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Mark A. Timko, Leah S. Sullivan, Suzanne E. Rizor, Rolland R. O'Connor, Corey D. Wright, Jessica L. Hannity, Cindy A. Fitzgerald, Michael L. Meagher, and Jim D. Stephenson
Blue Leaf Environmental, 2301 West Dolarway Road, Suite 3, Ellensburg, WA 98926, USA

John R. Skalski and Richard L. Townsend
Columbia Basin Research, Puget Sound Plaza 1325 4th Ave, Suite 1820, Seattle, WA 98101-2509, USA

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For copies of this document, please contact:

Curtis Dotson
Public Utility District No. 2 of Grant County
P.O. Box 878
Ephrata, WA 98823
(509) 754-3541

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Abstract

Behavioral and survival studies were conducted in 2010 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 steelhead (n=1,949) and sockeye (n=1,593), all of which were randomly selected from run-of-river fish. The origin of test fish was estimated to be 41% wild and 59% hatchery-reared steelhead along with 79% wild and 21% hatchery-reared sockeye. Fish were systematically released into the Columbia River in paired treatment-control groups between 4 May and 2 June 2010. To minimize tag battery life bias, transmitters were randomly mixed among all release sites and groups. In addition, control and treatment tags were simultaneously activated to ensure that paired groups had equivalent remaining battery life upon in-river mixing. A series of hydrophone arrays were strategically placed at multiple locations on the river and the hydropower dams (Wanapum and Priest Rapids) to detect and track acoustically tagged fish. Array detection efficiencies at all sites were estimated between 98.5% and 100%. 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. While the operational configuration of the Wanapum Dam fish bypass has not changed since completion, the Priest Rapids prototype bypass has been annually modified to increase passage efficiency. To increase passage efficiency during the top-spill bulkhead operations, in 2010 the sluiceway at Spill Bay 22 of Priest Rapids Dam was pinned closed and operated as a bottom-spill Tainter gate. Bottom-spill at Tainter gates 21 and 22 was an average of 5.9 kcfs/bay during the study. An increase in fish bypass at both dams was recorded in 2010. The Wanapum Dam fish bypass collected 77% of steelhead and 78% of sockeye in 2010, an increase from 2009 of 7% and 19%, respectively. The Priest Rapids Dam prototype bypass collected 57% of steelhead and 50% of sockeye, which was an increase from 2009 of 6% and 11%, respectively. We propose that environmental conditions contributed to the increase in prototype bypass passage. Passage survival was estimated at 0.8553 (0.0186) for steelhead and 0.9408 (0.0138) for sockeye through the Wanapum Development (Wanapum Dam and reservoir). Survival was higher for both species through the Priest Rapids Development (Priest Rapids Dam and reservoir); steelhead at 0.9037 (0.0171) and sockeye was estimated at 0.9688 (0.0139). Overall Project survival (both dams and reservoirs) was estimated at 0.7729 (0.0223) for steelhead and 0.9114 (0.0187) for sockeye. Steelhead survival estimates continue to fall below the requirements established in the 2008 NMFS Biological Opinion. While concrete survival has been high for steelhead at both Wanapum and Priest Rapids dams (99%), reservoir survival has been low. We believe the vast majority of mortalities occurring in the Project reservoirs are caused by predation from avian and fish piscivores.

Correspondence: Mark Timko +1.509.859.3141 (mtimko@blueleafenviro.com)
John Skalski +1.206.616.4851 (jrs@cbr.washington.edu)
Curtis Dotson +1.509.750.1999 (cdotson@gcpud.org)

Introduction

Wanapum and Priest Rapids dams and associated reservoirs in the Mid-Columbia River define the Priest Rapids Hydroelectric Project (Project). The Project began with the construction of Priest Rapids Dam in 1956, which was completed in 1961 and is operated by Public Utility District No. 2 of Grant County (Grant PUD). The construction of Wanapum Dam followed in 1959, and it was operational in 1963. Over the past 50 years, the physical structures at Wanapum and Priest Rapids dams and the riverine environment on the Mid-Columbia River has evolved into a complex Project that continues to vary with time and annual river flow.

At each of the dams, Grant PUD has actively worked to improve the downstream passage of juvenile salmonids with new turbines, bypass structures, and altered dam operations during the spring and summer out-migrations. Grant PUD has also researched, monitored, and sought to facilitate changes in environmental conditions to favor smolt survival throughout the Project. In addition to water quality monitoring, some of these projects have included a northern pikeminnow removal program, avian predation hazing, and the installation of avian deterrents (bird wires) below each dam, avian predation monitoring at known colonies on the Columbia River Plateau, and piscivorous predation studies of species that include walleye, northern pikeminnow, and small mouth bass.

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. This surface flow alternative, the Wanapum Fish Bypass (WFB), has proven successful. The design and testing of a prototype bypass at Priest Rapids Dam has been in progress since 2006 (Johnson et al. 2005; Robichaud et al. 2005; Sullivan et al. 2008; Timko et al. 2007a, 2007b, 2010). While early field studies showed mixed results as to the effectiveness of the Priest Rapids Dam prototype bypass (fish collection efficiency and survival), modifications in 2008 to the operation of the prototype bypass increased passage effectiveness (Sullivan et al. 2008). Modifications of operation at the Priest Rapids prototype bypass configuration in 2009 provided a higher measure of fish collection efficiency and survival when the bypass configuration included the use of sluice top-spill at Spill Bay 22 and bottom-spill at Tainter gate 21, along with the prototype top-spill bulkhead at bays 19 and 20 (Timko et al. 2010). Further modifications in the spring of 2010 were made to transform the sluiceway at Spill Bay 22 to bottom-spill as a Tainter gate, and planned bottom-spill was increased at Tainter gates 21 and 22 to an average 5.9 kcfs/bay. The result of this modification increased the overall flow of the prototype bypass configuration to an average of 27 kcfs.

Passage effectiveness was measured at both dams in two ways: by the proportion of fish that selected a particular passage route and more importantly, by the ultimate survival rate after selecting that passage route (Timko et al. 2007a, 2007b; Sullivan et al. 2008; Timko et al. 2010). Survival requirements at the Project include juvenile passage survival of 95% at each dam and 93% through a single development (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. In 2008 and 2009, steelhead survival studies were conducted and standards (93%) were met at the Wanapum Development. In 2009, sockeye survival studies commenced and all standards were 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 were 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) (Grant PUD 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 on 17 April 2008 (FERC 2008).

In this document, we present the findings of a survival and behavior study completed at the Project in 2010, where steelhead survival studies were conducted for the third consecutive year and sockeye survival studies were conducted for the second consecutive year, with the use of acoustic telemetry. Paired-release survival estimates using treatment and control groups are provided for both species at each development, Wanapum reservoir/dam and Priest Rapids reservoir/dam, and throughout the entire Project (both developments combined). In addition to comparisons in interspecies survival throughout the Project (steelhead and sockeye), migration rates, approach patterns, residence times, and passage behavior are presented with a focus on passage behavior at the WFB and the prototype bypass at Priest Rapids Dam.

Methods

Study Site – Wanapum (River Mile, RM, 416) and Priest Rapids dams (RM 397) are located on the Mid-Columbia River between Rock Island Dam (RM 453) and McNary Dam (RM 292) (Figure 1). Figure 1 illustrates the location of each dam and reservoir; 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. The powerhouse has a generating capacity of 1,071 megawatts (MW). During the 2010 acoustic tag study, turbine Unit 7 was off-line being retrofitted into a new advanced turbine. Located south of the powerhouse is the Wanapum Fish Bypass (WFB) which provides a non-turbine passage route for migrating salmonids. The WFB is a 290 ft long chute that was designed to pass a maximum flow of 20 kcfs, gradually decelerate fish without shear, and minimize total dissolved gas in the tailrace.

During the 2010 acoustic tag studies, the average flow at the WFB was 19.1 kcfs. Moving south from the WFB, the spillway joins the future unit slots 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 of the river (Timko et al. 2010).

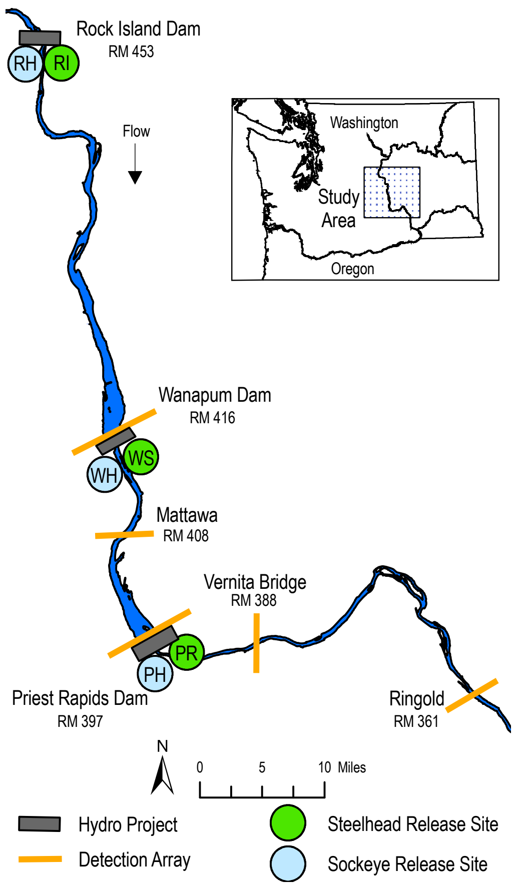


Figure 1. Study area from Rock Island Dam tailrace (RM 453) to RM 361. Release locations by species are illustrated (steelhead in green at RI, WS, and PR; sockeye in blue at RH, WH, and PH). Wanapum and Priest Rapids dams are located in the monitored reach at RM 416 and 397, respectively. The in-river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

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 2). In 2006, a surface-flow prototype top-spill bulkhead was installed to test fish behavior and passage efficiency at Tainter gates 19 and 20. The top-

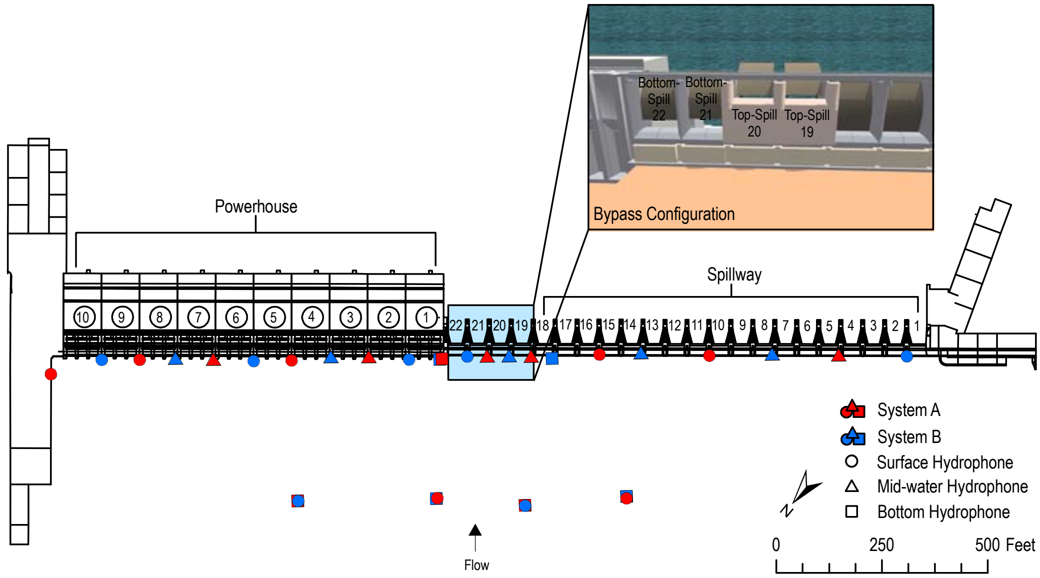


Figure 2. Schematic of Priest Rapids Dam hydroelectric facility (RM 397) is shown above with the corresponding hydrophone deployment locations that created an acoustic tag detection array. Two independent arrays were deployed in the forebay and are noted in red and blue. The prototype bypass of combined bottom-spill (Tainter gates 21 and 22) and top-spill (Spillway gates 19 and 20) is highlighted. The 2010 prototype bypass image is courtesy of Jacobs Engineering.

spill prototype is 100 ft wide and can spill up to 16 kcfs of surface water (8 kcfs per spill bay). In 2010, the top-spill was operated in conjunction with bottom-spill at Tainter gate 21 and 22 (previously the sluiceway) and was referred to as the "prototype bypass" (Figure 2). The projected total flow of the prototype bypass was 27.0 kcfs (8.0, 8.0, 5.5 and 5.5 kcfs through gates 19 to 22, respectively). However, during the period of data collection the average total flow was 24.9 kcfs (6.5, 6.5, 5.9 and 6.0 kcfs at gates 19 to 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 wheel gate slots, referred to as "gatewells" in the remainder of this report. Gatewells are water-filled vertical columns that extend from the ceiling of each turbine intake to the intake deck of the dam. Depending on the species and dam, at least 1% to 6% of smolts have been documented being temporarily entrained in the gatewells (Sullivan et al. 2008; Timko et al. 2010). Over the past several decades, dipping smolts from the gatewells has become an effective and reliable source of study fish (Park and Farr 1972; Timko et al 2010).

Similar to the methods described in Timko et al. (2010), 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 recirculating, ambient river water 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. Fish under 15.5 g were culled because they did not meet the 5% or less tag-weight to body-weight ratio.

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 Timko et al. (2010). Based on new research related to suture security, specifically during turbine passage, the surgical guidelines for the suture knot were altered. In 2010, the knots were created using a "double, single, single" throw technique compared to 2009 where the suture knots were completed with "double, double, double" throws (Blakely, pers. comm., 2010).

Acoustic Tags and Data Collection – Steelhead and sockeye were implanted with Hydroacoustic Technology, Inc. Model 795 Lm/PIT micro acoustic tags, a combination micro acoustic and PIT tag (5.0 x 17.5 mm, 0.65 g in air). PIT tags were combined with the micro acoustic tags to identify avian predation events through tag recovery at Caspian tern colonies. Tags were received from the manufacturer in 25 unique lots prior to the start of the study; however, replacement tags were received throughout the study to compensate for failed tags. To avoid potential effects of variability in the quality of manufactured tag lots, tag-life test tags were randomly sampled from each lot and were pre-assigned to tag life release groups prior to activation. The remaining tags were randomized and subsequently selected for surgical implantation into study fish. Replacement tags were randomized in the remaining pool of tags as they were received during the study. Furthermore, all tags were programmed (turned on) to match treatment and control groups so that as treatment and control fish 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 92 hydrophones (HTI Model 590). These include from upstream to downstream, Wanapum Dam (4 receivers; 37 hydrophones), Mattawa (1; 8), Priest Rapids Dam (2; 32), Vernita Bridge (1; 7) and lastly Ringold (1; 8) (Figure 1). A detailed description of hydrophone deployment at each of these sites can be referenced in Timko et al. (2010); Figure 2 illustrates the Priest Rapids Dam layout with the 2010 prototype bypass. Acoustic detection arrays at Wanapum and Priest Rapids dams were configured to enable three-dimensional (3D) tracking of fish near the bypass structures, while in-river arrays were limited to presence/absence information (Timko et al. 2010) (Appendix A). Each tag was programmed to have a unique pulse rate (2 to 5 sec) and a common pulse width (1 msec). 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 to a SQL Server® database and processed according to established protocols (Timko et al. 2010).

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 designated 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. The protocol was to release fish no higher than 10 ft from the surface of the river; release distance was recorded by a spotter on shore.

To estimate passage survival at Wanapum and Priest Rapids dams (and reservoirs) release-recapture methods were used (Zabel et al. 2005; Skalski et al. 2009a, 2009b, and 2009c; Timko et al. 2010). Paired treatment-control groups were released at successive dams and were used in conjunction to measure dam and reservoir (development) passage using acoustic detection arrays. Wanapum Dam and reservoir were tested with treatment and control groups released in the tailraces of Rock Island (RI/RH) and Wanapum (WS/WH) dams (Figures 1 and Appendices C and D). Priest Rapids Dam and reservoir were tested with treatment and control groups released in the tailraces of Wanapum (WS/WH) and Priest

Rapids (PR/PH) dams (Figures 1 and 3). Steelhead were released in 22 replicate groups and sockeye were released in 17 replicate groups at each release location (Figure 3 and Appendix B). 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).

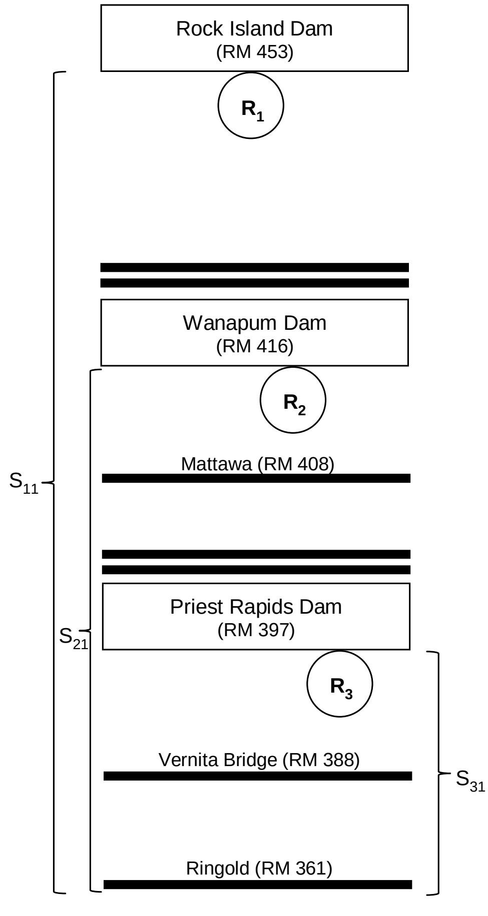
Survival Analyses – The primary survival analyses cited in this report were conducted by Columbia Basin Research (CBR) and are presented in Skalski et al. (2010). The survival of fish passing through the Wanapum Development included the proportion of fish passing through the Wanapum reservoir and dam that were detected at either Mattawa or in the forebay of Priest Rapids Dam. The survival of fish passing through the Priest Rapids Development included the proportion of fish passing through the Priest Rapids reservoir and dam that were detected downstream at Vernita Bridge or Ringold. The survival of fish passing through the entire Project included both dams and reservoirs and was the product of the Wanapum Development survival multiplied by the Priest Rapids Development survival.

Additionally, Ricker survival estimates were calculated, i.e., concrete passage at each dam. The Ricker survival equation was as follows:

$$\frac{[(\text{\# treatment fish detected downstream}) / (\text{\# treatment fish released})]}{[(\text{\# control fish detected downstream}) / (\text{\# control fish released})]}$$

In the case of concrete survival, treatment fish were those detected passing the dam and control fish were those released in the tailrace of each dam. For a fish to have survived passage at Wanapum Dam, a positive acoustic detection at Mattawa or Priest Rapids Dam forebay was required. For a fish to have survived passage at Priest Rapids Dam, a positive acoustic detection at Vernita Bridge or Ringold was required.

Conservative survival estimates were also inferred during this study, based on acoustic tag detection histories. For example, the reach survival of each species was calculated as the proportion of fish that passed through a reach and were detected at the next downstream acoustic



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

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

Figure 3. 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.

detection array (i.e., reach survival of steelhead between Mattawa and Priest Rapids Dam is the proportion of steelhead that passed through the Mattawa acoustic tag array and were detected in the forebay of Priest Rapids Dam).

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 WFB and the Priest Rapids prototype bypass. The effectiveness of each fish bypass was measured by fish passage efficiency (FPE), or the ratio of the number of fish selecting WFB or prototype bypass passage as compared to other passage routes. Another measurement used to estimate bypass 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 WFB or prototype bypass configuration (arc of 180°) and passed at the WFB or prototype bypass.

Relative Percent Passage – Relative percent passage (RPP) figures, (previously reported as density plots in Timko et al. 2010), were generated by creating a grid of 25 ft x 25 ft 2-dimensional cells or bins in the forebay and determining the number of individual fish that entered each bin. Using the eventual passage route of each fish, based on species that entered a bin, the RPP or proportion of fish that entered each cell and then passed via each route could be calculated. A contour was then created around the RPP for each bin in 10 percent increments to show areas of high and low use by fish based on eventual passage route.

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, 2010; 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 Wanapum and Priest Rapids dams from 2 May to 9 June 2010. Detailed conditions allowing comparison with previous years and ten year average conditions were provided by the Columbia River DART website and are shown in Figure 4. Flow and TDG saturation at both dams were generally lower in 2009 and 2010 than 2008. The TDG saturation in 2010 was similar to 2009 (Timko et al. 2010) and below the 10-year average. Total dissolved gas saturation peaked at Wanapum Dam in mid May at 115%, and peaks below Priest Rapids Dam were reached at 116% in early June. For comparison, in 2008, the TDG saturation reached 124% below both dams and was typically greater than 120% from mid May to the end of the study.

River flows in 2010 were lower than either 2008 or 2009 and were consistently below the 10 year average. Peak flows in 2010 were 150 kcfs below Wanapum Dam and 190 kcfs below Priest Rapids Dam. In contrast, the average flows during the 2008 field study were 175-184 kcfs with peaks reaching nearly 300 kcfs below Wanapum Dam. Water temperatures in 2010 ranged from 8.5-13.0 °C over the course of the field study, which is close to the 10 year average. However, water temperatures during the last week of May and first week of June were lower compared to the same period in 2008 and 2009 (Figure 4).

Fish Characteristics – Unlike previous years, the same model of combination acoustic-PIT tag (Lm/PIT) was used to tag both steelhead and sockeye in 2010. Hatchery reared run-of-river juvenile steelhead comprised 59% of the total 1,949 steelhead released, between 4 May 2010 and 31 May 2010, in paired replicates, with the remaining 41% being wild. The tailrace of Rock Island, Wanapum and Priest Rapids dams were the locations of release for paired replicates, RI

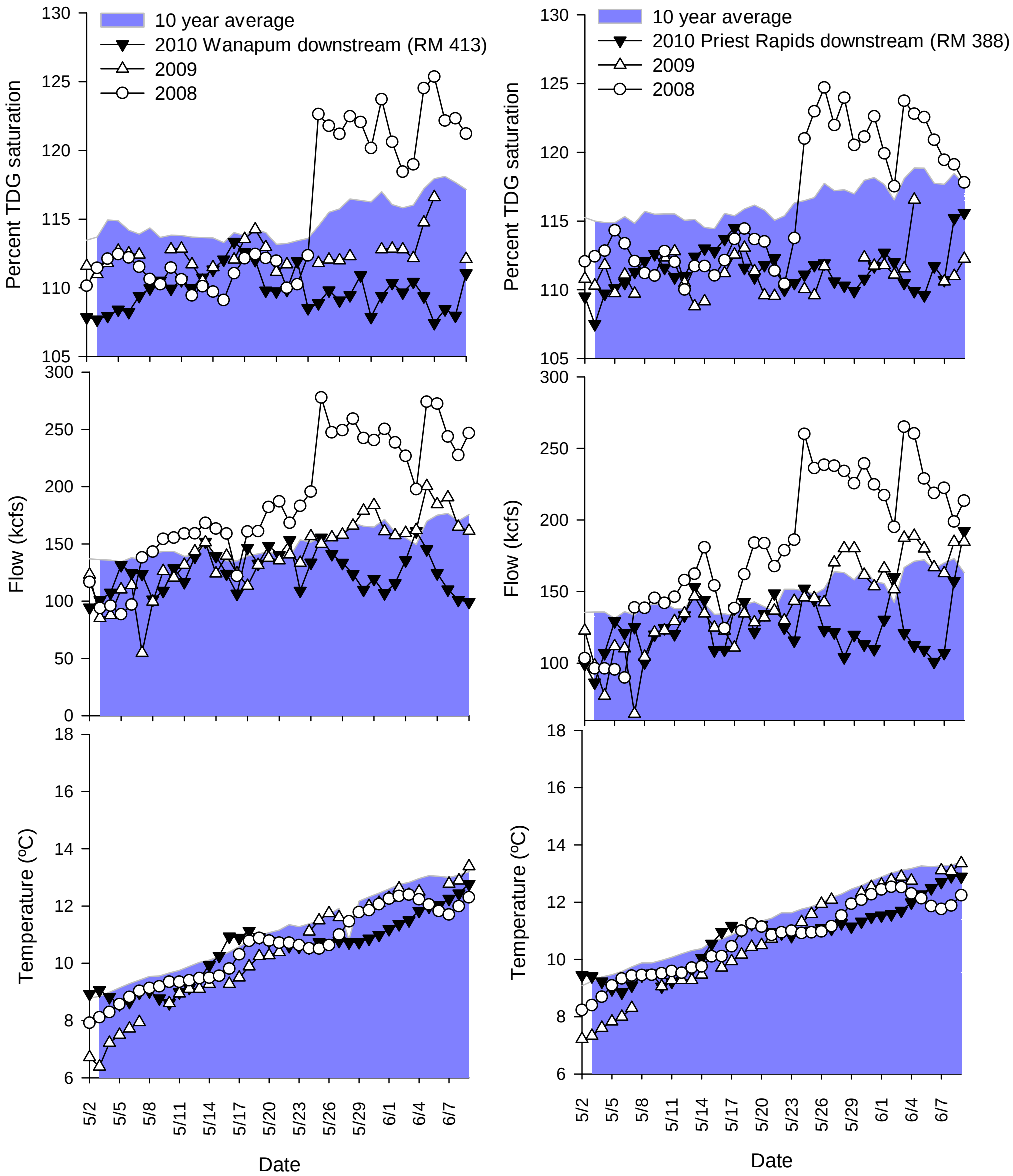


Figure 4. Daily median water quality values downstream of Wanapum and Priest Rapids dams are shown from 2 May – 9 June 2008-2010 along with the 10 year average which is depicted in blue. Unconnected points represent gaps where data were not available (data source: www.cbr.washington.edu/dart/dart.html).

(n=649), WS (n=650), and PR (n=650), respectively (Figure 1). There were an additional three steelhead released that were excluded from the survival estimates based on post surgical behavior abnormalities (release RI19 and PR07) and mortality (release WS07) prior to release.

Between 4 May 2010 and 2 June 2010, a total of 1,593 run-of-river juvenile sockeye, the majority being of wild origin (79%) and the remaining 21% hatchery reared, were collected, surgically implanted, and released in paired replicates at the same locations as steelhead; Rock Island Dam tailrace (RH, n=557), Wanapum Dam tailrace (WH, n=524), and Priest Rapids Dam tailrace (PH, n=512). An additional three fish were tagged, but were not used in data analysis for the following reasons: post-surgical equilibrium imbalance (release PH12), post surgical mortality (release PH13), and one fish escaped into the drainage trough and was recovered the following day (release PH14).

Based on the 2010 Rock Island run-timing smolt index (referenced on the Columbia River DART website of untagged run), all tagged steelhead were released between the 8th and 88th percentile of run-timing while sockeye were released between the 6th and 98th percentile. For comparison, during 2009 the tagged steelhead were released between the 4th and 78th percentile, and sockeye were released between the 17th and 72nd percentile of the run-timing index.

Lengths and weights of both species were not normally distributed ($P<0.050$) throughout the releases or release groups. There was no significant difference for lengths and weights between releases groups within species (one-way ANOVA, $P=0.318$ steelhead; $P=0.400$ sockeye). Steelhead fork lengths ranged from 127-222 mm (mean length at 191 mm) and weight ranged from 21.5-92.5 g (mean weight at 65 g) (Appendix B). Sockeye fork lengths ranged from 111-202 mm (mean length at 129 mm) and weight ranged from 15.5-88 g (mean weight at 21 g) (Appendix B).

Tag burden is defined as the tag to body-weight ratio calculated per fish. The average tag burden for steelhead was 1.2% (range 0.8-3.5%) while the average sockeye tag burden was 3.8% (range 0.9-5.2%). In 2009, steelhead were tagged with E/PIT tags and the average tag burden was 2.6%. Sockeye were tagged with the same acoustic tag model both years, however, a PIT tag was added to the Lm tag in 2010. The average tag burden for sockeye increased from 3.5% in 2009 (Lm) to 3.8% (Lm/PIT) and was due to the addition of the PIT tag.

Acoustic Tags – The average Lm/PIT tag weighed 0.76 g (range 0.69-0.83 g). To determine tag life, 121 tags were taken from all 25 lots, activated, and monitored. The average battery life of the tags was 28.3 days (range 11.1-58.4 days).

The results of the random tag distribution per tag lot and release site are presented in Table 1. The average tag failure rate was 4.0% for the Lm/PIT tags. Six lots in this series displayed unusually high failure rates averaging 7.2% (range 5.5-10.0%). These lots corresponded to the tag lots with the lowest reach survival estimates and were removed from survival analysis (highlighted in blue in Table 1). Without lots 10223, 10232, 10237, 10238, 10240, and 10241, the tag failure rate was 3.0% and average tag life was increased to 28.6 days (Skalski et al. 2010).

Data Collection – All acoustic tag detection systems were operational on 25 April 2010; data collection began on 4 May, the date of first release, and was completed after 58 days on 30 June 2010. Releases of tagged steelhead and sockeye began on 4 May at Rock Island Dam, and the first detection was recorded at Wanapum Dam on 5 May 2010. The last detection of sockeye was logged on 7 June 2010 and the last detection of steelhead was logged on 11 June 2010 at the Ringold in-river detection array. During the two months of monitoring, there were few interruptions in data collection (Appendix A, Table A.4). A total of 20.5 hr of data collection was lost, 4.2 hr of data collection were lost at the Vernita Bridge in-river detection array, and the remainder of interruptions occurred at Wanapum Dam. There were no interruptions in data collection at Priest Rapids Dam or the Mattawa or Ringold in-river arrays.

Over the study period, a total of 87.9 million individual detections of acoustic tags were recorded at all sites (Table A.5). A total of 3,376 released fish were detected migrating downstream at a minimum of one detection array (1,822 steelhead and 1,554 sockeye). Based on capture histories for both species, detection probability of 99.3% to 100% were estimated by Skalski et al. (2010) at all detection arrays; detailed results are provided by species, release site, and detection array in Skalski et al. (2010).

A small portion of the tagged steelhead and sockeye were also detected by PIT tag readers below our study area at McNary (RM 292, 7.3% steelhead and 11.8% sockeye), John Day (RM 216, 2.7% steelhead and 4.7% sockeye), and Bonneville (RM 146, 3.1% steelhead and 2.4% sockeye) dams as well as the Columbia River estuary experimental towing site (RM 19, 0.6%

steelhead and 0.3% sockeye) (Appendix A, Table A.6). Of the tagged steelhead and sockeye detected at downstream PIT tag readers, at least 98% were detected passing through one or more of the Grant PUD acoustic detection arrays (1.6% of the steelhead and 2.0% of the sockeye were not detected at any of the detection arrays).

Table 1. Tag failure rates during activation and a minimum 48 hour holding period of HTI Model Lm/PIT tag lots are listed below (includes all tags activated). A subset of the tags that were received and released per lot and location are displayed by release location. Both species were surgically implanted with the same tag type; tags were randomly selected from all tag lots in 2010. A total of 221 acoustic tags were recorded as failed with an overall 3.98 failure rate. The tags highlighted in blue were omitted from the Skalski et al. (2010) final survival analysis due to high activation and holding failure rates.

