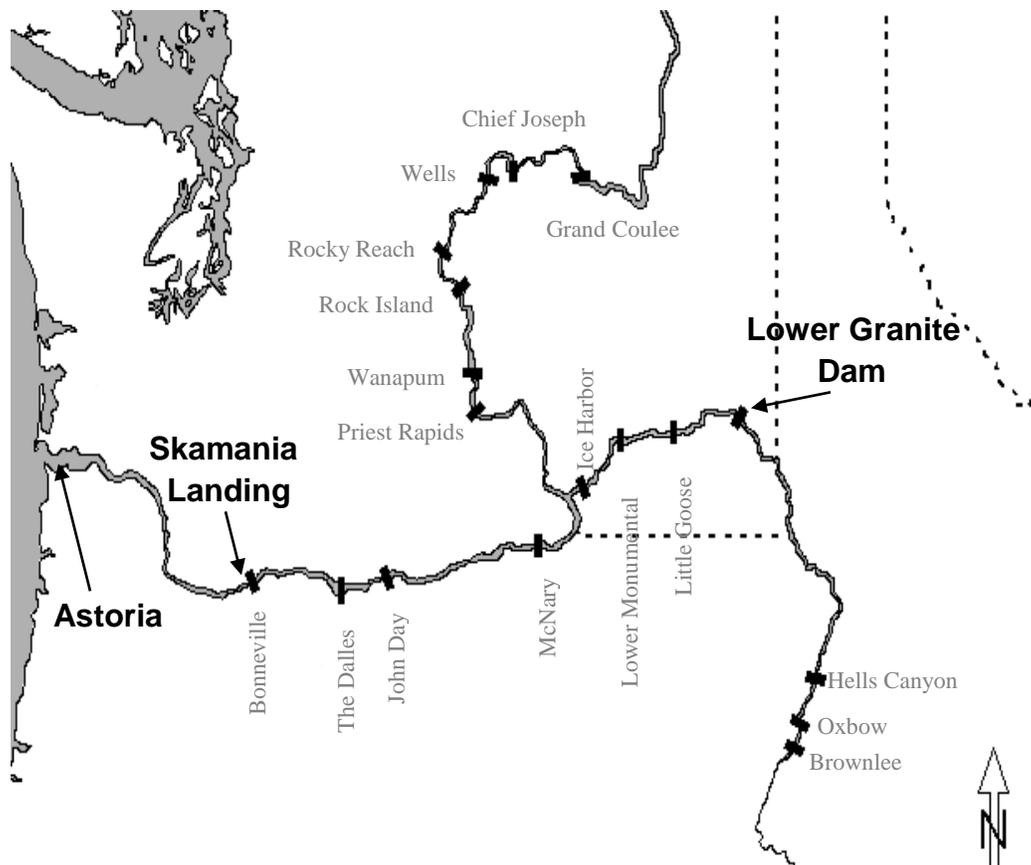


Figure 1. Study area showing Lower Granite Dam where fish were collected and PIT-tagged, the Skamania Landing barge release site (rkm 224), and the Astoria barge release site (rkm 10) during 2007.

METHODS

Fish Acquisition and Tagging

During spring 2007, we collected and PIT-tagged two groups of steelhead and two groups of yearling Chinook salmon smolts at Lower Granite Dam. Fish were tagged at the NOAA tagging facility on five consecutive Sundays from late April to May. Six tagging days were planned, but we were unable to obtain permission to begin the study on the first Sunday initially planned, so it was missed. Tagging followed the protocols and standards outlined in the PIT Tag Marking Procedures Manual (CBFWA 1999) for mass marking using simple PIT-tag injectors (see Marsh et al. 2001 for description of tagging methods used at this facility). After each tagging session, fish were transferred to the east-bank transport raceways for 24-h recovery.

The following day, one group of each species was loaded on an 8000-series transportation barge (except for the first trip in 2007 where a 2000-series barge was used because general transportation had yet to start) for release at Skamania Landing (rkm 224), where transported fish are typically released. A second group of each species was loaded on a 2000-series barge and released in the lower estuary at Astoria (rkm 10).

We attempted to tag sufficient numbers of both transported yearling Chinook salmon and steelhead to test a ratio of 1.3 (30% increase for Astoria release) for adults returning to the dam from releases at Astoria (T_A) vs. releases at Skamania Landing (T_S). This ratio (T_A/T_S) was based on an expected SAR of 1.0% at Lower Granite Dam for the Astoria releases (Table 1). For both yearling Chinook salmon and steelhead, we tagged hatchery and wild fish in proportion to those entering the juvenile bypass facility. While the expected ratio required us to tag 53,000 fish of each species, the actual number tagged varied in accordance with numbers of fish arriving at the dam.

Table 1. Required sample sizes based on expected SAR ($\alpha = 0.05$, $\beta = 0.20$) and T_A/T_S .

T_A/T_S Ratio	Expected Astoria SAR	Number of fish PIT-tagged at Lower Granite Dam	
		Astoria (rkm 10)	Skamania Landing (rkm 225)
1.2	1.00	48,000	57,000
1.2	0.75	64,000	76,000
1.2	0.50	95,000	114,000
1.3	1.00	23,000	30,000
1.3	0.75	31,000	40,000
1.3	0.50	46,000	58,000

Lower Granite Dam will serve as the principal recovery site for adults. Data acquired from other areas will be considered ancillary. To analyze results, statistical tests will be applied when adult returns for the study are complete. Confidence intervals for the T_A/T_S ratio will be calculated using the ratio (survival) estimate (Burnham et al. 1987) and its associated empirical variance. The study will produce an overall, statistically bound T_A/T_S estimate at Lower Granite Dam.

