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## Abstract

Acoustic telemetry studies were conducted in 2014 during continued assessment of juvenile steelhead (*Oncorhynchus mykiss*) downstream migratory survival and behavior through the Priest Rapids Project (Project area refers to the Wanapum and Priest Rapids dams and reservoirs), a hydroelectric Project that is owned and operated by Public Utility District No. 2 of Grant County, Washington on the Mid-Columbia River. Yearling Chinook salmon (*O. tshawytscha*), which were evaluated and found to have met survival performance standards between 2003 and 2005 were re-evaluated in 2014. Juvenile Salmon Acoustic Telemetry System (commonly referred to as JSATS) technology was used to address the study objectives. Acoustic transmitters were surgically implanted into 1,720 steelhead and 1,716 yearling Chinook salmon; fish were released in paired releases within the tailraces of Rock Island, Wanapum, and Priest Rapids dams between 30 April and 28 May 2014. Spatial data was collected in a series of detection arrays between Rock Island Dam (RM 453) and the Hanford Reach (RM 337). Array detection efficiencies at all sites were high, estimated between 97.7% and 100%. Additional emphasis was placed on the behavior of fish as they approached and passed downstream of Priest Rapids Dam at or near the new Priest Rapids Fish Bypass (PRFB) with additional two- and three-dimensional autonomous receivers that were arranged to track study fish directly upstream of the PRFB. Passage survival was estimated at 92.9% (SE 1.4%) for steelhead and 94.5% (SE 1.3%) for yearling Chinook salmon through the Wanapum Development (Wanapum Dam and Reservoir). Survival was higher for both species through the Priest Rapids Development (Priest Rapids Dam and Reservoir) with steelhead at 96.1% (SE 1.0%) and yearling Chinook at 96.1% (SE 0.9%) survival. The overall Project survival (both dams and reservoirs) was estimated at 89.3% (SE 1.6%) for steelhead and 90.8% (SE 1.5%) for yearling Chinook salmon. Steelhead survival estimates in the Wanapum Development fell slightly below the requirements established in the 2008 NMFS Biological Opinion of 93% by 0.06%, but were met in the Priest Rapids Development and the total Project estimates. Compared to previous studies completed in 2008-2010, the Project area was significantly altered by two events during the 2014 telemetry study. First, in the Wanapum Development, a fracture in the spillway of Wanapum Dam required a 28 ft decrease in the Wanapum Reservoir elevation (forebay elevation averaged 543 ft in 2014; typical operating elevation in 2008-2010 studies was 571 ft), resulting in increased spill at the Wanapum Dam and an 80% reduction in flow at the Wanapum Fish Bypass (WFB). The WFB operated at a reduced flow of 4 kcfs in 2014, whereas in previous studies it was typically operated at 20 kcfs. This decrease in flow at the WFB resulted in the bypass being selected by only 9.9% of the steelhead and 7.5% of yearling Chinook salmon that passed the dam in 2014; for comparison, in previous studies, up to 77% of the juvenile steelhead selected the WFB. The second change in the 2014 Project area was the operation of the new PRFB commenced (April 2014) at Priest Rapids Dam in the Priest Rapids Development, offering smolts a non-turbine passage route that consisted of three spill bays (20-22) that operated at an average total flow of 25.2 kcfs. The PRFB collected 47% of steelhead and 38% of yearling Chinook salmon. Tracking densities of tagged fish that passed through the PRFB indicated that most of the bypass collected fish were originally

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upstream of the powerhouse, near turbine units 1 and 2. Additional approach analysis of fish moving into the forebay at the hazard barrier also supported that fish upstream of the spillway were intercepted and passed at spill bays 1-18 while those fish upstream of the powerhouse were more likely to pass through either the powerhouse or the PRFB. Yearling Chinook salmon were more likely to pass through the powerhouse than steelhead, which was anticipated as yearling Chinook salmon in previous three-dimensional tracking studies traveled at deeper depths than steelhead. Based on the 2014 study results, it is anticipated that the PRFB collection efficiency will increase considerably when the spillway is closed during future spring out migrations.