			Release Location							
	Total	Failure	Rock Island		Wanapum		Priest Rapids		Life Test	
Tag Lot	Tags	Rate (%)	n	%	N	%	n	%	n	%
10223	219	6.39	39	0.03	51	0.04	44	0.04	5	0.04
10225	233	5.15	52	0.04	45	0.04	39	0.03	5	0.04
10227	232	1.29	55	0.05	45	0.04	50	0.04	5	0.04
10228	221	3.62	47	0.04	34	0.03	57	0.05	4	0.03
10229	227	3.08	54	0.04	48	0.04	47	0.04	5	0.04
10230	230	5.22	36	0.03	55	0.05	50	0.04	4	0.03
10232	238	5.46	53	0.04	51	0.04	53	0.05	5	0.04
10234	226	3.54	47	0.04	49	0.04	52	0.04	5	0.04
10235	223	3.59	50	0.04	56	0.05	42	0.04	4	0.03
10236	222	4.95	38	0.03	54	0.05	41	0.04	5	0.04
10237	225	7.11	56	0.05	46	0.04	43	0.04	5	0.04
10238	232	6.47	61	0.05	41	0.03	49	0.04	5	0.04
10239	221	1.36	59	0.05	39	0.03	51	0.04	5	0.04
10240	226	7.52	32	0.03	59	0.05	47	0.04	5	0.04
10241	221	9.95	49	0.04	54	0.05	46	0.04	5	0.04
10242	240	2.50	46	0.04	56	0.05	51	0.04	4	0.03
10243	125	4.00	29	0.02	22	0.02	27	0.02	5	0.04
10244	210	4.29	49	0.04	43	0.04	43	0.04	5	0.04
10245	233	2.58	39	0.03	46	0.04	56	0.05	5	0.04
10246	235	2.13	62	0.05	59	0.05	46	0.04	5	0.04
10247	234	3.42	52	0.04	50	0.04	48	0.04	5	0.04
10248	232	0.86	61	0.05	42	0.04	47	0.04	5	0.04
10251	229	1.31	40	0.03	42	0.04	53	0.05	5	0.04
10253	236	1.27	47	0.04	48	0.04	55	0.05	5	0.04
10256	181	2.76	53	0.04	39	0.03	25	0.02	5	0.04
Total	5,551	3.98	1,206	0.22	1,174	0.21	1,162	0.21	121	0.02

Survival Analysis – The survival estimates of steelhead and sockeye in 2010 were analyzed by Skalski et al. (2010) and completed without the use of tag lots 10223, 10232, 10237, 10238, 10240, and 10241. The survival estimate of steelhead at the Wanapum Development was 0.8553 (0.0186) and at the Priest Rapids Development was 0.9037 (0.0171). The joint Wanapum-Priest Rapids Project survival of steelhead was 0.7729 (0.0223). The survival estimate of sockeye at the Wanapum Development was 0.9408 (0.0138) and at the Priest Rapids Development was 0.9688 (0.0139). The joint Wanapum-Priest Rapids Project survival of sockeye was 0.9114 (0.0187). The survival estimates of steelhead in 2008 through 2010 and sockeye in 2009 and 2010 are shown with standard errors in Figure 5.

All survival estimates for both species yielded acceptable and smaller than required standard errors (NMFS 2004; NMFS 2008; Grant PUD 2006). 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. 2010).

Dam Survival – Based on acoustic tag detection histories, the Ricker survival estimates of steelhead and sockeye at each dam (commonly referred to as concrete survival) were calculated with the use of control fish released 0.5 km downstream of Wanapum and Priest Rapids dams. Table 2 lists the concrete survival estimates by year along with the average of steelhead in 2008-2010 and sockeye in 2009-2010. Overall, survival of both species that passed downstream of Wanapum Dam was greater than 98% for both species.

Steelhead that passed through the dam (treatment group) had higher survival rates than those that were released downstream of the dam (control group) and yielded a Ricker survival estimate of greater than 1.000. Over the past three years, the average concrete survival of steelhead at Wanapum Dam has been 1.011%. Ricker survival estimates of greater than 100% occurred when treatment fish (i.e., fish detected in the forebay of Wanapum Dam that passed downstream) survived at higher proportions than the control fish released 0.5 km downstream of the dam. The average sockeye concrete survival

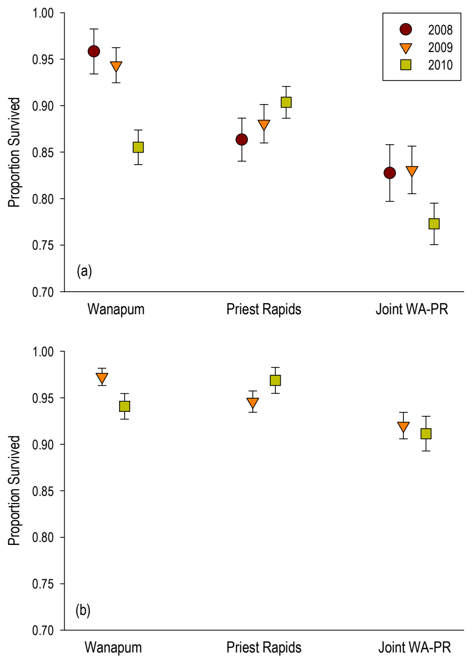


Figure 5. Survival estimates of (a) steelhead (2008-2010) and (b) sockeye (2009-2010) at the Wanapum Development (reservoir and dam), the Priest Rapids Development (reservoir and dam), and the Joint Wanapum-Priest Rapids Project (both developments combined).

Table 2. Summary of dam (concrete) Ricker survival estimates by species at Wanapum and Priest Rapids dams. An asterisk indicates where treatment fish (i.e., fish detected in the forebay of Wanapum Dam passing downstream) survived at higher rates than control fish released 0.5 km downstream of the dam.

		Ricker Survival Estimates	
	Year	Wanapum	Priest Rapids
Steelhead			
	2010	*1.013	0.997
	2009	*1.025	0.983
	2008	0.995	0.952
	Average$_{2008\text{-}2010}$	*1.011	0.977
Sockeye			
	2010	0.981	0.994
	2009	0.992	0.980
	Average$_{2009\text{-}2010}$	0.987	0.987

at Wanapum Dam during the past two studies has been 98.7%.

At Priest Rapids Dam, steelhead concrete passage has increased each year from 95% to nearly 100%. The average steelhead concrete survival at Priest Rapids Dam during the past three years of acoustic tag studies has been 97.7%. Sockeye survival at Priest Rapids Dam has also been high over the past two years and ranged from 98% to 99%.

Relative Route-Specific Survival – Similar to the methods employed in 2009, tagged steelhead and sockeye known to have successfully arrived at Wanapum and Priest Rapids dams in 2010 were used to estimate route-specific relative survivals through each dam (Timko et al. 2010). The analysis of relative route-specific survival excluded the six tag lots that were removed from the survival analysis (Skalski et al. 2010). At both dams, survival was quantified as relative to those fish that passed through the powerhouse. Steelhead that passed through the Wanapum WFB had significantly higher survival estimates (p-value 0.0255). While survival rates were higher for steelhead that passed through the Priest Rapids prototype bypass, they were not significantly different from those that passed through the powerhouse (p-value 0.1246) (Appendix C). Sockeye that passed at the Wanapum WFB experienced higher survival estimates, but not significantly higher than those that passed through the powerhouse (p-value 0.0945). Sockeye that passed through the Priest Rapids prototype bypass had a significantly higher survival estimate (p-value 0.0057) (Appendix D).

The majority of steelhead (77%) passed through the WFB at Wanapum Dam and were estimated to have an 8.4% higher survival likelihood; steelhead WFB survival relative to powerhouse survival was 1.0843 (0.0376). The majority of sockeye at Wanapum Dam also passed through the WFB (78%), with a 5.5% increase in survival through the WFB. At Priest Rapids Dam, the relative route-specific survival of steelhead through the prototype bypass was 1.0318 (0.0207) and sockeye was 1.0526 (0.0190), therefore, fish that passed through the prototype bypass had a higher survival rate than fish that passed through the powerhouse (steelhead at Δ+3.2% and sockeye at Δ+5.3%) (Appendix C and D).

Based on acoustic tag detection histories, 98.8% of steelhead that migrated past Wanapum Dam through the WFB were detected downstream, compared to 91.4% of steelhead that selected the powerhouse. Similarly, 97.6% of the sockeye that passed at the WFB were detected downstream, compared to 92.0% for those which selected the powerhouse. At Priest Rapids Dam, both species were 3% more likely to be detected downstream if they passed through the prototype bypass, compared to those that passed through the powerhouse (Table 3). Powerhouse survival of steelhead and sockeye were 94.9% and 95.2%, respectively, while survival through the prototype bypass for steelhead and sockeye were 97.9% and 98.2%, respectively.

Table 3. Number of tags that passed at each dam by route with the corresponding percentage of tags which were detected downstream, 2010. The percentage of tags listed for all routes reflects concrete passage survival for all passage routes; however, fish with upstream movement during last detection or passage into the gatewells or unknown location were not included.

	Wanapum Dam				Priest Rapids Dam			
	Steelhead		Sockeye		Steelhead		Sockeye	
Passage Route	n	%	n	%	n	%	n	%
All Routes	551	97.3	535	96.4	1,045	96.7	1,008	96.9
Powerhouse	116	91.4	113	92.0	411	94.9	496	95.2
Bypass/Top-Spill	435	98.9	422	97.6	633	97.9	512	98.2
Spillway	0	0.0	0	0.0	1	100.0	0	0.0

Table 4. Percent 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, and the average percent difference by RM between 2010 and 2009 are shown by species in bold.

Release Site	RIDM-WADM	WADM-MATT	MATT-PRDM	PRDM-VEBR	VEBR-RING
Steelhead					
Rock Island	86.5	97.1	96.1	96.7	90.7
Wanapum		95.7	94.6	96.7	89.2
Priest Rapids				97.1	85.7
Average % Loss by RM	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Sockeye					
Rock Island	97.1	96.4	98.8	96.6	97.8
Wanapum		98.1	98.6	96.8	97.9
Priest Rapids				97.3	97.2
Average % Loss by RM	*0.1*	*0.3*	*0.1*	*0.3*	*0.1*

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. 2010). The results in 2010 were similar to 2009; sockeye reach survival was generally higher compared to steelhead (Table 4). Sockeye reach survival by release group ranged from 96.4% to 98.8% and steelhead ranged from 85.7% to 97.1%. Between Rock Island Dam and Vernita Bridge, the reach with the lowest overall survival for steelhead was between Rock Island and Wanapum dams. The loss of steelhead by RM among each reach was similar for all other reaches at 0.4% loss per RM. However, there was an additional loss in steelhead survival calculated by RM (upstream of Vernita Bridge) below each dam in 2010. The greatest loss in sockeye by RM occurred directly downstream of both dams (0.3% loss in the first downstream reach of each dam).

Avian Predation – The 2010 Caspian tern colonies on the Columbia River Plateau experienced a poor breeding season, and a smaller breeding colony size was estimated at Potholes Reservoir compared to 2009 (approximately 366 breeding pairs compared to 487 in 2009; www.birdresearchnw.org). Similar to previous years, an annual investigation of avian predation via PIT tags recovered and/or detected at piscivorous bird colonies on the Mid-Columbia River was conducted by NOAA Fisheries, USGS-Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University, and Real Time Research. A total of 168 PIT tags that were associated with steelhead and sockeye released in the 2010 Grant PUD survival study were recovered (Figures 6 and 7). This accounted for 8.1% of all steelhead and <1% of all sockeye that were tagged and released in 2010 (158 out of 1,949 steelhead and 10 out of 1,593 sockeye). The majority of the tags detected (64%) were recovered from the islands in the Potholes Reservoir, which are predominantly populated by nesting Caspian terns (*Hydroprogne caspia*), along with some nesting California gulls (*Larus californicus*), and Ring-billed gulls (*L. delawarenis*) (Figure 8).

There were no significant differences in predation between the release groups of steelhead, nor were there any for fish condition factor ((10*weight^(1/3))/length). While sample size is low, there did appear to be some trends in steelhead total length and origin of fish from the tags collected at the Caspian tern nesting colony at Potholes Reservoir that may be of interest. We found that more than half (61%) of the steelhead taken had fork lengths that ranged from 190-210 mm; 53% of the total tagged steelhead in the 2010 survival study were recorded with fork lengths within this range. While some literature has shown that Caspian terns prefer steelhead in this range of fork lengths, our sample size is too small to detect any significant differences (Hostetter 2009; Roby et al. 2009). We also found that more than half of the steelhead taken were of hatchery origin in 2010 (n=104, 63.5% hatchery; 36.5% wild). Similar trends in tags recovered at Potholes Reservoir are now evident from 2008 (n=116, 82.7% hatchery; 17.3% wild) and 2009 (n=81, 69.8% hatchery; 30.2% wild) data sets.

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 paired acoustic tag was detected. Avian predation on steelhead in 2008-2010 have been summarized by reach and averaged based on the number of tags taken divided by the total number of river miles in Figures 6 and 7. Detailed avian predation events in 2008-2010 are listed in Appendix G, where the total percent by reach is shown along with the overall total number of PIT tags recovered within the study area.

There were few sockeye tags recovered in 2010 (less than 1%). Overall, there was an increase in the total number of steelhead taken by avian predators compared to each of the two previous years (Table G.2.). Avian impacts, as they relate to Project survival estimates, were similar to those of 2009. Of the total 8.1% steelhead taken in 2010, only 2.2% were taken upstream of Vernita Bridge (2.3% in 2008 and 2.6% in 2009). The average PIT tag detection efficiency at Potholes Reservoir in 2010 was estimated at 52% (A. Evans, pers. comm. 2010). The data in Appendix G has not been modified to account for PIT tag detection efficiency because current detection efficiency values associated with composite acoustic/PIT tags are unknown. If we could assume that the detection efficiency of PIT tags was equal to that of the composite acoustic/PIT tags, then we could extrapolate that at least 12.3% of the total tagged and released Grant PUD steelhead were consumed by avian predators in the Mid-Columbia Plateau, with a minimum of 3.3% consumed above Vernita Bridge. Furthermore, with the exception of Crescent Island, there is no available data on the deposition rate of tags at the sites investigated to further extrapolate the total number of consumed steelhead from the Grant PUD 2010 study.

The impact of avian predation on survival studies conducted by Grant PUD in 2010 was conservatively measured based on paired acoustic detection histories of recovered PIT tags. We estimated that avian predation decreased the overall survival estimates of steelhead by Δ-2.3% in the Wanapum Development and Δ-1.4% in the Priest Rapids Development. The overall avian impact to the Project (joint Wanapum-Priest developments) survival was Δ-3.2%. With few sockeye taken by avian predators, the survival estimates did not change at Priest Rapids Development; however, the survival of sockeye in the Wanapum Development decreased slightly by Δ-0.4% and the Project survival by Δ-0.3%.

As a standardized comparison, the percent of tags taken by river mile was also calculated for each reach by species (Table G.2. and G.3.). The percent of steelhead tags recovered by RM is shown in Figure 7. Similar to 2009, the reaches from Wanapum to Mattawa and Vernita Bridge to Ringold experienced the greatest increase in total number of predation events.

Interestingly, the number of Grant PUD survival study tags detected at Crescent Island significantly increased in 2010, particularly on the gull colony. There were a total of 60 tags detected at Crescent Island, 53 steelhead and seven sockeye tags. At the gull colony, three sockeye and 47 steelhead tags were detected, while only four sockeye and six steelhead tags were detected at the tern colony. In 2009, there were 16 Grant PUD survival study tags detected at Crescent Island, and of those, all tags were detected on the tern colony. Based on 2010 paired acoustic tag detections, nearly all of these tags were last detected emigrating past the final acoustic tag detection array at Ringold (one was last detected at MATT and one was last detected at VEBR). Therefore, predation that occurred on these smolts in 2010 did not impact the Grant PUD survival estimates, but has mid-Columbia River implications. Similarly, all tags detected at Crescent Island in 2009 were last detected at Ringold.

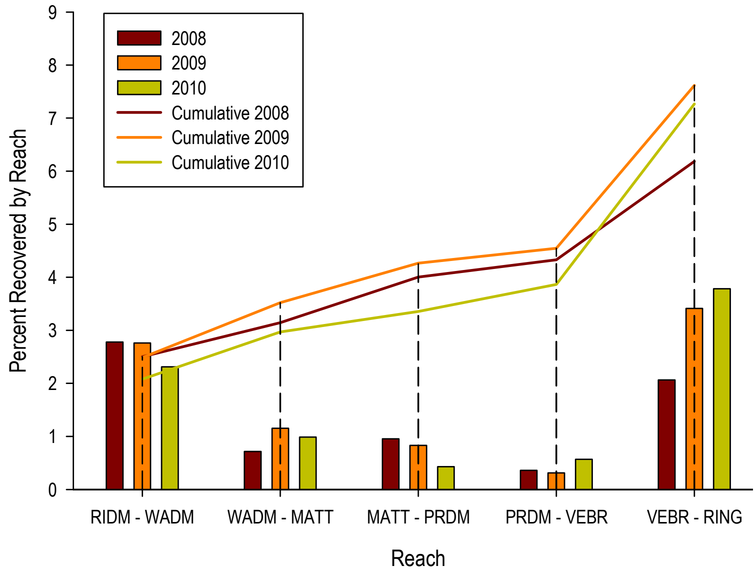


Figure 6. Percent recovered and cumulative percent recovered steelhead PIT tags detected at avian colonies on the Mid-Columbia River are illustrated with associated reach where the paired acoustic tag was last detected and assumed predated upon, 2008-2010.

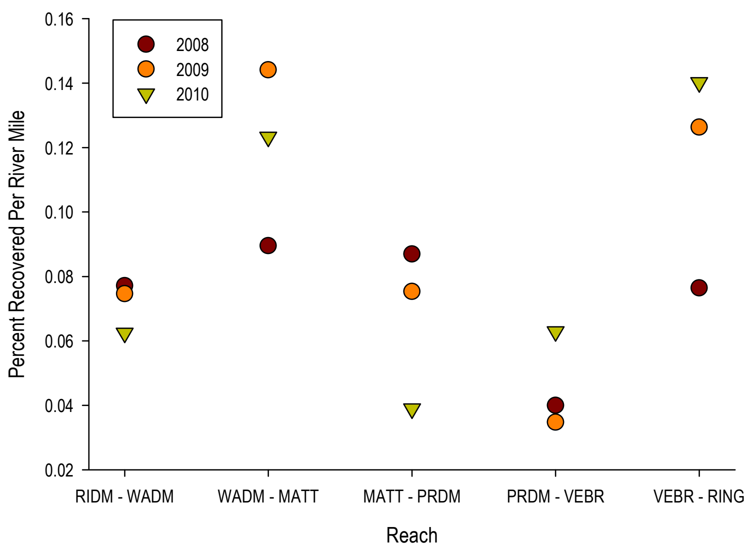
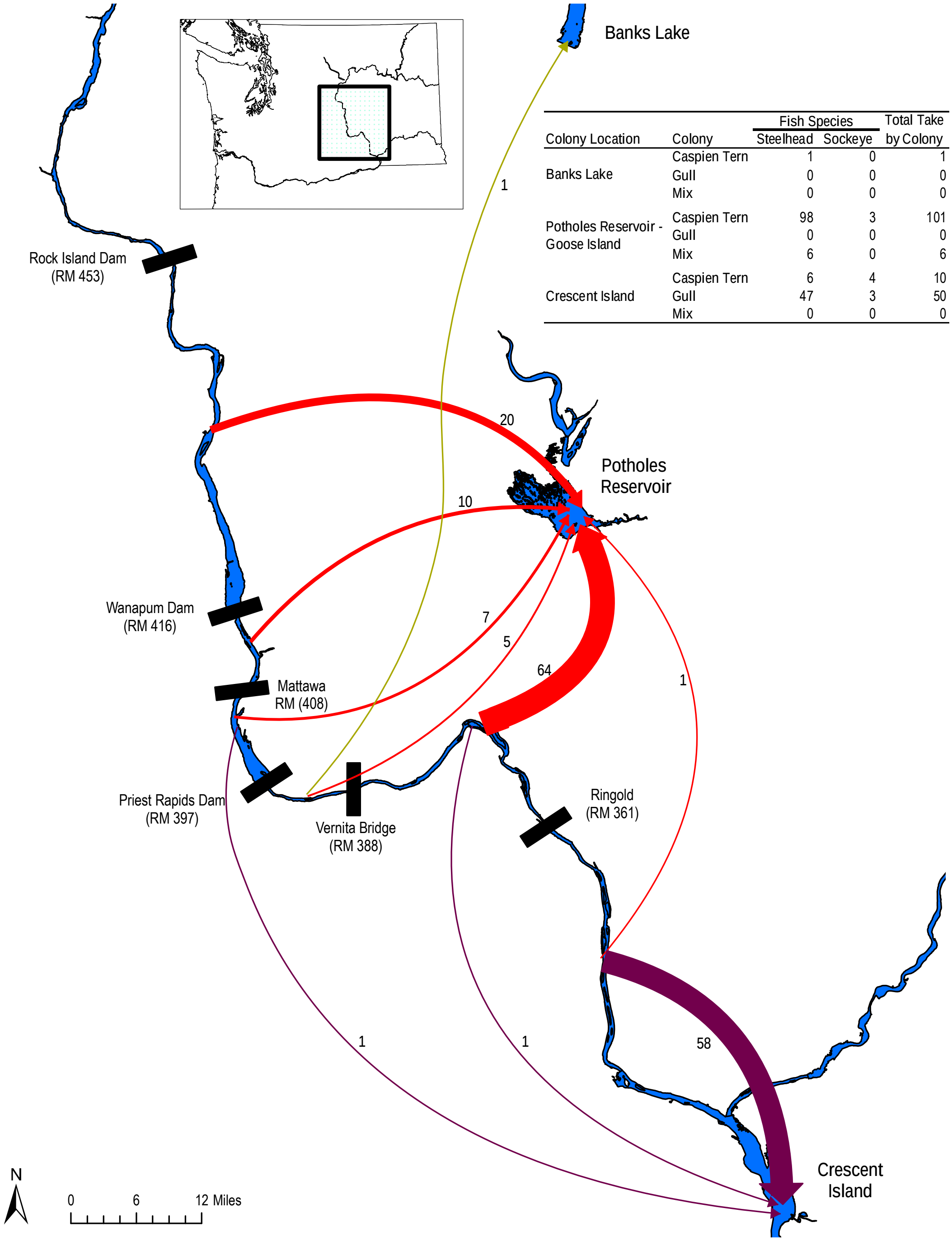


Figure 7. Percent recovered steelhead PIT tags detected at avian colonies on the Mid-Columbia River shown with avian predation estimated by river mile; PIT tag paired with acoustic tag last detection and assumed reach where predation occurred, 2008-2010.



Colony Location	Colony	Fish Species Steelhead	Fish Species Sockeye	Total Take by Colony
Banks Lake	Caspien Tern	1	0	1
	Gull	0	0	0
	Mix	0	0	0
Potholes Reservoir - Goose Island	Caspien Tern	98	3	101
	Gull	0	0	0
	Mix	6	0	6
Crescent Island	Caspien Tern	6	4	10
	Gull	47	3	50
	Mix	0	0	0

Figure 8. Avian predation by reach and recovery location of 2010 steelhead and sockeye 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. Summary table is included as a reference for total predation by colony (Banks Lake, Potholes Reservoir, or Crescent Island), avian predator (Caspian tern, California or Ring-billed gull, or a mix of both Caspian terns and gulls), and species (steelhead or sockeye).

Migration Travel Rates – In 2010, steelhead migration travel times were comparable to 2009, but slower than the prior three years (Figure 9). Similar to 2008-2009, the 2010 results continue to suggest that travel times correlate with average river flows during the study periods of each year. The median travel time from Rock Island Dam to Wanapum Dam was 60.7 hr, an 18.6% increase over the average median in 2006-2009 (Appendix E). Median travel time increased to Priest Rapids Dam by 34.1% (24.6 hr). Median travel time to in-river sites immediately below the dams, increased slightly to Mattawa (Δ+3.7% at 2.7 hr), but was equal to previous years for Vernita Bridge (2.1 hr). The median travel rates to Ringold were faster by 4.0% (7.5 hr) than in prior years (2006-2009 median is 7.8 hr).

Sockeye migration times for 2010 were slower than previous years (Figure 9). The exceptions are Priest Rapids Dam, with slightly faster travel rates in 2010 than in 2009 (one hour faster in 2010, 12.7 hr, compared to 13.6 hr in 2009) and Vernita Bridge, with equal times in 2010 and 2009 at 2.1 hr. When compared to the average median travel times throughout the Project in 2006-2009, travel times in 2010 increased between 3.9% and 14.8% at all sites (Appendix E).

Behavior Analyses Approach – Most steelhead and sockeye within 50 ft of the powerhouse at each dam were distributed in the top 40 ft of the water column, which is deeper than in 2009 when most fish were in the top 15 ft (Appendix F). Moving farther from the face of each dam, both steelhead and sockeye were closer to the surface with steelhead mostly 5-15 ft deep and sockeye 10-20 ft deep at distances of 100-300 ft, which is consistent with past years. Steelhead approaching each dam had a second peak in depth distribution at approximately 60 ft deep at a range of 300 ft from the dam but those fish moved shallower as they approached each dam. A similar pattern was seen for sockeye at Priest Rapid Dam but not for sockeye at Wanapum Dam.

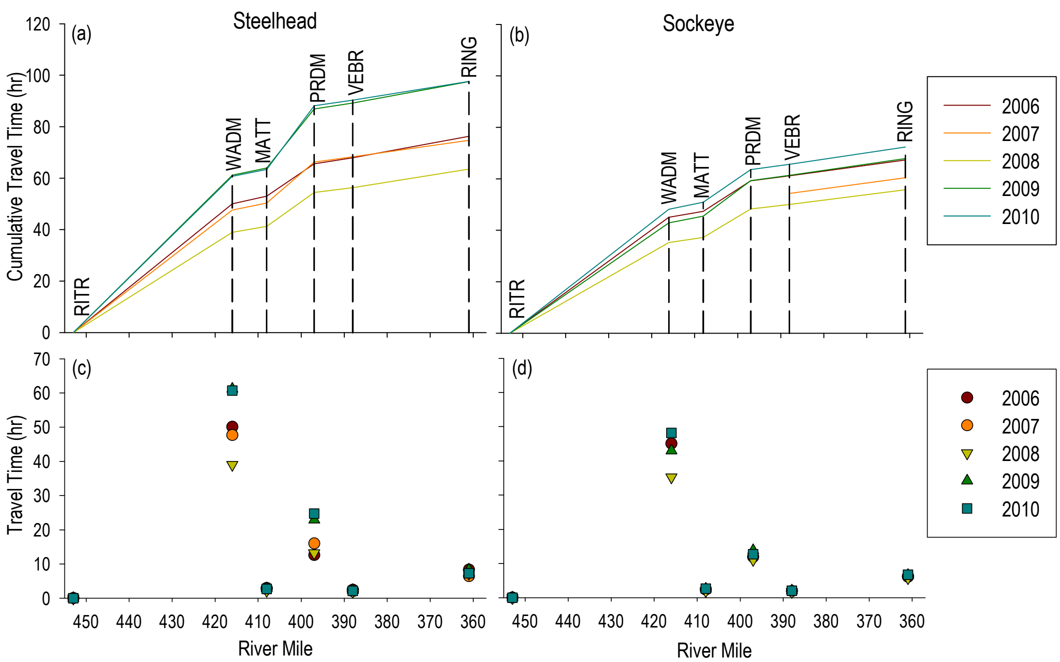


Figure 9. Median travel times to detection systems. Cumulative median travel time between each detection system by river mile for (a) steelhead and (b) sockeye. Non-cumulative median travel time from previous detection system by river mile for (c) steelhead and (d) sockeye.

Forebay Residence Times – Median forebay residence times of fish passing downriver of Wanapum and Priest Rapids dams increased in 2010 compared to all previous years. A one way ANOVA with pairwise analysis (Dunn's method) of log-transformed residence times revealed significant differences (P<0.050) for steelhead and sockeye at both dams. Residence times for steelhead passing both Wanapum and Priest Rapids dams were not significantly different between the years of 2010 and 2009, but a significant difference was observed between 2010 and 2008, 2007 and 2006. Sockeye passing both Wanapum and Priest Rapids dams exhibited significantly longer residence times between 2010 and all previous years. Steelhead and sockeye median residence times in 2010 follow the same trend as those recorded historically; times for steelhead passing either dam are consistently longer than those of sockeye (Table 5 and Figure 10). Only one steelhead passed Priest Rapids Dam via the spillway in 2010. Due to an insufficient sample size and large residence time (355 hr) this fish was excluded from data analysis. Median residence times of steelhead and sockeye passing Wanapum Dam were 2.4 hr and 1.3 hr, respectively. Steelhead and sockeye median residence times for Priest Rapids Dam were 1.5 hr and 0.5 hr, respectively. Detailed median residence times (by species, by dam, by passage route) are listed in Appendix E.

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. As a general rule, in 2010 steelhead were more likely to pass both dams at night. At Wanapum Dam, steelhead passed nearly two times more often at night, an average 32.6 steelhead passed per hour at night compared to 18.3 per hour that passed during the day. More pronounced diel passage was detected at Priest Rapids Dam where steelhead were three times more likely to pass at night; an average 77.2 steelhead per hour passed at night compared to 28.1 per hour during the day. This pattern of steelhead diel passage was similar to what was documented in 2009 (Timko et al 2010). Unique to 2010, an increase in steelhead passage in the middle of the day at Wanapum Dam was observed (Figure 11).

While there were slightly more sockeye that passed during nightfall at both dams, the frequency was much less pronounced compared to steelhead (Figure 11). At Wanapum Dam an average of 26.1 sockeye passed per hour during the night, while 20.4 sockeye passed during the day. At Priest Rapids Dam, an average of 48.1 sockeye passed per hour during the night while 39.2 sockeye per hour passed during the day.

