Behavior and Survival Analysis of Steelhead and Sockeye Through the Priest Rapids Hydroelectric Project in 2009

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Final Report

9 February 2010

Abstract

This study was conducted to assess juvenile steelhead (*Oncorhynchus mykiss*) and sockeye (*O. nerka*) downstream migratory behavior and survival through the Priest Rapids Project (Wanapum and Priest Rapids dams and reservoirs) that is owned and operated by Public Utility District No. 2 of Grant County, Washington on the Mid-Columbia River. Acoustic transmitters were surgically implanted into 2,096 steelhead and 1,943 sockeye, all of which were randomly selected from run-of-river fish. The origin of test fish was estimated to be 34% wild and 66% hatchery-reared steelhead and 60% wild and 40% hatchery-reared sockeye. Fish were systematically released into the Columbia River in paired treatment-control groups between May 2 and June 1, 2009. To minimize tag battery life bias, transmitters were randomly mixed among all release sites and groups, as control and treatment tags were simultaneously activated for each paired release. A series of hydrophone arrays were strategically placed at multiple locations on the river and the hydropower dams to detect and track acoustically tagged fish. Array detection efficiencies were estimated at nearly 100%; all array detection estimates for both species were measured between 0.9982-1.0000, with standard errors of less than 0.002. Passage survival was estimated at 0.9436 (0.0189) for steelhead and 0.9726 (0.0092) for sockeye through the Wanapum Dam and reservoir. Survival remained high at Priest Rapids Dam and reservoir for sockeye, which was estimated at 0.9460 (0.0114) but decreased for steelhead to 0.8806 (0.0206). Overall joint Project survival (both dams combined) was estimated at 0.8309 (0.0256) for steelhead and 0.9201 (0.0142) for sockeye. Priest Rapids Dam was fitted with a prototype top-spill in 2006, and a top-spill bypass system was completed at Wanapum Dam in 2008. Both of these bypass systems experienced a dramatic improvement in passage route efficiency in 2009. The Wanapum Dam bypass collected 70.2% of steelhead and 59.3% of sockeye in 2009 as compared to 53.5% and 32.1%, respectively, in 2008. The Priest Rapids Dam prototype top-spill collected 51.0% of steelhead and 39.2% of sockeye compared to 26.3% and 19.8%, respectively, in 2008. We propose that environmental conditions contributed to the increase in top-spill passage. The Mid-Columbia River flow was significantly reduced compared to the 2008 study period and 10-year average, along with river water temperatures, which were notably cooler during the majority of the study period. Additionally, we believe that steelhead and sockeye responded to these environmental variables with slower migration rates and increased residence times in the forebay of each dam. Consequently, fish spent more time swimming at the dams, which increased the frequency of fish that encountered the bypass/top-spill attraction flows and resulted in an increase in bypass/top-spill route selection.

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Introduction

Hydropower on the Columbia River began in 1933 with the construction of Rock Island Dam. Over the next 38 years, an additional 10 hydropower dams were constructed on the Columbia River, finishing with John Day Dam in 1971. It is widely recognized that cross-river dams have acted as impediments to downstream migrating juvenile and upstream migrating adult salmonids (Raymond 1979; Budy et al. 2002; McClure et al. 2003; Williams 2008). These impediments have adversely affected overall species survival and have contributed to population declines (Raymond 1979; Williams et al. 2001; Budy et al. 2002). In response to declining numbers, Columbia River steelhead (*Oncorhynchus mykiss*) was listed as threatened under the Endangered Species Act (ESA) in 1999. Columbia River sockeye (*O. nerka*) are not currently listed under the ESA; but Snake River sockeye have been listed as endangered since 1991.

Public Utility District No. 2 of Grant County, Washington (Grant PUD) is actively working to improve juvenile salmonid passage throughout the Priest Rapids Hydroelectric Project (Project), which includes Wanapum and Priest Rapids dams on the Mid-Columbia River. To improve passage at Wanapum Dam, a surface spill fish bypass was completed in 2008 to provide a safe and effective downstream passage alternative for juvenile migrants. Surface flow alternatives have proven successful at both Wanapum and Rocky Reach dams, where recently completed surface bypass systems are in operation; a prototype top-spill bypass was installed at Priest Rapids Dam in 2006 (Harmon and Park 1980; Ransom and Steig 1995; Coutant and Whitney 2000; Johnson et al. 2005; Robichaud et al. 2005; Timko et al. 2007a, 2007b). Previous studies have shown mixed results as to the effectiveness (fish collection efficiency and survival) of the Priest Rapids Dam prototype top-spill bypass. In 2008, modifications to the operation of the prototype top-spill included additional bottom and sluiceway spill at adjacent gates, which increased passage effectiveness and warranted further testing (Sullivan et al. 2008).

Passage effectiveness was measured in two ways: by the proportion of fish that selected a particular passage route and more importantly, the ultimate survival rate after selecting that passage route (Timko et al. 2007a, 2007b; Sullivan et al. 2008). Survival standards that need to be met at the Priest Rapids Project are juvenile passage survival of 95% at each dam and 93% through a single project (one dam and reservoir). An arithmetic mean of three consecutive years (for each species) is used to determine if the survival standard has been met.

These particular Performance Standards (passage survival rates) needing to be met for the Priest Rapids Project were established for Grant PUD under the “Reasonable and Prudent Alternatives” (RPAs) in the National Marine Fisheries Service (NMFS) 2004 Biological Opinion for the Priest Rapids Project (NMFS 2004) and adapted into the “Terms and Conditions” of the 2008 NMFS Biological Opinion (BiOp) (NMFS 2008). These same survival standards are required for species of salmonids that are not listed under the ESA and are required under the 2006 Priest Rapids Project Salmon and Steelhead Settlement Agreement (SSSA) (SSSA 2006). Both of these documents’ (BiOp and SSSA) requirements were incorporated into the Federal Energy Regulatory Commission’s (FERC) license that was issued to Grant PUD for the operation of the Priest Rapids Project in April 17, 2008 (FERC 2008).

In this document we present the findings of a survival and behavior study completed at the Priest Rapids Project in 2009. Paired-release survival estimates using treatment and control groups are provided for steelhead and sockeye at each reservoir and dam (Wanapum pool/dam and Priest Rapids pool/dam) and through the Project. Migration rates, vertical and horizontal approach patterns, residence times and passage behavior are presented with focus on the bypass at Wanapum Dam and the prototype top-spill at Priest Rapids Dam.

Methods

Study Site - Wanapum (RM 416) and Priest Rapids dams (RM 397) are located on the Mid-Columbia River between Rock Island Dam (RM 453) and McNary Dam at the convergence of the Snake and Columbia rivers (Figure 1). Figure 1 illustrates the location of each dam and reservoir,

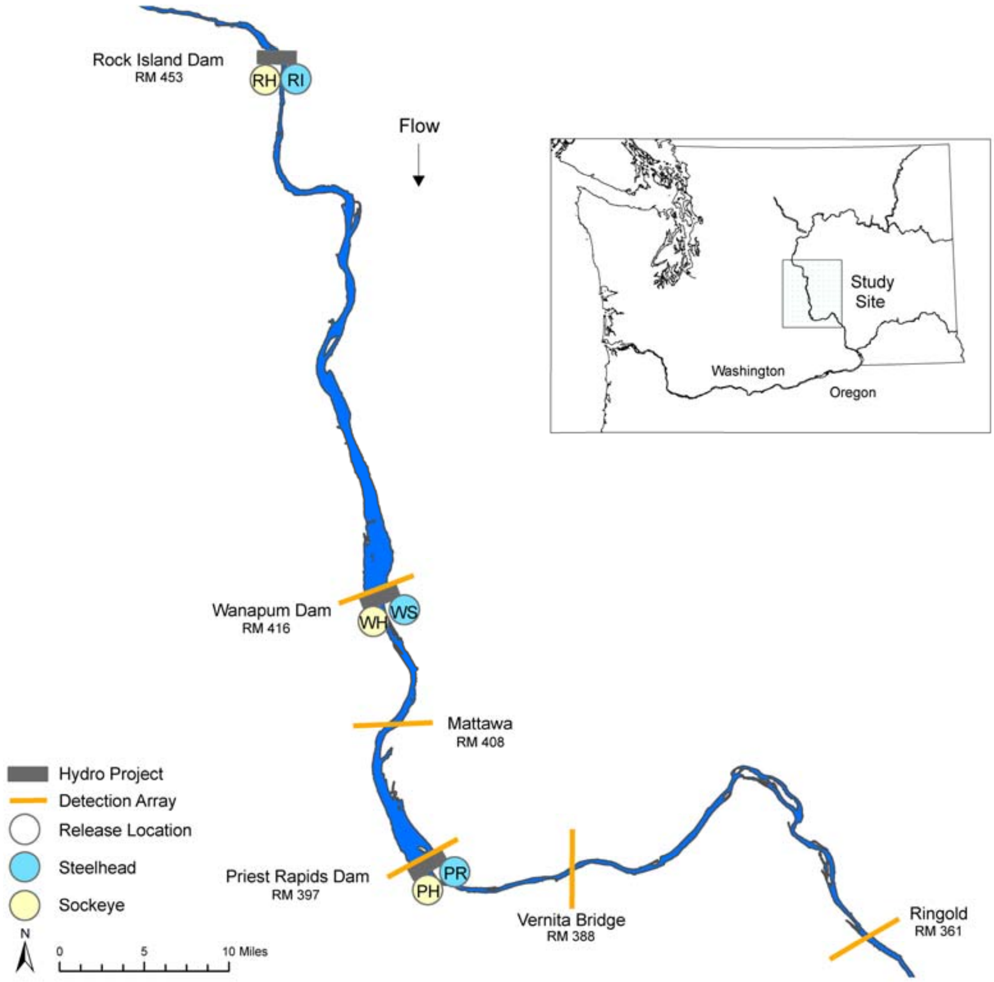


Figure 1. Study area from Rock Island Dam tailrace (RM 453) to RM 361, near the Washington Department of Fish and Wildlife Ringold Hatchery. Wanapum and Priest Rapids dams are located in the monitored reach at RM 416 and 397, respectively. The in-river detection arrays are noted above in orange. Release locations by species are illustrated (steelhead in blue at RI, WS, and PR; sockeye in yellow at RH, WH, and PH).

the Wanapum reservoir is the pool between Rock Island and Wanapum dams and the Priest Rapids reservoir is the pool between Wanapum and Priest Rapids dams. Both hydropower facilities are maintained and managed by Grant PUD.

Wanapum Dam operates 10 Kaplan turbine units, four of which are the new advanced turbines designed by Voith Siemens for the Department of Energy Advanced Hydro Turbine Program. Original and new turbines have a combined generating capacity of 1,071 megawatts (MW). Located south of the powerhouse is the Wanapum Future Unit Fish Bypass (WFUFB) which provides a non-turbine passage route for migrating salmonids. Operational in the spring of 2008, the WFUFB is a 290 ft long chute that was designed to pass a maximum of 20 kcfs, gradually decelerate fish without shear, and minimize total dissolved gas in the tailrace. Moving south from the WFUFB, the spillway joins the Future Units at a 45 degree angle, which extends to the southwest. The spillway contains 12 Tainter gates that open at the bottom to allow submerged flow at 65 ft below the surface (Figure 2).

Priest Rapids Dam operates 10 Kaplan turbine units with a combined generating capacity of 956 MW along the northeast end of the hydropower structure. The spillway (22 Tainter gates) joins the powerhouse near the middle of the dam and extends to the southwest (Figure 3). In 2006 a surface-flow prototype top-spill bulkhead was installed to test fish behavior and passage efficiency at Spillway gates 19 and 20. The top-spill prototype is 100 ft wide and can spill up to 16 kcfs of surface water (8 kcfs per spill bay). In 2009, the top-spill was operated in conjunction with bottom spill at Tainter gate 21 and surface spill at the sluiceway (Spill Bay 22), which was referred to as the "top-spill test configuration" (Figure 3). The average test configuration flow was 22.4 kcfs (7.0, 7.0, 7.5 and 0.9 kcfs through gates 19 – 22, respectively).

Collection and Surgery - Downstream migrating run-of-river steelhead and sockeye smolts were collected at Wanapum and Priest Rapids dams by dip netting fish from the emergency wheel gate slots (gatewells). Gatewells are water-filled vertical columns that extend from the ceiling of each turbine intake to the intake deck of the dam. The gatewells provide an exit route for salmonids prior to turbine entrainment and in turn have become an effective and reliable source of study fish (Park and Farr 1972; Sullivan et al 2008). All gatewell dipped fish were transported to the west bank of Wanapum Dam for sorting. After initial sorting of the smolts by species, size, and physical condition in a light MS-222 sedation, fish were held in 30 gal circular tubs with ambient river water re-circulating at approximately 6 gal/min for 24 hr prior to surgery. Study fish were removed from holding tubs and placed into an anesthesia bath (MS-222 at 60-80 mg/L) until a loss of equilibrium was obtained, at which time they were transferred to a surgical table and administered MS-222 through a gravity fed tube for the duration of the surgical procedure.

Acoustic transmitters were implanted into fish through an incision made along the mid-ventral line. Incisions were closed by two Vicryl coated sutures and fish were held for 24 hr prior to release. Fish handling was conducted by LGL Limited and detailed culling and surgical guidelines can be referenced in Appendix A.

Acoustic Tags and Data Collection - Two types of Hydroacoustic Technology, Inc. (HTI) Model 795 acoustic tags were implanted into study fish; steelhead received the E/PIT, a combination acoustic and PIT tag (6.8 x 21.8 mm, 1.65 g in air), and sockeye were implanted with the Lm acoustic tag (5.0 x 17.5 mm, 0.65 g in air). PIT tags were combined with steelhead E tags to identify avian predation events through tag recovery at Caspian tern colonies. All tags were received from the manufacturer in unique lots prior to the study (13 E/PIT lots and 17 Lm lots). To avoid potential effects of variability in tag lot quality, tag-life test tags were systematically sampled from each lot and randomly mixed before selection and activation of each tag-life test tag. The remaining tags were randomized and subsequently drawn from for surgical implant into test fish throughout the study. Furthermore, all tags were programmed (turned on) to match treatment and control groups so that as treatment and control fish (tags) mixed in-river, their tags had been active for the same amount of time.