## Introduction

Wanapum and Priest Rapids dams and the two reservoirs upstream of each dam in the Mid-Columbia River define the Priest Rapids Hydroelectric Project (Project), a Project that is owned and operated by Public Utility District No. 2 of Grant County (Grant PUD). Over the past several decades, Grant PUD has been addressing environmental concerns on the Mid-Columbia River related to the survival and condition of fish passing through the physical structures, and the riverine environment that has evolved and continues to vary with time. At each of the dams, Grant PUD has improved downstream passage conditions for juvenile salmonids with the installation of new, fish friendly turbines and bypass structures, along with optimization of operations of existing turbines during the spring and summer out-migration period. Grant PUD has also researched, monitored, and sought to facilitate changes in environmental conditions that favor smolt survival through the Project. In addition to water quality monitoring, Grant PUD maintains a northern pikeminnow (*Ptychocheilus oregonensis*) removal program, avian predation hazing, and has installed avian deterrents (bird wires) below each dam to decrease the risk of predation in the tailrace area. Moreover, Grant PUD actively supports and is directly involved with avian predation monitoring at known nesting colonies of Caspian terns (*Hydroprogne caspia)* and various gull species on the Columbia River Plateau. The PUD is also involved in piscivorous fish predation studies of species that include walleye (*Sander vitreus*), northern pikeminnow, and smallmouth bass (*Micropterus dolomieu*).

To improve passage at Wanapum Dam, a surface top-spill fish bypass was completed in 2008 to provide safe and effective downstream passage for juvenile migrants. This surface flow alternative, the Wanapum Fish Bypass (WFB), has proved successful in passing up to nearly 80% of the downstream migrants. With parallel objectives to the WFB, the Priest Rapids top-spill fish bypass or PRFB was operational for its inaugural season during the 2014 spring outmigration. Prior to the construction of this top-spill bypass structure, a prototype bulkhead at Priest Rapids Dam was installed, tested and modified annually between 2006 and 2010 to maximize a design that would effectively collect and pass smolts. Passage efficiency results were mixed during early trials (2006 and 2007), but collection efficiency increased annually as fish behavior became better understood and flow was augmented at or near the prototype to attract smolts. In 2010, fish collection at the prototype bypass peaked and collected 57% of migrating steelhead (*Oncorhynchus mykiss)*.

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; Timko et al. 2011). Columbia and Snake River hydropower facilities are federally regulated to meet established survival standards for juvenile salmonids migrating through their respective Projects. More specifically, for Grant PUD, the survival requirements include juvenile passage survival of 95% at each dam (concrete survival), 93% through a single development (one dam and reservoir, e.g., Priest Rapids Reservoir and Dam) and 86.5% through the entire Project (both developments combined). An arithmetic mean of three consecutive years (for each species) is used to determine if the survival standard has been met. These particular Performance Standards (passage survival rates) that need 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).

To measure the survival of downstream migrant juvenile steelhead, Grant PUD conducted annual survival studies between 2008 and 2010 using mark-recapture acoustic telemetry techniques and continued with a related predation study in 2011. Each year, paired smolt releases (treatment and control groups) were introduced into the tailraces of Rock Island, Wanapum, and Priest Rapids dams and survival was evaluated by downstream acoustic tag detection arrays. During these studies, concrete survival (95%) of steelhead was met at both dams; however steelhead survival through both the development (93%) and project survival (86.5%) have yet to be met consistently (Timko et al. 2007a, 2007b; Sullivan et al. 2008; Timko et al. 2010; Timko et al. 2011; Thompson et al. 2012). During three years of consecutive studies in 2003-2005 survival of downstream migrant yearling Chinook salmon (*O. tshawytscha*) were tested, and survival goals were met with a three-year weighted average of 86.6% (86.6% in 2003, 86.4% in 2004, and 86.9% in 2005) (Anglea et al. 2004, 2005a and 2005b). In this 2014 study, the survival standards for yearling Chinook salmon, previously met using PIT tags, were revisited to confirm that survival standards are still being met.

In this document, we present the findings of Project passage survival and behavior of steelhead and yearling Chinook salmon at the Wanapum and Priest Rapids developments in 2014. 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 through the entire Project. In addition to comparisons of interspecies survival in the Project, migration rates, forebay residence times, approach patterns, and passage behavior are presented with a focus on passage behavior at the PRFB.