Fish Releases

The Skamania Landing release groups were transported and released with normal transportation fish. We attempted to keep loading density and water volume replacement times between the Skamania Landing (8000 series) and Astoria (2000 series) barges as similar as possible, and not to exceed the loading density and replacement rates set by the U.S. Army Corps of Engineers. However, due to the unpredictable nature of fish passage, keeping loading densities equal proved to be difficult and was not always achieved.

The barge used for Astoria releases was towed with a separate vessel, mirroring the path of the Skamania Landing barge until after it passed Bonneville Dam, when it continued downstream to rkm 10 (except for the first trip in 2007 where both barges were towed by the same vessel). 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 auritus* from the nearby nesting colonies on East Sand Island in the Columbia River estuary (Table 2). Dissolved oxygen levels, water temperatures, and mortalities were monitored on the 2000-series barge using the same standard procedures used on the 8000-series barge.

Table 2. Release dates, times, and locations for PIT-tagged juvenile steelhead and yearling Chinook salmon smolts released at Skamania Landing and near Astoria during 2007. High tides for the Astoria releases are noted.

Release date	Astoria releases (rkm 10)		Skamania releases (rkm 224)	
	Time	High tide at rkm 10	Release date	Time
3-May	3:30 am	1:58 am	2-May	4:15 am
9-May	10:15 pm	8:22 pm	8-May	5:00 pm
17-May	3:00 am	1:31 am	16-May	4:50 am
23-May	10:00 pm	8:31 pm	23-May	8:30 am
31-May	2:20 am	12:51 am	29-May	7:50 pm

Pathogen Sampling

Fish were analyzed for the presence of two salmonid pathogens known to occur in the Snake and Columbia River basins: *R. salmoninarum*, the causative agent of bacterial kidney disease (BKD), and *N. salmonis*, an intranuclear microsporidian parasite that primarily infects lymphoblast cells and can cause a chronic, severe lymphoblastosis and a leukemic-like condition. Gill filament samples for determining the presence and levels of *R. salmoninarum* and the presence of *N. salmonis* were collected from fish in every release group during tagging. The goal was to sample 75 fish each of wild and hatchery Chinook salmon and wild and hatchery steelhead on each tagging date, for a total of 300 fish per replicate. The total number of fish sampled over the season was close to the goal of 1,500, but proportions of fish by species and origin varied depending on their availability at the dam on each tagging date (Table 3).

Table 3. Release numbers (mortalities removed) of PIT-tagged hatchery and wild steelhead and yearling Chinook salmon smolts that were gill-clipped, transported, and released at Skamania Landing by release date during 2007.

Tag date	Chinook salmon		Steelhead		Total
	Hatchery	Wild	Hatchery	Wild	
30-Apr	75	75	87	63	300
7-May	82	68	86	64	300
14-May	77	73	80	70	300
21-May	86	64	102	48	300
28-May	54	42	113	38	247
Total	374	322	468	283	1,447

Sample collection methodology followed the protocol for non-lethal gill filament sampling described by Schrock et al. (1994). Briefly, a 2 × 3-mm gill sample (approximately 10 mg) was removed from each fish using surgical scissors. Samples were placed in individual pre-weighed and labeled tubes, frozen immediately on dry ice, and transported to the USGS Western Fisheries Research Center for analysis. The use of pre-weighed tubes and transport of undiluted samples on dry ice instead of dilution in ethanol before transport enabled accurate weighing of samples. The PIT-tag code associated with each gill filament sample number was recorded.

At the same PIT-tagging stations where fish were collected for pathogen analyses, water samples were taken for quantification of *R. salmoninarum* in water at the juvenile fish facility. Water samples were taken four times during each tagging day: twice before the recirculating water in the tagging system was changed, and twice after the water was changed. Samples were preserved by addition of 0.01% thimerosal (final concentration) to each 500-mL water sample.

Bird Colony Sampling

Using PIT tags allowed us to obtain data from the NOAA Fisheries avian predation project to estimate predation rates of fish released in this study (Ryan et al. 2007). The avian predation project evaluates impacts of predation by Caspian terns and double-crested cormorants on juvenile salmonids by detecting PIT tags on piscivorous water bird colonies in the Columbia River Basin (Ryan et al. 2001, 2003). Comparing the rates of predation of PIT-tagged salmonids allowed us to determine whether fish released at Skamania Landing were more susceptible to predation by piscivorous birds than fish released at Astoria. The data also allowed us to observe any differences in predation rate that may be due to *R. salmoninarum* or *N. salmonis* infection. We used paired *t*-tests ($P < 0.05$) to compare predation rates between release locations.

Pathogen Analyses

Gill samples were weighed, processed, and tested for *R. salmoninarum* by two polymerase chain reaction (PCR) procedures: nested PCR (nPCR) and real-time quantitative PCR (qPCR). The nPCR was done according to the method of Chase and Pascho (1998). For the qPCR, the procedure of Chase et al. (2006) was followed, except that a non-fluorescent quencher was substituted for the fluorescent quencher dye (TAMRA) on the 3' end of the internal probe RS1262. The use of this modified probe, MGBRS1262, was intended to increase sensitivity of the qPCR. Some previous work had indicated that the original qPCR method of Chase et al. (2006) had a lower sensitivity than the nPCR (Elliott and Pascho 2004; McMichael et al. 2006), but only the qPCR can provide a measure of the infection levels in fish. Thus, testing a single sample by both PCR techniques was desirable to provide the most information.

For detection of *N. salmonis* in gill samples, the nested PCR method of Barlough et al. (1995) was followed, with several modifications. A commercially available PCR

buffer (Qiagen, Inc.¹) was included in the master mix, and the use of gelatin was omitted. A 2- μ L aliquot of the first round product was used in the nested round of amplification. Cycling conditions for both PCR rounds were changed to the following: 94°C for 5 min, followed by 35 cycles of 94°C for 30 s, 65°C for 60 s, and 72°C for 60 s, with a final extension of 72°C for 7 min. The current assay methodology can only determine the presence or absence of *N. salmonis*. A new methodology is being developed that may allow quantitative assaying in the near future.