Table 5. 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
Wanapum Dam		
Steelhead	2010	2.41
	2009	1.32
	2008	0.49
	2007	0.71
	2006	0.57
Sockeye	2010	1.32
	2009	0.64
	2008	0.16
	2007	n/a
	2006	0.24
Priest Rapids Dam		
Steelhead	2010	1.50
	2009	0.96
	2008	0.24
	2007	0.34
	2006	0.34
Sockeye	2010	0.52
	2009	0.40
	2008	0.12
	2007	0.20
	2006	0.25

Passage Route Efficiency – In 2010 an increase in non-turbine passage route efficiency (PRE), the proportion of fish that selected a particular route of passage, was recorded at Wanapum and Priest

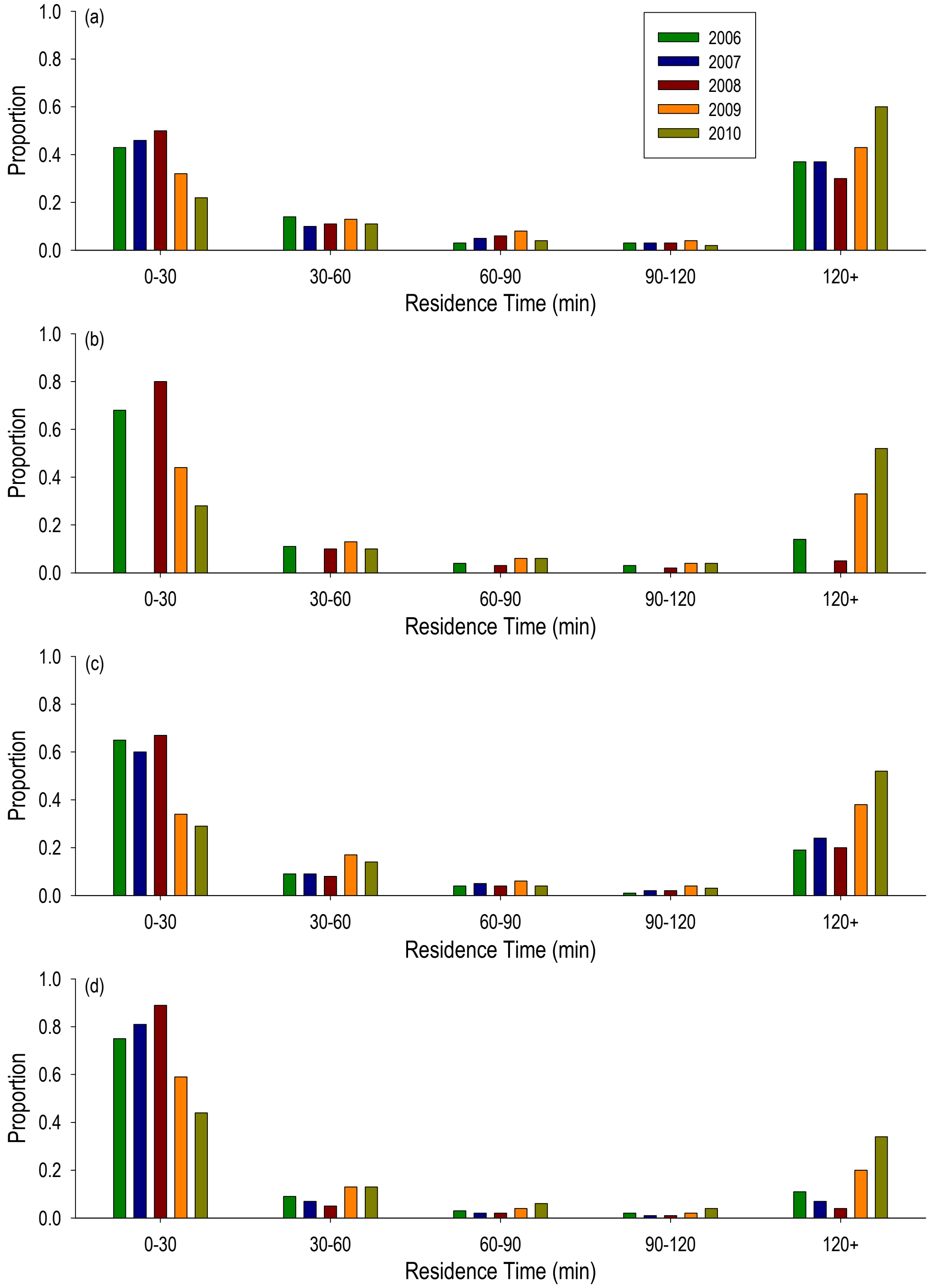


Figure 10. Relative proportion of forebay residence times for the years 2006-2010 in minutes. The figures show (a) steelhead at Wanapum Dam, (b) sockeye at Wanapum Dam, (c) steelhead at Priest Rapids Dam, and (d) sockeye at Priest Rapids Dam. Sockeye were not monitored in the forebay of Wanapum Dam in 2007.

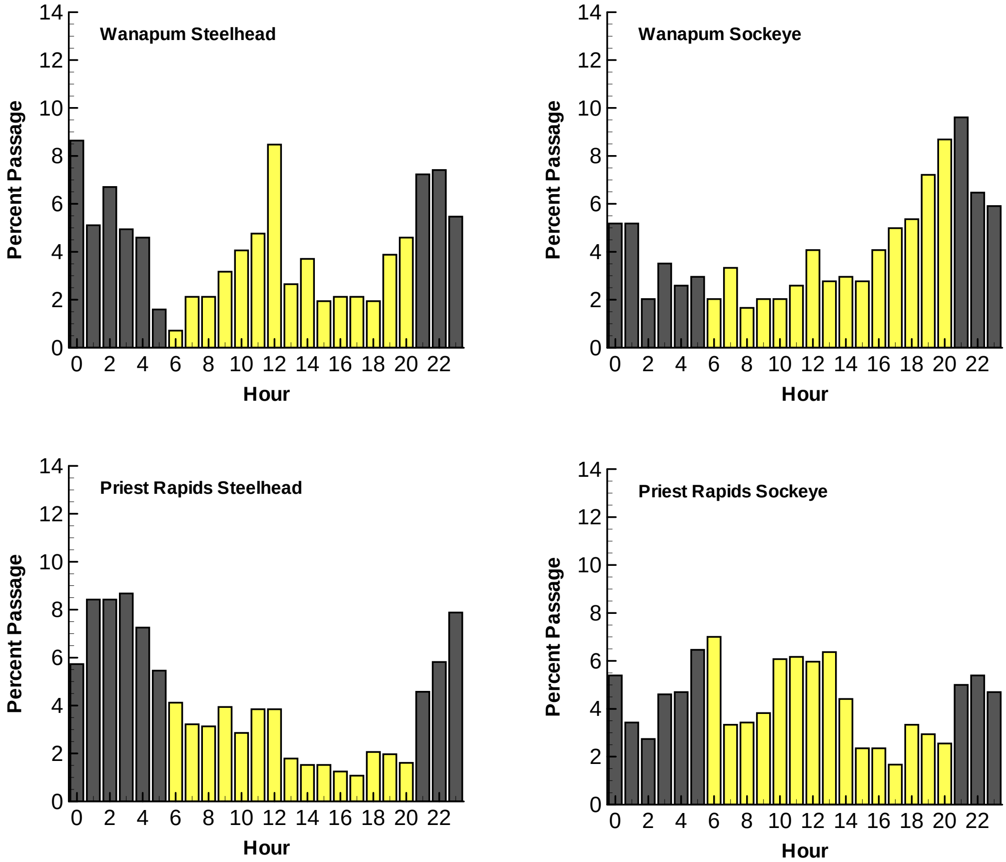


Figure 11. Percent passage of steelhead and sockeye binned by hour at Wanapum (top figures) and Priest Rapids (bottom figures) dams. Yellow indicates daytime passage events while gray indicates nighttime passage events.

Rapids dams compared to 2008 and 2009 studies (Sullivan et al. 2008; Timko et al. 2010) (Figures 12 and 13). At Wanapum Dam, the majority of steelhead and sockeye passed through the WFB (77.3% steelhead and 78.4% sockeye). There was an increase of passage at the WFB by steelhead of 7.1% and a significant increase in passage by sockeye at the WFB of Δ+19.1%. At the Wanapum Dam powerhouse, passage events were recorded at all turbine units by both species, except Unit 7, which was being retrofitted with a new, advanced turbine and was not operational during the spring study. The highest proportion of passage at the Wanapum Dam powerhouse occurred at Unit 8 (Figure 12). During the 2010 study, turbine units 2, 3, 6, and 8 at Wanapum Dam were operating at least 98% of the time, units 9 and 10 were operating at least 91% of the time, and units 1, 4, and 5 were operating less frequently from 49% (Unit 5) to 79% (Unit 4). There were no passage events of steelhead or sockeye at the Wanapum Dam spillway in 2010.

An increase in PRE at the prototype bypass at Priest Rapids Dam was recorded for both species in 2010; 57.3% of steelhead and 50.3% of sockeye (bottom-spill at Tainter gates 21 and 22 and top-spill at the prototype bulkhead at gates 19 and 20). Compared to the 2009 field studies, sockeye passage at the prototype bypass increased at a higher rate than steelhead, Δ+11.3% and Δ+6.3%, respectively. There was nearly an even split in passage of sockeye between the powerhouse and prototype bypass, 49.7% and 50.3%, respectively. The passage of steelhead was slightly skewed towards the prototype bypass, with powerhouse passage at 42.6% and prototype bypass passage at 57.3%.

The majority of powerhouse passage at Priest Rapids Dam occurred at turbine units 1-6 (Figure 13). Trends in powerhouse passage were correlated with units operating at the time of passage. During the 2010 spring study, turbine unit operation at Priest Rapids Dam varied at units 1-6 from 95% to 99% of the time tagged fish were passing the dam. However, the operation of units 7-10 was less frequent and ranged from 38% (Unit 10) to 89% (Unit 7). There was one steelhead passage event recorded at the Priest Rapids Dam spillway in 2010. A detailed list of passage percentages and annual comparisons from 2006-2010 can be referenced in Appendix F.

Passage Proportions Relative to Forebay Residence Times – The use of non-turbine passage routes was correlated with residence time in the forebay at each dam. At Wanapum Dam, passage at the WFB peaked at 96% for steelhead and 89% for sockeye of fish that passed the dam within one hour after the first forebay detection (Figure 14). The percent of steelhead that passed at the WFB was 75-80% when residence times were greater than one hour. At Priest Rapids Dam, sockeye passage at the prototype bypass peaked at 82% with a forebay residence time of 11 min (Figure 14). Once residence times exceeded 15 min, prototype bypass passage of sockeye dropped to 50%. Steelhead did not display a threshold of peak top-spill passage, but instead top-spill passage averaged approximately 50% with forebay residence times up to 25 min. After residence times exceeded 25 min, prototype bypass passage generally increased with increasing residence times (up to 100 hr).

The approach behavior of sockeye at Priest Rapids Dam that passed the prototype bypass within the first 11 minutes of residence time showed a trend of approaching from the spillway side of the dam rather than the powerhouse side; there were no noteworthy trends in steelhead approaching Priest Rapids Dam with shorter residence times (Appendix F). At Wanapum Dam, the largest percentage of fish passed through the WFB, which made it difficult to discern differences in approach behavior for steelhead or sockeye that passed through the powerhouse at varied residence times.

Relative Percent Passage – Similar to 2009, steelhead and sockeye passing Wanapum Dam in 2010 showed similar patterns in levels of Relative Percent Passage (RPP) to each other. Fish that passed through the powerhouse exhibited high RPP (90-100%) in front of units 5, 6 and 8 (Figure 15). The lower RPP in front of units 6 and 7 compared with past years can be contributed to unit 7 not being operational during the 2010 study. Relative percent passage was only 10-20% in front of the future units and spillway bays (Figure 15). Steelhead and sockeye that passed through the WFB were at the highest RPP (90-100%) roughly 300 to 500 ft in front of the spillway at approximately the same angle as the spillway (along the path of predominant flow). Within the 300 ft contour of the center of the WFB both species are found to have high RPP towards the future units, but steelhead also exhibit high RPP in front of powerhouse unit 10.

At Priest Rapids Dam, steelhead and sockeye that passed the powerhouse were at highest RPP in front of units 2 and 3, respectively. Steelhead exhibited moderate (60%) to high (100%) RPP and sockeye exhibited high RPP (80-100%) extending out several hundred feet from the dam along the path of predominant river flow (Figures 16 and 17). Fish were at the lowest RPP along the front of the spillway and directly in front of the prototype bypass. As in 2009, steelhead and sockeye that passed the prototype bypass were at highest RPP on the spillway side of the prototype bypass within the 300 foot contour from the center of the prototype bypass entrance and in front of the mid to high-numbered spillway bays (Figures 16 and 17). In 2010 RPP for steelhead that passed prototype bypass were high (70-100%) in front of the powerhouse units. This trend was not exhibited in 2009 where RPP values were calculated at 40-70% in front of the powerhouse units. The RPP of fish that passed the prototype bypass by bays (top-spill bays 19 and 20 and Tainter gates 21 and 22) are presented in Figure 16 and 17. Fish that pass through the top-spill bays 19 and 20 exhibited similar RPP patterns as seen in the prototype bypass figures, where the highest RPP values were found along the face of the spillway. Fish that pass the bottom-spill show highest RPP values extending from Tainter gates 21 and 22 out into the forebay along the path of predominant flow.

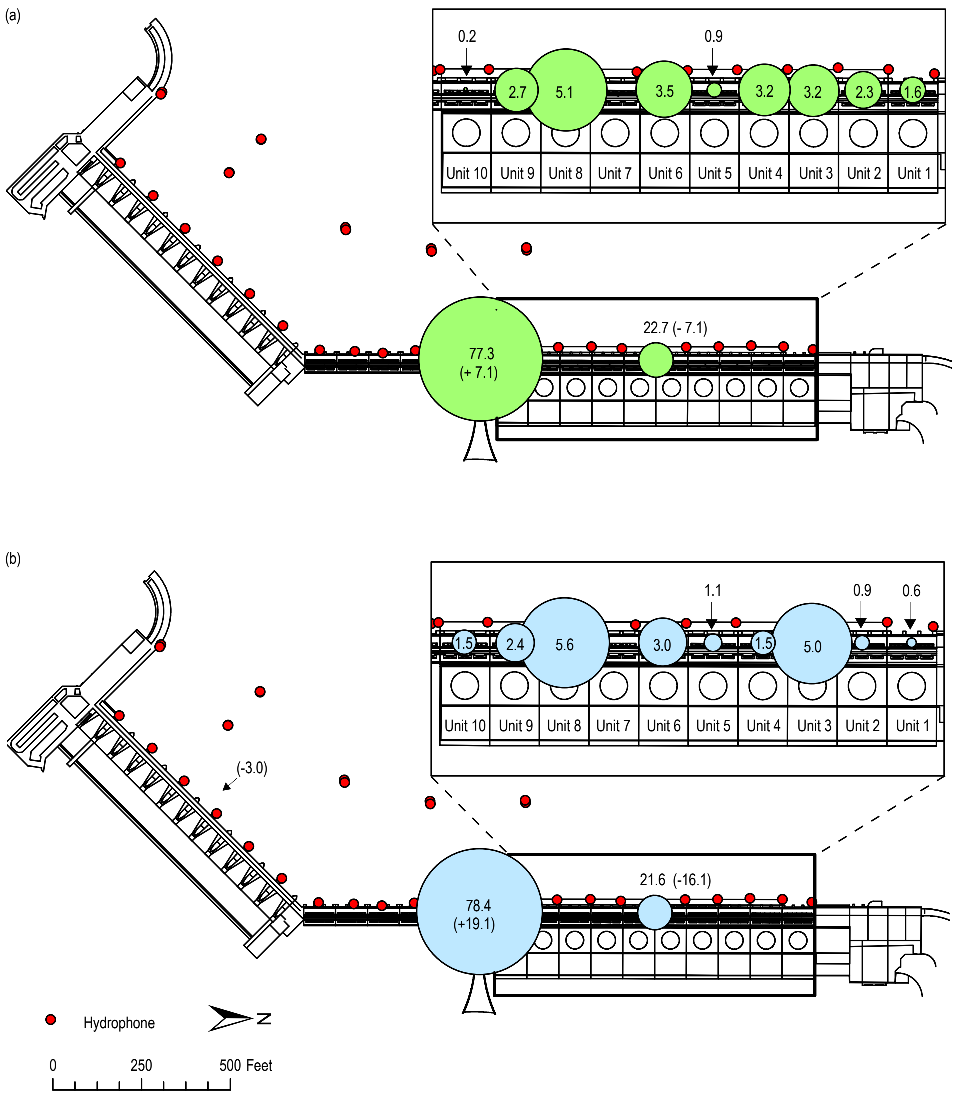


Figure 12. Passage proportions at Wanapum Dam in the spring of 2010; the top figure (a) presents steelhead (green) and the bottom figure (b) presents sockeye (blue). Detailed passage proportions shown by circles are proportional to percentages, with the detailed powerhouse passage two times larger than overall dam passage proportions. The 2010 passage proportions are compared to the 2009 in parenthesis (e.g., + indicates an increase in passage from 2009).

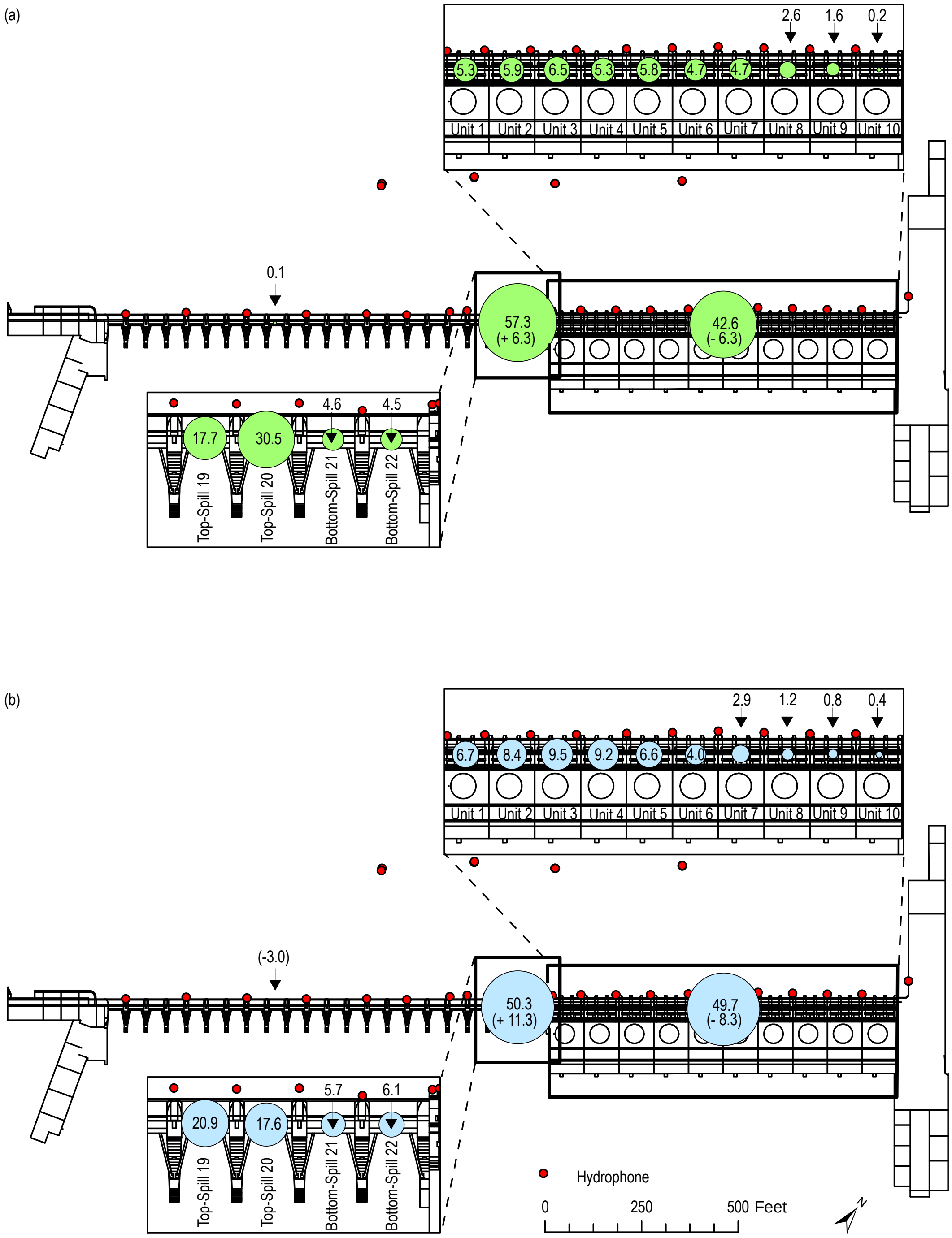


Figure 13. Passage proportions at Priest Rapids Dam in 2010; the top figure (a) presents steelhead (green) and the bottom figure (b) presents sockeye (blue). Detailed passage proportions shown by circles are proportional to percentages, with the detailed powerhouse passage two times larger than overall dam passage proportions. The 2010 passage proportions are compared to the 2009 in parenthesis (e.g., + indicates an increase in passage in 2010 compared to 2009).

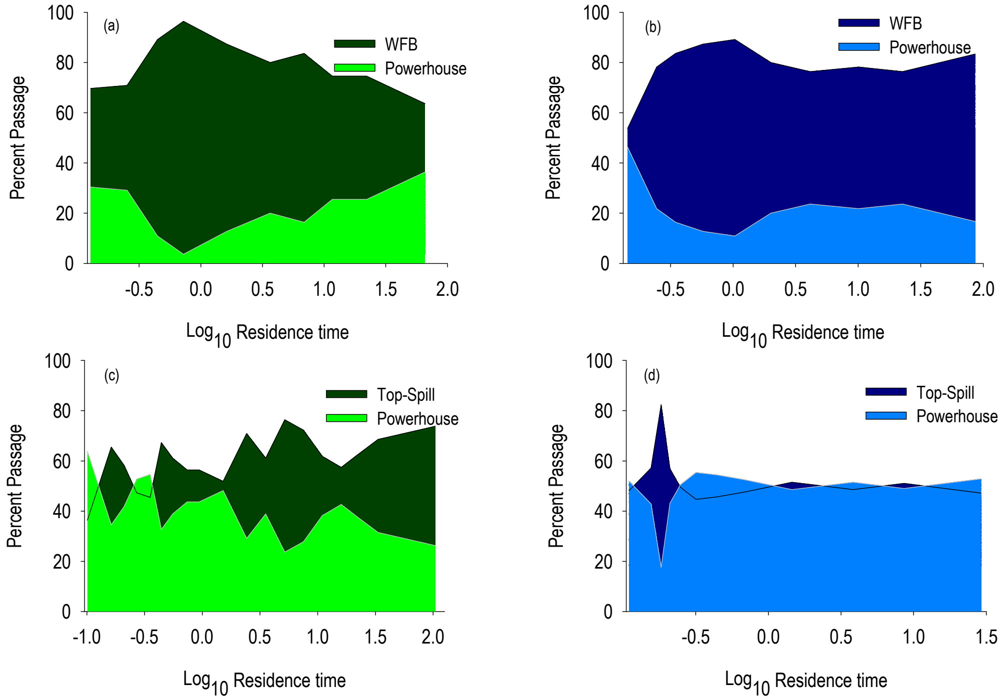


Figure 14. Percent passage by residence time (Log_{10}) at Wanapum and Priest Rapids dams of steelhead (a and c, presented in green) and sockeye (b and d, presented in blue). Percent passage at each dam is grouped by either bypass (WFB at Wanapum Dam or Top-Spill at Priest Rapids Dam) or powerhouse.

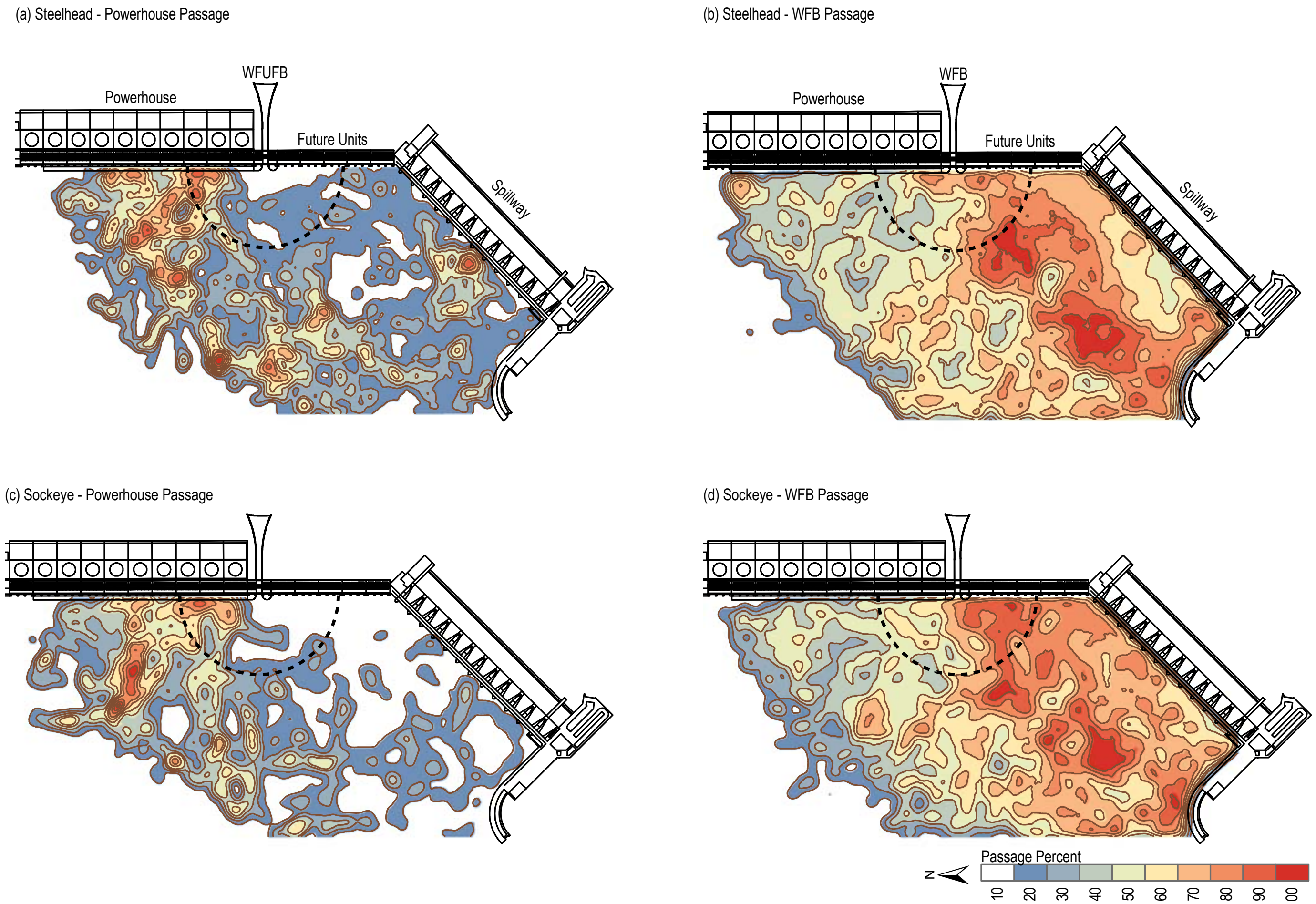


Figure 15. Passage percent bin densities of steelhead (a and b) and sockeye (c and d) passing the powerhouse and Wanapum Fish Bypass (WFB) at Wanapum Dam, 2010. Dotted line represents 300 ft contour from the center of the WFB.

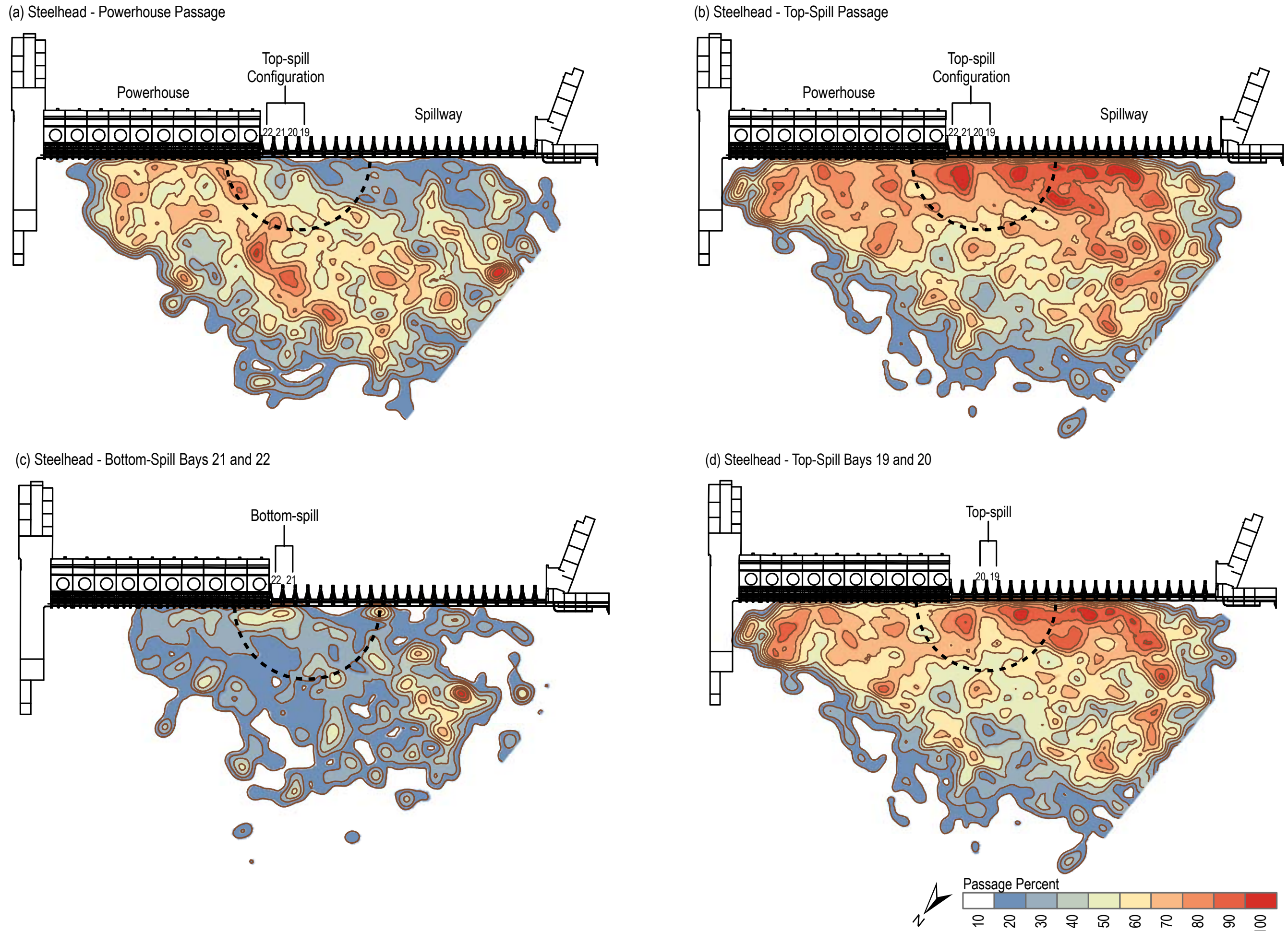


Figure 16. Passage percent densities for steelhead passing Priest Rapids Dam, 2010. Passage percent densities are presented at the (a) powerhouse, (b) test configuration, (c) bottom-spill (Tainter gates 21 and 22), and (d) prototype bypass (Spillway gates 19 and 20). Dotted line represents 300 ft contour from the center of the prototype bypass.