# Methods

## Study Site

The Project includes Priest Rapids Dam (River Mile, 'RM' hereafter, 397), constructed in 1956-1961, and Wanapum Dam (RM 416), constructed in 1959-1963. The two dams are located on the Mid-Columbia River, between Rock Island Dam (RM 453) and the Hanford Reach (Figure 1). Figure 1 illustrates the position of the Wanapum Reservoir as the pool between Rock Island and Wanapum dams, and the Priest Rapids Reservoir as 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 that were recently replaced with a new, advanced design by Voith Siemens for the Department of Energy Advanced Hydro Turbine Program, with a generating capacity of 1092 megawatts (MW). During spring and summer migration periods, the turbine units are operated in a 'fish mode' that generally consists of a 15.7 kcfs operation ceiling that minimizes turbine passage injury and mortality. Located south of the powerhouse is the Wanapum Fish Bypass (WFB) which provides a non-turbine passage route for migrating juvenile salmonids. The WFB (completed in 2008) is a 290 ft long chute designed to collect smolts and pass a maximum laminar flow of 20 kcfs over Wanapum Dam, gradually decelerating entrained fish without shear and minimizing total dissolved gas in the tailrace. South of the WFB, the spillway joins the future turbine unit slots at a 45 degree angle extending to the southwest. The spillway is comprised of 12 Tainter gates that pass submerged flow at 65 ft below the surface of the river (Timko et al. 2010).

Priest Rapids Dam operates 10 Kaplan turbine units along the northeast end of the hydropower structure with a combined generating capacity of 956 MW. The spillway is now comprised of 19 Tainter gates and runs from the southwest end of the dam towards the middle of the river (Figure 2). In 2014, a surface-flow, top-spill bypass, also referred to as the Priest Rapids Fish Bypass ('PRFB' hereafter), was completed to provide a non-turbine passage route for migrating juvenile salmonids. The PRFB was