For enumeration of *R. salmoninarum* in water samples, a membrane filtration-fluorescent antibody (MF-FAT) procedure, modified from that of Elliott and McKibben (1997), was used. Water samples were shaken to mix the contents, and large debris were allowed to settle for 5 min. Triplicate sub-samples were prepared from each water sample. For each sub-sample, a 5-mL aliquot of the sample was combined with 3 mL of phosphate-buffered saline (PBS, 0.01 M phosphate, pH 7.1) with 0.5% (by volume) Triton X-100 added (PBS-Triton). After vortex mixing, each sub-sample was triturated through a 22-gauge needle, and then filtered through a Nuclepore 0.2- μ m pore diameter filter.

After each filter was rinsed with 1-3 mL PBS Triton, 100 μ L of a 1:40 dilution (by volume) of fluorescein isothiocyanate-labeled anti-*R. salmoninarum* polyclonal antiserum (Kirkegaard and Perry Laboratories) was pipetted onto each filter. Filters were incubated in a humid chamber for 1 h at room temperature, then rinsed with 1-3 mL PBS-Triton, and counterstained with 1 mL Eriochrome Black T (Sigma; diluted 1:2000 wt.:vol in PBS). Filters were air dried, and cover glasses were mounted with pH 9 glycerol-DABCO mounting medium (Johnson et al. 1982). Each filter was examined by epifluorescence microscopy at 1000 \times magnification with a Zeiss Axiophot microscope. A total of 150 microscope fields were examined on each of three filters per water sample, and *R. salmoninarum* cells were counted.

Several statistical methods were used for pathogen analyses among groups of steelhead and Chinook salmon (Motulsky 1995; InStat 3, Graph Pad). Contingency tables were used to compare relative proportions of uninfected and infected fish for either *R. salmoninarum*, *N. salmonis*, or both pathogens. Fisher's exact test was used for analysis of 2 \times 2 tables, and a chi-square test was used to analyze larger contingency tables. For fish testing positive for *R. salmoninarum* by qPCR, *R. salmoninarum* level data (both raw data and log-transformed data) were first tested for normality by the

¹ Use of trade names does not imply endorsement by the USGS or National Marine Fisheries Service, NOAA.

Kolmogorov-Smirnov method. Because at least one data set in each comparison failed the normality test ($P < 0.05$) even after log transformation, the nonparametric Mann-Whitney test was used for comparison of two groups, and the Kruskal-Wallis test (single factor analysis of variance by ranks) was used to compare *R. salmoninarum* levels among three or more groups. Dunn's multiple comparison test was applied when a significant result ($P < 0.05$) was obtained by the Kruskal-Wallis test.

For each species, fork lengths of fish infected with one or both pathogens were compared with fork lengths of fish in which neither pathogen was detected. Because length data were not normally distributed, the Mann-Whitney test or Kruskal-Wallis test was used for these comparisons as previously described. Similar procedures were used for comparison of *R. salmoninarum* concentrations detected in water samples on different days. Correlation of *R. salmoninarum* level with fork length was evaluated using the nonparametric Spearman rank correlation test, and this test was also used to evaluate correlations of *R. salmoninarum* level with concentration of the bacterium in water samples.

RESULTS

Tagging

On five consecutive Sundays from late April through May, river-run yearling Chinook salmon and steelhead were collected and tagged with PIT tags at the Lower Granite Dam juvenile fish facility (Table 4). A total of 9,494 hatchery and 1,891 wild yearling Chinook salmon were tagged, loaded on a transport barge, and released at Astoria, while 14,390 hatchery and 2,991 wild yearling Chinook salmon were tagged, transported, and released at Skamania Landing. In total, 20,206 hatchery and 2,553 wild steelhead were released at Astoria, and 26,692 hatchery and 4,490 wild steelhead were released at Skamania Landing. Additional fish were added to the holds of both barges in an attempt to equalize densities. Due to the unpredictable nature of fish arrival and collection at the dam, equalizing densities proved to be difficult and was not always achieved (Table 5). However, final fish loading densities were far below maximum capacities on all barges.

Table 4. Release numbers of PIT-tagged wild (W) and hatchery (H) juvenile steelhead and yearling Chinook salmon by date at the Astoria and Skamania Landing release sites during 2007.

Release date	Skamania Landing				Astoria				Total
	Chinook salmon		Steelhead		Chinook salmon		Steelhead		
	H	W	H	W	H	W	H	W	
2 and 3 May	3,793	499	4,391	325	2,215	245	3,578	243	15,289
8 and 9 May	4,360	648	4,530	1,235	2,981	401	4,010	859	19,024
16 and 17 May	4,264	988	5,138	1,321	3,187	737	3,787	566	19,988
23 May	1,839	766	9,564	1,363	982	412	5,929	594	21,449
29 and 31 May	134	90	3,069	246	129	96	2,902	291	6,957
Total	14,390	2,991	26,692	4,490	9,494	1,891	20,206	2,553	82,707

Table 5. Numbers of PIT-tagged fish, and the number of untagged fish added to increase barge hold densities for the Skamania Landing (8000 series) and Astoria (2000 series) release barges, 2007. The total number pounds of fish in the barge holds are also shown.