Five unique locations were monitored for tagged fish by nine HTI Model 290 Acoustic Tag Receivers and 91 hydrophones (HTI Model 590). These include from upstream to downstream, Wanapum Dam (4 receivers and 37 hydrophones), Mattawa (1 and 8), Priest Rapids Dam (2 and 31), Vernita Bridge (1 and 7) and lastly Ringold (1 and 8) (Figure 2 and 3, Wanapum and Priest Rapids dams). Each tag was programmed to have a unique pulse rate (2.004 to 6.897 sec) and a common pulse width (1 msec). Acoustic detection arrays at the dams were configured to enable three-dimensional (3D) tracking of fish, while in-river arrays were limited to presence or absence information (Steig 1999; Steig et al 2001; Goodwin et al. 2006, Timko et al. 2007a, 2007b; Sullivan et al. 2008) (Appendix B). Detections, regardless of location, were accompanied by date/time, hydrophone ID, and signal strength (voltage) information and were stored in hourly files. Hourly files were uploaded in real-time to a SQL Server™ database and processed according to established protocols (Timko et al. 2007a, 2007b; Sullivan et al. 2008).

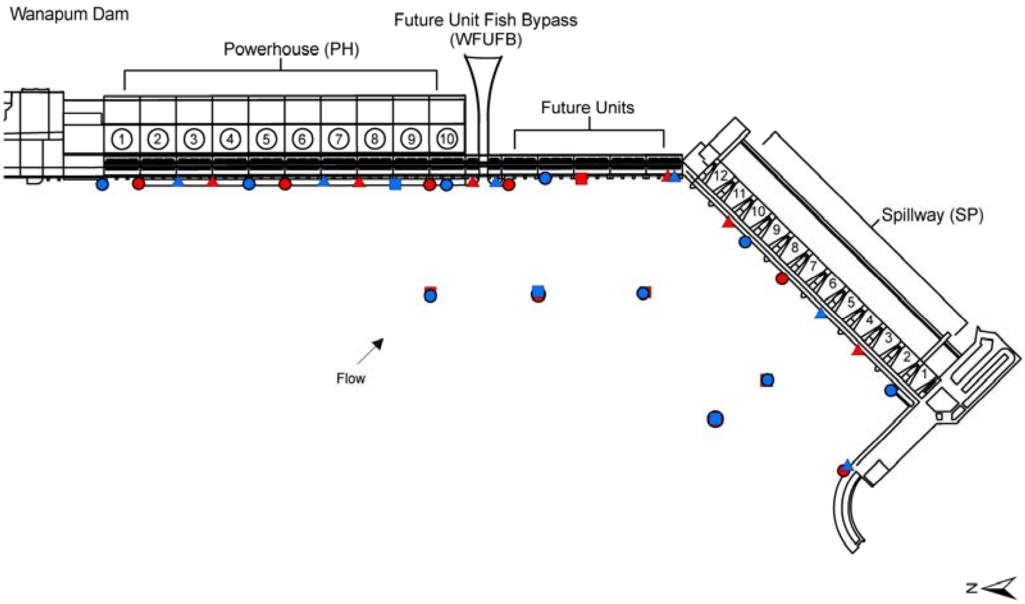


Figure 2. Schematic of Wanapum Dam hydroelectric facility (RM 416) is shown above with the corresponding hydrophone deployment locations that created an acoustic tag detection array. Two independent arrays were deployed in the forebay and are noted in red and blue.

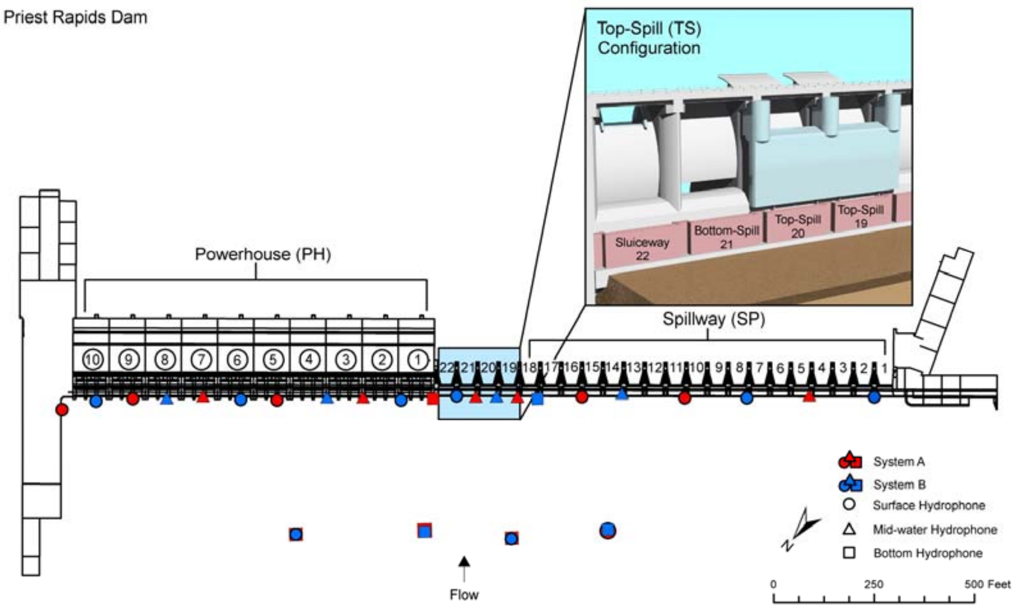
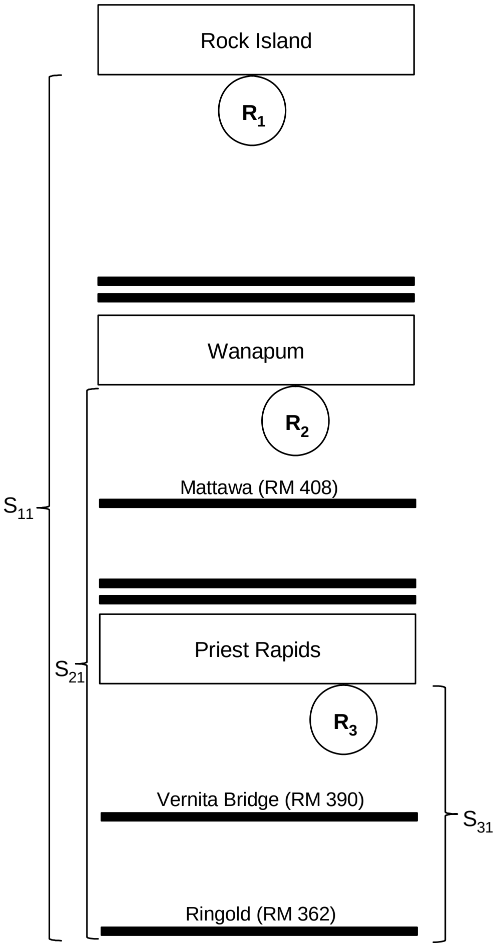


Figure 3. Schematic of Priest Rapids Dam hydroelectric facility (RM 397) is shown above with the corresponding hydrophone deployment locations that created an acoustic tag detection array. Two independent arrays were deployed in the forebay and are noted in red and blue.



Wanapum survival $S_{WAN} = \frac{S_{11}}{S_{21}}$

Priest Rapids survival $S_{PR} = \frac{S_{21}}{S_{31}}$

Figure 4. Survival study design is illustrated to depict release and detection locations throughout the Project, with particular emphasis on the estimation of survival at each dam. Black bars represent detection arrays.

Releases and Study Design - Steelhead and sockeye were released by helicopter in the tailraces of Rock Island, Wanapum, and Priest Rapids dams. Steelhead release groups were RI, WS, and PR while sockeye release groups were RH, WH, and PH, respectively, and are illustrated in Figure 1.

Approximately 1 hr prior to helicopter lift-off, fish were moved into specialized "fly-tanks" supplied with ambient river water, and tags were verified to ensure they were active and programmed correctly. Water flow was stopped 10 min prior to departure, at which time fly tanks were moved to the flight pad and oxygen tanks attached to the fly tanks were turned on. Release of fish was triggered from the cockpit of the helicopter by a thumb switch that was connected to the fly tank suspended below. Fish were released no higher than 10 ft from the surface of the river, which was verified by a spotter based on shore.

To estimate passage survival at Wanapum and Priest Rapids dams (and reservoirs) release-recapture methods were used (Zabel et al 2005; Timko et al 2007a, 2007b; Sullivan et al. 2008; Skalski et al. 2009a, 2009b, and 2009c). Paired treatment-control groups were released at successive dams, and were used in conjunction to measure dam and reservoir passage using acoustic detection arrays. Wanapum Dam and reservoir was tested with treatment and control groups released in the tailraces of Rock Island (RI) and Wanapum (WS) dams (Figures 1 and 4). Priest Rapids Dam and reservoir were tested with treatment and control groups released in the tailraces of Wanapum (WS) and Priest Rapids (PR) dams (Figures 1 and 4). Steelhead were released in 20 replicate groups and sockeye were released in 16 replicate groups at each release location (Figure 4 and Appendix C). There were fewer sockeye replicates because the duration of the sockeye migration run timing was predicted to be shorter than steelhead. Lastly, release quantities varied to mimic the bell shaped curve of the natural migration of fish (more fish were released during the middle of the study as compared to the beginning and end of the study).

Behavioral Analyses – In addition to estimates of survival, a number of techniques were used to analyze the data set for behavioral trends. Steelhead and sockeye were tracked in 3D at both Wanapum and Priest Rapids dams for thorough quantitative assessment of fish passage behavior at or near the WFUFB and the Priest Rapids prototype top-spill test configuration. The

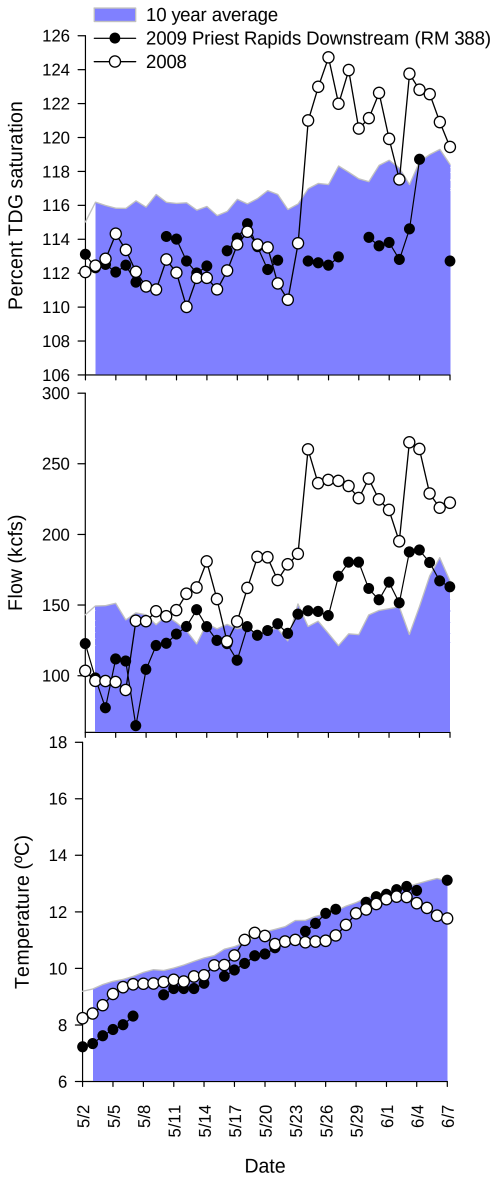


Figure 5. Daily median water quality values downstream of Priest Rapids Dam are shown from May 2 – June 7, 2008 and 2009 along with the 10 year average which is depicted in blue. Unconnected points represent gaps where data were not available (data source: www.cbr.washington.edu/dart/dart.html).

effectiveness of each fish bypass was measured by fish passage efficiency (FPE) or the ratio of the number of fish selecting top-spill passage as compared to other passage routes. Another measurement used to estimate bypass or top-spill effectiveness was Fish Collection Efficiency (FCE), which is a metric of estimating passage success of fish that enter a defined zone of influence (ZOI), in this case the proportion of fish that entered a zone extending 300 ft from the center of the top-spill (radius of 180°) and passed at the top-spill.

Various other analyses were performed to quantify fish behavior including: migration travel rates, approach distribution, and residence times and associated trends (Timko et al. 2007a, 2007b, Sullivan et al. 2008).

Results

Environmental Conditions – Environmental conditions, including percent Total Dissolved Gas (TDG) saturation, river flow as a function of tailwater elevation, and temperature were monitored downstream of Rock Island, Wanapum and Priest Rapids dams from May 2 to June 7, 2009. Detailed conditions were provided by the Columbia River DART website and are summarized in Appendix D for 2008-2009 and as the 10 year average. The environmental conditions measured at Priest Rapids Dam are shown in Figure 5. Flow and TDG saturation were generally lower in 2009 than 2008. Total dissolved gas saturation in 2009 was below the average for the past 10 years with peaks below Priest Rapids Dam reaching 118% in early June. In 2008 TDG saturation reached 124% below Priest Rapids Dam and was consistently greater than 120% from mid-May to the end of the study.

Flows in 2009 were closer to the 10 year average than in 2008 when peak flows of up to 250 kcfs were reached at each monitoring site. The average flow at all locations during the 2009 study ranged from 131.9-134.8 kcfs, compared to 174.9–183.6 kcfs during the 2008 field study. Water temperatures in 2009 were lower compared to the same period in 2008, in particular within the first three weeks of May (Figure 5).

Fish Characteristics - Combination acoustic-PIT tags (E/PIT) were surgically implanted in 2,100 run-of-river juvenile steelhead (34% wild and 66% hatchery) and released in paired replicates into the Priest Rapids Project. Paired replicate releases included Rock Island Dam tailrace (RI, n=800), Wanapum Dam tailrace (WS, n=650) and Priest Rapids Dam tailrace (PR, n=650) (Figure 1). Of the 2,100 steelhead that were released, 2,096 were used for data analysis (n=797 at RI, n=649 at WS, and n=650 at PR). Steelhead that were excluded from the study included two that were not initially released from the fly tank, one post surgical mortality, and one that suffered from poor health 24 hours post surgical implantation.

A total of 1,950 run-of-river juvenile sockeye (60% wild and 40% hatchery reared, with < 1% of unknown origin) were surgically implanted with the Lm acoustic tags and were released in paired replicates at the same locations as steelhead; Rock Island Dam tailrace (RH, n=650), Wanapum Dam tailrace (WH, n=650), and Priest Rapids Dam tailrace (PH, n=650). Seven sockeye that suffered from post surgical mortality were excluded from data analysis; a total of 1,943 were used for data analysis. Compared to the 2009 Rock Island run-timing smolt index (the untagged run), all tagged steelhead were released between the 4th and 78th percentile while sockeye were released between the 17th and 72nd percentile.