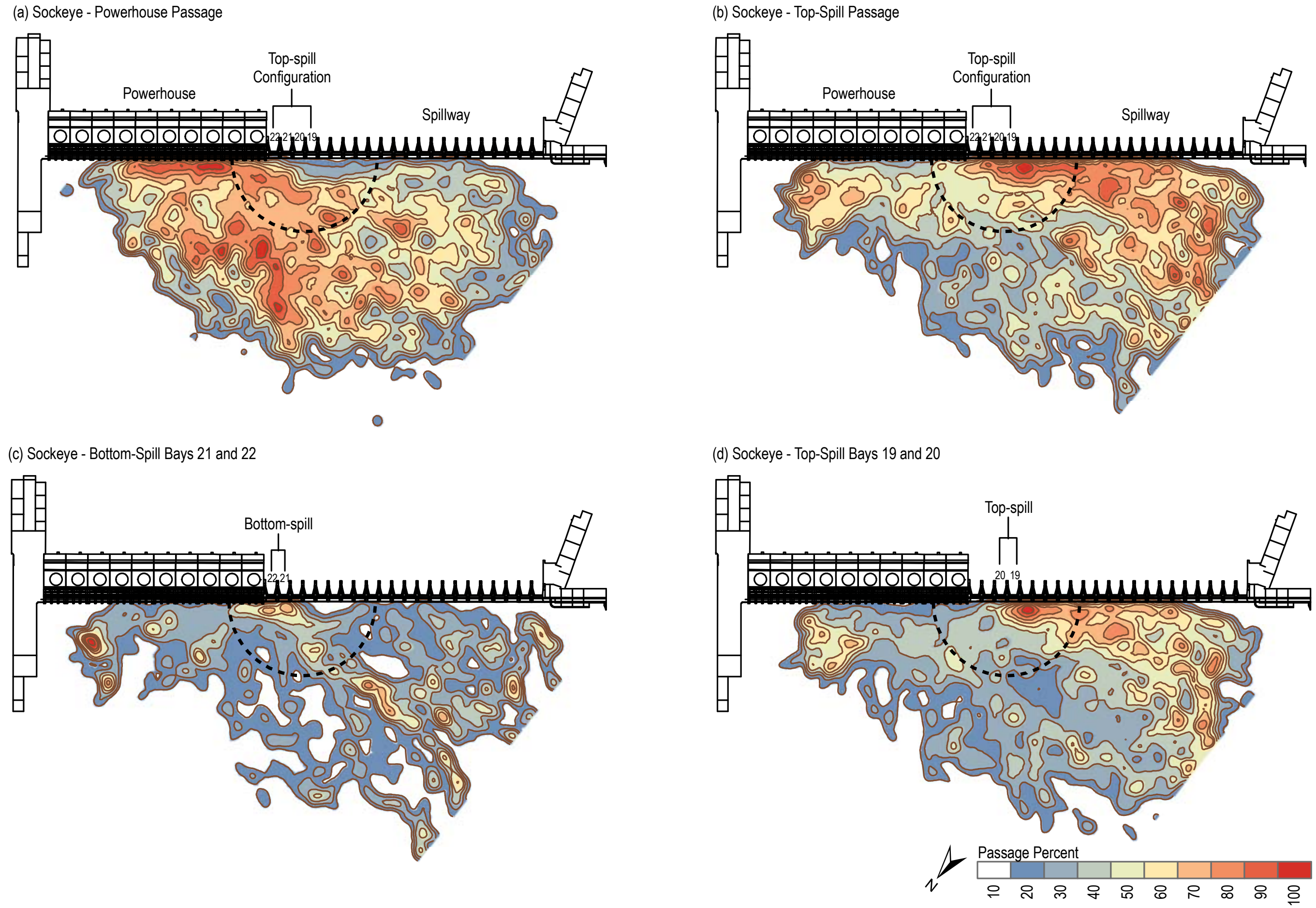


Figure 17. Passage percent densities for sockeye passing Priest Rapids Dam, 2010. Passage percent densities are presented at the (a) powerhouse, (b) test configuration, (c) bottom-spill (Tainter gates 21 and 22), and (d) prototype bypass (Spillway gates 19 and 20). Dotted line represents 300 ft contour from the center of the prototype bypass.

Bypass Non-Selection – Steelhead and sockeye smolts that approached within 300 ft of the WFB or Priest Rapids prototype top-spill bypass, but did not pass were termed "non-selection" fish. At the WFB, steelhead non-selection was distributed with a higher concentration near the powerhouse (Figure 18a). Steelhead that were detected closer to the powerhouse tended to be deeper (elevation 460-500 ft) than those directly in front of the WFB entrance and future units (elevation 556-575 ft). Sockeye non-selection was concentrated near the powerhouse and had elevation patterns similar to steelhead (Figure 18b).

At the Priest Rapids Dam top-spill, steelhead non-selection was concentrated near the powerhouse (elevations ranged from approximately 420-485 ft) (Figure 18c). Sockeye non-selection at the top-spill bypass was also concentrated near the powerhouse, similar range of elevations as steelhead (Figure 18d). There was little difference in elevations of non-selection for either steelhead or sockeye on the powerhouse and spillway side of the top-spill.

The WFB captured more fish to the right of the bypass centerline than were captured at the Priest Rapids prototype top-spill bypass. When comparing the closest position of non-selection fish to the bypass/top-spill at both dams, results suggest that the current prototype bypass at Priest Rapids Dam does not possess a strong enough surface attraction flow (Figure 18).

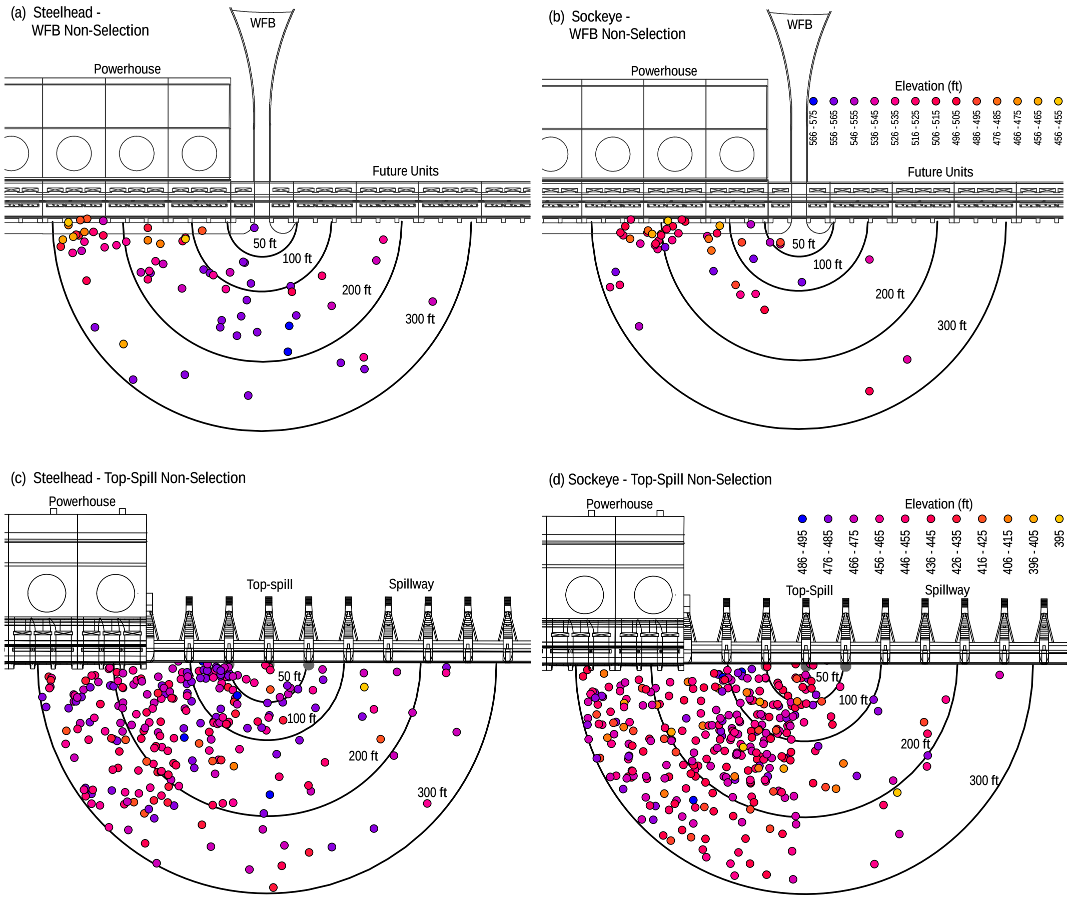


Figure 18. Steelhead and sockeye smolts that entered the 300 ft radial zone of influence in front of the Wanapum Fish Bypass (WFB) but were not captured are presented in the two upper graphics, a and b, respectively. At Priest Rapids Dam, steelhead and sockeye smolts that entered the 300 ft radial zone of influence directly upstream of the prototype bypass but did not pass are presented in the two lower graphics, c and d, respectively. Each point represents the closest approach location and elevation to the WFB or top-spill before non-selection.

Zone Entrance Efficiency – Zone entrance efficiency (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. ZEE was greater in 2010 than in past years for the prototype bypass at Priest Rapids Dam (i.e. more fish found the top-spill than in any previous study). In 2010, ZEE was measured at 78% for steelhead and 79% for sockeye; more than three quarters of all steelhead and sockeye entered the top-spill zone of influence (Table 6). The ZEE in 2010 continues a pattern of yearly increase for steelhead since 2006 and a continuing increase for sockeye since 2008 (Figure 19). Sockeye ZEE was just 19% in 2008 making the 2010 ZEE a more than four-fold increase. Steelhead ZEE has also increased by nearly two-fold between 2006 and 2010.

Fish Collection Efficiency – Fish collection efficiency (FCE) is a measure of top-spill passage of fish at Priest Rapids Dam where fish entered the 300 ft zone of influence (i.e., how many fish passed through the top-spill after swimming within 300 ft of the prototype bypass). The prototype bypass in 2010 was altered by removing the "sluiceway-spill" but was otherwise similar to 2008 and 2009 (top-spill at Spill bays 19 and 20, bottom-spill at Tainter gates 21 and 22). In 2010, FCE was slightly more for both steelhead (69%) and sockeye (59%) than in 2008 or 2009 (Table 6). As in previous years, there was greater than 95% collection efficiency at 50 ft from the top-spill for both species with decreasing efficiency at greater distances. This year, FCE at 300 ft was nearly 70% for steelhead and 60% for sockeye which is greater than in previous studies.

The percent of fish that passed the Priest Rapids Dam prototype bypass increased in 2010 with the overall increase in flow through the prototype bypass (Figures 20 and 21). The highest FCE and ZEE were estimated in 2010; the second highest FCE and ZEE were estimated in 2009 (exponential regression, R^2 values of steelhead was 0.64 and of sockeye was 0.50) (Figure 20). The ratio of fish to flow through the top-spill bulkhead of the prototype bypass increased for steelhead from 3.4 in 2009 to 4.7 in 2010, and for sockeye 3.2 in 2009 to 3.7 in 2010 (Table 7). The ratio of fish to flow through the bottom-spill of the prototype bypass decreased for steelhead and increased for sockeye; steelhead fish to flow for bottom-spill was estimated at 1.5 in 2009 and 1.0 in 2010, while sockeye was 0.8 in 2009 and 1.3 in 2010 (Table 7).

Table 6. 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
2010	Steelhead	0.78	0.69	0.54	0.57
	Sockeye	0.79	0.59	0.47	0.50
2009	Steelhead	0.72	0.66	0.47	0.51
	Sockeye	0.67	0.55	0.37	0.39
2008	Steelhead	0.42	0.59	0.25	0.33
	Sockeye	0.19	0.45	0.08	0.22
2007	Steelhead	0.42	0.34	0.14	0.19
	Sockeye	0.37	0.22	0.08	0.12
2006	Steelhead	0.40	0.39	0.16	0.15
	Sockeye	0.48	0.38	0.18	0.19

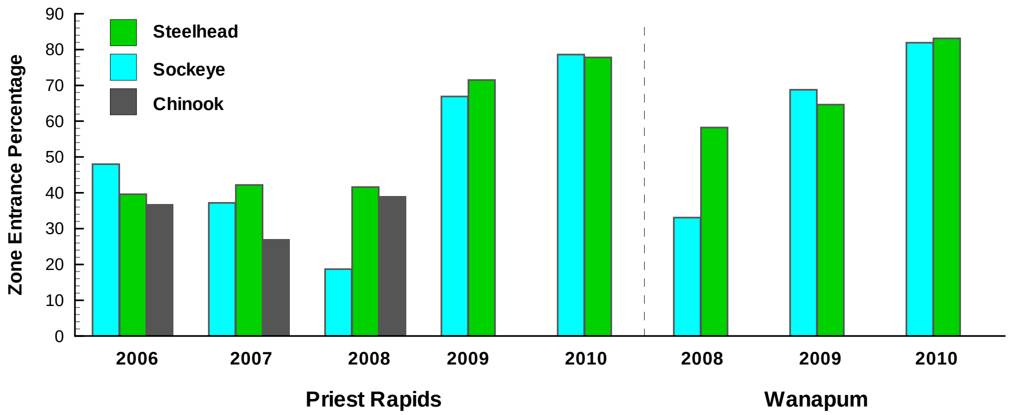


Figure 19. Percent of fish by species and year at Priest Rapids and Wanapum dams that entered a 300 ft radius from the prototype bypass (left) and WFB (right) divided by the total number of fish that passed the dam (defined as zone entrance efficiency) in the 2006-2010 field studies. Yearling Chinook were not studied in 2009-2010.

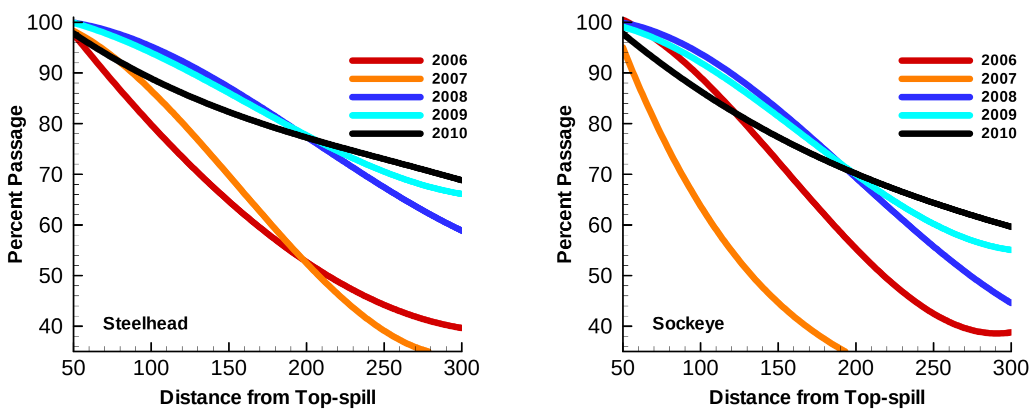


Figure 20. Percent passage of steelhead (left) and sockeye (right) that passed through the Priest Rapids Dam top-spill and were detected within 50, 100, 150, 200, 250, and 300 ft increments from the prototype bypass (2006-2010).

Table 7. The ratio of fish to flow at the Priest Rapids Dam prototype bypass, specifically top-spill and bottom-spill non-turbine passage routes are listed for 2006-2010. Passage events listed as top-spill consisted of passage at the prototype top-spill bulkhead (Spill bays 19 and 20) and sluiceway (sluiceway was operational 2008-2009). Passage events listed as bottom-spill consisted of passage through Tainter gates 1-18 and 21 as well as 22 in 2010 (sluiceway was removed in 2010). The sluiceway and Tainter gate 21 were not operated in 2006 or 2007.

	Top-Spill			Bottom-Spill		
Year	% Fish	% Flow	Fish to Flow	% Fish	% Flow	Fish to Flow
			Steelhead			
2010	48.2	10.3	4.7	9.1	9.3	1.0
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			
2010	38.5	10.3	3.7	11.8	9.3	1.3
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

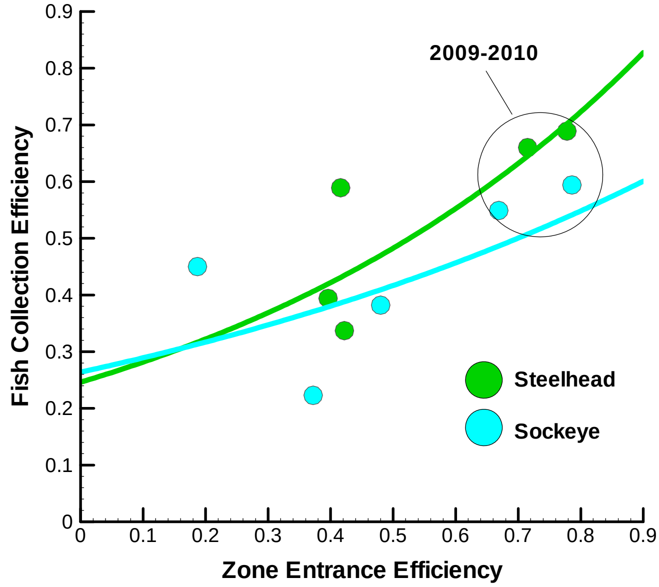


Figure 21. Fish collection efficiency (FCE) of the Priest Rapids Dam prototype bypass in 2006-2010 is displayed by an exponential regression with zone entrance efficiency (ZEE). Each point represents steelhead (green) or sockeye (cyan) evaluated per year. Increased passage route efficiency at the prototype bypass occurred as an increase in proportion of study fish entered the zone of influence (300 ft radius from the center of the top-spill configuration). The highest FCE and ZEE were estimated in 2010; the second highest FCE and ZEE were estimated in 2009. The exponential regression R^2 values of steelhead was 0.64 and of sockeye was 0.50.

Discussion

Studies have been conducted on the Columbia and Snake rivers for over a decade to measure downstream salmonid survival through hydropower developments. These studies have progressed in their use of technology and methodology. Early survival studies relied on PIT and radio tags. As acoustic tag technology evolved, it became more widely used. Acoustic tags offer substantial benefits over the earlier technologies which most importantly include very high detection efficiency. As a result, sample sizes, or the number of fish required to meet statistical requirement, has dropped dramatically (over 100 times in some cases). As technological advances have been made, advances in study design have followed suit. These advances include the randomization of tags from different production lots, standardization of surgical and fish transport protocols, distribution of fish surgeons to both treatment and control release groups, and systematic activation of tags to eliminate potential tag failure bias. As a result, in 2010 there were no statistical biases related to tag or surgical effect. Furthermore, the detection efficiency of tagged fish approached 100% for all acoustic arrays.

Survival – For the third consecutive year, the BiOp and SSSA performance standards for steelhead were not achieved at Priest Rapids Dam or through the joint Wanapum-Priest Rapids Project (Skalski et al. 2009b, 2009c, 2010). Surprisingly, and in contrast to 2008 and 2009, the performance standard at Wanapum Dam was also not met for steelhead. For the second consecutive year sockeye outperformed steelhead and met survival standards at Wanapum, Priest Rapids and through the joint Wanapum – Priest Rapids Project. Sockeye survival was 0.94 for the Wanapum Development (9% higher than steelhead), 0.97 for the Priest Rapids Development (7% higher than steelhead), and 0.91 through the joint Wanapum-Priest Project (14% higher than steelhead) (Table 8).

We previously suggested in Timko et al. (2010) several factors that may be contributing to the superior performance of sockeye as compared to steelhead. These factors are listed as follows: 1) smaller body size may be an advantage in downstream hydropower passage (Skalski et al. 2002), 2) faster downstream migration time which would reduce exposure to predators (avian and piscivorous), and 3) deeper swimming depth which reduces exposure to avian predation and total dissolved gas saturation. Further investigation over the past year has identified additional factors that may also be contributing to the differential survival between sockeye and steelhead, along with some factors that we believe can be eliminated as contributors to differential survival.

One potential reason for the loss of steelhead in both the Wanapum and Priest reservoirs could be overwintering. In this scenario, acoustic tags would expire due to battery failure and fish would become impossible to detect. Statistically, these fish would be considered mortalities and decrease overall survival estimates. Since 2008, studies conducted with juvenile steelhead by Grant PUD have been implanted with an acoustic/PIT combination tag. PIT tags do not require a battery (and thus do not expire) as they are activated at PIT detection arrays by electro-magnetic fields. To look for overwintering behavior, we queried the PIT Tag Information System (PTAGIS) for PIT tags which had been mated with acoustic tags and had not been detected at acoustic arrays. No PIT tags associated with missing acoustic tags were detected downstream of the Priest Rapids Project, thus no evidence was found for overwintering behavior. At this time, overwintering does not appear to be a factor in the depressed steelhead survival numbers as compared to sockeye.

Another hypothesis considered was that steelhead and sockeye were using different areas of the river during their downstream migration. It was hypothesized that steelhead were utilizing primarily shoreline regions of the river and sockeye were using the center, thalweg. If this theory were true, then perhaps steelhead were being exposed to predators at a higher rate than sockeye. An investigation of detection histories from 2009 and 2010 at all in-river arrays determined that both steelhead and sockeye make use of the same migration corridors (primarily the thalweg). Beeman et al. (2006) also found that there were no major differences in the in-river spatial distribution of emigrating steelhead smolts which tend to migrate mid-river. Cross-river distribution is unlikely to be a factor in survival differences between species.

An additional hypothesis for the greater loss of steelhead throughout the Priest Rapids Project was the apparent selection of steelhead by predators was at a higher rate than for sockeye (Antolos et al. 2005; Lyons et al. 2010). A number of species-specific factors may contribute to this, which included slower migration time, longer forebay residence time and shallower migration depth by steelhead. We have no direct data to validate these theories. We do, however, have data that suggests predation events are occurring in the forebay at both Wanapum and Priest Rapids dams. If an acoustic tag was last detected moving upstream away from the forebay it is classified as "net upstream" movement. This behavior is uncharacteristic of migrating juvenile salmonids and is likely indicative of direct piscivorous fish predation. Over the past two seasons (in which tagged steelhead and sockeye were both available to predators) we observed six times as many steelhead with net upstream detections at Wanapum and eight times at Priest Rapids, as compared to sockeye. Direct predation on steelhead at a higher rate than sockeye is likely one of the causes for the difference in Project survival between the species.

Avian Predation – Avian predators prey on salmonids throughout the Columbia Basin (Antolos et al. 2005; Collis et al. 2001; Lyons et al. 2010; Ryan et al. 2003). For example, 60% of the common merganser diet between Wells and Rock Island dams (on the mid-Columbia) is comprised of salmonids smolts; gulls in the same reach were found to have a diet consisting of 25% salmonid smolts (Parrish et al. 2004). Predation by birds on migrating smolts within the Priest Rapids Project was suspected in 2007 when researchers studying Caspian terns at the Potholes Reservoir colony discovered and returned hundreds of acoustic tags to Grant PUD. At that time there was no way to identify tags, as their batteries had expired and were not externally numbered. Tags could not be linked to a particular hydroelectric development, study area or even study year. Tags could be linked to an individual steelhead beginning in 2008 (sockeye in 2010) with the development of the acoustic/PIT combination tag.

Differential predation rates were observed in 2010 between steelhead and sockeye. Of the 168 tags recovered from the Potholes Reservoir, 158 (94%) were from steelhead smolts. The Caspian tern colony has grown by over 60% since 2007 to nearly 500 breeding pairs and was the largest colony of nesting Caspian terns on the Columbia Plateau in 2009 (BRNW 2010). PIT tag recoveries on the Potholes tern colony indicated that over 15.5% of Upper Columbia steelhead passing Rock Island Dam in 2009 were consumed by Caspian terns nesting at this one colony (Roby et al. 2010). Lastly, Hostetter et al. (2009) and Collis et al. (2009) noticed an increase in Caspian tern predation during low water years, similar to the Priest Rapids Project in both 2009 and 2010.

After multiple years of research it appears that steelhead are preferentially selected as a food source by avian and piscivorous fish predators. A combination of species specific factors that include travel time, residence time, vertical river position and size, have put juvenile steelhead at a distinct disadvantage compared to sockeye. The future of understanding and controlling predation of juvenile salmonids throughout the Priest Rapids Project, more specifically steelhead, may be critical in the process of achieving BiOp and SSSA survival standards.

Passage – All metrics for top-spill passage at Wanapum and Priest Rapids dams increased in 2010. Top-spill passage proportions at both Wanapum and Priest Rapids dams were remarkably high. The WFB collected 77.3% (increase of 7.1% over 2009) of migrating steelhead and 78.4% (increase of 19.1% over 2009) of migrating sockeye. The prototype bypass at Priest Rapids Dam also collected a high proportion of the migrating steelhead (57.3%, increased 6.3% from 2009) and sockeye (50.3%, increased 11.3% from 2009). At both of these hydroelectric dams, fish are selecting limited surface collection flow rather than the predominant powerhouse flows. At Wanapum Dam, the WFB on average passed 16.5% of the total river flow but entrained nearly 80% of the migrating steelhead and sockeye. Similarly, at Priest Rapids Dam, the prototype bypass passed

25% of the total river flow but entrained over half of the migrating study fish. The proportion of fish which entered the zone of influence (a 300 ft radial zone from the center of the top-spill) increased 6% for steelhead and 12% for sockeye in 2010 (ZEE). Similarly, fish collection efficiency (FCE) increased by 3% for steelhead and 4% for sockeye.

There appears to be a threshold effect with respect to residence time and top-spill passage. In 2010, there was an increase in both top-spill passage (both dams, both species) and an increase in forebay residence time (both dams, both species). Residence times of fish at Wanapum Dam increased by 83% for steelhead and 106% for sockeye when compared to residence times in 2009. At Priest Rapids Dam, residence time increased by 56% for steelhead and 30% for sockeye. Interestingly, we could find no conclusive evidence to support a direct correlation between fish with prolonged forebay residence times having greater top-spill passage selection.

Based on 3D swimming pathways, it appears that fish entering the forebay and passing at each dam can be defined as either “early committers” (fish that display direct passage behavior) or “millers” (fish that display in-direct, delayed passage behavior) and that there was a threshold time that defined these two groups. At Wanapum Dam, the WFB threshold time was approximately one hour, after which proportional use of the WFB decreased (though use of the WFB remained relatively high). At Priest Rapids Dam, the measured threshold for sockeye was 11 minutes, after which an equal number of fish selected either the top-spill or the powerhouse. There was no threshold effect for steelhead at Priest Rapids Dam.

Behavior – Behavioral analysis conducted in 2010 did not yield any notable differences in trends seen in 2009 at either Wanapum or Priest Rapids dams. In 2010, steelhead and sockeye approached Wanapum Dam primarily from the right bank and moved across the face of the spillway gates and entered the WFB (Spillbay gates were closed in 2010). Many of these fish would have only encountered the WFB flows and proceeded to pass there accordingly. Approaching Priest Rapids Dam, steelhead and sockeye also moved along the right bank (closer to the thalweg) and approached the prototype top-spill along the face of the spillway. Similar to Wanapum, spill gates at Priest Rapids were closed in 2010 and many fish (especially sockeye) took advantage of their first downstream passage opportunity and exited through the prototype top-spill. Steelhead tended to mill in the forebay prior to passage (by any exit route).

Summary – The 2010 study was marked by low river flow and cool water temperatures when compared to the 10-year average. Year to year variability with respect to river flow rates, temperature, total dissolved gasses, powerhouse operations, bird breeding success, and population dynamics of piscivorous fish predators can have a tremendous impact on fish survival. Even with the ever changing environmental variables, concrete survival at Wanapum and Priest Rapids dams has been high. Over the past two years concrete survival for steelhead has averaged 99.4% at Wanapum and Priest Rapids dams. These numbers reflect the effort which has gone into the construction of a very successful fish bypass at Wanapum Dam and the successful development of a prototype top-spill at Priest Rapids Dam. It is unlikely that concrete survival can be measurably improved.

Steelhead survival numbers are well below the BiOp and SSSA standards (FERC 2008). As concrete survival is currently extremely high, further modifications to either dam will not likely result in a measurable improvement at either dam. We have concluded that piscivorous predation by birds and fish are occurring in the reservoirs upstream of each development and are likely the primary causes of mortalities to steelhead in the Priest Rapids Project. If BiOp and SSSA standards are to be achieved, efforts must be made to understand and control the predation of juvenile salmonids.

Table 8. Summary of behavioral and survival characteristics measured in 2010 by species.

Parameter	Species: Steelhead	Species: Sockeye
Fish Characteristics		
Weight (g)	65 (21.5-92.5)	21 (15.5-88.0)
Length (mm)	191 (127-222)	129 (111-202)
Tag Burden	1.2% (0.8-3.5%)	3.8% (0.9-5.2%)
Project Survival		
Wanapum Development	0.8553 (0.0186)	0.9408 (0.0138)
Priest Development	0.9037 (0.0171)	0.9688 (0.0139)
Joint Wanapum-Priest Project	0.7729 (0.0223)	0.9114 (0.0187)
Wanapum Dam Survival		
WFB	98.9%	97.6%
Powerhouse	91.4%	92.0%
Priest Rapids Dam Survival		
Prototype Bypass	97.9%	98.2%
Powerhouse	94.9%	95.2%
Forebay Residence Times (hrs)		
Wanapum Dam (All Routes)	2.41	1.32
Priest Rapids Dam (All Routes)	1.53	0.52
Bypass Efficiency		
Wanapum Dam (WFB)		
Fish Collection Efficiency (FCE)	99.8 - 85.8%	99.7 - 89.4%
Passage Route Efficiency (PRE)	77.3%	78.4%
Zone Entrance Efficiency (ZEE)	83.1%	81.9%
Priest Rapids Dam – Top-Spill		
Fish Collection Efficiency (FCE)	98.0 - 68.9%	97.5 - 59.4%
Passage Route Efficiency (PRE)	57.3%	50.3%
Zone Entrance Efficiency (ZEE)	77.8%	78.6%
Reach Survival (%)		
Rock Island - Wanapum	86.5%	97.1%
Wanapum - Mattawa	95.9%	96.9%
Mattawa - Priest Rapids	95.4%	99.1%
Priest Rapids - Vernita Bridge	97.0%	96.8%
Vernita Bridge - Ringold	88.4%	97.4%
Travel Times (hrs)		
Rock Island - Wanapum	60.7	48.2
Wanapum - Mattawa	2.5	2.4
Mattawa - Priest Rapids	25.0	12.0
Priest Rapids - Vernita Bridge	2.1	2.0
Vernita Bridge - Ringold	6.9	6.5
Rock Island - Ringold	97.2	71.1

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Appendix A

Acoustic Array Positioning and System Detection Efficiency

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System ID	Number	HD Location	Orientation	Northing	Easting	Elevation
System A						
A1*	202	PH	surface	563201.7	1772611.4	549.4
A2*	204	PH	mid	563022.2	1772610.6	515.4
A3	206	PH	surface	562834.3	1772608.7	550.2
A4	208	PH	mid	562656.7	1772607.0	510.4
A5	210	PH	surface	562474.3	1772607.1	558.1
A6	212	WFUFB	mid	562372.9	1772610.4	497.6
A7	214	WFUFB	surface	562250.0	1772617.7	553.0
A8	216	WFUFB	bottom	562071.6	1772619.5	483.2
A9	220	WFUFB/SP	surface	561890.4	1772617.0	554.8
A10	222	SP	surface	561693.4	1772458.6	548.0
A11	224	SP	mid	561510.5	1772274.6	518.9
A12	226	SP	surface	561327.4	1772090.4	548.0
A13	228	SP	surface	561444.6	1771890.4	545.0
A14	230	Offshore - SP	bottom	561634.5	1772116.7	480.7
A15	232	Offshore - SP	surface	561724.3	1772023.5	551.2
A16	240	Offshore - SP/WFUFB	bottom	561962.4	1772271.5	486.2
A17	250	Offshore - WFUFB	surface	562204.5	1772330.6	546.6
A18	252	Offshore - WFUFB/SP	bottom	562473.8	1772334.8	484.6
*	288	GW	*hydrophone used to detect tagged fish removed from gatewells*			
System B						
B1*	201	PH	surface	563291.6	1772609.9	549.4
B2*	203	PH	mid	563108.1	1772611.2	515.4
B3	205	PH	surface	562924.5	1772607.6	550.5
B4	207	PH	mid	562742.7	1772608.4	517.6
B5	209	PH	bottom	562563.5	1772609.1	451.3
B6	211	WFUFB	surface	562385.4	1772607.7	556.3
B7	213	WFUFB	mid	562314.7	1772609.5	498.6
B8	215	WFUFB	surface	562160.0	1772618.0	555.2
B9	221**	WFUFB/SP	surface	561989.5	1772620.9	555.0
B10	223	SP	mid	561786.6	1772548.9	511.5
B11	225**	SP	surface	561602.4	1772366.1	547.7
B12	227	SP	mid	561420.2	1772182.1	517.5
B13	229	SP	mid	561441.4	1771896.2	515.0
B14	231	Offshore - SP	surface	561634.0	1772117.9	551.1
B15	233	Offshore - SP	bottom	561724.7	1772021.9	481.5
B16	241	Offshore - SP/WFUFB	surface	561963.5	1772278.5	550.0
B17	251	Offshore - WFUFB	bottom	562205.4	1772338.1	480.1
B18	253	Offshore - WFUFB/PH	surface	562472.9	1772327.8	552.2

Table A.2. The 2010 three-dimensional (3D) hydrophone configuration at Priest Rapids Dam is listed below. Table includes details for both data collection systems (System A and B), unique hydrophone identification number, location (PH = powerhouse, TS = top-spill, SP = spillway, GW = gatewell), orientation of mount within the water column, and hydrophone location coordinates (NAD 83 Washington State Plane South Feet). Hydrophones that were not used in 3D analysis are indicated by single asterisk. Hydrophones that failed intermittently or permanently to collect data are indicated by double asterisks.