Release date	Barge	Number tagged	Number not tagged	Total pounds
2 May	Skamania Landing	9,008	3,560	1,770
3 May	Astoria	6,281	5,841	1,707
8 May	Skamania Landing	10,773	6,328	1,989
9 May	Astoria	8,251	7,081	1,783
16 May	Skamania Landing	11,711	2,844	1,916
17 May	Astoria	8,277	5,328	1,791
23 May	Skamania Landing	13,532	8,626	3,211
23 May	Astoria	7,917	13,233	3,065
29 May	Skamania Landing	3,539	1,704	920
31 May	Astoria	3,418	1,052	784

Avian Predation

Based on PIT-tag recoveries on East Sand Island, we estimated that avian predators consumed a significantly higher proportion of fish released at Skamania Landing than of those released at Astoria. For both steelhead and yearling Chinook salmon, the avian predation rate was lower for fish released at Astoria during nighttime and on an ebb tide than for fish released 215 km upstream at Skamania Landing. On the East Sand Island tern and double-crested cormorant colonies, 12.7% of the tags from steelhead released at Skamania Landing were recovered, while 1.7% of the tags from steelhead released at Astoria were recovered. Smaller proportions of PIT tags from Chinook salmon were recovered on the colonies, but these recoveries still showed the trend of significantly higher predation rates for fish released at Skamania Landing (Table 6). Most recovered tags from both species and release sites were detected on the Caspian tern colony.

Table 6. Percentage of PIT tags detected on the East Sand Island Caspian tern and double-crested cormorant colonies for both steelhead and yearling Chinook salmon smolts from 2007 releases at Skamania Landing and near Astoria. A paired *t*-test was used to compare release locations.

Bird colony	Steelhead tags detected (%)		Chinook salmon tags detected (%)	
	Astoria	Skamania	Astoria	Skamania
Caspian tern	1.61	11.67	0.46	1.28
Paired <i>t</i> -test	$t = 5.30, P = 0.006$		$t = 3.44, P = 0.026$	
Double-crested cormorant	0.07	1.14	0.15	0.58
Paired <i>t</i> -test	$t = 3.43, P = 0.027$		$t = 2.40, P = 0.074$	

Date-Specific Predation Results

Tagged fish were released on five separate occasions between late April and the end of May at both the Skamania Landing and Astoria release sites (Table 4). The Astoria release groups showed lower tag proportions detected on both tern and cormorant colonies than did the Skamania Landing release groups for all replicates except the last release of Chinook salmon, from which no tags from either release site were detected (Table 7).

Table 7. Percentage of PIT tags detected by date on the East Sand Island Caspian tern and double-crested cormorant colonies for both steelhead and yearling Chinook salmon released during 2007.

Date release	Caspian tern		Double-crested cormorant	
	Astoria	Skamania	Astoria	Skamania
Steelhead tags detected (%)				
2 and 3 May	6.4	19.2	0.2	2.5
8 and 9 May	0.7	9.1	0.1	1.0
16 and 17 May	0.0	5.0	0.1	1.2
23 May	0.6	11.6	0.0	0.8
29 and 31 May	1.5	18.7	0.0	0.4
Chinook salmon tags detected (%)				
2 and 3 May	1.1	1.7	0.2	0.7
8 and 9 May	0.6	1.2	0.1	0.2
16 and 17 May	0.1	1.2	0.0	0.7
23 May	0.1	1.0	0.4	0.8
29 and 31 May	0.0	0.0	0.0	1.8

Pathogen Analyses

Overall results for prevalence of *R. salmoninarum* detected by nPCR and qPCR are shown in Table 8. The proportion of fish in which *R. salmoninarum* was detected by nPCR was significantly higher than that detected by qPCR in gill samples from hatchery Chinook salmon ($P < 0.0001$). Conversely, a significantly higher proportion of gill samples from hatchery steelhead tested positive for *R. salmoninarum* by qPCR than by nPCR ($P = 0.009$). No significant differences were observed between nPCR and qPCR in the proportions of wild Chinook salmon ($P = 0.37$) or wild steelhead ($P = 0.50$) gill samples testing positive for *R. salmoninarum*. By nPCR testing alone, no difference in *R. salmoninarum* prevalence was detected between wild and hatchery Chinook salmon ($P = 0.54$) or between wild and hatchery steelhead ($P = 0.53$). However, *R. salmoninarum* prevalence detected by nPCR was higher in wild and hatchery Chinook salmon than in either wild ($P = 0.007$) or hatchery steelhead ($P < 0.0001$). By qPCR testing alone, *R. salmoninarum* prevalence was significantly higher in wild Chinook salmon than in hatchery Chinook salmon ($P = 0.005$), but no difference in prevalence was detected between wild and hatchery steelhead ($P = 0.51$). *R. salmoninarum* prevalence was also higher ($P = 0.02$) by qPCR testing in wild and hatchery steelhead than in hatchery Chinook salmon.

Results for *N. salmonis* prevalence detected by nPCR are shown in Table 8. The prevalence of *N. salmonis* was significantly higher in hatchery steelhead than in wild steelhead, wild Chinook salmon, or hatchery Chinook salmon ($P < 0.0001$).

Table 8. Pathogen detection in gill samples from all tested fish. Detection of *Renibacterium salmoninarum* by nested PCR (nPCR) and quantitative PCR (qPCR) and detection of *Nucleospora salmonis* by nPCR in gill tissues from hatchery and wild Chinook salmon smolts and hatchery and wild steelhead smolts sampled non-lethally at the time of tagging from the five release groups of fish marked with PIT tags at Lower Granite Dam during 2007.