The distribution of steelhead and sockeye length and weight frequencies can be reviewed in Appendix C. There was no significant difference in the distribution of size between release groups within each species. Steelhead fork lengths ranged from 144–220 mm (mean length at 192 mm) and weight ranged from 30.5–89.5 g (mean weight at 65.5 g). Steelhead size was skewed to the right, towards the larger sized fish, with the largest quantity of fish being tagged with fork lengths between 195–199 mm (15.8%) and weights between 65–79 g (40.7%). Sockeye fork lengths ranged from 104–210 mm (mean length at 127 mm) and weight ranged from 12.5–85.5 g (mean weight at 20 g). Sockeye characteristics data was skewed towards the smaller sized fish, with the largest quantity of fish being tagged with fork lengths between 115–119 mm (19.5%) and weights between 15–19.5 g (40%). The average tag burden, or the tag to body weight ratio, for steelhead was 2.6% (range 1.8-5.6%) while the average sockeye tag burden was 3.5% (range 0.7-5.3%).

Acoustic Tags – The average E/PIT tag weighed 1.65 g (range 1.56-1.79 g) and the average Lm tag weighed 0.65 g (range 0.61-0.71 g). Fifty tags from the steelhead E/PIT tag series and 52 tags from the sockeye Lm series were programmed and monitored for tag life; the average tag battery life of the steelhead E/PIT tags was 25.8 days and the sockeye Lm tags was 21.5 days (tag life ranged from 6.1 to 49.0 days for the E/PIT tags and from 5.0 to 30.5 days for the Lm tags).

The results of the random tag distribution per tag lot and release site are shown in Table 1. The average tag failure rate of the E/PIT and Lm tag series was 1.8% and 2.3%, respectively. One tag lot in the Lm tag series exhibited an unusually high failure rate of 13.8% and was removed from the steelhead survival analysis (Table 1). The removal of this tag lot increased the average Lm tag life to 22.9 days because the first four tag failures were in tag lot 9817; the tag failure rate of the Lm tag series was 1.6% with the removal of tag lot 9817.

Data Collection – Acoustic tag detection systems were operational for a total of 56 days, from the first release, May 2, through June 26, 2009. Releases of tagged steelhead began on May 2 at Rock Island Dam and the first detection was recorded at Wanapum Dam on May 4, 2009. Sockeye releases began on May 14 and the last detection of both species was logged on June 7, 2009. During the nearly two months of monitoring, there was one period of interruption in data collection at the Mattawa in-river array, where a software error occurred and prevented data collection at this system for 3.5 hrs (of 12,960 total system hrs). Over the study period, a total of 66.6 million individual detections of acoustic tags were recorded at all sites combined. A total of 3,889 released fish were detected migrating downstream at a minimum of one detection array (1,986 steelhead and 1,903 sockeye). Based on capture histories, detection efficiencies of nearly 100% (range was 0.9982-1.0000 with standard errors below 0.002) were calculated for both tag series at all detection sites (Appendix B).

A small portion of the tagged steelhead were detected by PIT tag readers below our study area at McNary (RM 292), John Day (RM 216), and Bonneville (RM 146) dams as well as the Columbia River estuary experimental towing site (RM 19).

Table 1. Distribution of tag lots and failure rates per tag type are listed below. The subtotal per species indicates the proportion of all tags used in each release group. Tag lot 9817 was removed from survival analyses due to a significant proportion of premature tag failures within each lot.

		Failure	Rock Island		Wanapum		Priest Rapids		Life Test	
Tag Lot	Total	Rate (%)	n	%	n	%	n	%	n	%
Steelhead (E/PIT Tag)										
9101	188	2.47	78	0.10	57	0.09	48	0.07	5	0.10
9102	179	2.97	72	0.09	55	0.08	49	0.08	3	0.06
9103	184	3.32	72	0.09	62	0.10	45	0.07	5	0.10
9104	177	1.78	63	0.08	60	0.09	50	0.08	4	0.08
9105	172	0.86	60	0.08	54	0.08	54	0.08	4	0.08
9106	179	1.68	63	0.08	47	0.07	64	0.10	5	0.10
9107	180	1.72	57	0.07	55	0.08	63	0.10	5	0.10
9108	169	3.33	74	0.09	46	0.07	47	0.07	2	0.04
9109	169	1.26	63	0.08	56	0.09	46	0.07	4	0.08
9110	175	2.07	58	0.07	56	0.09	56	0.09	5	0.10
9111	140	1.64	50	0.06	39	0.06	49	0.08	2	0.04
9112	201	0.80	73	0.09	52	0.08	71	0.11	5	0.10
9113	33	0.00	14	0.02	10	0.02	8	0.01	1	0.02
$Subtotal_{ST}$	2,146		797	0.37	649	0.31	650	0.31	50	0.02
Sockeye (Lm Tag)										
9805	5	0.00	3	0.00	1	0.00	0	0.00	1	0.20
9806	122	3.85	29	0.04	43	0.07	47	0.39	3	0.02
9807	46	1.67	14	0.02	11	0.02	20	0.43	1	0.02
9808	161	0.94	50	0.08	61	0.09	46	0.29	4	0.02
9809	165	1.32	53	0.08	51	0.08	57	0.35	4	0.02
9810	165	1.40	43	0.07	62	0.10	56	0.34	4	0.02
9811	127	2.23	40	0.06	34	0.05	50	0.39	3	0.02
9812	159	2.96	60	0.09	55	0.08	40	0.25	4	0.03
9813	178	3.38	67	0.10	50	0.08	57	0.32	4	0.02
9814	164	0.93	63	0.10	50	0.08	47	0.29	4	0.02
9815	150	0.93	48	0.07	46	0.07	52	0.35	4	0.03
9816	145	3.02	49	0.08	52	0.08	40	0.28	4	0.03
9818	147	0.99	59	0.09	46	0.07	40	0.27	2	0.01
9819	94	1.56	26	0.04	28	0.04	36	0.38	4	0.04
9825	23	0.00	6	0.01	7	0.01	9	0.39	1	0.04
9827	11	0.00	5	0.01	3	0.00	3	0.27	0	0.00
$Subtotal_{SK}$	1,995		649	0.33	648	0.32	646	0.32	52	0.03

Table 2. Summary of survival studies at Wanapum and Priest Rapids dams and associated upstream reservoirs in 2008 and 2009 (Skalski et al. 2009c). Project passage survival estimates and standard errors are presented by species, year, and location. The asterisks indicate the overall Project survival shown as the product of both dams and reservoirs.

Species	Project	Year	$\hat{S}$	Standard Error
Steelhead	Wanapum	2009	0.9436	0.0189
		2008	0.9584	0.0242
	Priest Rapids	2009	0.8806	0.0206
		2008	0.8635	0.0232
	Joint W-PR*	2009	0.8309	0.0256
		2008	0.8276	0.0305
Sockeye	Wanapum	2009	0.9726	0.0093
	Priest Rapids	2009	0.9460	0.0114
	Joint W-PR*	2009	0.9201	0.0142

Survival Analysis – The survival estimate of steelhead at Wanapum project (one dam and reservoir) was 0.9436 (0.0189) and at Priest Rapids project (one dam and reservoir) was 0.8806 (0.0206) (Table 2) (Skalski et al. 2009c). The joint Wanapum-Priest Rapids survival of steelhead was 0.8309 (0.0256). The survival estimate of sockeye at Wanapum project was 0.9726 (0.0093) and at Priest Rapids project was 0.9460 (0.0114). The joint Wanapum-Priest Rapids survival of sockeye was 0.9201 (0.0142). All survival estimates for both species yielded acceptable and often times much smaller than required standard errors (Table 2) (NMFS 2004, NMFS 2008, SSSA 2006, Skalski et al. 2009c). The detailed paired-release survival analysis of steelhead and sockeye smolts through Wanapum and Priest Rapids dams is presented in a separate report (Skalski et al. 2009c).

Using the tagged steelhead and sockeye known to have successfully arrived at Wanapum and Priest Rapids dams, route-specific relative survivals were estimated through each dam in 2009. At both dams, survival was quantified as relative to those fish that passed through the powerhouse. Steelhead that passed through the Wanapum WFUFB and Priest Rapids top-spill test configuration had significantly higher survival estimates; sockeye that passed at the Priest Rapids top-spill also had a significantly higher survival estimate (Appendix E and F). The majority of steelhead (70%) passed through the WFUFB at Wanapum Dam and were estimated to have a 6.5% higher survival likelihood; steelhead route-specific relative to powerhouse survival was 1.0656 (0.0214). The majority of sockeye at Wanapum Dam also passed through the WFUFB (59%), and survival was not significantly different from sockeye that passed through the powerhouse. At Priest Rapids Dam, steelhead and sockeye survival was significantly higher through the prototype top-spill configuration than the powerhouse. The relative routes specific survival of steelhead through the prototype top-spill was 1.0862 (0.0228) and sockeye was 1.0451 (0.0175), which means fish that passed through the top-spill had a higher survival rate than fish that passed through the powerhouse (steelhead at Δ+8.6% and sockeye at Δ+4.5%) (Appendix F).

The results of the relative survival of draft tube released steelhead and sockeye that were released separate from this study in the immediate tailrace of Priest Rapids Dam, at the draft tube exit, are shown in Appendix E and F as they compare to the current control release location by helicopter. Additional methods and results associated with this group of draft tube released fish are shown in Appendix I.

Based on acoustic tag detection histories, we found that when fish selected the WFUFB at Wanapum Dam or the prototype top-spill at Priest Rapids Dam for passage, they were more likely to be detected downstream of each dam (Table 3). Ninety-nine percent of the steelhead that bypassed Wanapum Dam at the WFUFB were detected downstream compared to 92.9% of the steelhead which selected the powerhouse. Similarly, 98.4% of the sockeye that passed at the WFUFB were detected downstream compared to 96.2% for those which selected the powerhouse. At Priest Rapids Dam, 97.5% of steelhead that selected the prototype top-spill were detected downstream, 4.6% higher than steelhead that selected the powerhouse (92.9%). Sockeye that selected the prototype top-spill for passage were detected downstream at a slightly higher rate (1%) than those which selected the powerhouse (95.9% top-spill and 94.9% powerhouse).

Reach Survival – The acoustic tag detection histories were reviewed for both species and release sites; if a tag was detected downstream of a defined reach at a hydrophone array, the fish was presumed alive (Timko et al. 2007a). Sockeye reach survival was higher throughout all reaches compared to steelhead; sockeye reach survival by release group ranged from 95.4% to 99.3% and steelhead ranged from 86.2% to 97.1% (Table 4). Upstream of Vernita Bridge, the reach with the lowest overall survival for steelhead was between Rock Island and Wanapum dams. However, steelhead survival calculated by RM (upstream of Vernita Bridge) was lowest downstream of Wanapum and Priest Rapids dams, where approximately 0.5% of tagged fish were removed from the study per mile. The greatest loss in sockeye by RM occurred directly downstream of both dams.

Table 3. Number of tags that passed at each dam is listed by route with the corresponding percentage of tags which were detected downstream.

	Wanapum Dam				Priest Rapids Dam			
	Steelhead		Sockeye		Steelhead		Sockeye	
Passage Route	n	%	n	%	n	%	n	%
Powerhouse	198	92.9	234	96.2	499	92.9	654	94.9
Bypass/Top-Spill	513	99.0	378	98.4	621	97.5	465	95.9
Spillway	0	0.0	19	89.5	1	100.0	37	97.3

Table 4. Proportion of tags that were detected downstream of each river reach (defined by the acoustic tag detection arrays) are listed below by species and release site. The average percent of tag loss by river mile (RM), which is assumed as fish mortality, is also shown in italics.

	Percent of Acoustic Tags Detected by Reach (%)				
Release Site	RISD-WADM	WADM-MATT	MATT-PRDM	PRDM-VEBR	VEBR-RING
Steelhead					
Rock Island	92.0	97.1	94.6	95.6	91.7
Wanapum		94.6	96.0	94.7	89.6
Priest Rapids				97.1	86.2
Loss by RM	*0.2*	*0.5*	*0.4*	*0.5*	*0.4*
Sockeye					
Rock Island	98.1	97.2	99.0	95.4	98.6
Wanapum		98.3	98.6	95.4	99.3
Priest Rapids				97.4	97.9
Loss by RM	*0.1*	*0.3*	*0.1*	*0.4*	*0.1*

Table 5. Avian predation impacts by reach and river mile are presented based on the recovery of PIT tags at Banks Lake, Potholes Reservoir, the loafing areas upriver of Priest Rapids Dam, and Crescent Island (just upriver of McNary Dam). Quantity presented is the number of tags recovered from each reach, defined by the predation event occurring downstream of last acoustic detection. The total percent by reach is the total number of PIT tags recovered of those available in the reach that were detected migrating downriver with acoustic tags. Regions that experienced an increase in avian predation in 2009 are in bold.

	2008				2009			
Reach	Available Tags	Quantity Detected	% by Reach	% by RM	Available Tags	Quantity Detected	% by Reach	% by RM
Rock Island - Wanapum	648	18	2.78	0.08	797	22	2.76	0.07
Wanapum - Mattawa	1,257	9	0.72	0.09	1,388	16	1.15	0.14
Mattawa - Priest Rapids	1,150	11	0.96	0.09	1,328	11	0.83	0.08
Priest Rapids - Vernita	1,670	6	0.36	0.04	1,918	6	0.31	0.03
Vernita - Ringold	1,551	32	2.06	0.08	1,818	62	3.41	0.13
Ringold	1,317	5	0.38		1,621	17	1.05	
Total	1,880	81	4.31		2,096	134	6.39	

Avian Predation - The composite E/PIT tags implanted into steelhead in 2009 were monitored during the annual investigation of avian predation at islands with piscivorous bird activity in the Mid-Columbia River. These investigations were led by Real-Time Research in the Mid-Columbia River at Banks Lake, Potholes Reservoir, the loafing areas above Priest Rapids Dam, and Crescent Island which is located upriver of McNary Dam. A total of 134 PIT tags that were associated with steelhead released in the Grant PUD study area in 2009 were recovered (at least one tag was recovered at each investigation location). This accounted for 6.4% of all steelhead released in 2009 (134 out of 2,096 tagged and released steelhead) (Table 5). The majority of the tags detected (88%) were recovered from the islands in the Potholes Reservoir that are populated by nesting Caspian terns (*Hydroprogne caspia*) (Figure 6). There were no noteworthy differences in predation between the release groups of steelhead, and length and weight did not appear to be a factor in predation selection.