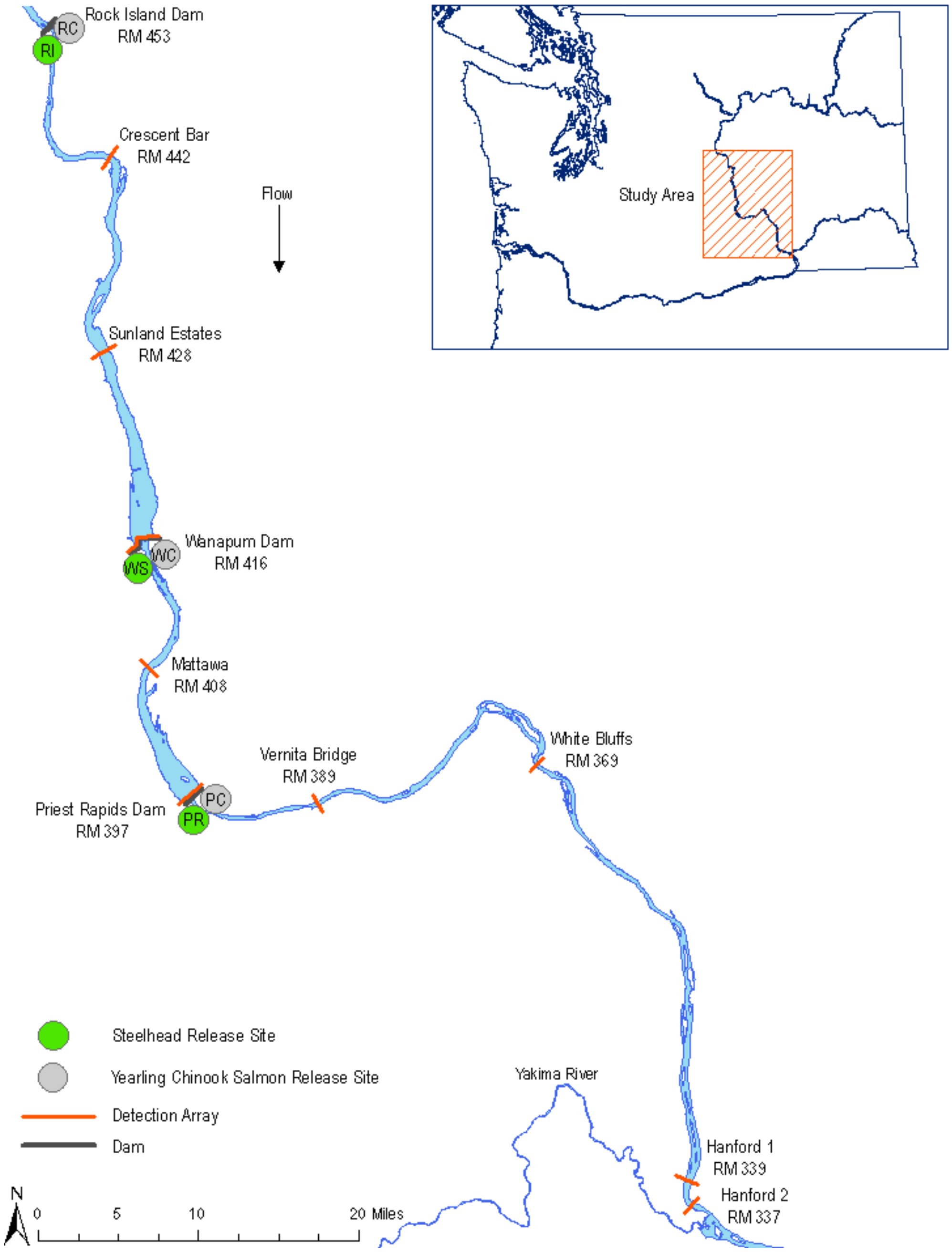



Figure 1. Study area from Rock Island Dam tailrace (RM 453) to RM 337, 45 miles upstream of McNary Dam. Location of steelhead releases are shown in green at Rock Island Dam (RI), Wanapum Dam (WS) and Priest Rapids Dam (PR) tailraces. Yearling Chinook salmon release locations are shown in grey at Rock Island Dam (RC), Wanapum Dam (WC) and Priest Rapids Dam (PC) tailraces. Detection arrays (orange bars), dams (grey bars), as well array identification and configuration are depicted.

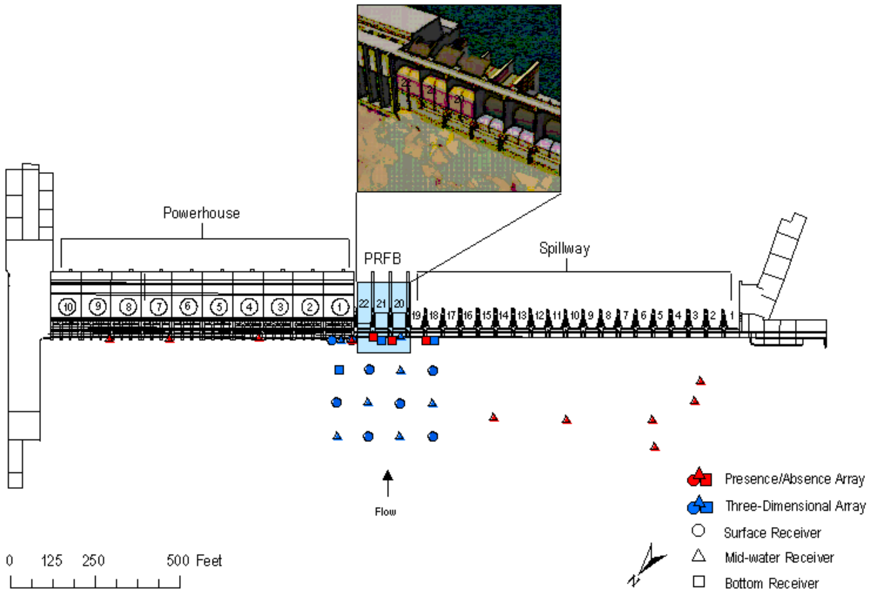



Figure 2. Schematic of Priest Rapids Dam is shown with the corresponding receiver deployment locations. Two independent detection arrays are depicted in red and blue as well as the relative receiver elevation. Fish bypass image courtesy of Jacobs Engineering.

designed to use Tainter gates 20, 21 and 22 which are the three spill bays closest to the powerhouse (Figure 2). The crest height of each spillway was raised approximately 35 ft (depth of water at the crest is just under 14 ft) and the three individual chutes are 40 to 44 ft wide.