Fish species	Number of positive fish/number sampled (%)		
	<i>Renibacterium salmoninarum</i>		<i>Nucleospora salmonis</i>
	nPCR	qPCR	nPCR
Chinook wild	88/322 (27%)	77/322 (24%)	19/322 (6%)
Chinook hatchery	94/318 (30%)	48/317 (15%)	14/318 (4%)
Steelhead wild	45/245 (18%)	52/245 (21%)	14/245 (6%)
Steelhead hatchery	77/468 (16%)	110/468 (24%)	141/468 (30%)

Among fish testing positive for *R. salmoninarum* by qPCR, *R. salmoninarum* levels were generally less than 100 bacteria per mg of gill sample; samples from only eight fish had *R. salmoninarum* concentrations exceeding this level. These fish included six hatchery steelhead (highest concentration 1,867 *R. salmoninarum* per mg), one hatchery Chinook salmon (highest concentration 333 *R. salmoninarum* per mg), and one wild Chinook salmon (highest concentration 313 *R. salmoninarum* per mg). Furthermore, fewer than half (17 to 38%) of the qPCR-positive fish of each species had *R. salmoninarum* levels above the threshold for consistent detection by the assay (5 bacteria per qPCR reaction; Table 9). *R. salmoninarum* levels in wild and hatchery Chinook salmon and wild and hatchery steelhead were not significantly different ($P = 0.65$; Table 9).

Table 9. Mean levels of *Renibacterium salmoninarum* detected by qPCR in smolts sampled non-lethally from the six release groups of fish marked with PIT tags at Lower Granite Dam during 2007.

Fish species	Number above threshold for consistent <i>R. salmoninarum</i> detection ^a /Total number positive by qPCR (%)	Geometric mean number <i>R. salmoninarum</i> per mg gill sample ^b (\pm SD)
Chinook salmon wild	29/77 (38%)	7 (\pm 3)
Chinook salmon hatchery	12/48 (25%)	7 (\pm 3)
Steelhead wild	34/52 (17%)	7 (\pm 2)
Steelhead hatchery	70/110 (29%)	9 (\pm 4)

^a Five bacteria per qPCR reaction.

^b Number of *R. salmoninarum* per mg calculated according to the following formula: (Number of *R. salmoninarum* per reaction x 40) / Sample weight, where 40 is the dilution factor

The proportions of fish testing positive for either *R. salmoninarum*, *N. salmonis*, or both, varied by species and sample date (Table 10). For both wild and hatchery Chinook salmon and steelhead, the highest percentages of fish positive for one or both pathogens were recorded for samples collected on 27 May. For wild Chinook salmon, proportions of fish positive for either or both pathogens were significantly higher for samples collected on 29 April, or 6, 20, or 27 May than for the samples collected on 13 May ($P < 0.0001$). For hatchery Chinook salmon, proportions of fish positive for either or both pathogens were significantly higher in samples collected on 27 May than for the samples collected on 29 April or 6 or 13 May ($P = 0.04$). For wild steelhead, proportions of fish positive for one or both pathogens were significantly higher for samples collected on 27 May than for samples collected on all other dates ($P = 0.003$).

For hatchery steelhead, the proportions of fish positive for either or both pathogens were significantly higher for samples collected on 29 April, 20 May and 27 May than for those collected on 6 May ($P = 0.0002$) or 13 May ($P = 0.01$).

Table 10. Proportions of fish testing positive for *Renibacterium salmoninarum* only, for *Nucleospora salmonis* only, for both pathogens, or for neither pathogen among all fish sampled on each date from PIT-tagged groups at Lower Granite Dam in 2007.

Sample date and fish species	Number tested	Number positive <i>R. salmoninarum</i> * (%)	Number positive <i>N. salmonis</i> only (%)	Number positive <i>R. salmoninarum</i> and <i>N. salmonis</i> (%)	Number with neither pathogen detected (%)
29 Apr					
Chinook W	75	34(45%)	6(8%)	3 (4%)	32 (43%)
Chinook H	19	7 (37%)	0	0	12 (63%)
Steelhead W	25	9 (36%)	0	1 (4%)	15(60%)
Steelhead H	87	34 (39%)	13 (15%)	5 (6%)	35 (40%)
6 May					
Chinook W	68	37 (54%)	0	0	31(46%)
Chinook H	82	27 (33%)	2 (2%)	1 (1%)	52 (63%)
Steelhead W	64	18 (28%)	1 (2%)	0	45 (70%)
Steelhead H	86	12 (14%)	15 (17%)	4 (5%)	55 (64%)
13 May					
Chinook W	73	15 (21%)	1 (1%)	0	57 (78%)
Chinook H	77	21 (27%)	5 (6%)	0	51 (66%)
Steelhead W	70	22 (31%)	4 (6%)	0	44 (63%)
Steelhead H	80	17 (21%)	15 (19%)	14 (18%)	46 (43%)
20 May					
Chinook W	64	25 (39%)	0	1 (2%)	38 (59%)
Chinook H	86	42 (49%)	0	1 (1%)	43 (50%)
Steelhead W	48	13 (27%)	1 (2%)	0	34 (71%)
Steelhead H	102	25 (25%)	24 (24%)	7 (7%)	46 (45%)
27 May					
Chinook W	42	19 (45%)	5 (12%)	3 (7%)	15 (36%)
Chinook H	54	26 (48%)	2 (4%)	3 (6%)	23 (43%)
Steelhead W	38	18 (47%)	2 (5%)	5 (13%)	13 (34%)
Steelhead H	113	31 (27%)	27 (24%)	17 (15%)	38 (34%)
All dates					
Chinook W	322	130 (40%)	12 (4%)	7 (2%)	173 (54%)
Chinook H	318	123 (39%)	9 (3%)	5 (2%)	181 (57%)
Steelhead W	245	80 (33%)	8 (3%)	6 (2%)	151 (62%)
Steelhead H	468	119 (25%)	94 (20%)	47 (10%)	220 (47%)

* Positive for *R. salmoninarum* by nPCR, qPCR, or both PCRs.

When data were combined for all sample dates, the proportions of fish positive for either or both pathogens was significantly higher for hatchery steelhead than for wild steelhead ($P = 0.0002$) or hatchery Chinook salmon ($P = 0.007$). Proportions of hatchery steelhead and wild Chinook salmon positive for either or both pathogens were not significantly different ($P = 0.07$). Overall, one or both pathogens were detected in 46% of the wild Chinook salmon, 43% of the hatchery Chinook salmon, 38% of the wild steelhead, and 53% of the hatchery steelhead.