Avian predation events in 2008 and 2009 are listed in Table 5, where the total percent by reach is shown along with the overall total number of PIT tags recovered within the study area. Reach is defined by release site or detection array to the next downstream acoustic detection array and the number of available tags is the sum of tags that were released or detected at the start of each reach. The PIT tags that were recovered and associated with a Grant PUD acoustic tag were assigned to a stretch of the river within the Project; it was assumed that the predation event occurred downriver of the last site where the mated acoustic tag was detected.

Although there was a 2% increase in the total number of study fish taken by avian predators in 2009, avian impacts as they relate to Project survival estimates were similar to those of 2008. Of the 6.4% steelhead taken in 2009, only 2.6% were taken upstream of Vernita Bridge (2.3% in 2008) where Project survival estimates were likely impacted by predation events. The data in Table 5 has not been modified to account for PIT tag detection efficiency because current values were unknown at the time of this report.

As a standardized comparison, the percent of tags taken by river mile was also calculated for each reach. Amongst all of the reaches, the reach between Vernita Bridge and Ringold experienced the greatest increase in total number of predation events compared to 2008 (Δ+1.35%). The reach between Wanapum and Mattawa also experienced an increase in avian predation, with an estimated loss of 0.5% per RM (Table 5).

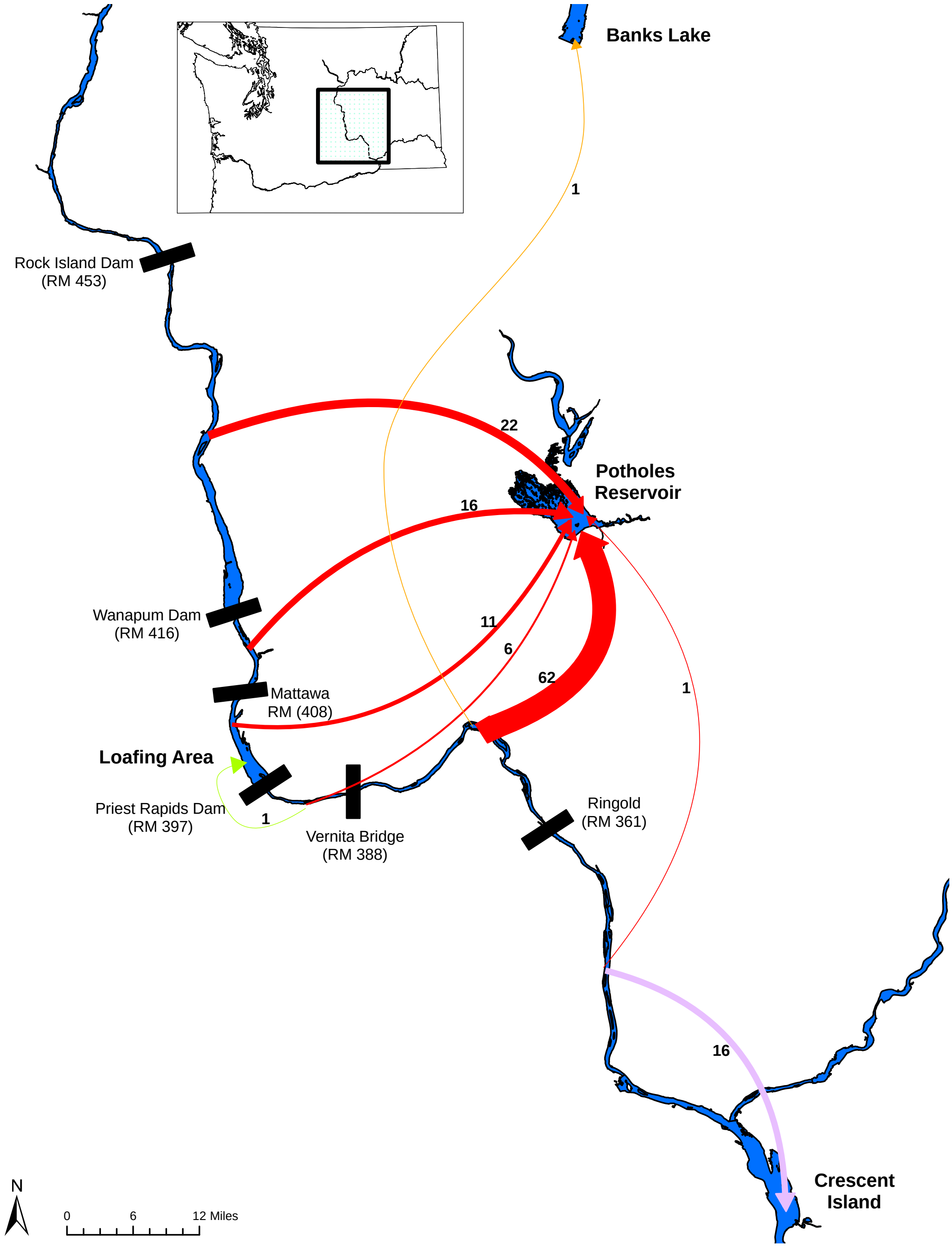


Figure 6. Avian predation by reach and recovery location of 2009 steelhead PIT tags is illustrated. Arrows do not indicate flight paths or exact point of predation, rather the transfer of PIT tags from a reach to the deposition location where tags were detected. Line width represents the relative quantity of PIT tags transferred.

Migration Travel Rates – In 2009, the steelhead migration travel rates were significantly slower than the past three study years and was especially evident in the reservoirs upriver of both dams (Figure 7). Results suggest that travel times were correlated with the average river flows in each year during the test periods (Figure 7). The median travel time to Wanapum Dam from the tailrace of Rock Island Dam was 61.1 hr, a 25.0% increase over the average median travel time of 2006-2008 (Appendix G). Median travel time to Priest Rapids Dam increased to 23.1 hr, 39.5% higher than past years. Though less pronounced than at the dams, the travel times to in-river sites in the shorter reaches immediately downriver of both dams increased slightly at Mattawa (Δ+3.9%) and Vernita Bridge (Δ+2.1%). The median travel rates to Ringold were slower by 17.3% than in previous years.

Sockeye migration times also showed a general slowing in 2009 over previous years, though not as prominent as steelhead (Figure 7). Average median travel times to all sights were up slightly with the exception of travel time to Wanapum Dam which was faster in 2009 (42.9 hr) than in 2006 (45.1 hr). When comparing the 2009 travel times to the average median of 2006-2008, they were longer in 2009 at all sites with an increase between 5.6% and 16.0%.

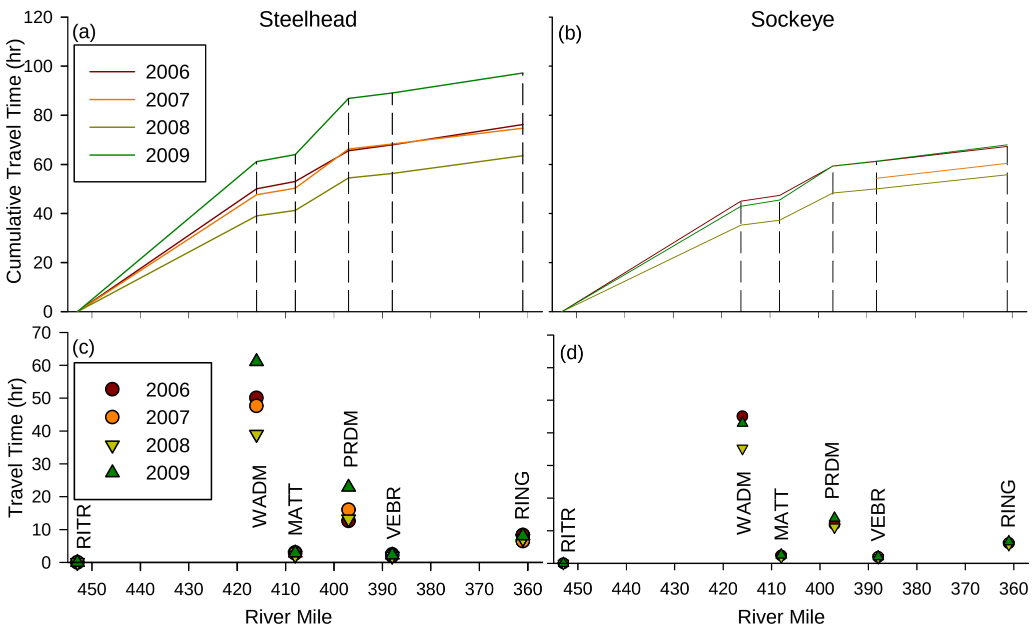


Figure 7. Median travel times to detection systems. Cumulative median travel time between each detection system by river mile for (a) steelhead and (b) sockeye. Non-cumulative median travel time from previous detection system by river mile for (c) steelhead and (d) sockeye.

Behavior Analyses

Approach - Most steelhead and sockeye approached the powerhouse at both dams in the top 15 ft of the water column. Figures 8 and 9 present steelhead and sockeye approach behavior (additional approach patterns shown in Appendix H). At Wanapum Dam, there was a second peak at 50 ft deep (approximate elevation 520 ft) for both species as they approached within 100 ft of the powerhouse. Steelhead and sockeye that were detected 100 to 300 ft from the powerhouse were predominately in the top 10 ft of the water column. At Priest Rapids Dam, steelhead were concentrated in the top 10 ft of the water column within 50 ft of the dam, and in the top 15 ft within 50 to 300 ft of the dam (Figure 8). The majority of sockeye that were detected within 50 ft of Priest Rapids Dam were concentrated in the top 15 ft of the water; however, compared to the approach distribution of steelhead within 50 ft of the dam, a greater proportion of sockeye were recorded at depths of 65 ft below the surface (approximate elevation 420 ft). At 50 to 200 ft from the dam, sockeye were most commonly detected in the top 15 ft of the water column, and at 200 to 300 ft from the dam they were primarily 10-20 ft deep.

Forebay Residence Times - The median forebay residence times of fish passing downriver of Wanapum and Priest Rapids dams were significantly longer in 2009 than 2006, 2007, or 2008 (Table 6). A t-test of log transformed residence time for annual comparisons at each dam by species consistently resulted in a p-value of less than 0.001. The median residence times of steelhead and sockeye at Wanapum Dam was 1.32 hr and 0.64 hr, respectively. At Priest Rapids Dam, the median residence times of steelhead and sockeye passing the dam was 0.96 hr and 0.40 hr, respectively. At both dams, the median residence times of steelhead was longer than those of sockeye and is consistent with previous research (Table 6 and Appendix G). The median residence times of each species at each dam are listed by passage route in Appendix G.

Diel Passage - To assign day or night passage, the last detection for each fish was recorded, compared to sunrise/sunset date and time for that specific passage time, and assigned the day or night passage block. A higher percentage of steelhead and sockeye passed both Wanapum and Priest Rapids dams during the nighttime blocks as compared to daytime blocks (Figure 10). At Wanapum Dam an average of 41.3 steelhead and 34.5 sockeye passed per hour during the night, while 24.1 steelhead and 21.8 sockeye passed during the day. This pattern was more exaggerated at Priest Rapids Dam, where an average of 85.2 steelhead and 58.7 sockeye passed per hour during the night; while 33.4 steelhead and 47.6 sockeye per hour passed during the day (Figure 10).

Passage Route Efficiency – Passage Route Efficiency (PRE) is defined as the proportion of fish selecting a particular route of passage. In 2009, an increase in non-turbine passage was recorded at Wanapum and Priest Rapids dams (Figure 11 and Figure 12). At Wanapum Dam, 70.2% of steelhead and 59.3% of sockeye passed through the WFUFB and most of the remaining fish passed through the powerhouse. An increase of passage at the WFUFB by steelhead and sockeye compared to 2008 field studies was Δ+16.7% and Δ+27.2%, respectively. A small number (3%) of sockeye exited via the spillway during limited periods of inadvertent spill. A significant increase in passage at the top-spill test configuration of Priest Rapids Dam was recorded for both species; 51% of steelhead and 39% of sockeye passage events occurred at the top-spill test configuration (sluiceway at Tainter gate 22, Tainter gate 21, and the prototype top-spill bulkhead at Spill Bay gates 20 and 19). Compared to the 2008 field studies, the increase in steelhead and sockeye passage at the top-spill configuration was significant at Δ+17.7% and Δ+16.8%, respectively.

Table 6. Annual comparison of median forebay residence times at Wanapum and Priest Rapids dams presented in hours and do not include fish that were entrained in the gatewells, had an unknown passage location, or were last recorded with net upstream movement.

Species	Year	All Routes (hr)
Wanapum Dam		
Steelhead	2009	1.32
	2008	0.49
	2007	0.71
	2006	0.57
Sockeye	2009	0.64
	2008	0.16
	2006	0.24
Priest Rapids Dam		
Steelhead	2009	0.96
	2008	0.24
	2007	0.34
	2006	0.34
Sockeye	2009	0.40
	2008	0.12
	2007	0.20
	2006	0.25