### *JSATS Tags and Data Collection*

Salmonids were surgically implanted with a Lotek *Model L-AMT-1.421* JSATS acoustic transmitter (11.1 x 5.5 x 3.7mm, 0.32 g in air, three second burst at 416.7 kHz) and a Biomark PIT tag (12 mm). JSATS acoustic tags were received from the manufacturer in three separate tag lots throughout the study period. To avoid potential effects of variability in the quality of manufactured tag lots, tags were randomly selected from each lot for tag-life testing (proportional to the total number of tags received per lot) and were pre-assigned to tag-life release groups prior to activation. The remaining tags were randomized, assigned to release groups, and subsequently selected for surgical implantation into study fish. Replacement tags were randomized during the study. All tags for each treatment and control release group were activated simultaneously to ensure equal tag activation time across experimental groups.

Nine river-spanning arrays comprised of 84 Teknologic Autonomous Receivers (‘receivers’ hereafter) collected data from tagged fish during their downstream migration. From upstream to downstream, the arrays included: Crescent Bar (3 receivers), Sunland Estates (4), Wanapum Dam (16), Mattawa (4), Priest Rapids Dam (37), Vernita Bridge (4), White Bluffs (4), Hanford 1 (4), and Hanford 2 (4) (Figure 1; Appendix A, Figures A.2 – A.5). It is noteworthy that various receivers throughout the study area were replaced mid-season due to equipment malfunction (e.g., data collection space maximized, battery power expired, or logger damaged by debris (Appendix A, Table A.5).

Acoustic receivers at the in-river arrays were deployed from a research boat by davit arm and were anchored to the river bottom by concrete and rebar anchors. A large zinc-coated ring held the tie-ups to the anchors and served as the attachment point for acoustic release units (InterOceans *Model 111-D* acoustic releases) (Appendix A, Figure A.1). Acoustic releases were controlled by a surface command unit that allowed remote sonic-mechanical release of the anchor system, similar to Thompson et al. 2012. At both dams, receivers were deployed in two separate arrays; one along the Boat Restricted Zone (BRZ or Hazard Barrier) and the second in the immediate forebay of the dam. Acoustic receivers at the BRZ of each dam were suspended from the hazard barrier between shock-absorbing tethers and large weights at overlapping detection range intervals. Receivers deployed on the dam face were installed either by a diver into a fixed bracket or from the deck on a pier nose cage mount.

The forebay array at Priest Rapids Dam was configured to enable three-dimensional (3D) tracking of tagged fish near the PRFB. The setup consisted of a combination of *Teknologic 2/3D Autonomous Receivers* that were deployed at varied depths offshore of the dam and directly on the upstream face of the dam to provide spatial positioning estimates in the x, y, and z planes (Figure 2). All autonomous 3D receivers were equipped with a beacon tag that transmitted periodic pings that allowed for post hoc synchronization of receiver time and location. All other detection arrays at the dams were designed to provide only presence/absence data rather than spatial positioning.

At the completion of data collection, the receivers were recovered and the raw data were downloaded from each receiver's memory card to a data server using Teknologic software *Autonode uSD Extractor,* where the data was then processed, filtered and analyzed accordingly. The filtering methods were based on the US Army Corps of Engineers protocols that have been used on previous JSATS studies by various researchers in the Columbia River Basin (Skalski et al. 2010a, 2010b; Thompson et al. 2012). Three-dimensional positioning in the forebay of Priest Rapids Dam, near the PRFB, was completed by Teknologic Engineering. The position of tagged fish was estimated in 2D (x, y) and 3D (x, y, z) using Teknologic's 2/3D detection proprietary processing software. Generally speaking, positioning was resolved based on the time of arrival that a tag was detected on five or more nodes with a minimum of two nodes anchored to the face of the dam that were deployed on multiple planes with defined locations (x, y, and z by node pressure sensors or measured during diver installation). The differences in time of arrival in combination with the known deployment locations of each receiver provided sufficient information to solve for the three unknowns (x, y, and z) using a process of simultaneous equations. Positioning was refined with upper and lower elevation boundaries (e.g., the highest forebay elevation during the 2014 study was 489 ft and therefore no fish could have been detected at any higher elevation, i.e., "out of water").

*Collection and Surgery*

Downstream migrating run-of-river steelhead and yearling Chinook salmon smolts were collected at Wanapum and Priest Rapids dams by dip-netting from the wheel gate slots ('gatewell' hereafter) as in previous studies (Sullivan et al. 2009; Timko et al. 2010, 2011). Gatewells are water-filled vertical columns that extend from the ceiling of each turbine intake to the intake deck of the dam. Since 1977, smolts have been collected from the gatewells in the dams of the Priest Rapids Project, which has been an effective and reliable source of fish for behavioral and survival studies (Park and Farr 1972; Timko et al 2010). Depending on the fish species and particular dam, a documented 1% to 6% of smolts become temporarily entrained in the gatewells (Sullivan et al. 2009; Timko et al. 2010; O'Connor 2012).