System ID	Number	HD Location	Orientation	Northing	Easting	Elevation
System A						
A1*	500	PH	surface	479157.5	1789109.7	479.3
A2	502	PH	mid	479049.1	1788966.7	450.0
A3	504	PH	surface	478934.9	1788826.5	471.0
A4	506	PH	mid	478816.1	1788681.8	446.5
A5	508	PH/TS	bottom	478708.5	1788550.5	411.6
A6	510	TS	mid	478640.6	1788463.1	452.4
A7	512	TS/SP	mid	478576.0	1788381.4	452.1
A8	520	SP	surface	478470.2	1788265.6	464.8
A9	522	SP	surface	478310.3	1788061.4	474.2
A10*	524	SP	mid	478120.3	1787813.8	457.9
A12	530**	Offshore - PH	bottom	479184.7	1788608.7	419.2
A13	532	Offshore - PH/TS	surface	478977.1	1788354.7	461.4
A14	534	Offshore - TS/SP	bottom	478857.6	1788181.1	400.1
A15	536	Offshore - SP	surface	478698.0	1788002.6	462.0
A16*	514**	PH	surface	479315.0	1789253.0	480.0
*	588	GW	*hydrophone used to detect tagged fish removed from gatewells*			
System B						
B1*	501	PH	surface	479213.4	1789180.0	472.9
B2	503	PH	mid	479103.7	1789037.7	450.0
B3	505	PH	surface	478991.8	1788896.8	480.0
B4	507	PH	mid	478871.9	1788751.9	456.9
B5	509	PH	surface	478760.2	1788611.1	470.6
B6	511	TS	surface	478667.5	1788509.1	475.9
B7	513	TS	mid	478607.7	1788422.7	451.8
B8	521	SP	bottom	478544.8	1788347.6	416.7
B9	523	SP	mid	478407.6	1788182.7	461.9
B10	525	SP	mid	478213.7	1787938.2	461.0
B11*	527	SP	surface	478020.4	1787693.8	480.0
B12	531	Offshore - PH	surface	479185.3	1788607.9	466.4
B13	533	Offshore - PH/TS	bottom	478975.8	1788355.1	430.1
B14	535	Offshore - TS/SP	surface	478859.6	1788180.5	478.5
B15	537	Offshore - SP	bottom	478692.3	1788006.2	395.9
B16	515	PH/TS	bottom	478712.8	1788554.4	418.0

Table A.3. The 2010 hydrophone deployment configuration at each of the in-river detection sites, (Mattawa, Vernita Bridge, and Ringold), is listed below. Table includes each unique hydrophone identification number and hydrophone location coordinates (NAD 83 Washington State Plane South Feet). All in-river hydrophones were attached to an anchor and deployed on the river bottom. Hydrophones that failed intermittently or permanently to collect data are indicated by double asterisks.

System ID	Hydrophone	Northing	Easting
Mattawa			
MATT	401**	522945.6	1778854.0
MATT	402	523182.1	1778658.2
MATT	403	523426.3	1778456.6
MATT	404	523673.0	1778253.9
MATT	405	523921.1	1778054.1
MATT	406	524160.9	1777850.8
MATT	407**	524404.9	1777647.7
MATT	408	524631.0	1777460.9
Vernita Bridge			
VEBR	601	476967.8	1830436.7
VEBR	602	477078.0	1830651.3
VEBR	603	476824.6	1830645.7
VEBR	604	476594.4	1830732.1
VEBR	605	476370.8	1830829.1
VEBR	606	476109.8	1830813.0
VEBR	607	476214.1	1831031.6
Ringold			
RING	701	458737.6	1924854.5
RING	702	458552.4	1925037.6
RING	703	458483.9	1924783.1
RING	704	458298.8	1924599.8
RING	705	458112.5	1924413.9
RING	706	457923.7	1924228.3
RING	707	457839.8	1923979.0
RING	708	457663.4	1924178.4

Table A.4. A summary of data collection failure events by system is listed with details of date and time, total time (duration in hours), and a brief explanation of lost data collection. A total of 20.5 hours of data collection was lost; there were no failure events at Priest Rapids Dam or in-river Mattawa and Ringold detection hydrophone arrays.

Hydrophone Array	Start Date/Time	End Date/Time	Duration (hr)	Comments
Wanapum Dam, Powerhouse System A	6/4/2010 8:02	6/4/2010 9:30	1.47	power loss at dam
Wanapum Dam, Powerhouse System B	6/4/2010 8:02	6/4/2010 9:29	1.45	power loss at dam
Wanapum Dam, Spillway System B	6/12/2010 20:00	6/13/2010 9:18	13.30	computer failed
Vernita Bridge	5/13/2010 17:00	5/13/2010 21:14	4.23	generator and power alarm failed
		Total	**20.45**	

Table A.5. Total number of acoustic tag detections, commonly referred to as echoes, at each hydrophone array that was deployed in the study area in 2010. Detection information for hydrophones at each dam and system are combined (i.e., Wanapum A includes all detections from Powerhouse System A and Spillway System A). First and last acoustic detection date and time are also listed.

Detection Site	First Detection	Last Detection	Number of Detections
Wanapum A	5/5/10 7:38:49 PM	6/6/10 1:10:15 PM	7,848,741
Wanapum B	5/5/10 7:38:50 PM	6/6/10 1:10:21 PM	8,765,478
Mattawa	5/6/10 3:46:10 AM	6/6/10 3:42:48 PM	257,225
Priest Rapids A	5/6/10 4:32:25 PM	6/9/10 4:26:02 AM	31,927,717
Priest Rapids B	5/6/10 4:31:29 PM	6/9/10 4:25:52 AM	35,831,611
Vernita Bridge	5/6/10 7:13:23 PM	6/9/10 6:11:06 AM	1,928,433
Ringold	5/7/10 1:44:13 AM	6/11/10 5:05:38 AM	816,451
		Total Number of Detections:	**87,375,656**

Table A.6. The 2009-2010 PIT tag quantities of steelhead and sockeye detected downstream of the study area are listed below and include McNary, John Day, and Bonneville dams along with an experimental estuary detection tow. Release site is in the tailrace of each dam, approximately 0.5 km downstream of each dam. The quantity of PIT tags recaptured was reported by PTAGIS (http://www.ptagis.org/). A total of 128 unique PIT tag detections from all recapture sites are reported. An overall decrease in steelhead PIT detections was noticed and could be due in part to a decrease in sample size released in 2010, as well as a decrease in survival between 2009 and 2010.

Year	Species	Release Site	McNary	John Day	Bonneville	Estuary	Total Detected
2010	Steelhead	Rock Island	42	13	17	5	77
		Wanapum	52	10	18	5	85
		Priest Rapids	48	29	25	2	104
	Sockeye	Rock Island	64	28	9	1	102
		Wanapum	60	27	13	4	104
		Priest Rapids	64	19	17	0	100
2009	Steelhead	Rock Island	105	55	9	8	177
		Wanapum	108	52	10	4	174
		Priest Rapids	107	76	20	2	205

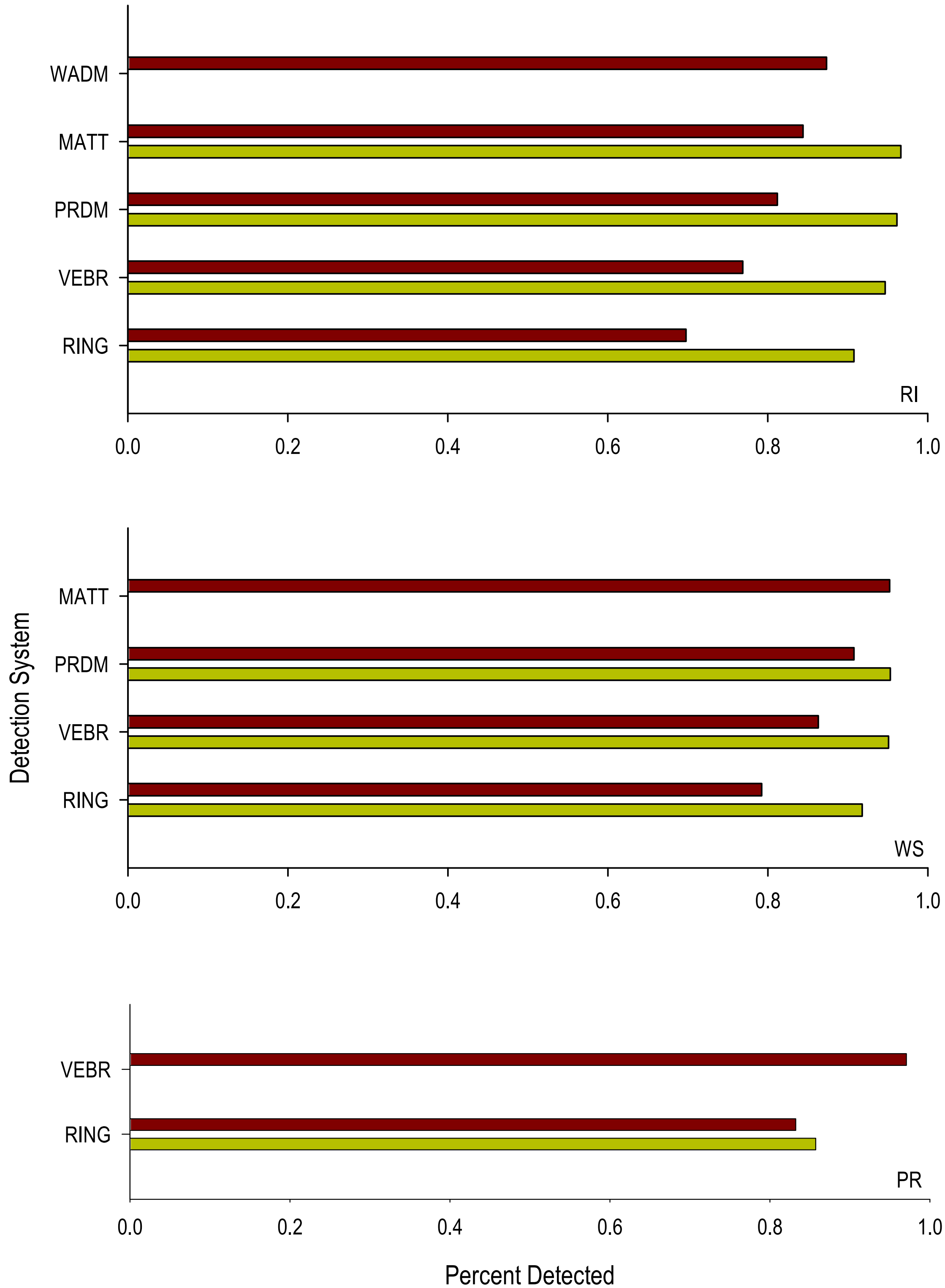

Figure A.1. The 2010 absolute percent detection of steelhead by release group are displayed above (RI = Rock Island, WS = Wanapum, and PR = Priest Rapids dams). Red bars present the calculation from total released, and the yellow bars present the percent detection between systems from the positive detection at the nearest upstream system.

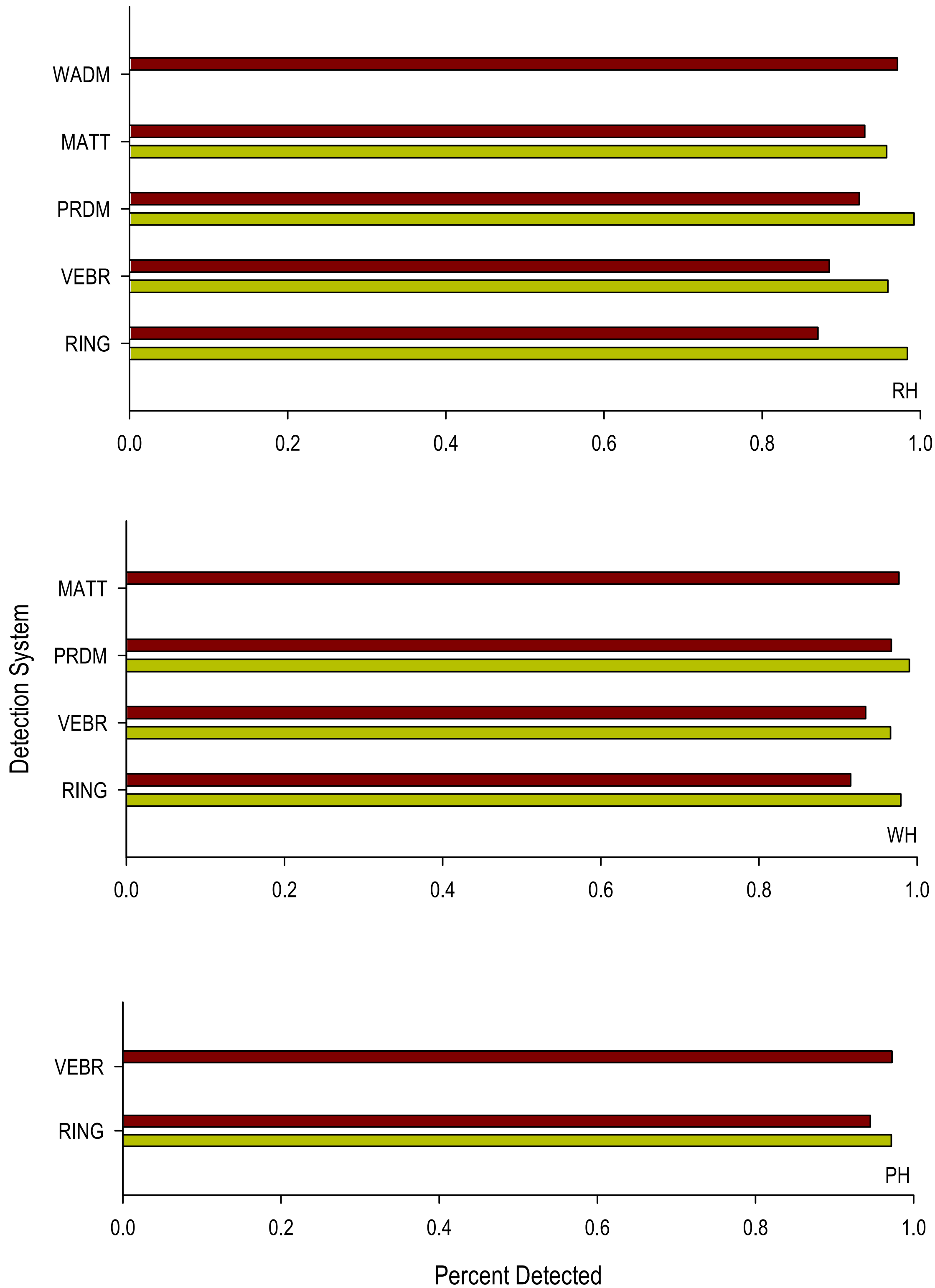

Figure A.2. The 2010 absolute percent detection of sockeye by release group are displayed above (RH = Rock Island, WH = Wanapum, and PH = Priest Rapids dams). Red bars present the calculation from total released, and the yellow bars present the percent detection between systems from the positive detection at the nearest upstream system.

Appendix B

Fish Handling and Release Characteristics

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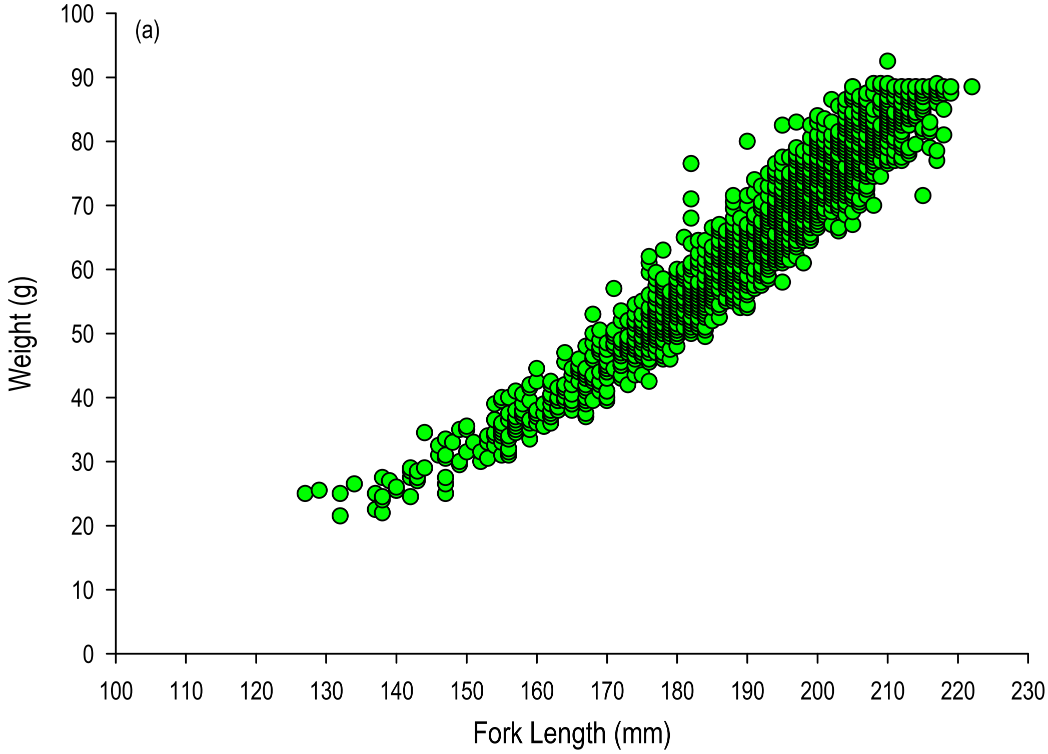
Table B.1. The quantities of steelhead and sockeye that were collected, tagged, and released by release groups during the spring of 2010. A number of sockeye releases were canceled when the number of fish collected was inadequate to continue tagging (release groups RH19 and RH20 at Rock Island, WH17, WH19, and WH20 at Wanapum, and PH17, PH19, and PH20 at Priest Rapids dams).

Release Groups and Number of Fish Released														
Steelhead						Sockeye						Date		
RI	n_{RI}	WS	n_{WS}	PR	n_{PR}	RH	n_{RH}	WH	n_{WH}	PH	n_{PH}	Collection	Surgery	Release
RI01	18					RH01	20					2-May	3-May	4-May
						RH02	2					1-May	4-May	5-May
RI02	19						19					2-May	4-May	5-May
RI03	21	WS01	18					WH01	20			4-May	5-May	6-May
RI04	24	WS02	19	PR01	18			WH02	21	PH01	20	5-May	6-May	7-May
RI05	26	WS03	21	PR02	19					PH02	21	6-May	7-May	8-May
RI06	29	WS04	24	PR03	21	RH03	24					7-May	8-May	9-May
RI07	32	WS05	26	PR04	24	RH04	27					8-May	9-May	10-May
				PR05	9							8-May	10-May	11-May
RI08	35	WS06	29		17	RH05	29	WH03	24			9-May	10-May	11-May
		WS07	31	PR06	28	RH06	32	WH04	27	PH03	24	10-May	11-May	12-May
RI09	38	WS08	35	PR07	31	RH07	34	WH05	29	PH04	27	11-May	12-May	13-May
RI10	40			PR08	35	RH08	39	WH06	32	PH05	29	12-May	13-May	14-May
RI11	43	WS09	38			RH09	44	WH07	34	PH06	32	13-May	14-May	15-May
RI12	43	WS10	40	PR09	38	RH10	45	WH08	39	PH07	34	14-May	15-May	16-May
RI13	40	WS11	43	PR10	40			WH09	41	PH08	36	15-May	16-May	17-May
RI14	38	WS12	43	PR11	43			WH10	23	PH09	18	16-May	17-May	19-May
RI15	35	WS13	40	PR12	43					PH10	45	18-May	19-May	20-May
RI16	32	WS14	38	PR13	41	RH11	42					19-May	20-May	21-May
RI17	29	WS15	35	PR14	38	RH12	37					20-May	21-May	22-May
RI18	26	WS16	32	PR15	35	RH13	35	WH11	42			21-May	22-May	23-May
RI19	23	WS17	29	PR16	32	RH14	33	WH12	40	PH11	42	22-May	23-May	24-May
RI20	21	WS18	26	PR17	29	RH15	30	WH13	39	PH12	39	23-May	24-May	25-May

Table B.1. (*Continued*) The quantities of steelhead and sockeye that were collected, tagged, and released by release groups during the spring of 2010.

Release Groups and Number of Fish Released														
Steelhead						Sockeye						Date		
RI	**n_{RI}**	**WS**	**n_{WS}**	**PR**	**n_{PR}**	**RH**	**n_{RH}**	**WH**	**n_{WH}**	**PH**	**n_{PH}**	**Collection**	**Surgery**	**Release**
RI21	19	WS19	24	PR18	26	RH16	27	WH14	36	PH13	38	24-May	25-May	27-May
								WH15	32			25-May	26-May	27-May
RI22	18	WS20	21	PR19	24	RH17	21			PH14	36	26-May	27-May	28-May
		WS21	19	PR20	21	RH18	17	WH16	26	PH15	28	27-May	28-May	30-May
		WS22	19	PR21	19							28-May	29-May	30-May
										PH16	17	28-May	30-May	31-May
				PR22	19						11	29-May	30-May	31-May
								WH18	19			30-May	31-May	1-Jun
										PH18	15	31-May	1-Jun	2-Jun



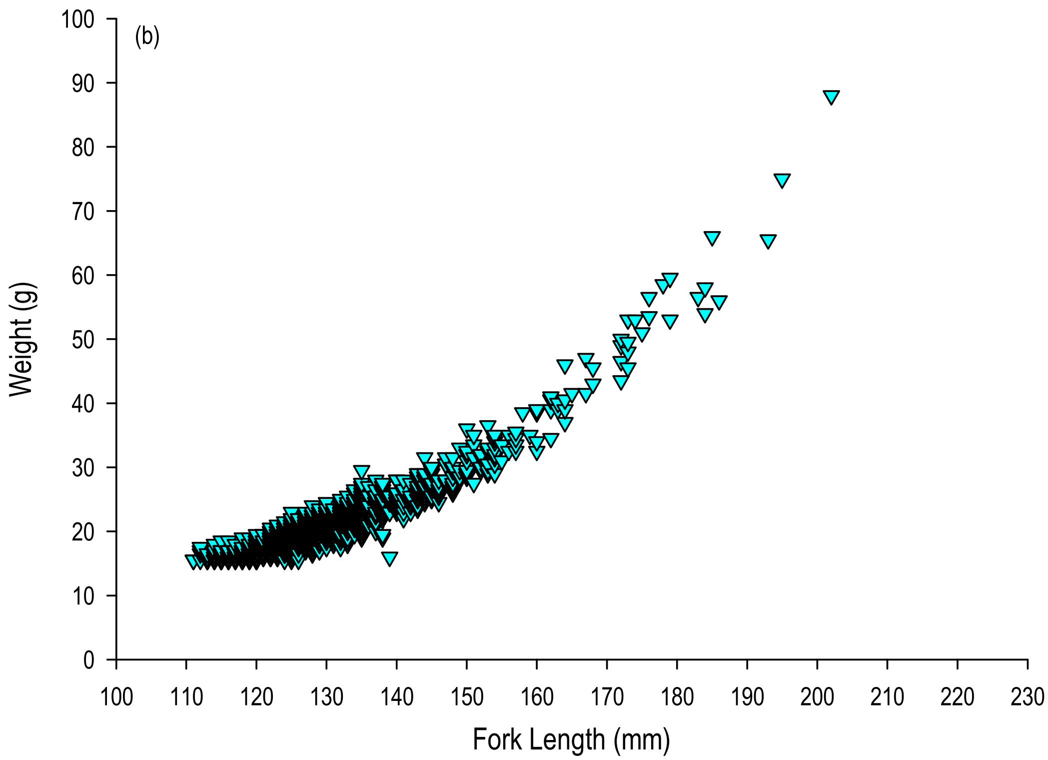


Figure B.1. Size distribution of tagged (a) steelhead (n=1,945, green circles) and (b) sockeye (n=1,591, cyan triangles) that were released for the 2010 Grant PUD survival analysis.

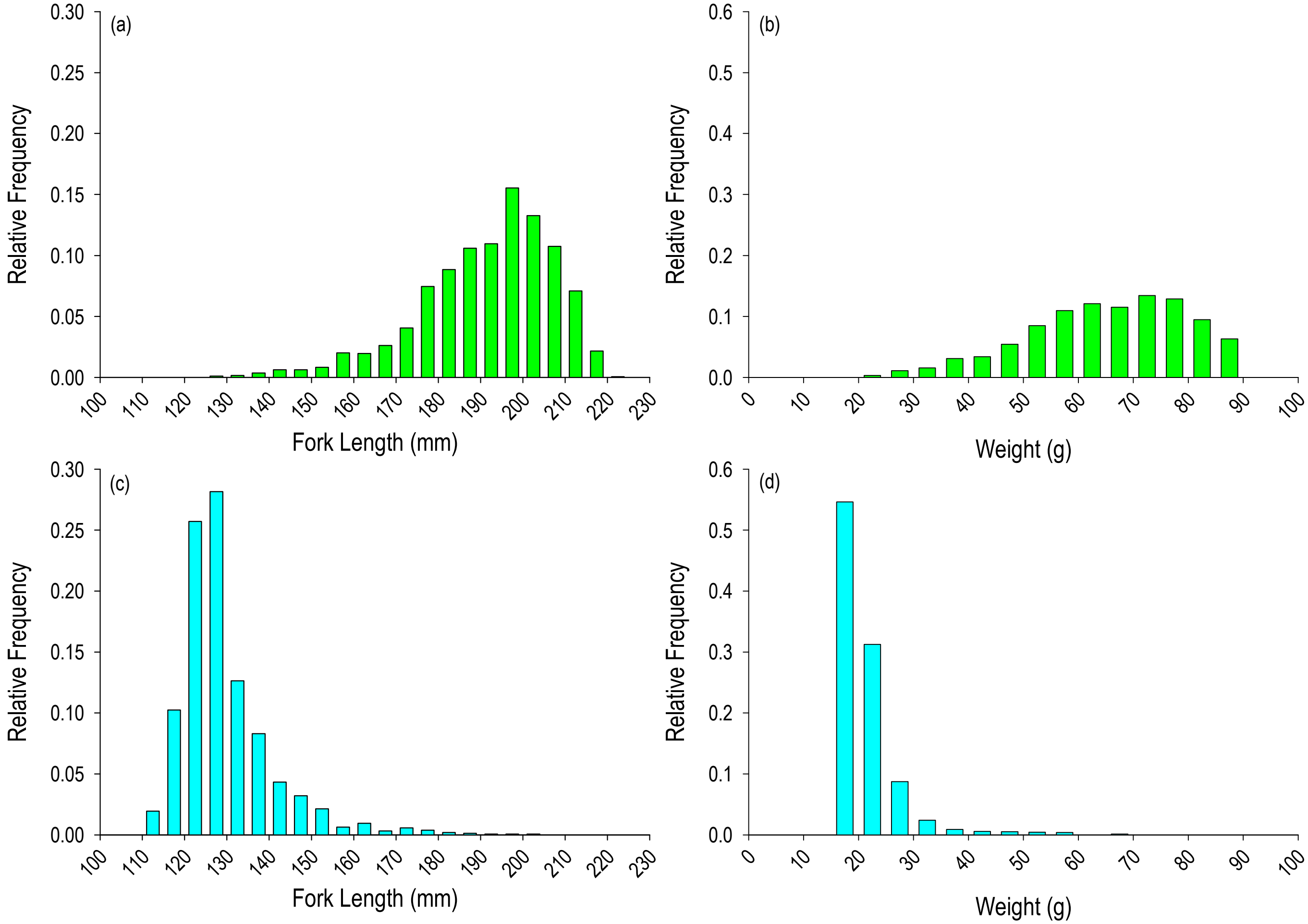


Figure B.2. Relative frequency of length and weight of tagged steelhead (shown in green, n=1,945) and sockeye (shown in cyan, n=1,591) released in the 2010 survival analysis. The fork length in millimeters of (a) steelhead and (c) sockeye as well as the weight in grams of (b) steelhead and (d) sockeye are shown above. The average steelhead fork length was 191.1 mm (range 127.0-222.0 mm) and weight was 65.0 g (range 21.5-92.5 g). The average sockeye fork length was 128.9 mm (range 111.0-202.0 mm) and weight was 21.0 g (range 15.5-88.0 g).

Appendix C

Route-Specific Relative Survivals for Steelhead

Columbia Basin Research
University of Washington
School of Aquatic & Fishery Sciences
1325 Fourth Ave., Suite 1820
Seattle, Washington 98101-2509
www.cbr.washington.edu

The steelhead route-specific relative survival estimates were provided by Dr. John Skalski and Rich Townsend of Columbia Basin Research. The survival estimates are relative to powerhouse passage at each dam.

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Route-Specific Relative Survivals for Steelhead

Wanapum Dam

The Columbia Basin Research estimated route-specific relative survivals and passage proportions of steelhead through Wanapum Dam using the steelhead known to have successfully arrived at the dam, (i.e., tagged fish detected at the double array), and are shown in Tables C.1-4.

Table C.1. Estimated passage abundance at the Wanapum forebay double-arrays of acoustic-tagged steelhead smolts released from Rock Island tailrace are listed. The 1 denotes detection and the 0 denotes not detected at the Wanapum primary and secondary forebay arrays (standard errors are in parentheses).