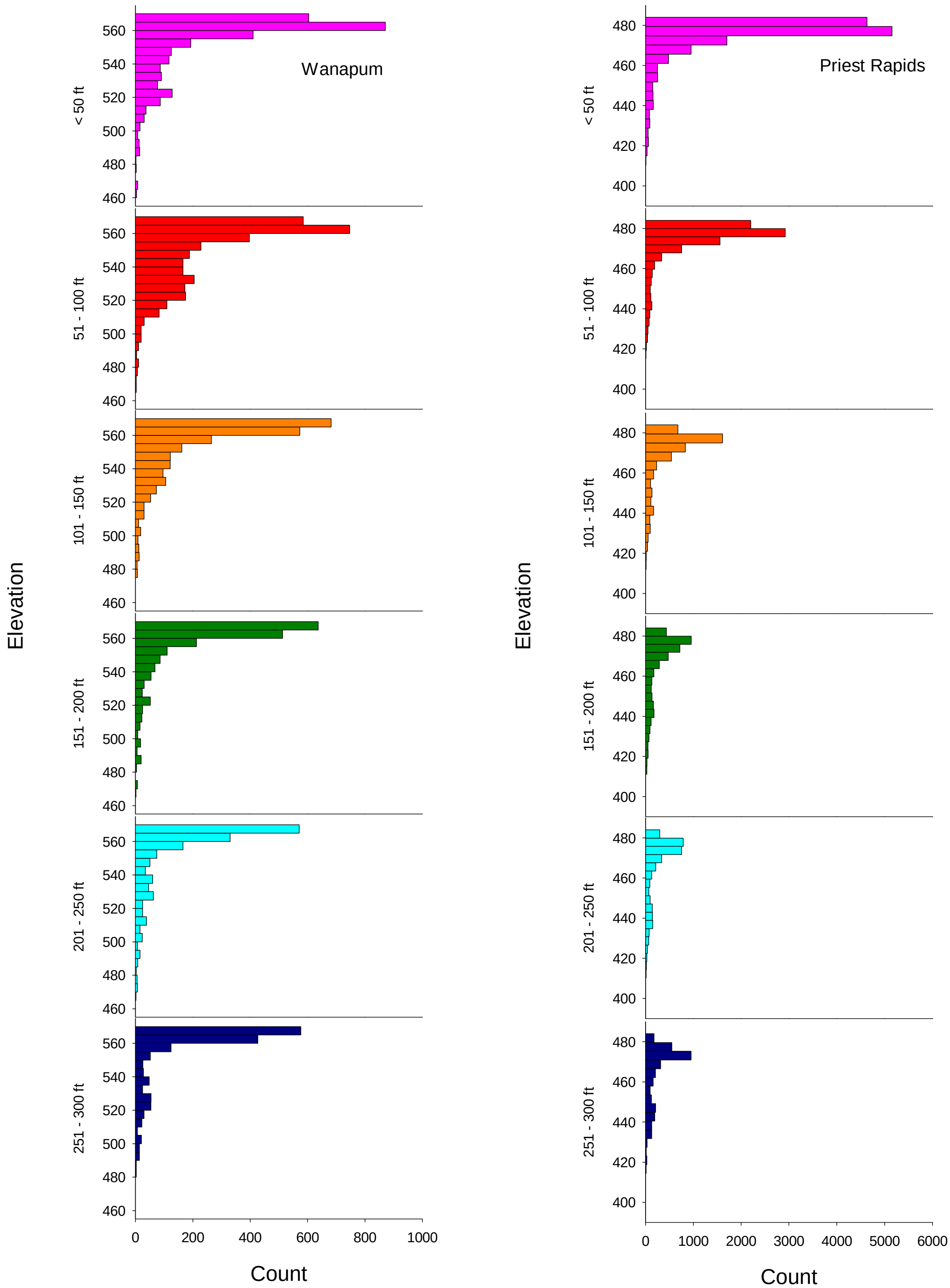


Figure 8. Approach elevations (depth) for steelhead at Wanapum (left) and Priest Rapids (right) dams in 2009 are illustrated as distance increased from the face of each dam. Pink represents fish within 50 ft of the powerhouse, red 51-100 ft, orange 101-150 ft, green 151-200 ft, light blue 201-250 ft, and dark blue 251-300 ft. Fish locations were normalized by proportion of residence time with a maximum of 100 locations per fish.

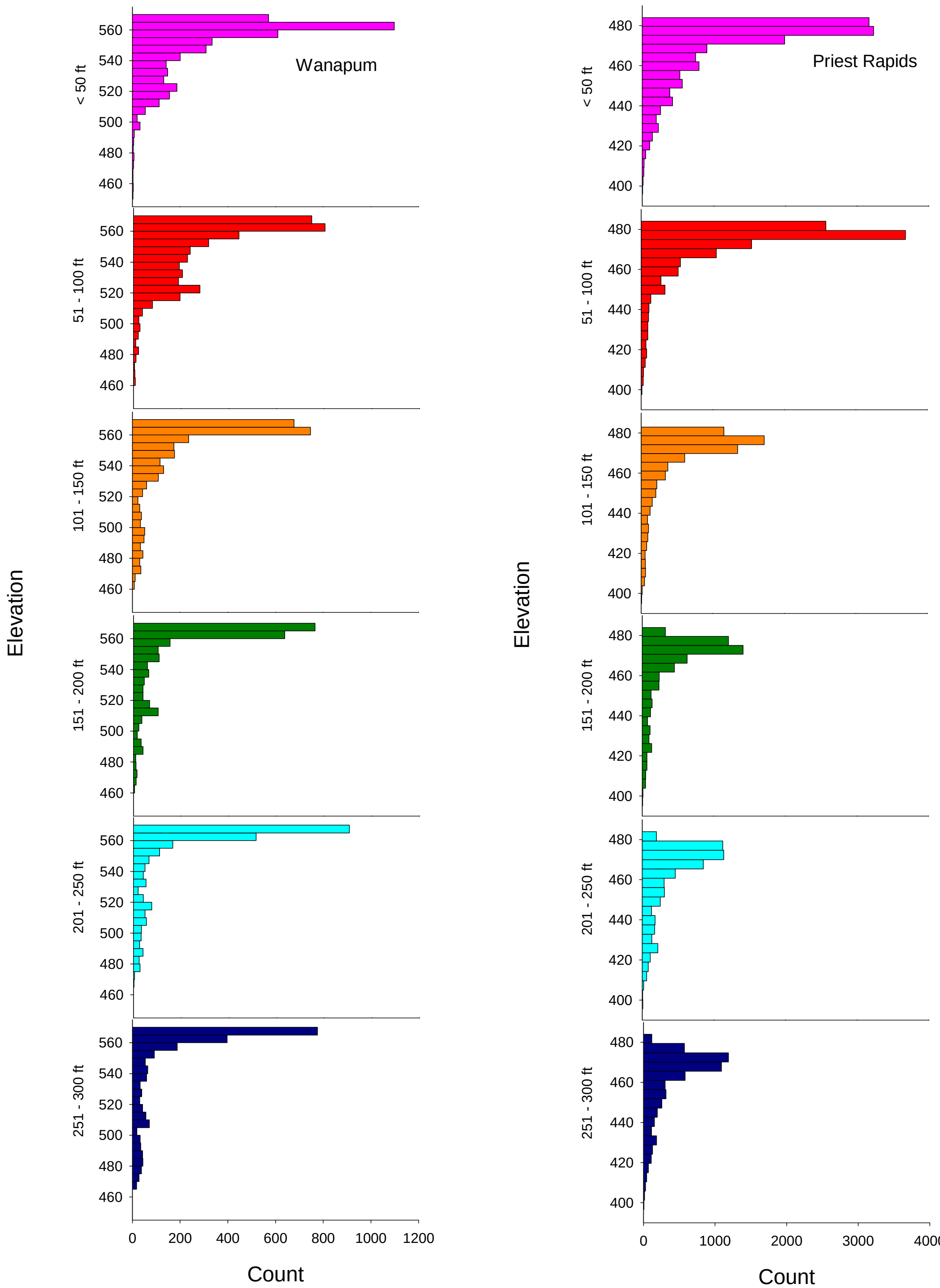


Figure 9. Approach elevations (depth) for sockeye at Wanapum (left) and Priest Rapids (right) dams in 2009 are illustrated as distance increased from the face of each dam. Pink represents fish within 50 ft of the powerhouse, red 51-100 ft, orange 101-150 ft, green 151-200 ft, light blue 201-250 ft, and dark blue 251-300 ft. Fish locations were normalized by proportion of residence time with a maximum of 100 locations per fish.

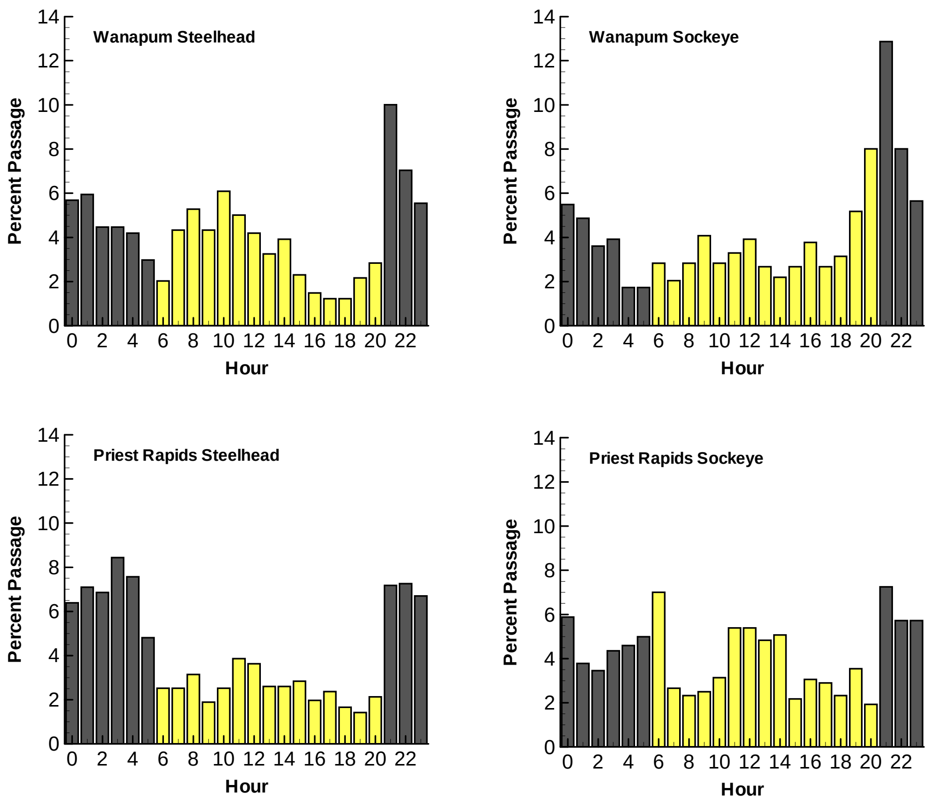


Figure 10. Percent passage of steelhead and sockeye binned by hour at Wanapum (top figures) and Priest Rapids (bottom figures) dams. Yellow indicates daytime passage events while gray indicates nighttime passage events.

At Priest Rapids Dam there was a split in passage of steelhead between the powerhouse and top-spill configuration, 49% and 51%, respectively, and few steelhead passage events occurred at the spillway. Sockeye were more apt to pass through the powerhouse (58%). A detailed list of passage percentages and annual comparisons from 2006-2009 can be referenced in Appendix H.

Density Plots - Steelhead and sockeye passing both Wanapum and Priest Rapids dams showed similar patterns in regard to passage densities. At Wanapum Dam, fish that passed the powerhouse were at highest density in front of units 6 and 7 and were at lowest densities in front of the future units and low numbered spillway bays (Figure 13). Fish that passed the WFUFB were at highest density within the 300 ft contour extending from the WFUFB entrance and also in front of the future units and low to mid-numbered spillway bays (Figure 13).

At Priest Rapids Dam, fish that passed the powerhouse were at highest density in front of units 1 through 5, extending out several hundred feet from the dam along the path of predominant river flow (Figure 14). Fish that passed the powerhouse were at lowest densities in front of units 8 through 10 and along the spillway. Fish that passed the top-spill were at highest densities on the spillway side of the top-spill within the 300 foot contour from the top-spill entrance and in front of the mid to high-numbered spillway bays (Figure 14). Steelhead and sockeye that passed the top-spill were also present in low to medium-density in front of powerhouse unit 7. Fish that passed the top-spill were at lowest density in front of the powerhouse (except unit 7) and spillway bays 1 through 7.

Sounding - Steelhead and sockeye smolt sounding events were compared at Wanapum and Priest Rapids dams. A sounding event was defined as moving down in the water column at least 10 ft and back up again within a 10 minute time frame. Across both species and dams most sounding events occurred in the upper water column. At Wanapum Dam both species had comparatively few sounding events (less than 10) regardless of passage route when compared to Priest Rapids Dam fish. At Priest Rapids Dam steelhead that passed the top-spill sounded over 30 times in the upper water column (Figure 15). Both steelhead and sockeye that passed the powerhouse sounded over 20 times in the upper water column. However, sockeye that passed through the top-spill sounded much less frequently (less than 15 events) (Figure 15).

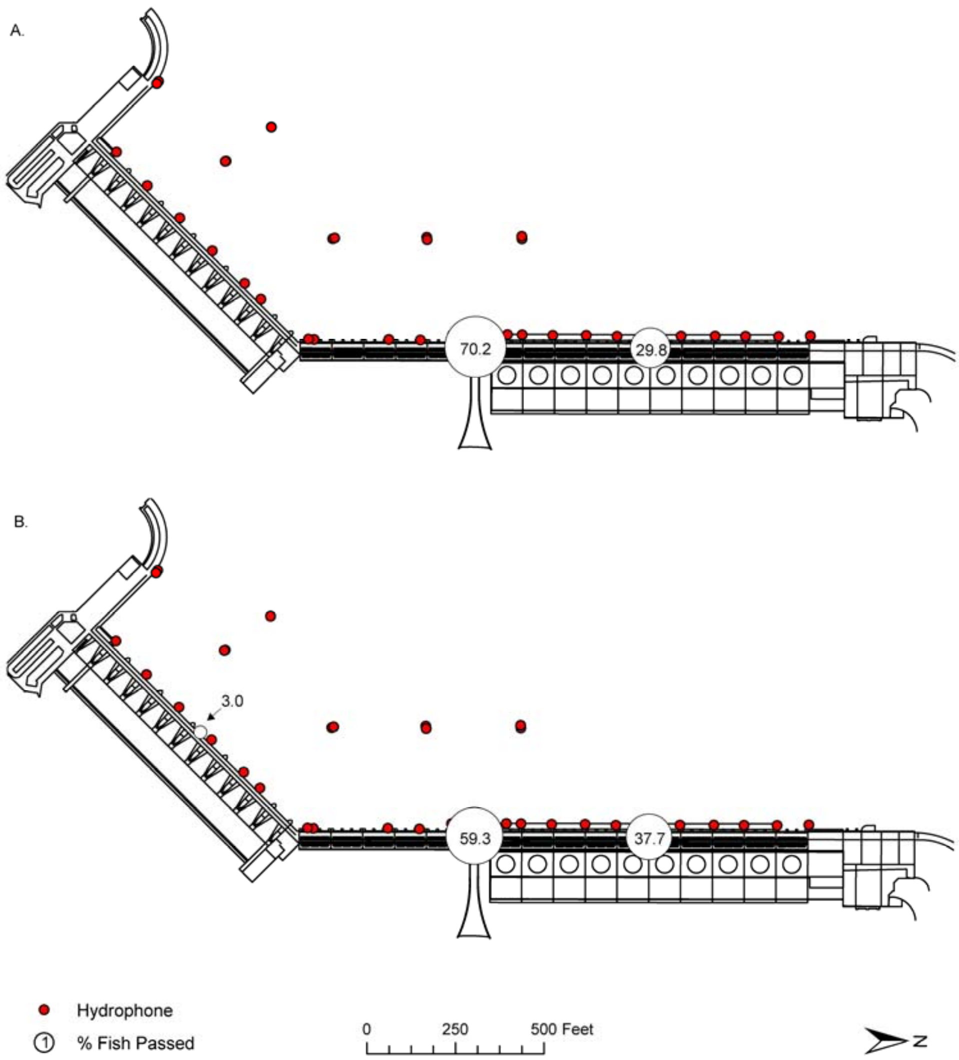


Figure 11. Passage proportions at Wanapum Dam in the spring of 2009; the top figure (A) presents steelhead and the bottom figure (B) presents sockeye.