In 2014, all gatewell-dipped fish were transported to the west bank of Wanapum Dam for sorting. After initial sorting in a light MS-222 solution by species, size, and physical condition, selected fish were held in recirculating ambient river water for 24 hr prior to surgery to ensure robustness. Immediately before surgery, fish were removed from holding tanks and placed into an anesthetic bath (MS-222 at 60-80 mg/L) until loss of equilibrium occurred, 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 g were excluded because they were too small to meet the recommended maximum 3% tag burden (tag to body-weight ratio).

Acoustic tags and passive integrated transmitters (PIT) were implanted into fish through an incision made along the mid-ventral line; incisions were closed by two 5-0 Vicryl PLUS coated sutures. All study fish were held for 24 hr prior to release to ensure tag retention and post-surgery survival. Fish handling was conducted by LGL Limited. Detailed culling and surgical guidelines can be referenced in the LGL Limited Standard Operating Procedures that were provided in Appendix A of Timko et al. 2010.

*Release and Study Design*

Acoustic-tagged steelhead and yearling Chinook salmon 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 yearling Chinook salmon release groups were RC, WC, and PC, respectively (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 operational. 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. Once fly-tanks were transported to the release point, the release of fish was triggered from the cockpit of the helicopter by a thumb switch that was connected to the fly-tank suspended below. Fish were released no higher than 10 ft from the surface of the river; release distance was observed by a person 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. 2011; Timko et al. 2011; Thompson et al. 2012). Paired treatment-control groups were released at successive dams and were used in conjunction to measure dam and reservoir (development) passage using JSATS acoustic detection arrays. Wanapum Dam and Wanapum Reservoir were tested with treatment and control groups released in the tailraces of Rock Island (RI/RC) and Wanapum (WS/WC) dams (Figure 1 and Figure 3). Priest Rapids Dam and Priest Rapids Reservoir were tested with treatment and control groups released in the tailraces of Wanapum (WS/WC) and Priest Rapids (PR/PC) dams (Figure 1 and Figure 3). Steelhead were released in 19 replicate groups (n=1,720) and Chinook salmon were released in 21 replicate groups (n=1,716) at each release location (Appendix B, Table B.1). There were fewer steelhead replicates due to a delay in collecting sufficient steelhead migrants during the early season. 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 Appendix B, Table B.1).

*Survival Analysis*

The primary survival analyses cited in this report were conducted by Columbia Basin Research (CBR) and are presented in Skalski et al. (2014). 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 at Priest Rapids Dam. Survival 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 White Bluffs. Project survival included both dams and reservoirs and was the product of the Wanapum Development survival multiplied by the Priest Rapids Development survival. Reach survivals and tag detection probabilities were estimated by Skalski et al. (2014).

Additionally, *Ricker* survival estimates were calculated to estimate concrete survival at each dam. The *Ricker* survival equation was as follows:

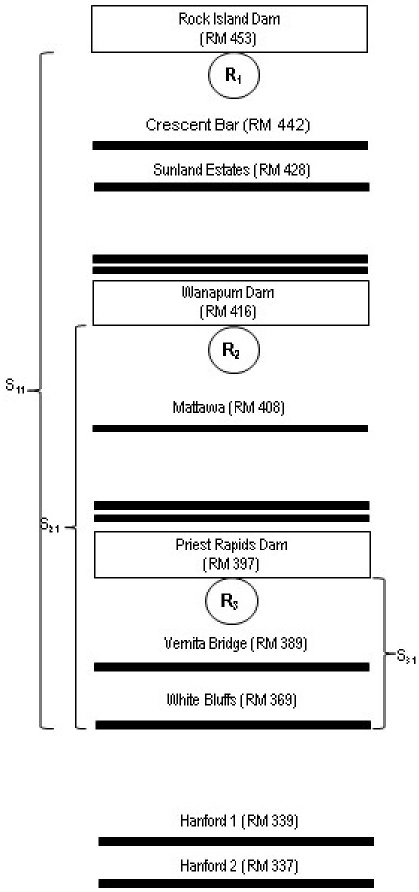
$$\frac{[(\text{\# treatment fish detected downstream}) / (\text{\# treatment fish released}^{1})]}{[(\text{\# control fish detected downstream}) / (\text{\# control fish released})]}$$