	Detection History			
Wanapum Dam Route	**11**	**10**	**01**	**Est. Total**
Powerhouse	87	0	0	87 (0)
Gatewell	7	0	0	7 (0)
Fish Bypass	325	0	0	325 (0)

Table C.2. Estimates of acoustic-tagged steelhead smolt passage proportion with standard errors for each route through Wanapum Dam are shown (standard errors are in parentheses).

Route	Passage Proportion
Powerhouse	0.2076 (0.0198)
Gatewell	0.0167 (0.0063)
Fish Bypass	0.7757 (0.0204)

Table C.3. Detection histories of acoustic-tagged steelhead in the survival study at Wanapum Dam are listed. Downstream detections are at Mattawa and the double-array in the forebay of Priest Rapids Dam.

Wanapum Passage Route	Downstream Detection History				Released
	11	**10**	**01**	**00**	
Powerhouse	72	7	0	8	87
Gatewell	7	0	0	0	7
Fish Bypass	312	8	0	5	325

Table C.4. Estimates of acoustic-tagged steelhead route-specific relative survival at Wanapum with standard errors are shown ([1]Indicates that the null hypothesis is route survival equals survival through the powerhouse, 2-sided). The survival of steelhead that passed through the WFUFB was significantly higher (8.4%) than those that passed through the powerhouse. Survival was also 10.1% higher for those that were entrained in the gatewells, dipped, transported, and released downstream of the dam.

Parameter	Relative Survival to the Powerhouse	H_0: *RS* = 1[1] P-value
$RS_{\text{Gatewell/PH}}$	1.1013 (0.0376)	0.0070
$RS_{\text{Fish Bypass/PH}}$	1.0843 (0.0376)	0.0255

Priest Rapids Dam

Using the steelhead known to have successfully arrived at Priest Rapids Dam, (i.e., tagged fish detected at the double array), Columbia Basin Research estimated route-specific relative survivals and passage proportions through the dam and are shown in Tables C.5-8.

Table C.5. Estimated passage abundance at the Priest Rapids Dam forebay double-arrays of acoustic-tagged steelhead smolts released from Wanapum tailrace is listed. The 1 denotes detection and the 0 denotes not detected at the Priest Rapids primary and secondary forebay arrays (standard errors are in parentheses).

	Detection History			
Priest Rapids Dam Route	**11**	**10**	**01**	**Est. Total**
Powerhouse	175	0	0	175 (0.0)
Gatewell	28	0	0	28 (0.0)
Top-spill	235	0	0	235 (0.0)

Table C.6. Estimates of acoustic-tagged steelhead smolt passage proportion with standard errors for each route through Priest Rapids Dam are shown (standard errors are in parentheses). Fish that passed through the top-spill include all fish that passed through the prototype top-spill bulkhead along with those that passed through Tainter gates 21 and 22 through bottom-spill.

Route	Passage Proportion
Powerhouse	0.3995 (0.0234)
Gatewell	0.0639 (0.0117)
Top-spill	0.5365 (0.0238)

Table C.7. Detection histories of acoustic-tagged steelhead in the survival study at Priest Rapids Dam are listed. Detections are at Vernita Bridge and Ringold arrays.

Priest Rapids Passage Route	Downstream Detection History				Released
	11	10	01	00	
Powerhouse	150	16	0	9	175
Gatewell	19	2	0	7	28
Top-spill	207	22	1	5	235

Table C.8. Estimates of acoustic-tagged steelhead route-specific relative survival at Priest Rapids Dam with standard errors are shown. Only one fish went through the spillway at Priest Rapids ([1]Indicates that the null hypothesis is route survival equals survival through the powerhouse, 2-sided). The survival of steelhead that passed through the top-spill bypass configuration was 3.2% higher than those that passed through the powerhouse. Survival was significantly higher (7.9%) for those that were entrained in the gatewells, dipped, transported, and released downstream of the dam.

Parameter	Relative Survival to the Powerhouse	H_0: $RS = 1$[1] P-value
$RS_{\text{Gatewell/PH}}$	0.7907 (0.0874)	0.0166
$RS_{\text{Top Spill/PH}}$	1.0318 (0.0207)	0.1246

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Appendix D

Route-Specific Relative Survivals for Sockeye Salmon

Columbia Basin Research
University of Washington
School of Aquatic & Fishery Sciences
1325 Fourth Ave., Suite 1820
Seattle, Washington 98101-2509
www.cbr.washington.edu

The sockeye route-specific relative survival estimates were provided by Dr. John Skalski and Rich Townsend of the Columbia Basin Research. The survival estimates are relative to powerhouse passage at each dam.

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Route-Specific Relative Survivals for Sockeye Salmon

Wanapum Dam

The Columbia Basin Research estimated route-specific relative survivals and passage proportions through Wanapum dam using the sockeye salmon known to have successfully arrived at Wanapum Dam (i.e., tagged sockeye detected at the double array). Results are shown below in Tables D.1-4.

Table D.1. Estimated passage abundance at the Wanapum Dam forebay double-arrays of acoustic-tagged sockeye salmon smolts released from Rock Island tailrace are listed. The 1 denotes detection and the 0 denotes not detected at the Wanapum Dam primary and secondary forebay arrays (standard errors are in parentheses).

	Detection History			
Wanapum Dam Route	**11**	**10**	**01**	**Est. Total**
Powerhouse	92	0	0	92 (0)
Gatewell	3	0	0	3 (0)
Fish Bypass	318	0	0	318 (0)

Table D.2. Estimates of acoustic-tagged sockeye salmon passage proportion and standard errors for each route through Wanapum Dam are listed (standard errors are in parentheses).

Route	Passage Proportion
Powerhouse	0.2228 (0.0205)
Gatewell	0.0073 (0.0042)
Fish Bypass	0.7700 (0.0207)

Table D.3. Detection histories of acoustic-tagged sockeye in the survival study at Wanapum Dam are listed. Downstream detections are shown at Mattawa and the double-array in the forebay of Priest Rapids Dam.

Wanapum Passage Route	Downstream Detection History				Released
	11	**10**	**01**	**00**	
Powerhouse	84	1	0	7	92
Gatewell	2	0	0	1	3
Fish Bypass	304	4	2	8	318

Table D.4. Estimates of acoustic-tagged sockeye route-specific relative survivals at Wanapum Dam with standard errors are listed ([1]Indicates that the null hypothesis is that route survival equals survival through the powerhouse, 2-sided). The survival of sockeye that passed through the WFUFB was not significantly higher than those that passed through the powerhouse.

Parameter	Relative Survival to the Powerhouse	H_0: $RS = 1$[1] P-value
$RS_{\text{Gatewell/PH}}$	0.7216 (0.2954)	0.3459
$RS_{\text{Fish Bypass/PH}}$	1.0551 (0.0330)	0.0945

Priest Rapids Dam

Using the sockeye salmon known to have successfully arrived at Priest Rapids Dam (i.e., tagged sockeye detected at the double array), estimated route-specific relative survivals and passage proportions through the dam are shown in Tables D.5-8.

Table D.5. Estimated passage abundance at the Priest Rapids forebay double-arrays of acoustic-tagged sockeye salmon smolts released from Wanapum tailrace are shown. The 1 denotes detection and the 0 denotes not detected at the Priest Rapids primary and secondary forebay arrays (standard errors are in parentheses).

	Detection History			
Priest Rapids Dam Route	11	10	01	Est. Total
Powerhouse	199	0	0	199 (0.0)
Gatewell	5	0	0	5 (0.0)
Top-spill	178	0	0	178 (0.0)

Table D.6. Estimates of acoustic-tagged sockeye salmon passage proportion with standard errors for each route through Priest Rapids Dam are listed (standard errors are in parentheses). Fish that passed through the top-spill include all fish that passed through the prototype top-spill bulkhead along with those that passed through Tainter gates 21 and 22 through bottom-spill.

Route	Passage Proportion
Powerhouse	0.5209 (0.0256)
Gatewell	0.0131 (0.0058)
Top-spill	0.4660 (0.0255)

Table D.7. Detection histories of acoustic-tagged sockeye in the survival study at Priest Rapids Dam are shown. Detections are at Vernita Bridge and Ringold arrays.

Priest Rapids Passage Route	Downstream Detection History				Released
	11	10	01	00	
Powerhouse	184	4	0	11	199
Gatewell	5	0	0	0	5
Top-spill	174	3	0	1	178

Table D.8. Estimates of acoustic-tagged sockeye route-specific relative survival at Priest Rapids Dam with standard errors are listed. The survival of sockeye that passed through the top-spill bypass configuration, along with those that were gatewell dipped, was significantly higher than those that passed through the powerhouse by 5.2% to 5.5%.

Parameter	Relative Survival to the Powerhouse	H_0: $RS = 1$[1] P-value
$RS_{\text{Gatewell/PH}}$	1.0585 (0.0182)	0.0013
$RS_{\text{Top Spill/PH}}$	1.0526 (0.0190)	0.0057

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Appendix E

Migration Travel Rates and Forebay Residence Times

List of Tables

Table E.1. Summary of median travel times measured in hours for all release groups are listed by species. Median travel times were measured from either the time of release (in the tailrace of each dam) or last detection at the previous site to the first detection at the next downstream detection site. Cumulative travel times, measured from the time of release to first detection at a given site, are in parenthesis.

Species	Release Site	WADM	MATT	PRDM	VEBR	RING
Steelhead	Rock Island Dam	60.7	2.5 (63.2)	25.0 (88.2)	2.1 (90.3)	6.9 (97.2)
	Wanapum Dam		2.8	24.1 (26.9)	2.1 (29.0)	7.1 (36.1)
	Priest Rapids Dam				2.2	8.4 (10.6)
Sockeye	Rock Island Dam	48.2	2.4 (50.6)	12.0 (62.6)	2.0 (64.6)	6.5 (71.1)
	Wanapum Dam		3.0	13.3 (16.3)	2.0 (18.3)	6.8 (25.1)
	Priest Rapids Dam				2.2	6.9 (9.1)

Table E.2. Median travel times measured in hours for all release groups are listed by species and study year. Median travel times were measured from either the time of release or last detection at the previous site to the first detection at the next downstream detection site. The average median time calculated for 2006-2009 and the percent change in 2010 compared to the 2006-2009 average at each release site is presented below.

Species	Year	WADM	MATT	PRDM	VEBR	RING
Steelhead	2010	60.7	2.7	24.6	2.1	7.5
	2009	61.1	2.7	23.1	2.2	8.9
	2008	39.0	2.2	13.2	1.9	7.4
	2007	47.5	2.6	16.0	2.0	6.4
	2006	50.1	3.0	12.6	2.4	8.3
	2006-2010 Average	**51.7**	**2.6**	**17.9**	**2.1**	**7.7**
	2010 % Difference	*17.4*	*3.8*	*37.4*	*0*	*-2.6*
Sockeye	2010	48.2	2.7	12.7	2.1	6.7
	2009	42.9	2.6	13.6	2.1	6.6
	2008	35.9	2.0	11.0	1.7	5.8
	2007				1.9	6.2
	2006	45.1	2.4	11.9	1.9	6.1
	2006-2010 Average	**43.0**	**2.4**	**12.3**	**2.0**	**6.3**
	2010 % Difference	*12.1*	*12.5*	*3.3*	*5.0*	*6.3*

Table E.3. Annual median travel times in hours of steelhead and sockeye from Wanapum Dam to each detection array are presented by passage route, 2007-2010. Sockeye were not monitored at Wanapum Dam in 2007. There were no steelhead detected passing through the spillway in 2009 or 2010, nor were there any sockeye detected passing through the spillway in 2010.

		Powerhouse				Future Unit Bypass				Spillway			
Species	**Year**	**MATT**	**PRDM**	**VEBR**	**RING**	**MATT**	**PRDM**	**VEBR**	**RING**	**MATT**	**PRDM**	**VEBR**	**RING**
Steelhead	2010	3.0	24.5	2.1	6.9	2.4	25.0	2.1	6.9				
	2009	3.2	23.0	2.1	7.3	2.5	22.1	2.1	7.3				
	2008	2.5	15.6	1.9	6.4	2.1	13.9	1.9	6.3	2.1	9.1	1.7	6.0
	2007	2.8	16.2	2.0	6.4					2.3	16.9	2.0	6.6
Sockeye	2010	2.6	13.3	2.0	6.5	2.4	11.8	2.0	6.5				
	2009	2.5	13.2	2.0	6.5	2.3	12.4	2.0	6.4	2.1	10.5	1.8	5.7
	2008	2.2	12.0	1.7	5.9	2.1	12.1	1.7	5.7	1.9	10.3	1.6	5.8

Table E.4. Annual median travel times in hours of steelhead and sockeye from Priest Rapids Dam to each detection array are presented by passage route, 2007-2010. There were one steelhead detected passing through the spillway in 2009 and 2010. There were no sockeye detected passing through the spillway in 2010.

		Powerhouse		Top-Spill Configuration		Spillway	
Species	**Year**	**VEBR**	**RING**	**VEBR**	**RING**	**VEBR**	**RING**
Steelhead	2010	2.1	7.1	2.1	6.9	2.3	6.2
	2009	2.2	7.3	2.2	7.5	2.0	6.5
	2008	1.9	6.5	1.8	6.5	1.8	6.4
	2007	2.0	6.4	2.0	6.4	5.6	8.0
Sockeye	2010	2.0	6.5	2.0	6.7		
	2009	2.0	6.5	2.0	6.5	1.7	5.7
	2008	1.7	5.8	1.7	5.8	1.7	5.5
	2007	1.9	6.2	1.9	6.2	2.1	6.1

Table E.5. The annual comparison of median forebay residence times are presented in hours for steelhead and sockeye at Wanapum Dam, 2006-2010. Fish not included in the estimate are those that were entrained in the gatewells, last detected with net upstream movement or the passage route was unknown. The Wanapum Future Unit Fish Bypass (WFUFB) was not operational until the spring of 2008. The operation of the spillway fluctuated from year to year and was not always available as a means of passage. Sockeye were not monitored for passage at Wanapum Dam in 2007.

Species	Year	Count	All Routes	Powerhouse	WFUFB	Spillway
Steelhead	2010	551	2.41	4.82	2.03	
	2009	711	1.34	0.73	1.45	
	2008	536	0.50	0.17	0.97	0.30
	2007	781	0.49	0.45		1.02
	2006	184	0.44	0.38		0.83
Sockeye	2010	535	1.32	0.89	1.34	
	2009	631	0.66	0.37	0.97	1.18
	2008	491	0.16	0.09	0.32	0.20
	2006	753	0.21	0.20		0.30

Table E.6. The annual comparison of median forebay residence times are presented in hours for steelhead and sockeye at Priest Rapids Dam, 2006-2010. Fish not included in the estimate are those that were entrained in the gatewells, last detected with net upstream movement or the passage route was unknown. The sluiceway, Tainter gate 21 and Tainter gate 22 were not operational in 2006 or 2007. The operation of the spillway fluctuated from year to year and was not always available as a means of passage; there was only one steelhead passage event at the spillway in 2010.

Species	Year	Count	All Routes	Powerhouse	Top-Spill	TG 21 and 22	Spillway
Steelhead	2010	1,045	1.53	0.88	2.45	1.83	355.38
	2009	1,175	0.96	0.76	0.71	2.20	0.74
	2008	1,007	0.24	0.22	0.22	0.74	0.17
	2007	919	0.34	0.33	0.37		0.16
	2006	599	0.33	0.33	0.68		0.13
Sockeye	2010	1,008	0.52	0.55	0.37	0.79	
	2009	1,209	0.40	0.46	0.28	0.48	0.11
	2008	525	0.12	0.13	0.10	0.12	0.13
	2007	678	0.19	0.20	0.16		0.20
	2006	1,102	0.25	0.26	0.23		0.13

Table E.7. Annual comparison of median residence times (presented in minutes) for steelhead and sockeye at Mattawa, Vernita Bridge, and Ringold detection arrays. Downstream sockeye migration was not monitored upstream of Priest Rapids Dam in 2007.

Species	Year	MATT	VEBR	RING
Steelhead	2010	3.0	3.6	3.6
	2009	4.8	4.8	3.6
	2008	5.4	3.0	3.0
	2007	4.8	3.0	2.4
	2006	7.8	3.0	4.8
Sockeye	2010	2.4	3.6	3.6
	2009	3.6	3.6	2.4
	2008	3.6	2.4	2.4
	2007		2.4	1.8
	2006	4.2	1.8	3.6

Appendix F

Behavioral Analyses

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In-River Migration Patterns

The downstream movement of steelhead and sockeye smolts at the in-river acoustic detection arrays was analyzed using detection histories, more specifically the hydrophone closest to each fish at the time of movement across the arrays in 2006-2010. Figures F.1 – F.3 display the movement of steelhead (green) and sockeye (grey) at Mattawa (Figure F.1), Vernita Bridge (Figure F.2), and Ringold (Figure F.3) for 2006-2010. The number of hydrophones at each location varied; however, they are generally spaced evenly across the river bed at each site. Left bank signifies the eastern shoreline and right bank signifies the western shoreline. Based on the acoustic detection histories, there did not appear to be any trends that would indicate that steelhead and sockeye emigrate through different habitats. For example, we did not find that sockeye were more apt to be moving through the mid-channel while steelhead were more apt to be moving downstream along the shoreline.

Approach Trends

Approach elevations (depth) were analyzed for steelhead and sockeye smolts at each dam, similar to the 2009 data set presented in Timko et al. 2010. To provide the greatest accuracy in depth positioning, fish positions outside the perimeter of offshore hydrophones (greater than 300 ft from each dam) were excluded. Position data for each fish were normalized by proportion of residence time with a maximum of 100 points per fish to eliminate bias caused by "milling" fish. Histograms were created to describe the depth distribution of fish positions located within 50 ft of the dam, 51-100 ft, 101-150 ft, 151-200 ft, 201-250 ft, and 251-300 ft (Figures F.4 – F.7).

Forebay Residence Times and Flow

The residence times of steelhead and sockeye were investigated by project flow at Wanapum and Priest Rapids dams and are displayed in Figure F.8. At both dams, the variation in forebay residence times by both species displayed a decrease during at high flow conditions (flow greater than 200 kcfs). We feel that additional annual data is warranted at high flows to determine if this change in variation is significant.

Passage Proportions Relative to Forebay Residence Times

The passage proportions relative to residence times of steelhead and sockeye were investigated at Wanapum and Priest Rapids dams. There were no discernable trends in the Wanapum Dam data sets, which is likely due to the heavy volume of fish passage through the WFUFB, and therefore, are not presented. At Priest Rapids Dam, there were little trends noted in steelhead as well and are also not presented. However, sockeye passage proportions relative to forebay residence times displayed a pattern of sockeye with residence times less than 11 min were significantly more likely to pass through the bypass configuration by 82% and most commonly approached the dam from the upstream of the spillway; sockeye with residence times that exceeded 15 min appeared to pass Priest Rapids Dam through the bypass configuration at a rate of approximately 50% (Figure F.9).

Passage Route Efficiency, Zone Entrance Efficiency, and Fish Collection Efficiency

The passage route efficiency (PRE) at Wanapum and Priest Rapids dams are listed in Tables F.1 and F.2, respectively, for 2006-2010. Zone entrance efficiency (ZEE) at the Wanapum Dam WFUFB and Priest Rapids Dam bypass top-spill configuration are listed in Table F.3. Fish collection efficiency (FCE) at Wanapum Dam in 2008-2010 and Priest Rapids Dam in 2006-2010 are listed in Tables F.4 and F.5, respectively. All tables have data segregated by species.

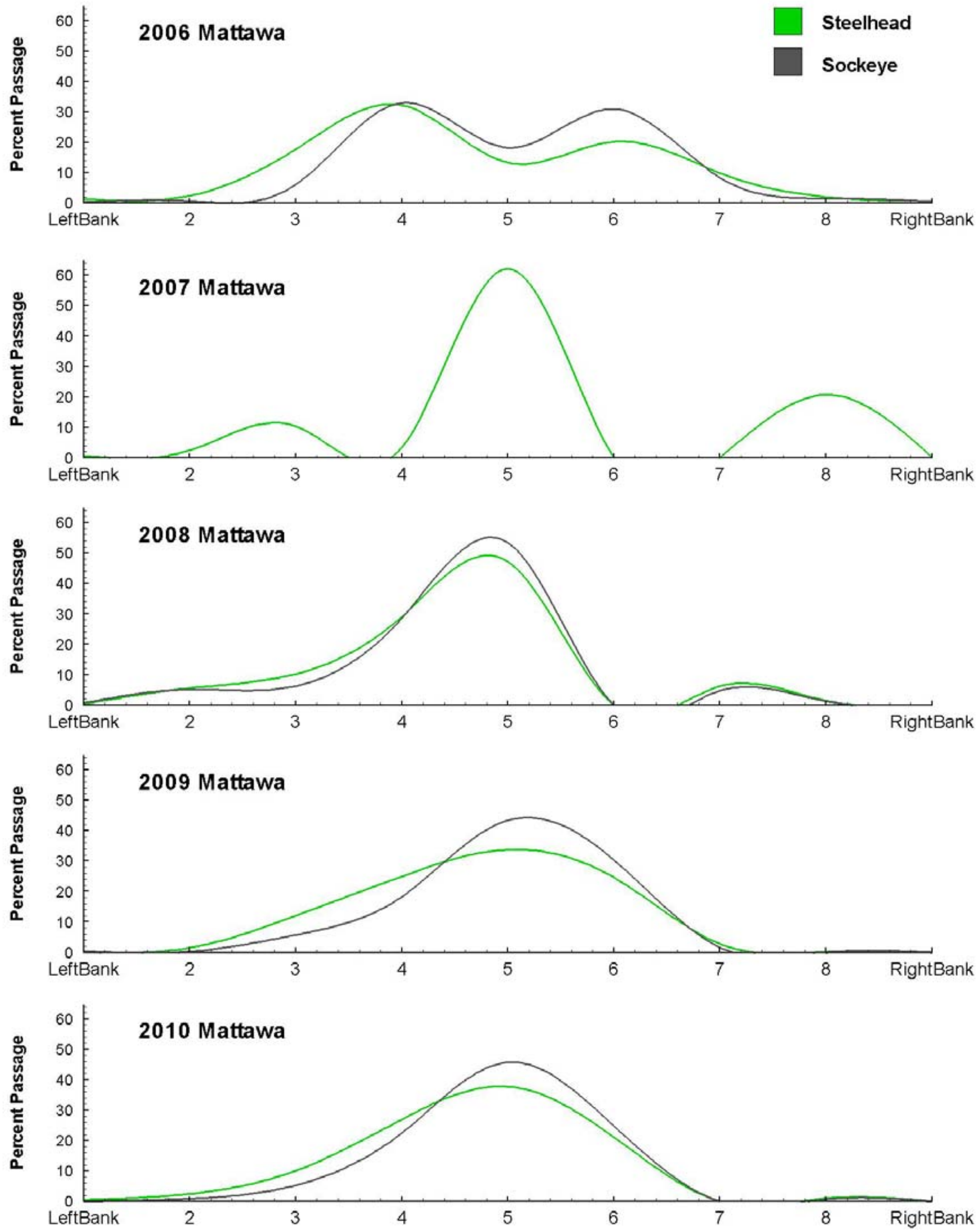

Figure F.1. Percent passage selection by steelhead (green) and sockeye (grey) at the Mattawa in-river detection array (2006-2010). The left bank indicates the eastern shoreline and the right bank indicates the western shoreline. The majority of both species were detected moving downstream in the center of the channel, closest to the mid-channel hydrophones 4, 5, and 6.

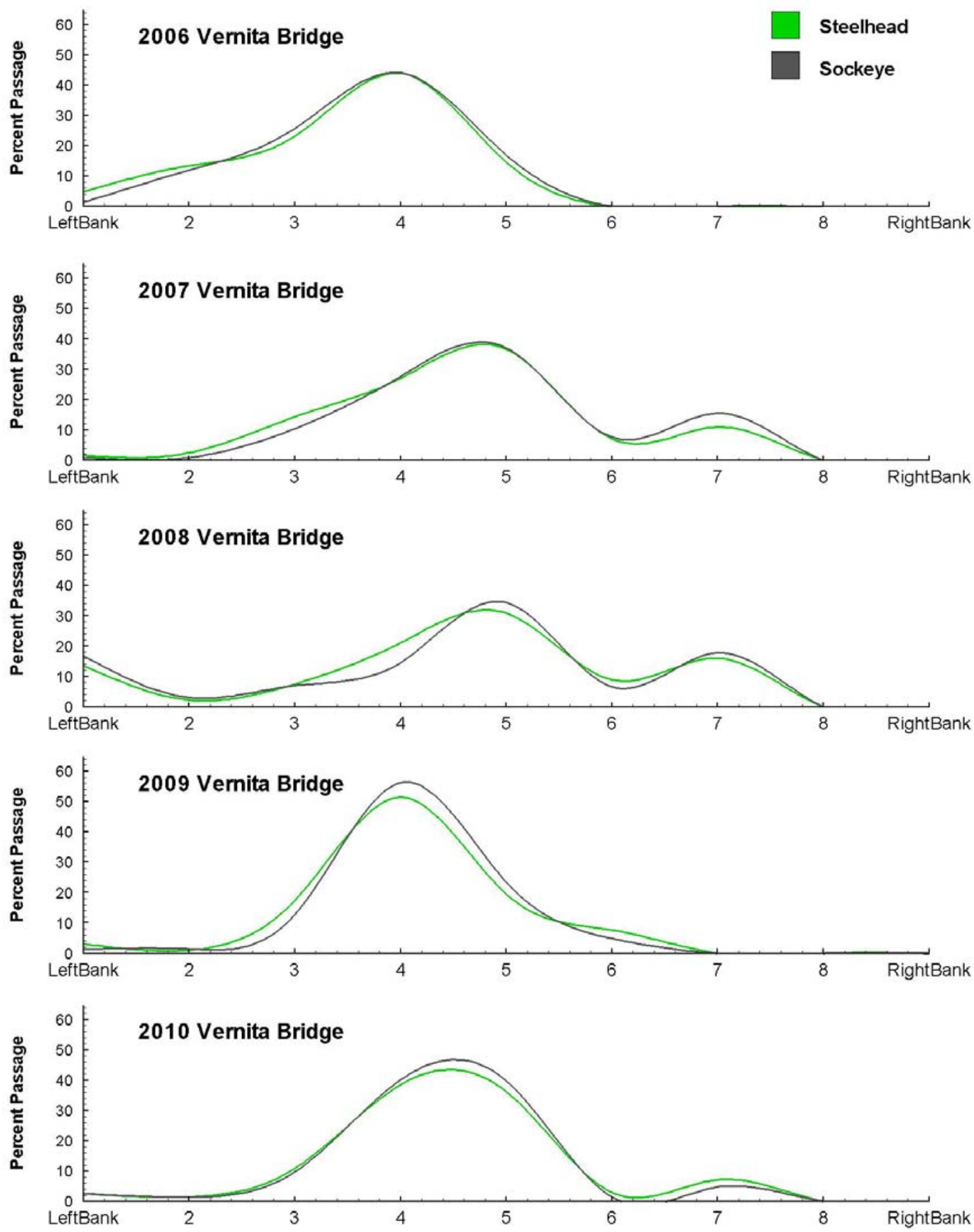

Figure F.2. Percent passage selection by steelhead (green) and sockeye (grey) at the Vernita Bridge in-river detection array (2006-2010). The left bank indicates the eastern shoreline and the right bank indicates the western shoreline. The majority of both species were detected moving downstream in the center of the channel, closest to the mid-channel hydrophones 3 through 6.

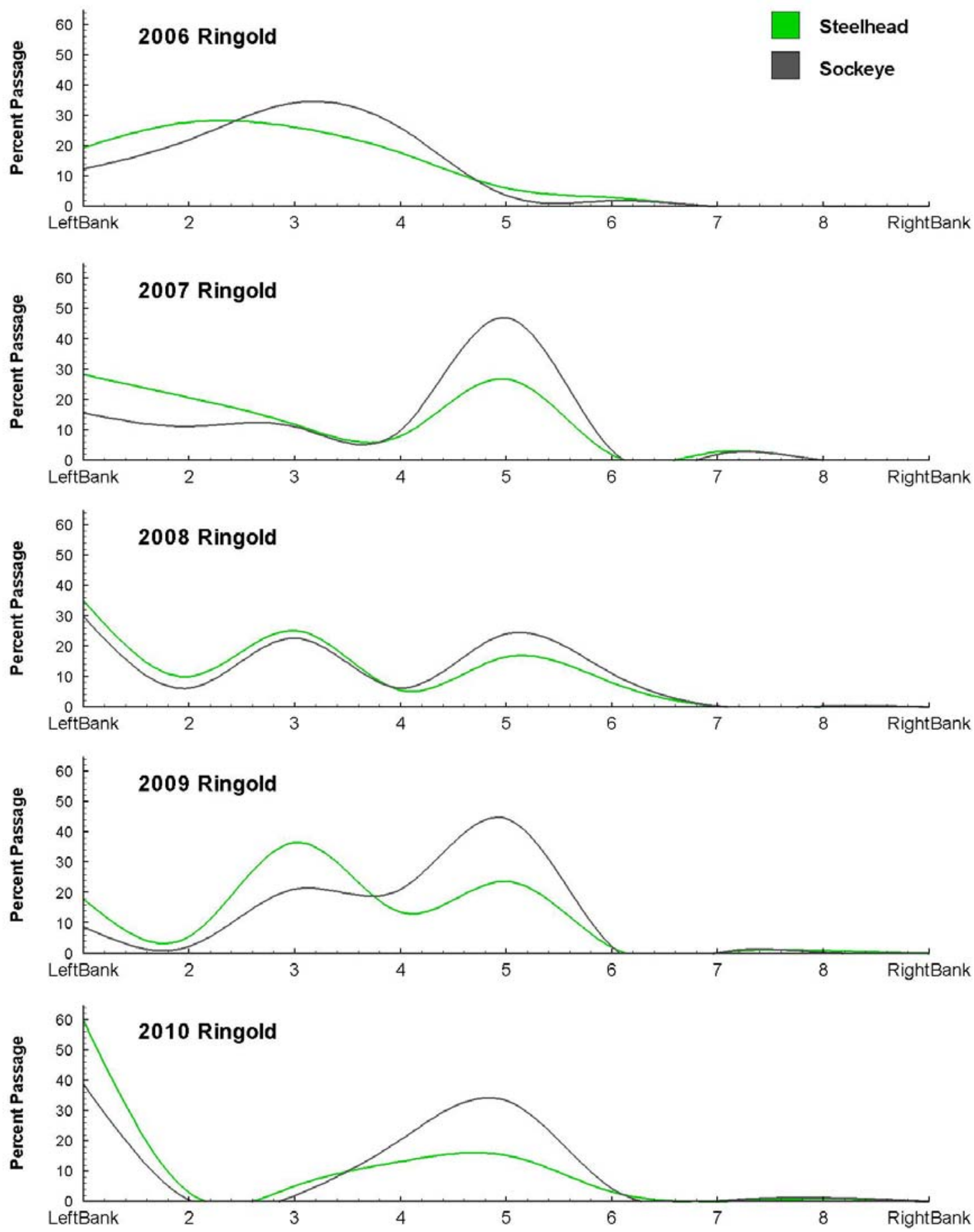

Figure F.3. Percent passage selection by steelhead (green) and sockeye (grey) at the Ringold in-river detection array (2006-2010). The left bank indicates the eastern shoreline and the right bank indicates the western shoreline. Overall, the majority of both species were detected moving downstream between the left bank and center of the channel, closest to the hydrophones 1 through 6, with some annual variation of more pronounced mid-channel downstream emigration.