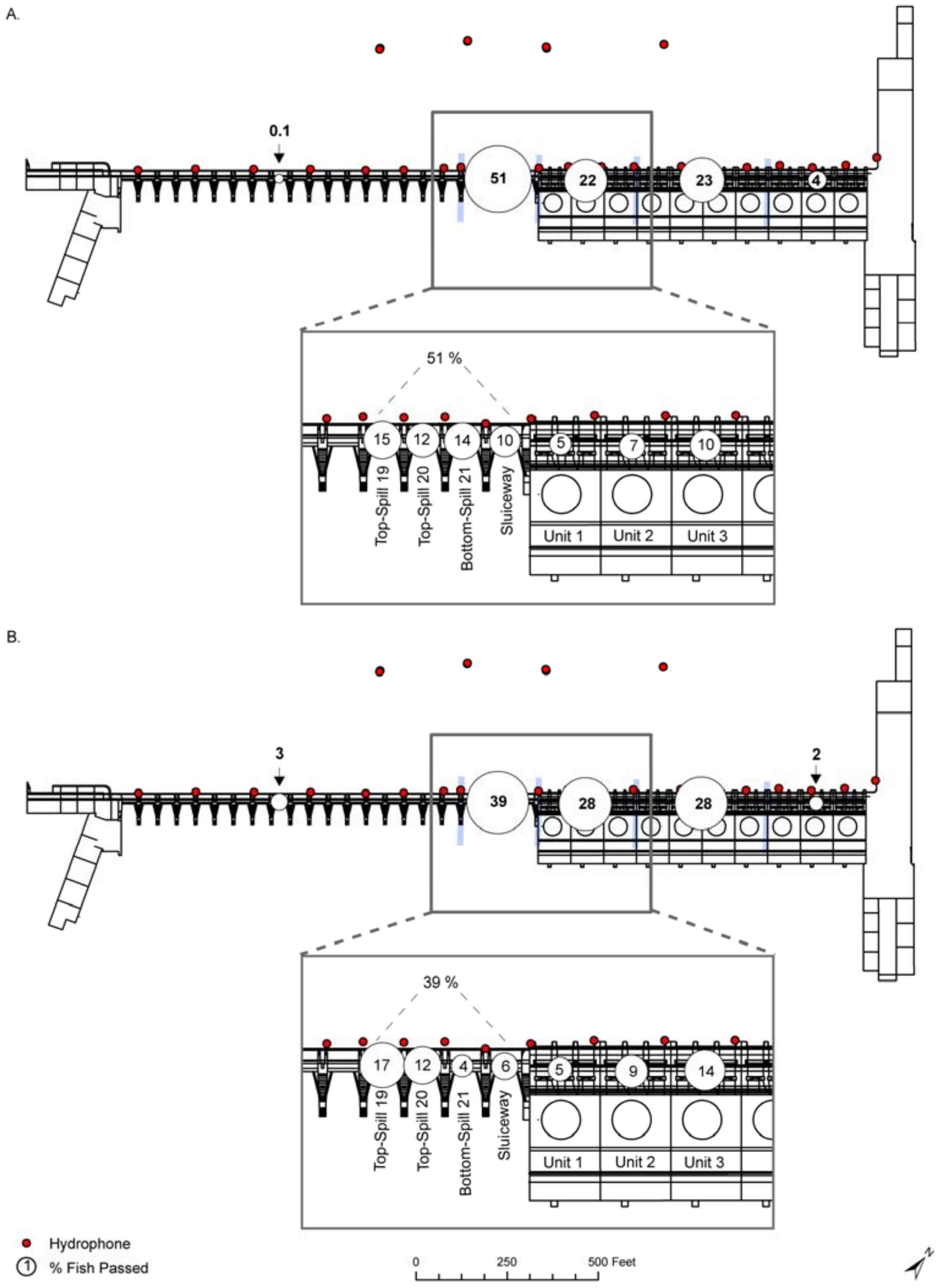


Figure 12. Passage proportions at Priest Rapids Dam in 2009; the top figure (A) presents steelhead and the bottom figure (B) presents sockeye. Detailed passage proportions at the powerhouse (turbine Units 1-3) and top-spill configuration are highlighted.

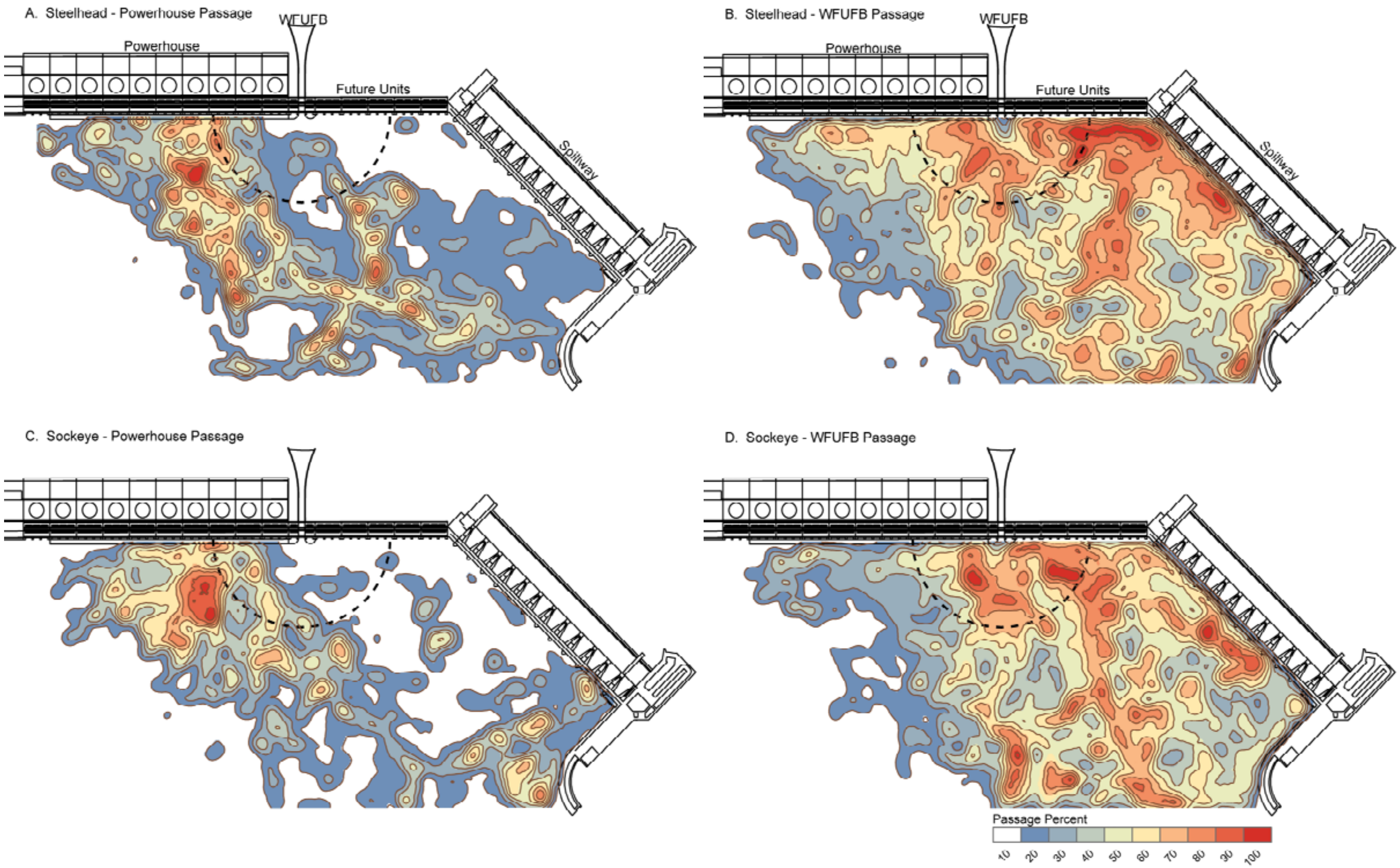


Figure 13. Passage percent bin densities for steelhead and sockeye passing Wanapum Dam in 2009. Dotted line represents 300 ft contour from the center of the WFUFB.

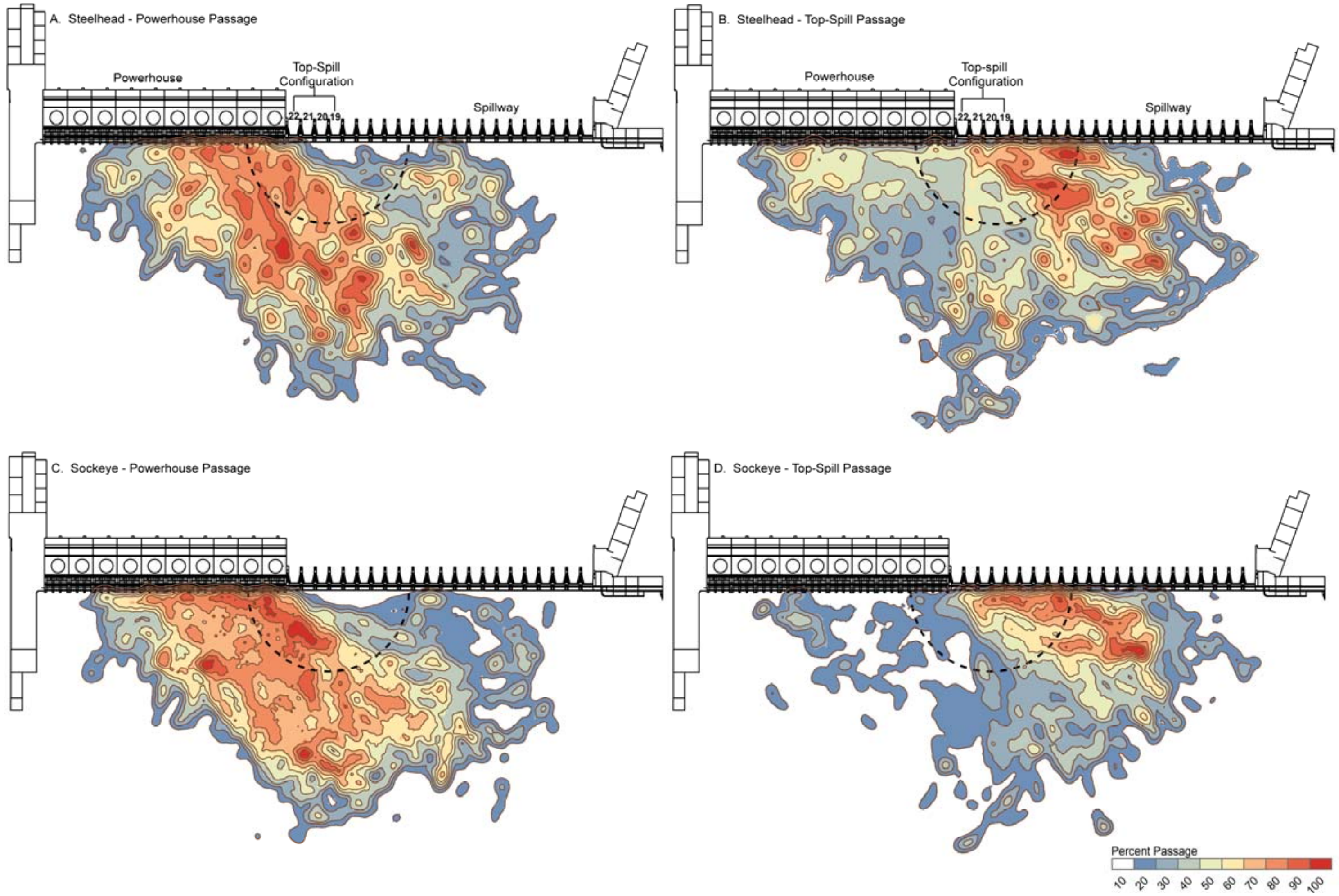


Figure 14. Passage percent bin densities for steelhead and sockeye passing Priest Rapids Dam in 2009. Dotted line represents 300 ft contour from the center of the top-spill.

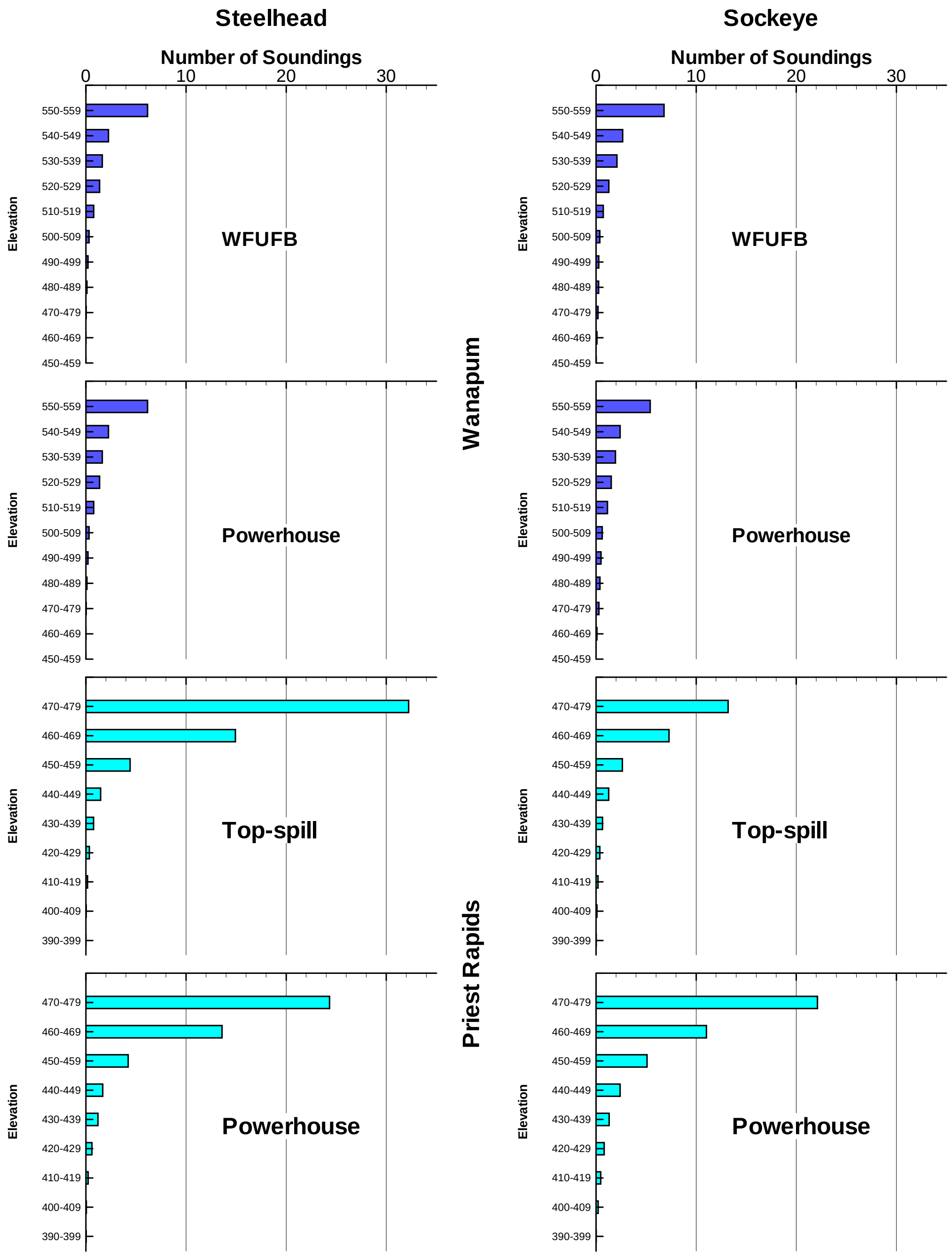


Figure 15. Sounding behavior and passage location (powerhouse or WFUFB/top-spill) of steelhead and sockeye at Wanapum (top four figures) and Priest Rapids (bottom four figures) dams, 2009.