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 White Bluffs was required

*Behavioral Analysis*

In addition to estimates of survival, a number of techniques were used to analyze the dataset for behavioral trends. The effectiveness of the fish bypass was measured by fish passage efficiency (FPE), or the ratio of the number of fish selecting the WFB or the PRFB as compared to other passage routes. Passage route designations used a study

[1] Quantities of treatment fish released refers to a 'virtual release' in which fish detected immediately above Wanapum or Priest Rapids dam (i.e. the forebay) were used to populate this equation.




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 through each development. Black bars represent detection arrays.

fish's final detection history in conjunction with relative detection amplitudes to conclude route selection.

Two and three dimensional tracking was conducted at Priest Rapids Dam for thorough quantitative assessment of fish passage behavior at or near the PRFB. The position data were used to evaluate Fish Collection Efficiency (FCE); a metric to estimate passage success of fish that enter a defined zone of influence (ZOI). In this case, FCE was defined as the proportion of fish that entered a zone extending 300 ft from the center of the PRFB (arc of 180°) and passed through the PRFB.

To illustrate trends in where fish that passed at the PRFB were collected from, normalized density plots of unique fish that passed through the forebay were generated. Densities figures were created using a grid of 10 ft x 10 ft two-dimensional cells or bins in the forebay and percentages were determined by the number of individual fish that entered each bin. The normalized density plots illustrate where fish were in the forebay before passage selection occurred. Relative percent passage (RPP) figures were also created by species using the same grid, but were calculated as the proportion of fish that entered each 10 ft x 10 ft bin, and then passed through the PRFB verses other routes. A contour was then created around the normalized density and RPP data for each bin in 10 percent increments to show areas of high and low use by fish.

Various other analyses were performed to quantify fish behavior including: migration travel rates, approach distribution, and forebay residence times (Timko et al. 2007a, 2007b, 2010, 2011; Sullivan et al. 2009).

## Results

### *Project Operations*

The survival and behavior studies conducted in 2014 occurred during atypical Project operations. The Wanapum Reservoir was lowered and the forebay of Wanapum Dam was decreased by approximately 28 ft to an average elevation of 543 ft; typical forebay operation elevations are at an average of 571 ft. The drop in elevation occurred prior to the start of these studies to alleviate water pressure on a spillway fracture that was observed on February 27, 2014. A summary of project operations in the spring of 2014 are shown in Figure 4.

During the 2014 spring field studies, the average flow through the WFB was 4 kcfs, a marked decline from the average flow in 2008-2011 of approximately 20 kcfs (Figure 4). Discharge from the Wanapum Dam powerhouse was also decreased in 2014; the average powerhouse discharge was 114 kcfs, which was approximately 60% of maximum operation. For comparison, between 2006 and 2010, the minimum average spring powerhouse discharge was recorded at 108 kcfs (2010, notably a low water flow year) and a maximum average spring powerhouse discharge was 136 kcfs (2007). During the 2014 study, the average total spill (across all spill bays, but excluding the bypass) was 58 kcfs, which was generally higher than the average spill discharge during prior behavior studies that ranged from 7 kcfs (2009) to 70 kcfs (2006 and 2008). Average total discharge for Wanapum Dam was 179 kcfs in 2014. From 2006 to 2010, the average total discharge during field studies ranged from 134 kcfs in 2009 to 220 kcfs in 2011.

The combined average flow over the PRFB was 25.2 kcfs, with an average of 8.4 kcfs at each of the three spill bays (Figure 4). The average flow at the PRFB in 2014 was similar to the total flow of the prototype bypass configurations that were evaluated in 2010 where the maximum combined average flow through four spill bays was 25 kcfs (Spill Bay 19 and 20 as top-spill and Spill Bay 21 and 22 as bottom-spill). Additionally, the average powerhouse and total project discharge at Priest Rapids Dam in 2014 was 121 and 193 kcfs, respectively. Similar to Wanapum Dam, the discharge at Priest Rapids Dam in 2014 fell within the historic ranges of operation flows during survival and behavior studies conducted in 2006-2010. Average powerhouse discharge ranged from 101 kcfs (2010) to a maximum of 154 kcfs in 2007. The average total spill recorded in 2014 was 70 kcfs, which excludes the bypass. The average total spill for prior field studies ranged from 3-5 kcfs (2007, 2009-2010) to the highest discharges recorded in 2006 and 2008 of 26-27 kcfs. The average total project discharge in 2006-2010 ranged from 132 kcfs (2009) to 209 kcfs (2008).