Hatchery or wild Chinook salmon and wild steelhead that tested positive for either *R. salmoninarum* or *N. salmonis* or both pathogens did not differ significantly in length ($P \geq 0.18$) compared to fish that tested negative for both pathogens. However, hatchery steelhead that tested positive for one or both pathogens were significantly longer ($P = 0.004$) than those that tested negative for both pathogens. Although hatchery steelhead that tested positive for *R. salmoninarum* did not differ significantly in length ($P = 0.68$) from those that tested negative for *R. salmoninarum*, hatchery steelhead that tested positive for *N. salmonis* were significantly longer ($P < 0.0001$) than those that were negative for the pathogen. There was no significant correlation between length and *R. salmoninarum* level detected in gill samples for wild ($P = 0.51$) or hatchery Chinook salmon ($P = 0.21$) or wild ($P = 0.17$) or hatchery steelhead ($P = 0.06$).

Among PIT tags recovered from the East Sand Island tern and cormorant colonies, 105 (7 Chinook salmon and 98 steelhead) were from fish that had been sampled at Lower Granite Dam for detection of *R. salmoninarum* and *N. salmonis*. Of fish with PIT tags recovered on bird colonies, 33% of wild and 50% of hatchery Chinook salmon and 64% of wild and 57% of hatchery steelhead were positive for one or both pathogens (Table 11).

Table 11. Proportions of fish testing positive for *Renibacterium salmoninarum* only, for *Nucleospora salmonis* only, for both pathogens, or for neither pathogen among fish sampled at Lower Granite Dam during 2007, with PIT tags subsequently recovered on the East Sand Island piscivorous bird colonies.

Fish species	Number tested	Number			
		<i>R. salmoninarum</i> positive only* (%)	<i>N. salmonis</i> positive only (%)	<i>R. salmoninarum</i> and <i>N. salmonis</i> positive (%)	Number with neither pathogen detected (%)
Chinook W	3	1 (33%)	0	0	2 (67%)
Chinook H	4	2 (50%)	0	0	2 (50%)
Steelhead W	14	7 (50%)	1 (7%)	1 (7%)	5 (36%)
Steelhead H	84	19 (23%)	21 (25%)	8 (10%)	36 (43%)

* Positive for *R. salmoninarum* by nPCR, qPCR, or both PCRs.

Overall, 30% of the fish testing positive for *R. salmoninarum* by qPCR had levels of the bacterium above the threshold for consistent detection by the assay (5 bacteria per qPCR reaction; Table 12). *R. salmoninarum* concentrations for qPCR-positive fish ranged from 4 to 17 bacteria/mg for wild steelhead and from 2 to 1,466 bacteria/mg for hatchery steelhead. The single qPCR-positive wild Chinook salmon had an *R. salmoninarum* concentration of 17 bacteria/mg.

Table 12. Mean levels of *Renibacterium salmoninarum* detected by qPCR in smolts sampled at Lower Granite Dam during 2007, with PIT tags subsequently recovered on the East Sand Island piscivorous bird colonies.

Fish species	Number of fish above threshold for consistent <i>R. salmoninarum</i> detection ^a by qPCR/total positive (%)	Geometric mean number <i>R. salmoninarum</i> per mg gill sample ^b (\pm SD)
Chinook salmon wild	1/1 (100%)	--- ^c
Chinook salmon hatchery	0	---
Steelhead wild	0/5	9 (\pm 2)
Steelhead hatchery	6/17 (35%)	14 (\pm 4)

^a Five bacteria per qPCR reaction.

^b Number of *R. salmoninarum* per mg calculated according to the following formula: (Number of *R. salmoninarum* per reaction \times 40) / Sample weight, where 40 is the dilution factor

^c Single qPCR-positive fish had 17 *R. salmoninarum* per mg gill sample.

R. salmoninarum concentrations in water samples taken from the Lower Granite Dam tagging station ranged from no bacteria detected to 6.3×10^5 bacteria per mL (Table 13). The highest *R. salmoninarum* concentrations detected in water samples were obtained from samples taken on 29 April; the highest daily mean *R. salmoninarum* concentration in qPCR-positive gill snip samples (13 bacteria per mg tissue) was recorded on that same date (Table 14). For all sample dates except 29 April, daily mean *R. salmoninarum* concentrations in water samples were ≤ 2 bacteria per mL (Table 14).

Table 13. Mean *Renibacterium salmoninarum* concentrations in water samples taken from the PIT-tagging station from which fish were also sampled for pathogen testing at Lower Granite Dam, 2007. After the first two water samples were taken each day, water in the recirculating system was changed.

Sample date and time	Mean <i>R. salmoninarum</i> /mL (range)
29 April	
9:25 a.m.	1 (0 - 2)
12:00 noon	564,789 (513,554 - 626,068)
12:55 p.m.	344,226 (251,764 - 401,040)
2:50 p.m.	24 (11 - 36)
6 May	
9:30 a.m.	0
11:40 a.m.	0
12:30 p.m.	1 (0 - 2)
3:00 p.m.	0
13 May	
9:15 a.m.	0
11:35 a.m.	0
12:25 p.m.	0
2:15 p.m.	1 (0 - 4)
20 May	
9:15 a.m.	0
11:30 a.m.	0
12:30 p.m.	1 (0 - 2)
2:20 p.m.	0
27 May	
9:30 a.m.	1 (0 - 4)
12:00 noon	3 (0 - 4)

Table 14. Mean levels of *Renibacterium salmoninarum* detected by qPCR in daily samples of smolts (both species combined) sampled non-lethally during PIT-tagging at Lower Granite Dam in 2007. Also shown are mean daily concentrations of *R. salmoninarum* detected by MF-FAT in water samples taken at the tagging station from which fish were sampled. For the gill sample results, means not sharing a common letter are significantly different ($P < 0.001$).