Bypass Non-Selection - Steelhead and sockeye smolts that approached within 300 ft of the Wanapum Dam WFUFB or Priest Rapids Dam top-spill but did not pass at these locations were termed "non-selection." At the WFUFB, steelhead non-selection was distributed with a higher concentration towards the powerhouse side (Figure 16a). Steelhead on the powerhouse side tended to be deeper (approximate elevation 460-500 ft) than steelhead directly in front of the WFUFB entrance and future unit side (approximate elevation 556-575 ft). Sockeye non-selection was concentrated to the powerhouse side and had elevation patterns similar to steelhead non-selection (Figure 16b).

At the Priest Rapids Dam top-spill steelhead non-selection was concentrated to the powerhouse side with fish elevations ranging from approximately 420-485 ft (Figure 16c). Elevations of steelhead non-selection on the spillway side were primarily shallower, ranging from 446-485 ft. Sockeye non-selection at the Priest Rapids Dam top-spill was also concentrated to the powerhouse side with a similar range of elevations as steelhead (Figure 16d). Sockeye non-selection on the spillway side tended to be shallower than the powerhouse side with approximate elevations ranging from 456-485 ft.

When comparing the closest position of non-selection fish to the bypass/top-spill at both dams, results suggest that the current prototype top-spill at Priest Rapids Dam does not possess a strong enough surface attraction flow (Figure 16). The WFUFB captured more fish to the right of the bypass centerline than were captured at the Priest Rapids top-spill.

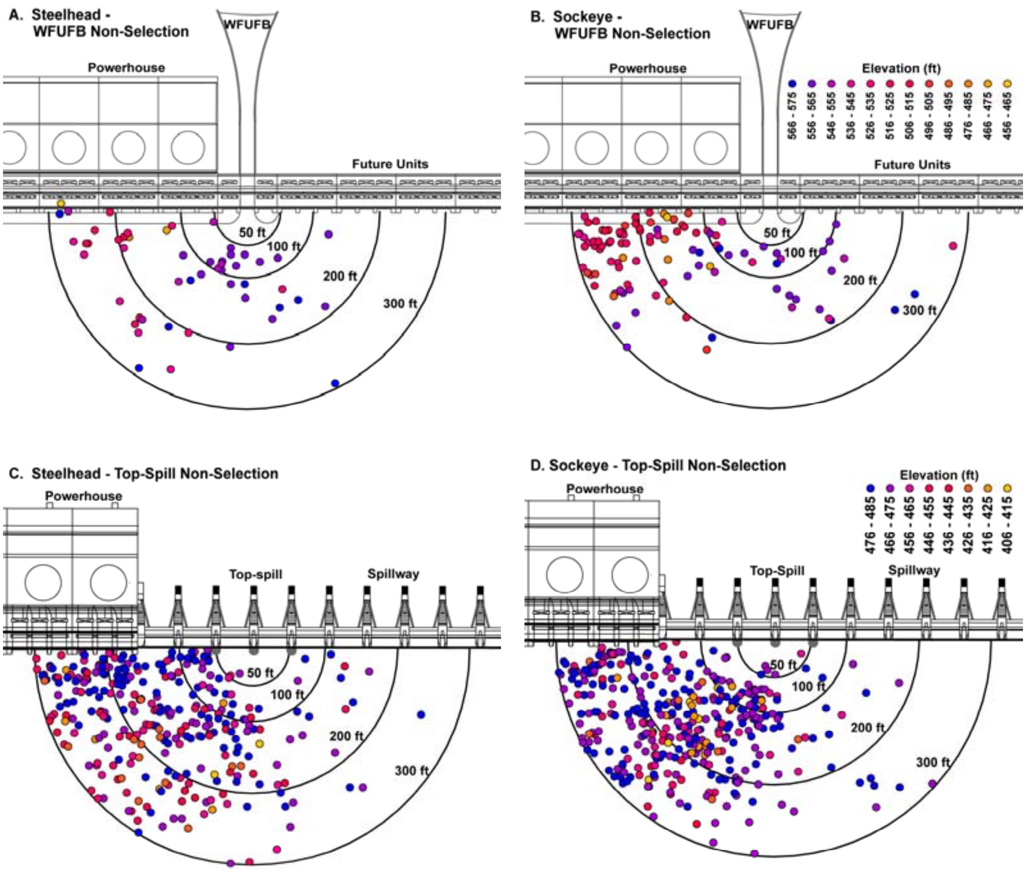


Figure 16. Steelhead and sockeye smolts that entered the 300 ft radial zone of influence in front of the Wanapum Future Unit Fish Bypass and the Priest Rapids top-spill but did not pass. Each point represents the closest approach location and elevation to the WFUFB or top-spill before non-selection.

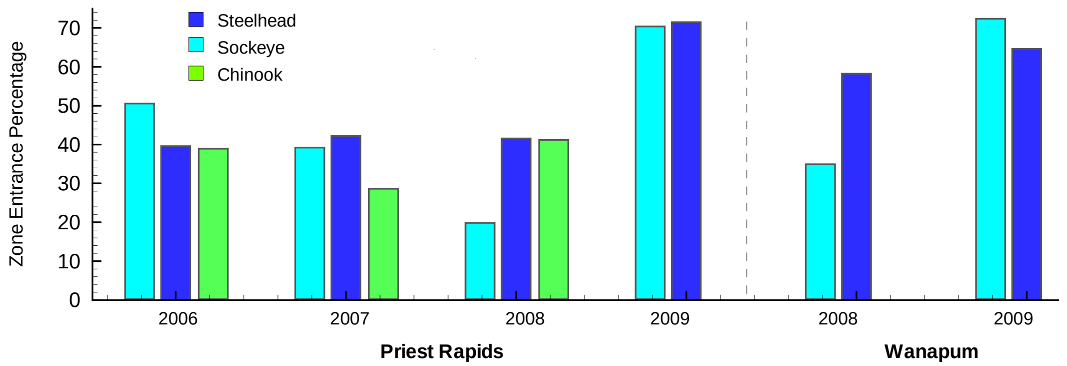


Figure 17. Percent of fish by species and year at Priest Rapids and Wanapum dams that entered a 300 ft radius from the prototype top-spill bulkhead (left) and WFUFB (right) divided by the total number of fish that passed the dam (defined as zone entrance efficiency) in the 2006–2009 field studies. Yearling Chinook were not studied in 2009.

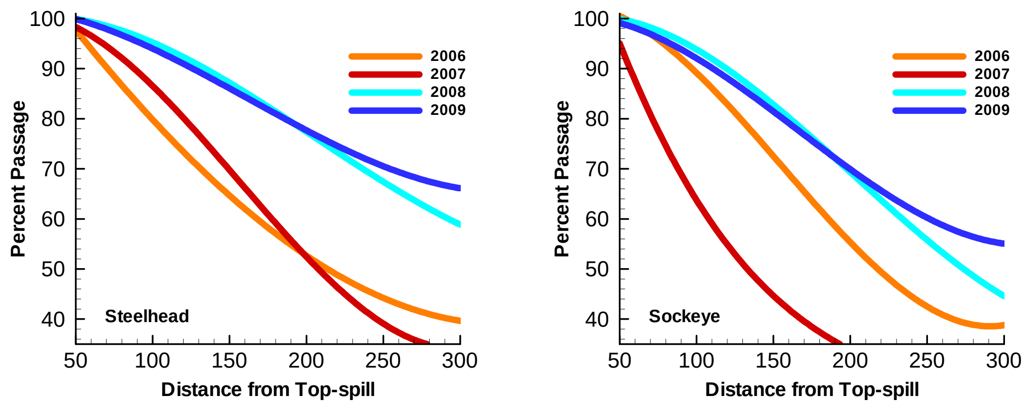


Figure 18. Percent passage of steelhead (left) and sockeye (right) that passed through the Priest Rapids Dam top-spill and were detected within 50, 100, 150, 200, 250, and 300 ft increments from the prototype top-spill bulkhead in 2006 through 2009.

Zone Entrance Efficiency - Zone entrance efficiency (ZEE) was greater in 2009 than has been measured over the past three years for the top-spill at Priest Rapids Dam (i.e. more fish found the top-spill than in any previous study). ZEE is a measure of the ratio of fish which encounter the top-spill (to within 300 ft of the entrance) to the total population of approaching fish. In 2009 ZEE was measured at 66.9% for sockeye and 71.5% for steelhead, two-thirds of all sockeye and steelhead entered the top-spill zone of influence. This represents a ZEE which is nearly double the 3-yr average (2006-2008) of 36.7% for steelhead, sockeye and Chinook combined. A ZEE in 2009 of 66.9% for sockeye was also 19% higher than the historical high which was recorded in 2006 at 48.0% for sockeye (Figure 17).

Fish Collection Efficiency - Fish collection efficiency (FCE) is a measure of top-spill passage of fish which entered the 300 ft Zone of Influence (i.e. how many fish passed via the top-spill after getting within 300 ft of it). FCE performance was consistent between 2008 and 2009, which was not surprising as the test configuration was the same for both years (top spill at gates 19/20, bottom spill at gate 21 and sluice spill at gate 22). Nearly 100% collection efficiency at 50 ft from the top-spill for both species and 40% to 50% collection at 300 ft for sockeye and 60% to 70% at 300 ft for steelhead was measured. A marked increase in FCE was noted in 2008 and 2009 after modifying the top-spill test configuration from surface spill at gates 19/20 exclusively (2006 and 2007) to surface spill at 19/20, bottom spill at gate 21 and sluice spill at gate 22 (Figure 18 and Appendix H).

Discussion

A goal of all researchers conducting survival studies should be to eliminate potential biases that may be introduced. Biases may include: surgical, holding and release effects, variability in tag quality, data collection and processing. Consistency must be maintained throughout the study at all levels or biases may contaminate the results. Variability in the performance of electronics, particularly with high volumes of tags, must always be considered when conducting large-scale biotelemetry survival studies. Previous survival studies have been hampered by the variability in tag quality and tagger effects. By systematically sampling, randomizing, distributing, and activating tags by release group, we were able to eliminate tag bias, despite the introduction of one tag lot that performed poorly. In addition, no negative tagger effects were revealed in 2009. Furthermore, the detection efficiency of tagged fish approached 100% for all acoustic arrays.

Survival - Similar to the 2008 steelhead survival results, the BiOp and SSSA performance goals for steelhead were exceeded at Wanapum Dam, but survival goals were not successfully met at Priest Rapids Dam or through the joint Wanapum-Priest Rapids Project (Skalski et al. 2009b, 2009c). The 2009 sockeye survival results met the BiOp and SSSA performance goals at each dam and through the joint Wanapum-Priest Rapids Project. Sockeye outperformed steelhead by 10% in the joint Wanapum-Priest Rapids Project; survival results indicate sockeye survived 3% higher at Wanapum Dam and 7% higher at Priest Rapids Dam.

The superior performance of sockeye compared to steelhead may be related to migration travel rate and body size. The smaller body size of sockeye may have multiple advantages compared to steelhead during their outmigration. Previous studies of juvenile salmonid at Snake and Columbia river projects (Lower Granite, Wanapum, Rocky Reach, and Bonneville) between 1995 and 2000 depicted that fish size was significantly related to turbine passage survival (Skalski et al. 2002). Skalski et al. (2002) found that as fish size increased, turbine passage mortality increased (mean total length ranged from 82.0-342.9 mm). While the data presented by Skalski et al. (2002) did not specifically represent sockeye smolts, our results indicate that the smaller body size of sockeye was advantageous to turbine passage as sockeye were 3.2% more likely to survive passage at Wanapum Dam and 2% at Priest Rapids Dam than steelhead. We suggest that sockeye were more successful at powerhouse passage because their size may have decreased the likelihood of injury during turbine passage by strike, shear, or rapid changes in pressure.

Sockeye, which are successful at dam passage in the Priest Rapids Project, also have advantages over steelhead during river migration between dams. Sockeye migrate faster than steelhead, thus are less likely to be exposed to avian and piscivorous predation. An additional behavior trait reducing predation risk of sockeye to birds and other fish is their tendency to swim deeper in the water column (Dauble et al. 1989, Scheuerell and Schindler 2003). While piscivorous predation can be measured through acoustic tag detection histories and reach survival, avian predation of sockeye could not be detected as they were not PIT tagged. We recommend that PIT tags be included in future sockeye survival studies, similar to the protocols used in 2008 and 2009 steelhead survival studies.

Previous studies have demonstrated that hatchery-reared fish have slower migration rates and decreased survival (Kostow 2004; Plumb et al. 2006; Serrano et al. 2009). In 2009, hatchery-reared steelhead and sockeye compromised 66% and 40%, respectively, of the tagged and released study fish. We found no evidence to support previously reported trends of slower migration rates and forebay residence times when we compared hatchery-reared versus wild fish within each species. While mixed results of survival by species and source, hatchery versus wild, were found; we did not find that hatchery fish were less likely to survive.