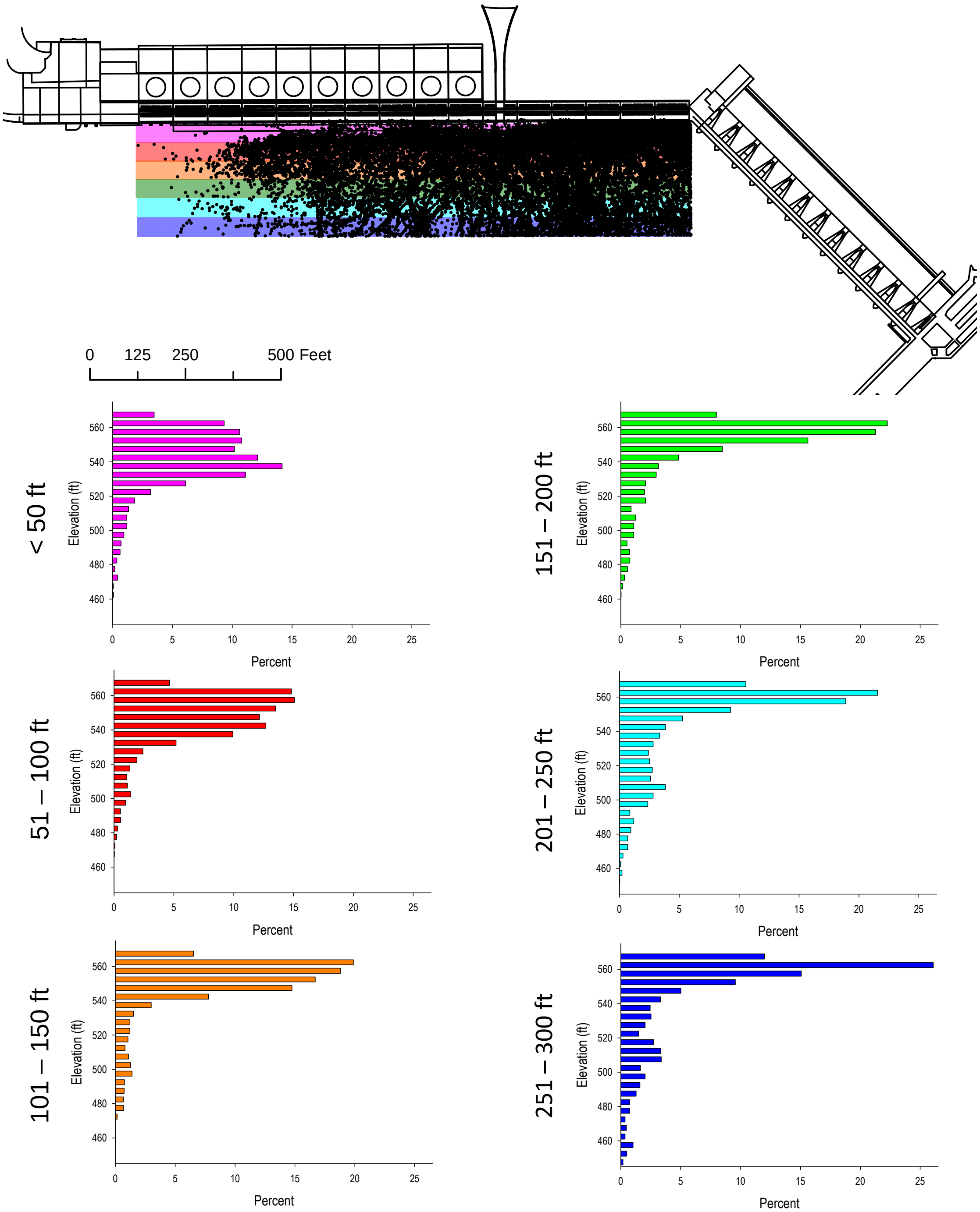

Figure F.4. Approach elevations (depth) of steelhead at Wanapum Dam in 2010 are illustrated above. Pink represents fish within 50 ft of the powerhouse, red 51-100 ft, orange 101-150 ft, green 151-200 ft, light blue 201-250 ft, and dark blue 251-300 ft. Fish locations were normalized by proportion of residence time with a maximum of 100 points per fish.

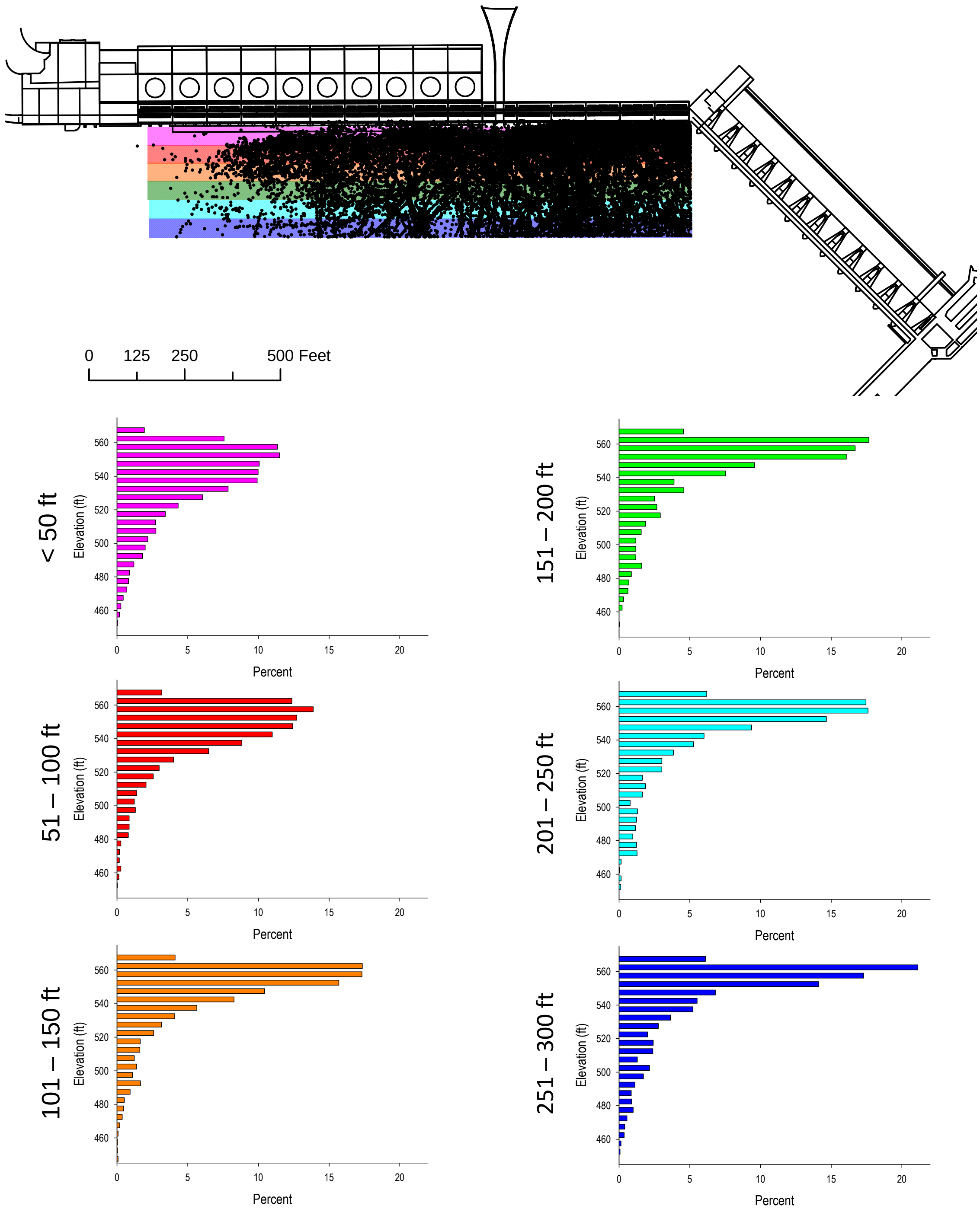

Figure F.5. Approach elevations (depth) of sockeye at Wanapum Dam in 2010 are illustrated above. Pink represents fish within 50 ft of the powerhouse, red 51-100 ft, orange 101-150 ft, green 151-200 ft, light blue 201-250 ft, and dark blue 251-300 ft. Fish locations were normalized by proportion of residence time with a maximum of 100 points per fish.

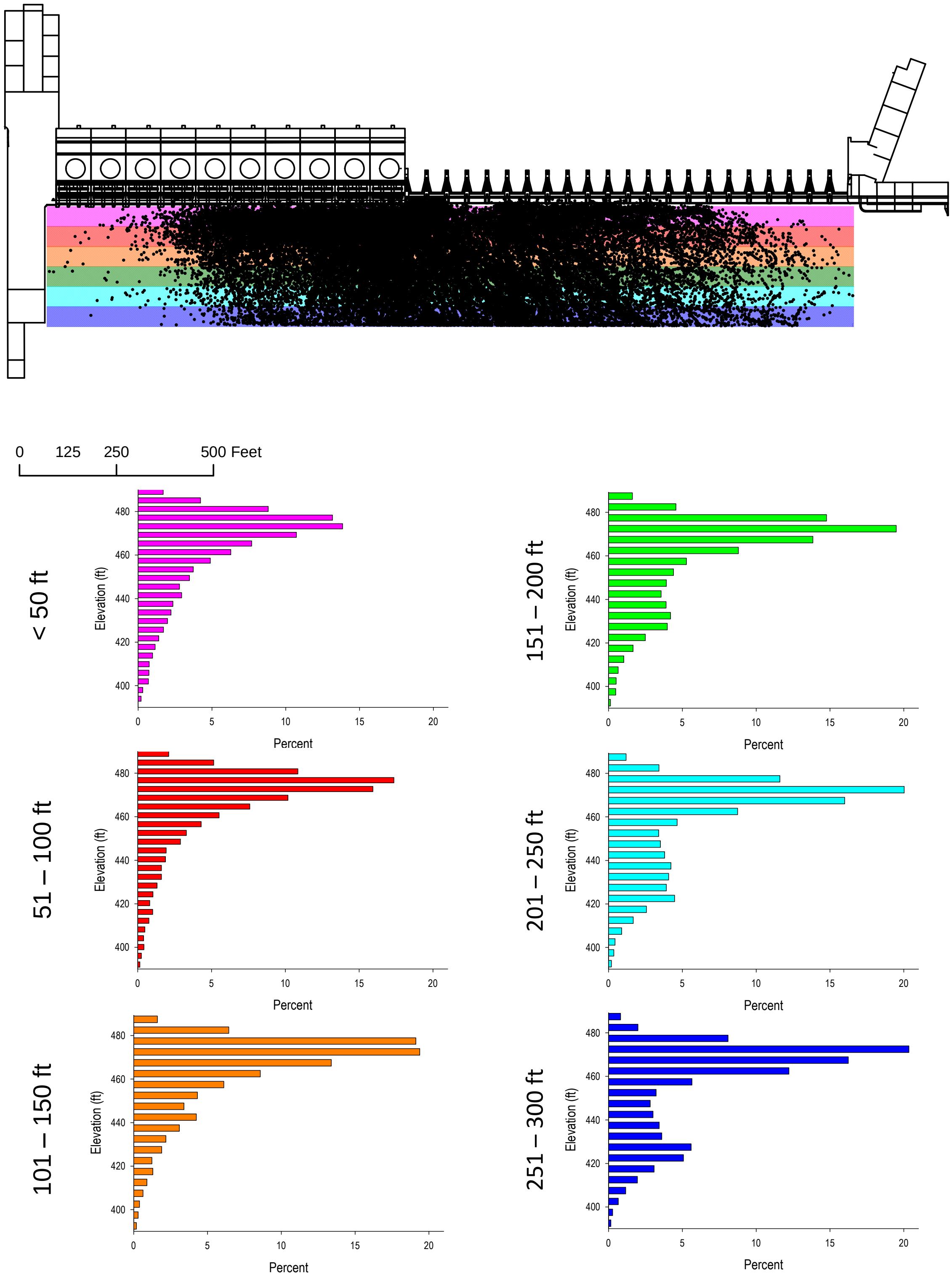

Figure F.6. Approach elevations (depth) of steelhead at Priest Rapids Dam in 2010 are illustrated above. Pink represents fish within 50 ft of the dam, red 51-100 ft, orange 101-150 ft, green 151-200 ft, light blue 201-250 ft, and dark blue 251-300 ft. Fish locations were normalized by proportion of residence time with a maximum of 100 points per fish.

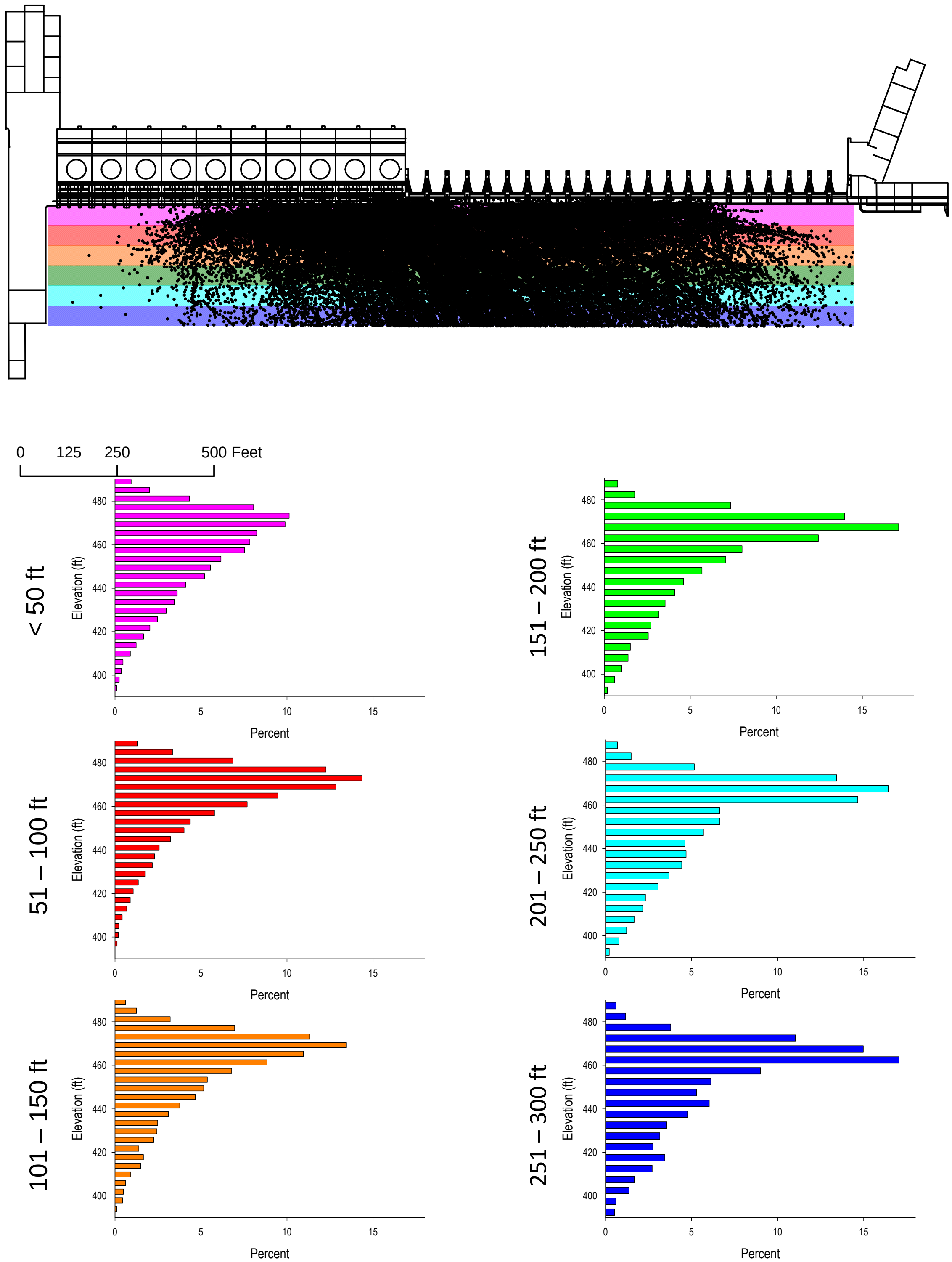

Figure F.7. Approach elevations (depth) of sockeye at Priest Rapids Dam in 2010 are illustrated above. Pink represents fish within 50 ft of the dam, red 51-100 ft, orange 101-150 ft, green 151-200 ft, light blue 201-250 ft, and dark blue 251-300 ft. Fish locations were normalized by proportion of residence time with a maximum of 100 points per fish.

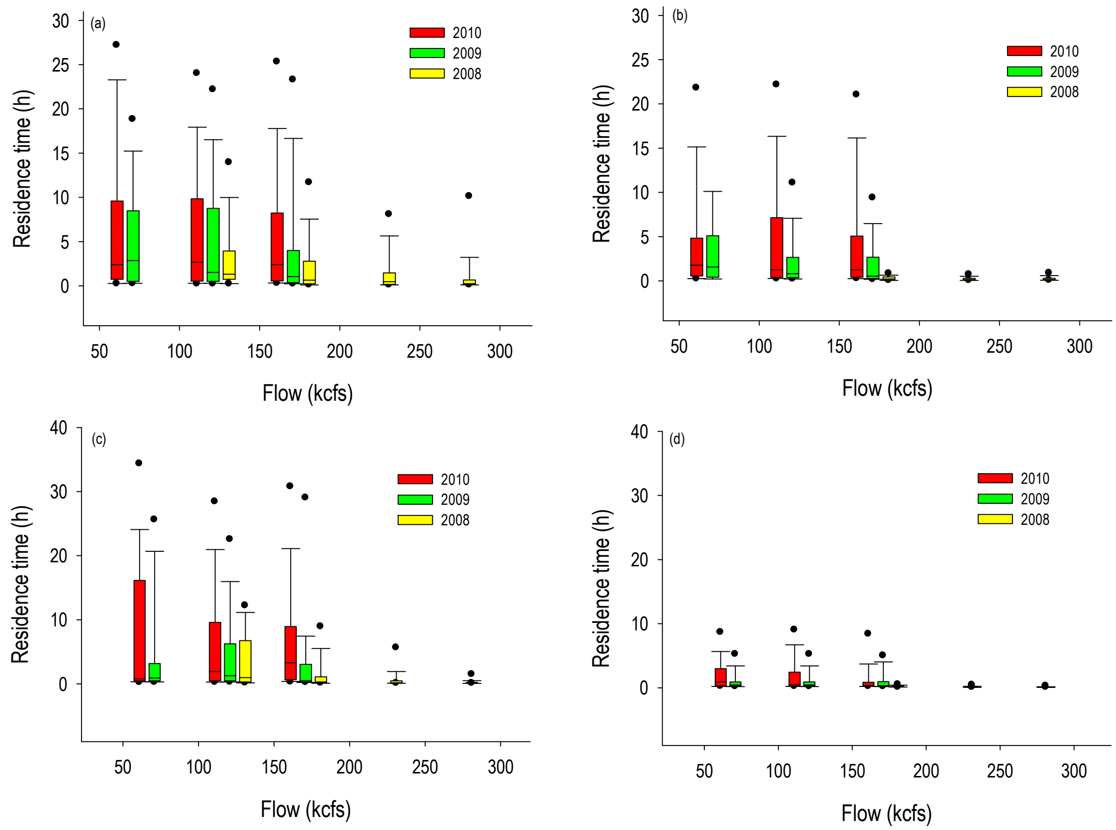

Figure F.8. Residence time by flow at Wanapum Dam of (a) steelhead and (b) sockeye and Priest Rapids Dam of (c) steelhead and (d) sockeye. The variation in forebay residence times by both species was noticeably decreased during high flow conditions (flow greater than 200 kcfs) at both dams.

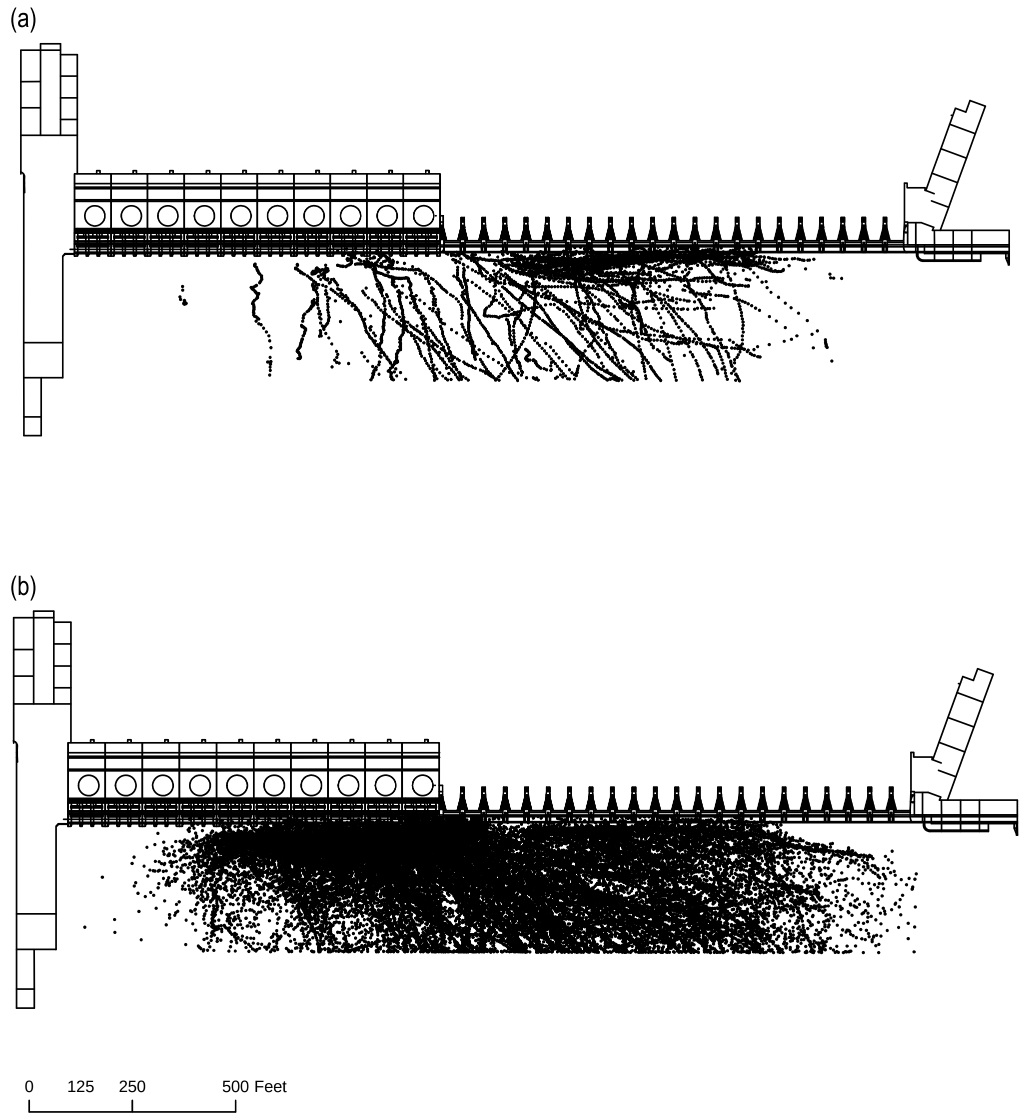

Figure F.9. The two-dimensional positions of sockeye that passed Priest Rapids Dam with residence times of less than 11 min are displayed in (a) where 82% of passage events were at the bypass top-spill and bottom-spill configuration at Spill bays 19-22. Sockeye that passed the dam with residence times of more than 11 min are displayed in (b) where 50% of passage events occurred at the bypass configuration. Graphic illustrates behavioral differences in approach and passage of sockeye at the Priest Rapids top-spill configuration at varied residence times.

Table F.1. The passage route efficiencies (PRE) of downstream migrant steelhead and sockeye through Wanapum Dam from 2006-2010 are shown below. Sockeye were not monitored at Wanapum Dam in 2006-2007; however, sockeye tagged and released by Chelan PUD upstream of Wanapum Dam were monitored in 2008. Powerhouse passage includes fish that were entrained in the gatewells. Passage events that could not be identified or fish last detected upstream are not included in PRE estimates.

Year	Passage Route	n_i	n_{total}	PRE_i
Steelhead				
2010	Powerhouse	128	563	22.7%
	WFUFB	435	563	77.3%
	Spillway	0	563	0.0%
2009	Powerhouse	218	731	29.8%
	WFUFB	513	731	70.2%
	Spillway	0	731	0.0%
2008	Powerhouse	187	555	33.7%
	WFUFB	297	555	53.5%
	Spillway	71	555	12.8%
2007	Powerhouse	747	1120	66.7%
	Top-Spill/Sluiceway	300	1120	26.8%
	Spillway	73	1120	6.5%
2006	Powerhouse	154	319	48.3%
	Top-Spill/Sluiceway	116	319	36.4%
	Spillway	49	319	15.4%
Sockeye				
2010	Powerhouse	116	538	21.6%
	WFUFB	422	538	78.4%
	Spillway	0	538	0.0%
2009	Powerhouse	240	637	37.7%
	WFUFB	378	637	59.3%
	Spillway	19	637	3.0%
2008	Powerhouse	237	502	47.2%
	WFUFB	161	502	32.1%
	Spillway	104	502	20.7%

Table F.2. The passage route efficiencies (PRE) of downstream migrant steelhead and sockeye through Priest Rapids Dam. Sockeye PRE was calculated in 2006-2008 by monitoring a portion of the Chelan PUD tagged and released sockeye upstream of the Priest Rapids Project. Powerhouse passage includes fish that were entrained in the gatewells. In 2010, top-spill passage events included all events through the top-spill configuration, which included top-spill bulkhead at Spill Bays 19 and 20 along with bottom-spill at Tainter gates 21 and 22 (the sluiceway was removed during the 2010 smolt emigration). In 2008-2009, top-spill passage events included all events through the top-spill configuration, which included top-spill bulkhead at Spill Bays 19 and 20 along with bottom-spill at Tainter gates 21, and top-spill at the sluiceway through Tainter gate 22. Top-spill configuration for 2006 and 2007 included only passage events through the top-spill bulkhead at Spill Bays 19 and 20.

Year	Passage Route	n_i	n_{total}	PRE_i
Steelhead				
2010	Powerhouse	471	1105	42.6%
	Top-Spill	633	1105	57.3%
	Spillway	1	1105	0.1%
2009	Powerhouse	616	1254	49.1%
	Top-Spill	637	1254	50.8%
	Spillway	1	1254	0.1%
2008	Powerhouse	625	1062	58.9%
	Top-Spill	352	1062	33.1%
	Spillway	85	1062	8.0%
2007	Powerhouse	791	978	80.9%
	Top-Spill	183	978	18.7%
	Spillway	4	978	0.4%
2006	Powerhouse	460	624	73.7%
	Top-Spill	95	624	15.2%
	Spillway	69	624	11.1%
Sockeye				
2010	Powerhouse	506	1018	49.7%
	Top-Spill	512	1018	50.3%
	Spillway	0	1018	0.0%
2009	Powerhouse	715	1237	57.8%
	Top-Spill	485	1237	39.2%
	Spillway	37	1237	3.0%
2008	Powerhouse	348	531	65.5%
	Top-Spill	119	531	22.4%
	Spillway	64	531	12.1%
2007	Powerhouse	624	708	88.1%
	Top-Spill	84	708	11.9%
	Spillway	0	708	0.0%
2006	Powerhouse	818	1132	72.3%
	Top-Spill	217	1132	19.2%
	Spillway	97	1132	8.6%

Table F.3. The percent zone of entrance efficiency of the Wanapum Future Unit Fish Bypass (WFUFB) and Priest Rapids Dam top-spill configuration for steelhead, sockeye and yearling Chinook in 2006-2010.

	Wanapum (WFUFB)		Priest Rapids (Top-Spill Bypass Configuration)		
Year	**Steelhead**	**Sockeye**	**Steelhead**	**Sockeye**	**Chinook**
2010	83.1%	81.9%	77.8%	78.6%	
2009	64.6%	33.1%	71.5%	66.9%	
2008	58.2%	68.8%	41.6%	18.7%	39.1%
2007			42.2%	37.2%	27.1%
2006			39.6%	48.0%	36.9%

Table F.4. Fish collection efficiency (FCE) of steelhead and sockeye smolts at the Wanapum Dam Future Unit Bypass (WFUFB), 2008-2010. Collection zone is defined as the radius extending 300 ft from the center of the WFUFB.

Collection Zone (ft)	2010	2009	2008
Steelhead			
50	99.8%	100.0%	100.0%
100	98.8%	97.2%	95.3%
150	95.3%	94.8%	90.7%
200	91.2%	93.1%	88.3%
250	89.6%	90.7%	86.2%
300	85.8%	89.0%	81.4%
Sockeye			
50	99.7%	100.0%	100.0%
100	98.5%	96.5%	95.8%
150	95.7%	90.9%	87.6%
200	94.1%	87.0%	79.0%
250	91.5%	81.6%	71.5%
300	89.4%	75.6%	67.7%

Table F.5. Fish collection efficiency (FCE) of steelhead and sockeye smolts at the Priest Rapids Dam top-spill configuration, 2006-2010. The collection zone in 2008-2010 was defined as the radius extending 300 ft from the center of the top-spill configuration (at the junction of Spill Bay gates 20 and 21). The top-spill configuration included the prototype top-spill bulkhead at Spill bays 19 and 20 along with Tainter gates 21 and 22, sluiceway (top-spill in 2008-2009, bottom-spill in 2010). In 2006-2007, the collection zone was defined as the radius extending 300 ft from the center of the prototype top-spill bulkhead (at the junction of Spill Bay gates 19 and 20).

Collection Zone (ft)	2010	2009	2008	2007	2006
Steelhead					
50	98.0%	99.8%	100.0%	97.9%	97.3%
100	88.3%	94.3%	94.9%	87.6%	81.3%
150	83.0%	85.9%	87.6%	69.5%	63.1%
200	77.1%	77.4%	77.2%	50.9%	52.9%
250	72.8%	70.9%	67.4%	40.8%	44.8%
300	68.9%	66.0%	58.9%	33.7%	39.4%
Sockeye					
50	97.5%	98.9%	100.0%	95.2%	100.0%
100	87.2%	92.7%	93.8%	63.4%	90.5%
150	76.7%	80.9%	81.8%	44.4%	72.0%
200	69.8%	69.7%	71.4%	35.1%	53.7%
250	65.0%	60.7%	54.2%	26.5%	44.4%
300	59.4%	54.9%	45.0%	22.3%	38.2%

Appendix G

Mid-Columbia River Avian Predation

List of Tables

Table G.1. Summary of steelhead and sockeye PIT tags detected and/or physically recovered from the avian colonies at Banks Lake, Potholes Reservoir, and Crescent Island (avian predators included Caspian terns, California gulls, and Ring-billed gulls) in 2010. Data is summarized by species and release site with the proportion of avian consumption estimated based on the number of recovered tags taken by total released at each site. Single asterisk indicates gatewell study fish released at Wanapum Dam and double asterisks indicates gatewell study fish released at Priest Rapids Dam.