Sample date	Geometric daily mean <i>R. salmoninarum</i> per mg gill sample (\pm SD)	Geometric daily mean <i>R. salmoninarum</i> per mL water sample (\pm SD)
29 April	13 (\pm 4) y	1517 (\pm 401)
6 May	6 (\pm 3) x	<2
13 May	5 (\pm 2) x	<2
20 May	4 (\pm 2) x	<2
27 May	11 (\pm 2) y	2 (\pm 2)

Preliminary Adult Returns

During 2007 and 2008 (through 27 August), jack and 2-ocean Chinook salmon and 1-ocean and 2-ocean steelhead returned from releases made in 2006. Based on these preliminary returns, transporting smolts to the estuary appeared to provide a modest improvement in SARs for steelhead, but not for yearling Chinook salmon. For steelhead, based on incomplete returns (returns are expected to continue through spring 2009), 504 adults returned from the Skamania Landing releases with an estimated SAR of 1.21, while 445 adults returned from the Astoria releases with an estimated SAR of 1.52, resulting in a T_A/T_S of 1.26 (Table 15). For the yearling Chinook salmon jacks and 2-ocean adults that have returned so far, there have been 124 from the Skamania Landing releases with an estimated SAR of 0.51, and 49 from the Astoria releases with an estimated SAR of 0.30, resulting in a T_A/T_S of 0.59. We will need to wait several years for complete adult returns from multiple release years to determine the efficacy of releasing transported salmonids at rkm 10 instead of the traditional release site at rkm 225.

Table 15. Number of adults and smolt-to-adult returns (SARs) from 2006 releases of yearling Chinook salmon and steelhead at Skamania Landing (rkm 225) and Astoria (rkm 10) based on 2007 and 2008 returns through 27 August 2008 (jacks and 1-ocean for yearling Chinook salmon and 1- and 2-ocean for steelhead). The ratio of the SARs (T_A/T_S) is also shown.

	Yearling Chinook salmon			Steelhead		
	Number	SAR	T_A/T_S	Number	SAR	T_A/T_S
Skamania	124	0.51		504	1.21	
Astoria	49	0.30		445	1.52	
			0.59			1.26

DISCUSSION

One goal of this study was to evaluate whether releasing transported salmonids downstream from the Astoria Bridge could increase survival to ocean entry. We hypothesized that using this release site would increase survival to ocean entry by allowing fish to avoid some avian predators in the Columbia River estuary. Steelhead 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 PIT tags from yearling Chinook detected at the dam that year.

In 1998 the major site of tag recovery was Rice Island, which was then home to the largest Caspian tern colony in North America (Collis et al. 2002). Ryan et al. (2002, 2003) and Glabek et al. (2003) reported similar results in subsequent years, as the tern colony was relocated from Rice Island to East Sand Island. To optimize survival, smolts were released in our study at night on an ebb tide, during which time we expected most would pass by the bird colonies and reach the ocean in one tidal cycle (Ledgerwood et al. 2001). Our results supported this hypothesis, showing that a significantly higher proportion of salmon released at Skamania were found on both large avian colonies in the estuary compared to their cohorts released at Astoria.

In addition to facilitating the avoidance of avian predators, the release of fish near Astoria could improve survival in other ways. The release site downstream from Bonneville Dam near Skamania Landing has the highest rate of predation by northern pikeminnow *Ptychocheilus oregonensis* in the Columbia River (Ward et al. 1995). By transporting smolts further downstream to Astoria, this source of potential mortality can be avoided. Release in the lower estuary also allows smolts to avoid migrating through the Willamette River confluence area, where high levels of toxic chemicals have been found (Spromberg et al. 2008). Barged fish would still pass through this area (and be exposed to the same water as inriver migrant fish), but they would likely be exposed to any toxic chemicals for a shorter duration. Finally, during years with low flow/high water temperature, steelhead migrants often residualize in reservoirs late in the migration. Few of these residuals survive to migrate the following spring (Williams et al. 2005). Releasing them near the mouth of the river in strong current during an ebb tide might encourage these fish to migrate rather than overwinter in reservoirs, thus improving overall SARs.

In the end, the more important question is not which release site allows juvenile salmonids to survive at greater rates to ocean entry, but rather which release site produces

the greatest SAR. It is conceivable that survival to ocean entry could be higher for fish released at Astoria, but that even with higher short-term survival, these fish could return at the same or lower rates than fish released at Skamania Landing. This could occur if fish released at Astoria were not physiologically prepared to enter seawater. Conversely, the group released at Astoria could be in better condition due to avoiding migration through the lower Columbia River, and could produce higher SARs. Ultimately, the success of either release site will be determined by examining differences in SARs among release groups. In addition, the effects of transporting smolts farther downstream on adult upstream migrational delay and homing ability will need to be evaluated.

Another goal of the study was to monitor the prevalence of the fish pathogens *R. salmoninarum* and *N. salmonis* and the levels of *R. salmoninarum* by non-lethal testing of subsamples of fish PIT-tagged at Lower Granite Dam. Both *R. salmoninarum* (see Alcorn et al. 2005 for summary) and *N. salmonis* (Wongtavatchai et al. 1995) can cause chronic infections and have immunosuppressive properties. Although infections with either pathogen can be directly fatal, they can also allow for opportunistic infections with other pathogens.