Avian Predation - A known source of juvenile salmon mortality throughout the Columbia River basin is avian predators, more specifically Caspian terns. In 2009, we observed a 2.1% increase in tern predation on tagged steelhead throughout the entire study area (4.3% in 2008 and 6.4% in 2009) (Sullivan et al. 2008). The majority of increased avian predation in 2009 was discovered downstream of Vernita Bridge, at the edge of the Grant PUD acoustic detection arrays and did not affect the 2009 survival estimates. It is not surprising that the Potholes Reservoir colonies are feeding below Vernita Bridge, for it is the closest geographic feeding location.

The number of breeding pairs in the Caspian tern colonies at Potholes Reservoir increased in size from 293 breeding pairs to 440 between 2008 and 2009. The nesting colony of Caspian terns at the Potholes Reservoir is now the largest nesting colony in the Mid-Columbia River and is of concern to Grant PUD. In particular, there is concern that as this nesting colony increases in size, it could increase the home range of its food source and increase feeding pressure upstream of Vernita Bridge. If this occurs, survival estimates will decrease within the Project.

A series of overhanging, stainless steel wires commonly referred to as "bird wires," were installed in the tailraces of each dam prior to the 2009 outmigration of juvenile salmon. While it was not in the scope of the study to determine where avian predation events occurred within a reach, the bird wires were unsuccessful at decreasing the overall avian predation events recorded between 2008 and 2009. Whether predation was reduced in the immediate tailrace of Wanapum, under the bird wires, or avian predators simply moved downstream to feed, the end result was an increase in predation. Similarly, there was no noticeable difference in avian predation below Priest Rapids Dam between 2008 and 2009.

Fish Collection and Passage Route Efficiency - There was no increase in collection efficiency at either dam in 2009; the top-spill was no better at collecting fish entering the zone of influence, (300 ft radius from the center of the top-spill), compared to field studies conducted in 2008. Based on 2009 FCE results, our expectations were that PRE would be similar between 2008 and 2009; however, PRE dramatically outperformed FCE and more fish passed at the WFUFB and Priest Rapids top-spill test configuration.

At Wanapum Dam, steelhead selected the WFUFB at a rate of 70.2% in 2009 compared to 53.5% in 2008. An increasing trend was also recorded in sockeye passage where 59.3% selected the WFUFB in 2009 compared to 32.1% in 2008. At Priest Rapids Dam, 51.0% of steelhead passed through the top-spill test configuration in 2009 compared to 26.3% in 2008. Similarly, 39.0% of sockeye in 2009 and 19.8% in 2008 passed through the top-spill configuration. At Priest Rapids Dam, the top-spill test configuration of 2008 and 2009 outperformed that of 2006/2007 with respect to FCE. In other words, the addition of the top-spill at the sluice (Tainter gate 22) and bottom-spill at Tainter gate 21 increased fish passage at the top-spill.

How could an increase of 25% in top-spill passage occur (i.e., sockeye at Wanapum from 2008 to 2009) when FCE remained the same? A series of environmental conditions in 2009 may have affected steelhead and sockeye migration behavior, specifically with respect to top-spill selection. The majority of the 2009 field study was conducted at cooler water temperatures compared to 2008 and the entire study was below the 10-year water temperature average. River flow conditions were also below those recorded in 2008 and similar to the 10-year average. Additionally, total dissolved gas in the study area throughout 2009 was noticeably lower than the 10-year average.

Measureable responses by steelhead and sockeye to these environmental changes included decreased migration rates (increased overall migration time) and increased forebay residence times. On average, steelhead completed their migration through the study area, from Rock Island Dam to Ringold, 34 hr slower than they did in 2008; sockeye traveled 11 hr slower than in

2008. Other studies have also shown that river flow and water temperature can influence migration travel rates (Berrgren and Filardo 1993; Giorgi et al. 1997; Smith et al. 2002; Manning et al. 2005; Plumb et al. 2006; Zabel et al. 2008). Additional benefits of lower water temperatures this year may have included decreased risk of disease, such as bacterial kidney disease (BKD, *Renibacterium salmoninarum*); warmer water temperatures typically have adverse affects on fish infected with bacteria, such as BKD, *Aeromonas salmoncida* and *A. hydrophila* (Groberg et al. 1978; Sanders et al. 1978; Jones et al. 2007).

While decreased migration rates were detected within each reach, the primary areas where fish migration rates decreased were in the Wanapum and Priest Rapids reservoirs. We found a significant increase in time spent of 22.1 hr for steelhead and 6 hr for sockeye between Rock Island and Wanapum dams. In previous years, the decreased rates of travel to Wanapum Dam occurred near the dam, between Sunland Estates and Wanapum Dam, but it was not directly measured this year. An increase in median travel time of 10 hr for steelhead and 2.6 hr for sockeye was recorded from Mattawa to Priest Rapids Dam.

Once fish arrived at either Wanapum or Priest Rapids dams, median forebay residence time increased in 2009. Steelhead took an additional 49 min to pass at Wanapum and 43 min to pass at Priest Rapids dams. Sockeye spent an additional 28 min and 17 min to pass at Wanapum and Priest Rapids dams in 2009. While this increase in residence time may appear trivial, it took sockeye 24 min to pass at the Priest Rapids Dam top-spill in 2009 compared to 7 min in 2008, an increase of over 300%.

An increase in residence time translated into a presumed increased search behavior (i.e. milling) and the opportunity for fish to locate the top-spill zone of influence at either dam; therefore, an increase in Zone Entrance Efficiency (ZEE). Based on four years of research at Priest Rapids Dam and two years at Wanapum Dam, the success of top-spill passage appears to be driven by both ZEE and FCE (Table 7). Historically we have directly measured PRE as a proportion of fish passage at the top-spill; however, PRE may also be calculated as a function of ZEE and FCE as shown in Table 7 (i.e., ZEE x FCE = PRE). As ZEE or FCE increase, PRE also increases. We found a strong correlation between ZEE and PRE ($R^2 = 0.94$, exponential regression), meaning that top-spill success is closely related to ZEE in addition to top-spill configuration (Figure 19).

Considering annual variability, especially with respect to environmental conditions, when making management decisions about or related to bypass engineering and construction is important. In 2009, environmental conditions were ideally suited for salmonid top-spill selection at both dams. We caution that 2009 was an anomaly and may not reflect actual bypass performance during a year with typical environmental conditions. To achieve non-turbine passage goals of at least 30% during a normal year, FCE must increase. The most effective way to increase FCE is by adding additional flow to the Priest Rapids top-spill design. A marked improvement in PRE was observed between 2007 and 2008 which is directly correlated to increased flow by a change in top-spill configuration.

Behavior - Behavioral analyses conducted in 2009 did not yield any notable differences in trends seen in previous years as fish approached and passed Wanapum and Priest Rapids dams. Behavioral trends over the past four years have been consistent with respect to the distribution of fish in the forebay that have selected the powerhouse and bypass (WFUFB/top-spill). The powerhouse at Priest Rapids Dam is out competing the top-spill within the 300 ft zone of influence while the opposite is occurring at Wanapum Dam (Figures 13 and 14). While the WFUFB is designed to pass more flow than the current Priest Rapids top-spill configuration, it is critical to remember that the hydraulic environment at each dam is different.

Flow effectiveness, the ratio of fish that passed by flow, was estimated at the top-spill and bottom-spill at Priest Rapids Dam (i.e., percent fish divided by percent flow; Table 8). Flow effectiveness doubled for steelhead in 2008 and 2009 when bottom-spill was added to the bypass configuration. Sockeye also exhibited an increase in flow effectiveness, as percent flow through the top-spill increased.

The authors looked for additional behavior trends which were correlated to the operation of the Priest Rapids Dam powerhouse. Data from the 2008 and 2009 field studies were grouped in 10 kcfs flow blocks, from a minimum of 30-39 kcfs to 160-169 kcfs through the powerhouse. Surprisingly, we found no correlation between residence time and survival by increased powerhouse flow (Appendix H). The only positive behavior response to increased powerhouse flow was powerhouse passage selection by steelhead

Table 7. Priest Rapids Dam top-spill passage route efficiency by year and species listed by two metrics, first as a product of zone entrance efficiency (ZEE) and fish collection efficiency (FCE) and second as a proportion of the number of fish in the forebay that passed through the top-spill by species. The difference between the PRE product (predicted PRE) and the proportion (actual PRE) is likely due to the annual environmental and hydraulic variability between the two variables, ZEE and FCE.

				PRE	
Year	Species	ZEE	FCE	Product	Proportion
2009	Steelhead	0.715	0.660	0.47	0.51
	Sockeye	0.669	0.549	0.37	0.39
2008	Steelhead	0.416	0.589	0.25	0.33
	Sockeye	0.187	0.450	0.08	0.22
2007	Steelhead	0.422	0.337	0.14	0.19
	Sockeye	0.372	0.223	0.08	0.12
2006	Steelhead	0.396	0.394	0.16	0.15
	Sockeye	0.480	0.382	0.18	0.19

Table 8. Ratio of fish to flow at Priest Rapids Dam top-spill and bottom-spill passage routes, 2006-2009. Passage events listed as top-spill consisted of passage at the prototype top-spill bulkhead (Spillbays 19 and 20) and sluiceway. Passage events listed as bottom-spill consisted of passage through Spillbays 1-18 and 21. The sluiceway and Spillbay 21 was not operated in 2006 or 2007. An asterisk in 2006 indicates river flow was exceptionally high and inadvertent spill was necessary.

	Top-Spill			Bottom-Spill		
Year	% Fish	% Flow	Fish to Flow	% Fish	% Flow	Fish to Flow
Steelhead						
2009	36.7	10.8	3.4	13.6	9.1	1.5
2008	25.5	9.6	2.7	14.8	11.6	1.3
2007	18.5	7.9	2.3	0.4	1.3	0.3
2006	15.4	7.5	2.1	11.0	15.0	0.7
Sockeye						
2009	34.5	10.8	3.2	7.6	9.1	0.8
2008	17.1	9.6	1.8	14.7	11.6	1.3
2007	9.9	7.9	1.2	0.0	1.3	0.0
2006	19.6	7.5	2.6	8.5	15.0	0.6

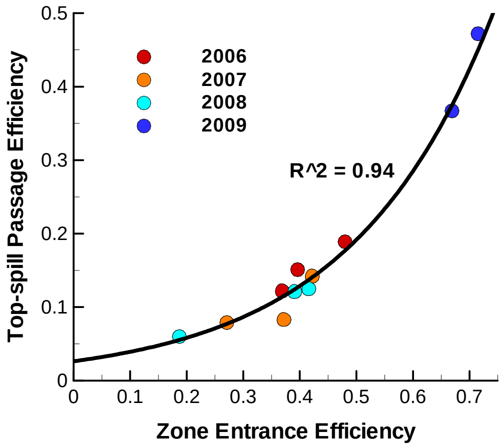


Figure 19. Fish collection efficiency of the Priest Rapids Dam top-spill in 2006-2009 is displayed by an exponential regression. Each point represents a species evaluated per year; yearling Chinook was not monitored in the spring of 2009. Increased passage route efficiency at the top-spill occurred as an increase in proportion of study fish entered the zone of influence (300 ft radius from the center of the top-spill).

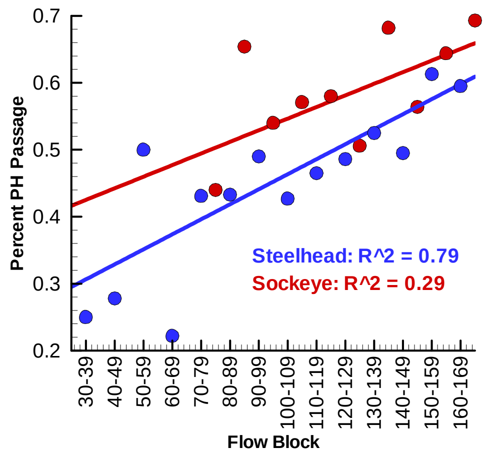


Figure 20. Linear relationship between the percent of steelhead (shown in blue) and sockeye (shown in red) that passed through the powerhouse at Priest Rapids Dam at increased flow (kcfs) in the 2008 and 2009 field data is illustrated (weighted regression).

(R^2 = 0.79, weighted linear regression) (Figure 20); the proportion of powerhouse passage increased with increasing flow. There was little correlation in proportion of sockeye that passed at the powerhouse with increased flow (R^2 = 0.29, weighted regression). This finding, in conjunction with historical forebay residence times, indicates sockeye pass through the powerhouse without hesitation or consideration of flow volume. Conversely, steelhead appeared to be more active at volitionally choosing a downstream passage location, with significantly increased residence times and higher likelihood of passage at the powerhouse during increased power generation.

Summary – Survival studies with acoustic telemetry have been conducted by Grant PUD since 2006. Protocols have been refined each year to remove biases and we feel that our study design, paired with these protocols, is robust. Sockeye survival estimates exceeded the performance goals of the BiOp and SSSA at Wanapum and Priest Rapids dams as well as throughout the Project in 2009. Steelhead survival estimates exceeded the BiOp and SSSA standards at Wanapum Dam for the past two years; however, they have not met those performance goals required at Priest Rapids Dam or throughout the Project.

Considerable effort continues at Priest Rapids Dam to design a bypass that not only collects fish but safely passes them downstream of the dam as quickly as possible. The increase in steelhead passage survival at Priest Rapids Dam hinges on the ability of Grant PUD to construct such a bypass. Top-spill passage at Priest Rapids Dam has two codependent variables, zone entrance efficiency and fish collection efficiency. We have found that zone entrance efficiency is strongly correlated with environmental conditions, primarily low river flow, which is beyond the control of Grant PUD. However, adaptive management techniques could be considered to increase flow at the top-spill during high flow years, which would provide additional hydraulic cues for migrating smolts. Conversely, during low flow years, less flow at the top-spill will be needed to meet fish collection and survival requirements.

Acknowledgements

We thank the Public Utility District No. 2 of Grant County for funding this study and their staff who were critical to its success, notably: Curtis Dotson, Pat Burdick, Tom Dresser, Ed Perez, Robert Weedmark, and Gerry O'Keefe, along with dozens of fisheries specialists. LGL, led by Dave Robichaud, Anita Blakley, Lucia Ferreira, and Megan Mathews performed an extraordinary job at sorting and tagging study fish. We would also like to thank Central Valley helicopters for flying over 2,000 miles and expertly releasing 108 groups of test fish into the river. We thank Real-Time Research for their efforts scouring the avian colonies and collaboration. A special thanks to Duncan Hay of Oakwood Consulting Inc. for review and feedback of this document. Lastly, we would like to thank our numerous summer technicians for their long hours of diligent work.

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