Species	**Release Site**	**Number Recovered**	**Total Released**	**% Avian Consumed**
Steelhead	Rock Island (RI)	55	649	8.5%
	Wanapum (WS)	52	650	8.0%
	Priest Rapids (PR)	51	650	7.8%
	Priest Rapids (PP)	54	600	9.0%
	Wanapum (GA)*	7	60	11.7%
	Wanapum (GB)*	4	60	6.7%
	Priest Rapids (GC)**	4	62	6.5%
	Priest Rapids (GD)**	4	60	6.7%
	Total	*231*	*2,791*	*8.3%*
Sockeye	Rock Island (RH)	4	557	0.7%
	Wanapum (WH)	4	524	0.8%
	Priest Rapids (PH)	2	512	0.4%
	Priest Rapids (PD)	3	376	0.8%
	Wanapum (GE)*	0	60	0.0%
	Wanapum (GF)*	0	60	0.0%
	Priest Rapids (GG)**	0	60	0.0%
	Priest Rapids (GH)**	0	60	0.0%
	Total	*13*	*2,209*	*0.6%*

Table G.2. Avian predation impacts of **steelhead** 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 (McNary Reservoir). Quantity presented is the number of survival use tags (only steelhead released in the tailraces of Rock Island, Wanapum, and Priest Rapids dams) that were 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 2010 are in bold. Gatewell study fish and draft tube pilot study fish are not included.

		2008				2009				2010			
Reach	River Mile (RM)	Available Tags	Quantity Detected	% by Reach	% by RM	Available Tags	Quantity Detected	% by Reach	% by RM	Available Tags	Quantity Detected	% by Reach	% by RM
Rock Island - Wanapum	453 - 416	648	18	2.78	0.08	797	22	2.76	0.07	649	15	2.31	0.06
Wanapum - Mattawa	**416 - 408**	**1,257**	**9**	**0.72**	**0.09**	**1,388**	**16**	**1.15**	**0.14**	**1,217**	**12**	**0.99**	**0.12**
Mattawa - Priest Rapids	408 - 397	1,150	11	0.96	0.09	1,328	11	0.83	0.08	1,167	5	0.43	0.04
Priest Rapids - Vernita	397 - 388	1,670	6	0.36	0.04	1,918	6	0.31	0.03	1,767	10	0.57	0.06
Vernita - Ringold	**388 - 361**	**1,551**	**32**	**2.06**	**0.08**	**1,818**	**62**	**3.41**	**0.13**	**1,691**	**64**	**3.78**	**0.14**
Ringold	361 -	1,317	5	0.38		1,621	17	1.05		1,509	52	3.45	
Total		**1,880**	**81**	**4.31**		**2,096**	**134**	**6.39**		**1,949**	**158**	**8.11**	

Table G. 3. Avian predation impacts of **sockeye** 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 survival use tags (only sockeye released in the tailraces of Rock Island, Wanapum, and Priest Rapids dams) that were 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 2010 are in bold. Gatewell study fish and draft tube pilot study fish are not included.

Reach	River Mile (RM)	Available Tags	Quantity Detected	% by Reach	% by RM
Rock Island - Wanapum	453 - 416	557	1	0.180	0.005
Wanapum - Mattawa	416 - 408	1,065	1	0.094	0.012
Mattawa - Priest Rapids	408 - 397	1,030	0	0.000	0.000
Priest Rapids - Vernita	397 - 388	1,533	0	0.000	0.000
Vernita - Ringold	388 - 361	1,481	1	0.068	0.003
Ringold	361 -	1,449	7	0.483	
Total		**1,593**	**10**	**0.628**	

Appendix H

Priest Rapids Alternative Release Site:
Summary of Steelhead and Sockeye Draft Tube Release Results

List of Tables

List of Figures

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Introduction and Methods

After the 2006 and 2007 survival and behavior studies were completed, concerns arose about the possible impact that the location and release technique had on the steelhead and sockeye control groups (release groups PR and PH, respectively). Grant PUD wanted to investigate the potential effects of avian predation to determine if there was any discernable difference in survival of fish that passed via the Priest Rapids Dam directly into the tailrace and those released via helicopter (traditional method of release). To assess the impacts of location and release technique, separate steelhead and sockeye control release groups (release groups PP and PD, respectively) were implemented in 2008 and 2009. Both PP and PD groups were released into the tailrace via an induction pipe. Following the 2009 study, it was recommended to Grant PUD by Blue Leaf Environmental that the Priest Rapids draft tube release of both species continue for an additional year to confirm that the difference in survival results between the 2008 and 2009 studies were an effect of the avian deterrent wire arrays in the tailrace of Priest Rapids Dam and not due to annual environmental variability (Timko et al. 2010).

During the 2010 survival and behavior study, 600 steelhead (release group PP) and 376 sockeye (release group PD) were released into the tailrace through an induction pipe (approximately 100 ft long) that ran from the transformer deck to 10 ft below the surface of the draft tube exit in the B slot of Unit 2. Fish handling, tagging, transportation and release of groups PP and PD were identical to those outlined in Appendix I of Timko et al. 2010.

Results

Acoustic Tags

Steelhead and sockeye in the PP and PD release groups were tagged with HTI Lm/PIT tags, a combination micro acoustic and PIT tag. The tags were programmed with repetition rates that ranged from 2 ms to 5 ms. The tags used to implant the draft tube releases had an average weight of 0.76 g and ranged from 0.69 g to 0.8 g (in air). The average tag burden of draft tube released steelhead and sockeye was 1.3% (range 0.8-3.4%) and 3.8% (range 1-5.2%), respectively. The average tag burden of draft tube released fish was comparable to the tag burden of steelhead (1.2%) and sockeye (3.8%) that were released in the survival study.

Data Collection and System Performance

Data collection systems downstream of Priest Rapids (Vernita Bridge and Ringold) were operational prior to the first release on 7 May 2010 and functionally collected data through 29 June 2010. The generator and power alarm failed to function at the Vernita Bridge system on 14 May 2010 resulting in 4.2 hrs of interrupted data collection. The total detections at Vernita Bridge and Ringold for both release groups in the tailrace of Priest Rapids Dam are outlined in table H.1. Columbia Basin Research estimated the detection efficiency to be 100% at the Vernita Bridge detection array.

Table H.1. Total number of acoustic tag detections for draft tube released steelhead and sockeye at each hydrophone array deployed downstream of Priest Rapids Dam in 2010. First and last acoustic detection date and time is also listed.

Detection Site	First Detection	Last Detection	Number of Detections
Vernita Bridge	5/7/2010 13:54:12	6/2/2010 0:14:02	316,485
Ringold	5/7/2010 20:47:05	6/9/2010 2:50:36	187,824
		Total Number of Detections:	**504,309**

Fish Characteristics

The PP release group was comprised of 600 run-of-river juvenile steelhead. Wild steelhead made up 47% of the total PP release group; the remaining 53% were hatchery-reared. A total of 377 run-of-river sockeye were tagged for the PD release group (78% wild and 22% hatchery-reared). One sockeye experienced post-surgical mortality and was subsequently removed from data analysis.

Size distribution and length and weight frequencies of draft tube released steelhead and sockeye are illustrated in Figures H.1 and H.2. The range of fork lengths and weights of both tagged species in 2010 were similar to those tagged in 2009 (Timko, et al 2009). Tagged steelhead were skewed slightly to the right towards the larger fish. The mean steelhead fork length and weight was 190.5 mm and 63.6 g, respectively. Tagged sockeye were skewed to the left, towards the smaller fish. The mean sockeye fork length and weight was 128.4 mm and 20.7 g, respectively.

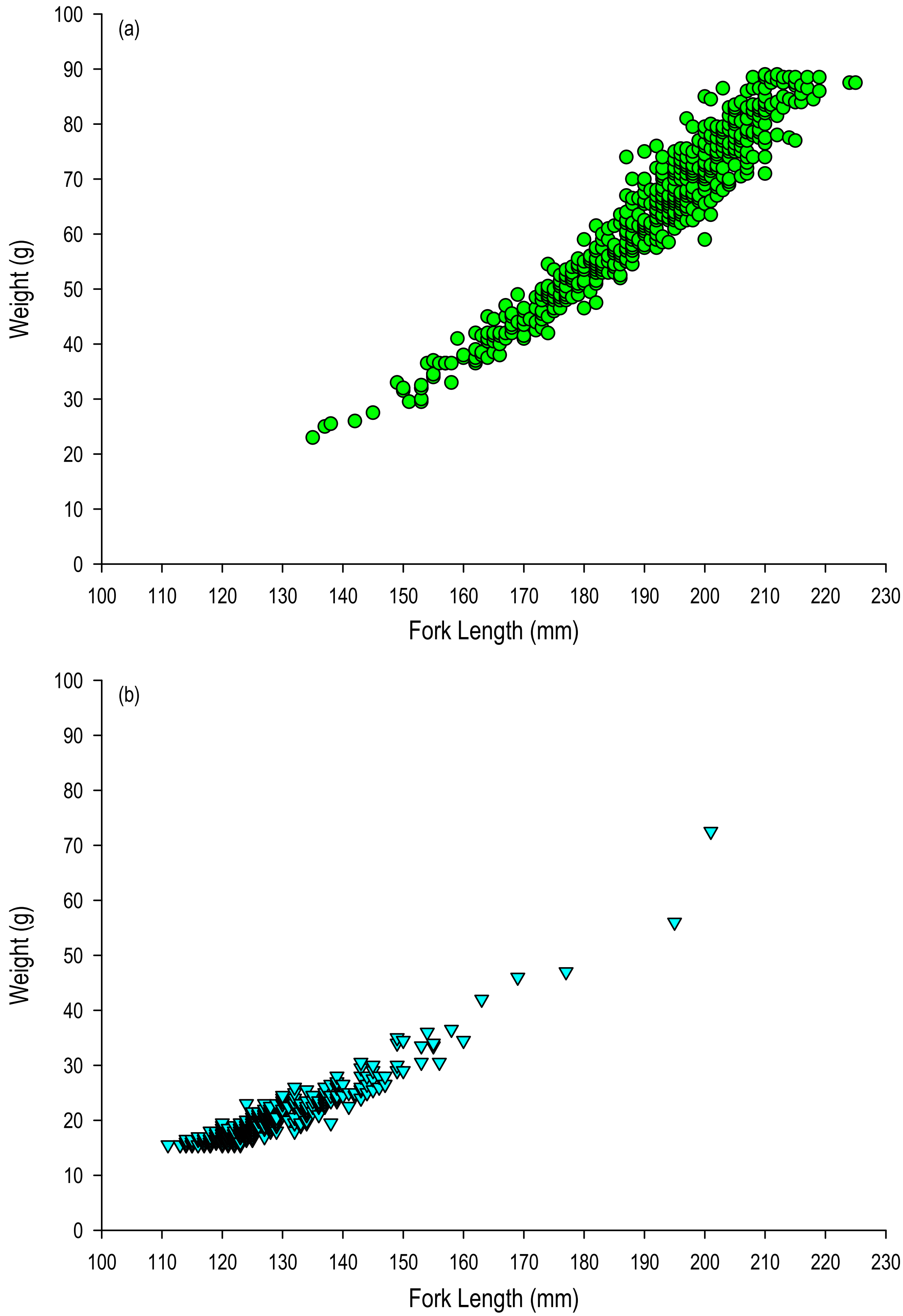

Figure H.1. Size distribution of (a) steelhead (n=600, green circles) and (b) sockeye (n=376, cyan triangles) released at the draft tube exit of Priest Rapids Dam, 2010.

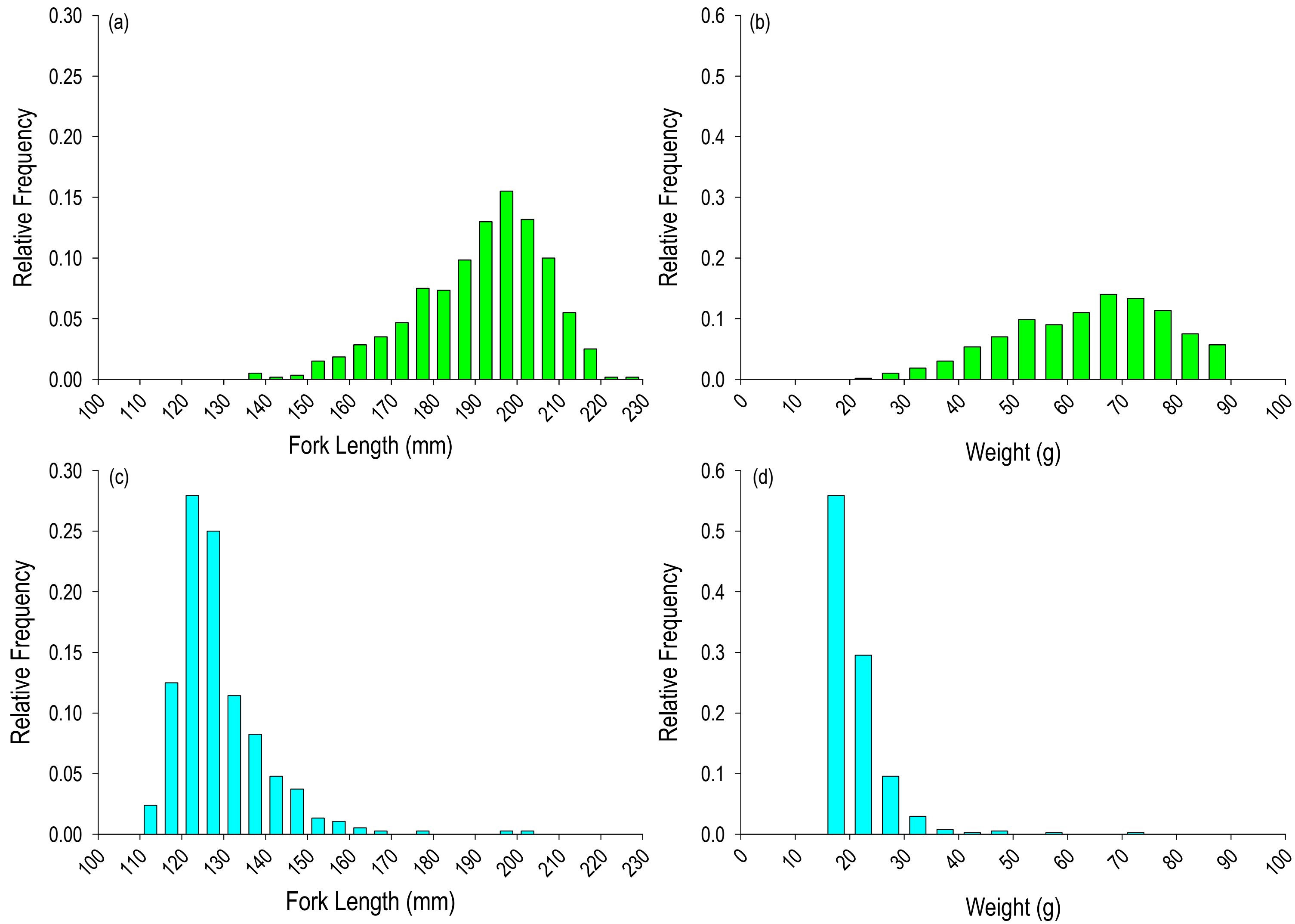

Figure H.2. The frequency of length and weight of tagged steelhead (shown in green, n=600) and sockeye (shown in cyan, n=376) released in the 2010 at Priest Rapids Dam draft tube exit. The fork length in millimeters of (a) steelhead and (c) sockeye as well as the weight in grams of (b) steelhead and (d) sockeye are shown above. The average steelhead fork length was 190.5 mm (range 135.0-225.0 mm) and weight was 63.6 g (range 23.0-89.0 g). The average sockeye fork length was 128.4 mm (range 111.0-201.0 mm) and weight was 20.7 g (range 15.5-72.5 g).

Releases

Steelhead draft tube releases occurred from 7 May through 31 May 2010. One release was scheduled per day, however, weather constraints (low cloud cover/inversion and high winds) that prevented fish from being collected for tagging and the helicopter from releasing the paired PR group, resulted in 4 releases being delayed by a day. Similar weather conditions and a lack of sizeable sockeye entrained in the gatewells impeded the ability to release the 22 planned groups, totaling 550 sockeye. Eight sockeye (PD) releases were cancelled; a total of 376 sockeye were tagged and released between 8 May and 28 May 2010 (Table H.2.).

Table H.2. The collection, surgery, and release dates of steelhead (release group PP) and sockeye (release group PD) that were released at the exit of a draft tube in the immediate tailrace of Priests Rapids Dam in 2010. Due to a lack of available study fish for tagging, fish tagged and released in sockeye release group PP10 and PD08 were taken from two different collection dates (see below).

Release Groups and Number of Fish Released						
Steelhead		**Sockeye**		**Date**		
PP	**n_{PP}**	**PD**	**n_{PD}**	**Collection**	**Surgery**	**Release**
PP01	18			5-May	6-May	7-May
PP02	18	PD01	19	6-May	7-May	8-May
		PD02	20	6-May	7-May	8-May
PP03	20			7-May	8-May	9-May
PP04	23			8-May	9-May	10-May
PP06	16	PD03	21	10-May	11-May	12-May
PP07	29	PD04	23	11-May	12-May	13-May
PP08	32	PD05	25	12-May	13-May	14-May
		PD06	29	13-May	14-May	15-May
PP09	34	PD07	31	14-May	15-May	16-May
PP10	22	PD08	2	14-May	16-May	17-May
	14		13	15-May	16-May	17-May
PP11	18			16-May	17-May	19-May
PP12	39	PD10	38	18-May	19-May	20-May
PP13	43			19-May	20-May	21-May
PP14	40			20-May	21-May	22-May
PP15	37			21-May	22-May	23-May
PP16	37	PD11	38	22-May	23-May	24-May
PP17	35	PD12	40	23-May	24-May	25-May
PP18	33	PD13	41	24-May	25-May	27-May
		PD14	36	25-May	27-May	28-May
PP19	27			26-May	27-May	28-May
PP20	23			27-May	28-May	30-May
PP21	21			28-May	29-May	30-May
PP22	21			29-May	30-May	31-May

Detections

Absolute percent detection of steelhead in 2010 was similar to 2008 and 2009. Tagged steelhead that were released into the draft tube exit were detected at higher rate at Vernita Bridge (97.5%) than at Ringold (84%). As in 2009, the draft tube released sockeye had higher absolute detection than steelhead at both locations and detections were highest at Vernita Bridge (97.6%) compared to Ringold (93%) (Figure H.3). Historically, tailrace released sockeye have had a higher survival rate than steelhead below Priest Rapids Dam. In 2010, the draft tube released steelhead and sockeye follow the same trend as previously noted.

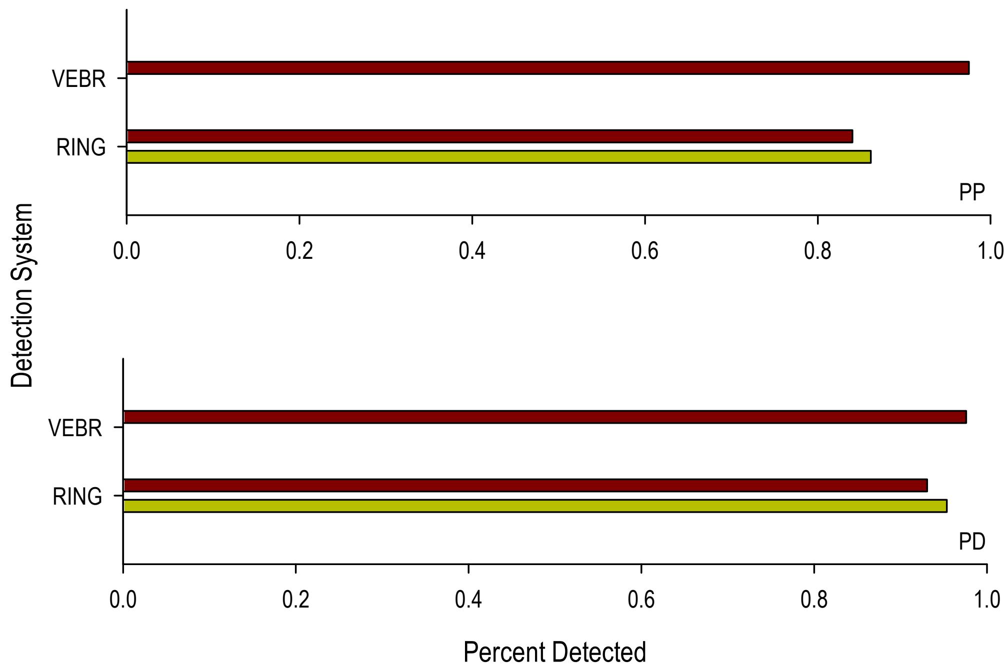

Figure H.3. Absolute percent detection of steelhead (PP) and sockeye (PD) released at a draft tube exit at Priest Rapids Dam, 2010. Red bars present the calculation from total released and the yellow bars present the percent detection between Vernita Bridge (VEBR) and Ringold (RING) from the positive detection at the nearest upstream system.

Survival

In 2010, the survival and detection probabilities were not significantly different between fish that were released at the exit of the draft tube or by helicopter in the tailrace of Priest Rapids Dam. For steelhead, reach survivals differed by less than 0.01 (0.9806 and 0.9716, draft tube and helicopter releases, respectively). For sockeye, the reach survivals were virtually identical, 0.9766 for these released in the exit of the draft tube and 0.9767 for fish released by helicopter (Table H.3). Similar to 2010, the difference in survival of the draft tube exit and traditional release for both species in 2009 was nearly indistinguishable.

Avian Predation

A total of 57 PIT tags were detected at avian nesting sites in the Potholes Reservoir and Crescent Island (upstream of McNary Dam) that were associated with acoustic tags released in the draft tube exit of Priest Rapids Dam (Table H.4). PIT tags associated with steelhead made up 95% of the tags detected; only three of the detected PIT tags were from sockeye. The highest proportion of tags from PP and PR release groups were detected at the Potholes Reservoir (61%); the majority of those recovered from the Caspian tern colony (n=32) and the remaining few from a mix of tern and gull colony (n=3). All but one of the tags last acoustic detection was at the Vernita Bridge array, which suggests that the fish were predated upon between RM 388 and 361 (Ringold array). The remaining 39% of the tags were detected at Crescent Island and were predated upon by gulls (n=17) and terns (n=5) after the Ringold detection array.

For comparison of avian tern and gull predation between draft tube releases and the traditional helicopter releases, in 2010 the proportion of PP and PR tags that were detected at Potholes Reservoir was nearly equal at 34 (5.7% of release group detected) and 38 (5.9% of release group detected), respectively. There was only one sockeye from release group PD detected at Potholes Reservoir. Similar trends were detected at Crescent Island, where the same proportions of PIT tags per release site (both species) were detected. All but one of the traditional helicopter released steelhead tags detected at Crescent Island were predated upon by gulls after detection at Ringold (n=11).

Table H.3. Estimates of downstream survival (survival to Vernita Bridge), capture probability (detection at Vernita Bridge), and capture parameters (λ) at Ringold for single release estimates of steelhead and sockeye released in the tailrace of Priest Rapids Dam at a draft tube exit or by helicopter 0.5 km downstream of the dam. Standard errors of the CJS estimates are unadjusted for tag-life and presented in parentheses. This data, including relative survival (*RS*), was analyzed and provided by Columbia Basin Research.

Release Group	Survival to Vernita Bridge	Detection at Vernita Bridge	λ
Steelhead			
Draft Tube	0.9806 (0.0064)	1.00 (0.0023)	0.8568 (0.0164)
Traditional	0.9716 (0.0075)	1.00 (0.0022)	0.8685 (0.0154)
	Draft tube to traditional release	**H_0: *RS* = 1[2] P-value**	
Relative Survival	1.0000 (0.6030)	0.3613	
Sockeye			
Draft Tube	0.9766 (0.0087)	1.00 (0.0027)	0.9486 (0.0129)
Traditional	0.9767 (0.0076)	1.00 (0.0023)	0.9709 (0.0086)
	Draft tube to traditional release	**H_0: *RS* = 1[2] P-value**	
Relative Survival	1.0000 (0.1503)	0.9931	

Table H.4. Summary of PIT tags recovered at Potholes Reservoir and Crescent Island avian colonies associated with steelhead and sockeye released at the exit of a draft tube in the tailrace of Priest Rapids Dam.

	Potholes Reservoir			Crescent Island			Total by
Species (Release Group)	**Caspian Tern**	**Gull**	**Mix**	**Caspian Tern**	**Gull**	**Mix**	**Location**
Steelhead (PP)	31	0	3	4	16	0	54
Sockeye (PD)	1	0	0	1	1	0	3
Total by Location	**32**	**0**	**3**	**5**	**17**	**0**	**57**

Downstream PIT Detections

A total of 415 unique PIT tag detections from all recapture sites are reported. An overall decrease in steelhead PIT detections between 2009 and 2010 was noticed (Table H.5) and could be due in part to a decrease in sample size released in 2010; 50 less steelhead were released in 2010. Sockeye were tagged, for the first time in 2010, with a combined acoustic/PIT tag so avian predation pressure could be assessed. Sockeye were detected at a higher rate than steelhead at McNary and John Day (sockeye detection at 13.6% and 7.4% compared to steelhead at 10.8% and 4.7%, respectively). Detection switches further downstream with steelhead having a higher detection rate than sockeye at Bonneville and the estuary (steelhead detection at 4.7% and 2.2% compared to sockeye at 4.0% and 0.3%, respectively).

Table H.5. The 2009-2010 PIT tag quantities of steelhead and sockeye detected downstream of the study area are listed below and include McNary, John Day, and Bonneville dams, along with an experimental estuary detection tow. Release site is in the tailrace of each dam, approximately 0.5 km downstream of each dam. The quantity of PIT tags recaptured was reported by PTAGIS (http://www.ptagis.org/). A total of 415 unique PIT tag detections from all recapture sites are reported.

Species	Year	McNary	John Day	Bonneville	Estuary	Total Detected
Steelhead	2010	65	28	22	13	128
		123	51	13	5	192
Sockeye	2009	51	28	15	1	95

Migration Travel Time

Migration travel time was defined as the time it took a fish to move between the release site and downstream detection arrays. Steelhead released in 2010, PP and PR releases, exhibited faster median travel times than steelhead released in 2009 (Table H.6 and H.7). Between 2009 and 2010, for both PP and PR releases, cumulative travel times increased by 20.6% and 24.3%, respectively. The percent difference in cumulative travel times for steelhead released in 2008 compared to 2010 was minimal; 6% increase for PP and 5% for PR. Sockeye median travel times were relatively steady in 2008 and 2009 for both the draft tube (PD) and traditional (PH) release group. A slight increase in sockeye cumulative travel times of 1% was seen in 2010 compared to 2009. Comparison of cumulative annual median travel times of draft tube releases (10.0 hr and 8.6 hr in 2010 for steelhead and sockeye, respectively) to traditional releases (10.6 hr and 9.1 hr in 2010 for steelhead and sockeye, respectively) shows that draft tube fish move through the system at a slightly faster rates (Table H.6 and H.7).

Table H.6. Annual median travel times measured in hours for steelhead (release group PP) and sockeye (release group PD) released at a draft tube exit of Priest Rapids Dam. Cumulative travel times, measured from the time of release to first detection at a given site, are in parenthesis. Sockeye were not released at this location or in the tailrace of Priest Rapids Dam in 2008.

Year	VEBR	RING
Steelhead (PP)		
2010	2.2	7.8 (10.0)
2009	2.9	9.7 (12.6)
2008	2.0	8.7 (10.7)
Sockeye (PD)		
2010	2.1	6.5 (8.6)
2009	2.1	6.4 (8.5)

Table H.7. Annual median travel time of non-draft tube released steelhead (release group PR) and sockeye (release group PH) in the tailrace of Priest Rapids Dam are shown below. Sockeye were not released in the tailrace of Priest Rapids Dam in 2008.

Year	VEBR	RING
Steelhead (PR)		
2010	2.2	8.4 (10.6)
2009	2.4	11.6 (14.0)
2008	1.8	9.3 (11.1)
Sockeye (PH)		
2010	2.2	6.9 (9.1)
2009	2.1	6.9 (9.0)

Table H.8. Summary of steelhead and sockeye relative survival and standard errors by two release methods, draft tube exit or helicopter, in 2008-2010. Sockeye were not tagged and released by Grant PUD in the tailrace of Priest Rapids Dam in 2008. Steelhead release group PP was released in the exit of the draft tube and PR was released in the tailrace, approximately 0.5 km downstream of the dam. Sockeye release group PD was released in the exit of the draft tube and PH was released in the tailrace, approximately 0.5 km downstream of the dam.

Year	Draft Tube	Helicopter
Steelhead	**PP**	**PR**
2010	0.9806 (0.0064)	0.9716 (0.0075)
2009	0.9769 (0.0059)	0.9708 (0.0066)
2008	0.9014 (0.0168)	0.9645 (0.0076)
Sockeye	**PD**	**PH**
2010	0.9766 (0.0087)	0.9767 (0.0076)
2009	0.9881 (0.0044)	0.9867 (0.0047)

Conclusions

The primary purpose of this three-year study was to determine if fish that passed through the dam volitionally (survival based treatment groups) were more susceptible to avian predation compared to fish that were released by helicopter (survival based control groups). While significant differences were detected between the two release sites of steelhead in 2008 (6%, see Table H.8), the method of release did not appear to have an effect on subsequent migration success in 2009 or 2010. It is believed that the difference in 2008 occurred prior to the installation of the avian deterrent wire arrays in the tailrace of Priest Rapids Dam because there was an increase in avian predation immediately downstream of the dam. The wire arrays appear to have deterred avian predation in the immediate tailrace of Priest Rapids Dam for both species and in turn, there does not appear to be a difference in avian predation between the two release methods.

A behavioral difference that has been observed between the two release sites is a variation in median travel time by steelhead between 2008 and 2010. There was a significant increase in median and cumulative median travel times of steelhead in 2009, compared to 2008 and 2010. While we are unsure how to explain these differences, there are at least a few possible explanations. First, it is possible that the release method influenced downstream egress directly after release. For example, fish released by helicopter may have been more disoriented directly after release from the fly tanks and took slightly longer to regain downstream orientation than those fish released in the exit of a draft tube. Secondly, environmental conditions and dam operations, such as flow and spill, varied by year; spill and flow through the spillway, directly upstream of the helicopter release site, was limited in 2009. Lack of spill may have also played a role in a longer period of time needed by steelhead to orient to the downstream flow post-release. Additionally, an increase in flow was applied to the total bypass configuration in 2010 that might have assisted helicopter released fish into downstream orientation more quickly than those from 2009.

Based on the results of this study conducted in 2008 through 2010, it is our recommendation to Grant PUD that there is no further need to investigate the release methodology of the survival and behavioral control group. Data from 2009 and 2010 has illustrated that traditional helicopter released fish encounter similar environmental pressures, such as predation, as fish that pass volitionally through the dam.

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