The PCR testing data from gill snip samples taken from fish at Lower Granite Dam indicated a significantly lower *R. salmoninarum* prevalence ($P < 0.0001$) for each species in 2007 compared with 2006. The detected *R. salmoninarum* prevalence was 77% in 2006 and 43% in 2007 for wild Chinook salmon, 72% in 2006 and 40% in 2007 for hatchery Chinook salmon, 73% in 2006 and 35% in 2007 for wild steelhead, and 70% in 2006 and 35% in 2007 for hatchery steelhead. Data from qPCR testing also indicated significantly lower *R. salmoninarum* levels in gill samples from each species in 2007 compared with 2006 ($P < 0.0001$). Whereas 52 to 55% of qPCR-positive fish in 2006 had *R. salmoninarum* levels at or above the threshold for consistent detection by the assay (5 bacteria per qPCR reaction), only 17 to 38% of qPCR-positive fish in 2007 had *R. salmoninarum* levels at or above this threshold.

Year-to-year variation in prevalence and severity of *R. salmoninarum* infections, similar to that observed in our 2006 and 2007 results, has been previously reported among salmonid smolts (Pascho and Elliott 1989; Elliott and Pascho 1991, 1993; Elliott et al. 1997; Vanderkooi and Maule 1999). Although PCR results of the present research cannot be directly compared to enzyme-linked immunosorbent assay (ELISA) results of past studies, limited evidence suggests that the majority of fish tested by PCR in the present study would have shown negative or low *R. salmoninarum* antigen levels by ELISA testing (Chase et al. 2006) and would not have been considered clinically diseased (e.g., showing grossly visible kidney lesions had they been sacrificed) at the time of sampling.

In general, the *R. salmoninarum* counts obtained by MF-FAT quantification of bacteria in water samples from the tagging station at Lower Granite Dam in 2006 and 2007 were consistent with the PCR findings from fish tissue samples, and suggested that lower *R. salmoninarum* levels in fish in 2007 resulted in reduced shedding of the bacterium into the water of tagging troughs. In 2006, daily mean *R. salmoninarum* concentrations in water samples ranged from 13 to 38 bacteria per mL of water, whereas in 2007, these daily means were ≤ 2 bacteria per mL for all sample dates except 29 April. The anomalous data recorded on 29 April 2007, with a daily mean *R. salmoninarum* concentration of 1,517 bacteria per mL (and a range between 1 and 564,789 bacteria per mL, depending on the time that samples were taken during the day), indicated that some fish with severe *R. salmoninarum* infections passed through the tagging station on that date and shed the bacterium into the water. This hypothesis is supported by fact that the only fish (two hatchery steelhead) in the 2007 sample with *R. salmoninarum* levels exceeding 1,000 bacteria per mg of tissue were sampled on 29 April.

Evidence from previous work indicates that the high *R. salmoninarum* concentrations detected in the tagging station water on 29 April 2007 were sufficient to establish infections in juvenile Chinook salmon (Elliott and Pascho 2004; Alcorn et al. 2005). However, the minimum exposure time required for successful waterborne transmission of *R. salmoninarum* to fish at these bacterial concentrations is unknown. Results of earlier studies indicate that fish marking procedures may enhance waterborne transmission of *R. salmoninarum* to juvenile Chinook salmon, or may contribute to exacerbation of existing infections (Elliott and Pascho 2001; 2004).

As in 2006, the *N. salmonis* prevalence was significantly higher in hatchery than in wild steelhead or yearling Chinook salmon (hatchery or wild) in 2007. Whereas *N. salmonis* prevalence in hatchery steelhead was $> 20\%$ for both years, prevalence in wild steelhead and yearling Chinook salmon was $\leq 6\%$ for both years. The 30% prevalence of *N. salmonis* detected in hatchery steelhead sampled at Lower Granite Dam in 2007 was significantly higher ($P = 0.009$) than the 23% prevalence detected in hatchery steelhead in 2006. *N. salmonis* has recently been recognized as a cause of mortality in certain stocks of steelhead reared in hatcheries in Idaho (Kathy Clemens, Idaho Fish Health Center, U.S. Fish and Wildlife Service, personal communication). Although the lack of a qPCR procedure prevented assessment of *N. salmonis* levels in the 2007 gill snip samples, recent development of qPCR methodology for this pathogen should enable quantification of *N. salmonis* levels in the 2008 samples.

The presence of *R. salmoninarum*, *N. salmonis*, or both pathogens did not appear to influence the susceptibility of steelhead and Chinook salmon to predation by piscivorous birds, although the low number of PIT tags recovered on East Sand Island from pathogen-tested Chinook salmon (7 fish total, including 3 wild fish and 4 hatchery fish) and wild steelhead (14 fish total) precluded meaningful analyses for these smolt groups. A lack of preferential predation on infected fish was not surprising, considering the relatively low *R. salmoninarum* levels in the majority of fish tested. Nevertheless, the PIT tag from one of the two hatchery steelhead found to have an *R. salmoninarum* level exceeding 1,000 bacteria per mg of gill tissue in the Lower Granite sample was recovered from the Caspian tern colony on East Sand Island. The *N. salmonis* levels could not be determined.

Previous studies with coho and Atlantic salmon found that release of transported smolts to the estuary or ocean resulted in higher adult return rates than release to freshwater (Solazzi et al. 1991; Gunnerod et al. 1988). Studies to evaluate the release of transported steelhead in the Columbia River estuary (Tongue Point) vs. Skamania Landing were conducted from 1992 to 1994 (smolt release years). For the 1994 release year, the ratio of Tongue Point to Skamania Landing adult returns was 3.0, while for the other two release years it was near 1.0. However, these results were inconclusive because too few adults returned from all three release years (Marsh et al. 1996, 1998, 2000). The return and detection of PIT-tagged adults at Lower Granite Dam over the next several years will be required to determine whether adult returns are improved by releasing transported yearling Chinook salmon and steelhead smolts to a site further downstream in the Columbia River estuary (rkm 10) than the traditional release site at Skamania Landing. Based on preliminary adult returns from this study, transporting smolts to the Astoria release site appears to provide a modest benefit to steelhead, but not for yearling Chinook salmon. However, these results may change with additional adult returns or might vary by release year.

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