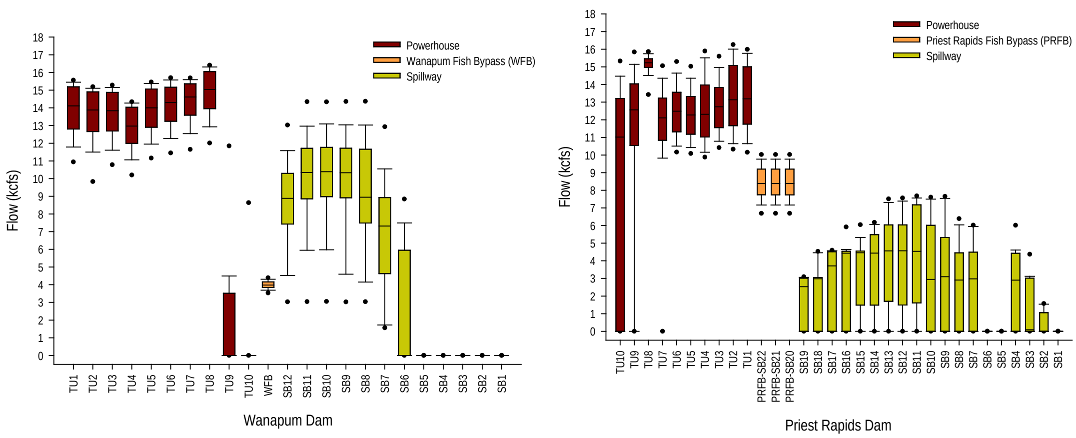



Figure 4. Project operations summarized at each dam, Wanapum Dam (left) and Priest Rapids Dam (right), and categorized by powerhouse (turbine units, TU, 1-10), fish bypass, or spillway (spill bays, SB). Box plots illustrate 5th and 95th percentiles and highlight the median, 25th and 75th percentiles of flow (kcfs).

*Environmental Conditions*

Environmental conditions including Total Dissolved Gas (TDG) saturation, river flow as a function of tailwater elevation, and temperature were monitored from 28 April to 23 June, 2014 downstream of Rock Island, Wanapum and Priest Rapids dams as well as at Pasco, Washington (RM 330), which is located seven miles downstream of the Hanford 2 detection array. Daily median conditions for 2014 are depicted along with the 10-year average conditions, in Figures Figure 5 and Figure 6, allowing for comparison. Data were procured from the Columbia River DART website and Grant PUD dam operation records. In general, TDG, river flow, and temperature at all sites were higher in 2014 than the 10-year average. However, there was a sharp decline in TDG and flow at all sites in early June followed by a return to 10-year average conditions by the end of the month.

TDG saturation peaked at all sites between 29 May and 3 June, 2014. The highest TDG saturation was recorded downstream of Wanapum Dam on 1 June at 126% with peaks at Rock Island and Priest Rapids dams (at 123%) aligned with peaks in river flow. The highest recorded TDG saturation at Pasco, WA during the study period was 117%. For comparison, the 10-year average TDG saturation at all sites was consistently below 120%.

River flow in 2014 was consistently above the 10-year average. Peak flow in 2014 was 233 kcfs below Rock Island Dam, 216 kcfs below Wanapum Dam, 241 kcfs below Priest Rapids Dam, and 237 kcfs at Pasco, WA. Flows peaked at all sites on 1 June. These peaks in flow were followed by a sharp decline to a low occurring on 15 June at all sites, ranging from 116 kcfs at Rock Island Dam to 123 kcfs at Pasco, WA. In contrast, the 10-year average flow trends upward throughout the study period, ranging from 132 kcfs downstream of Rock Island Dam in late April to 238 kcfs at Pasco, WA in late June.

Water temperatures in 2014 were slightly above the 10-year average, ranging from 7.7 to 16.8°C over the course of the field study. The 10-year average values over the same period of time were similar and ranged from 7.9 to 15.5 °C.

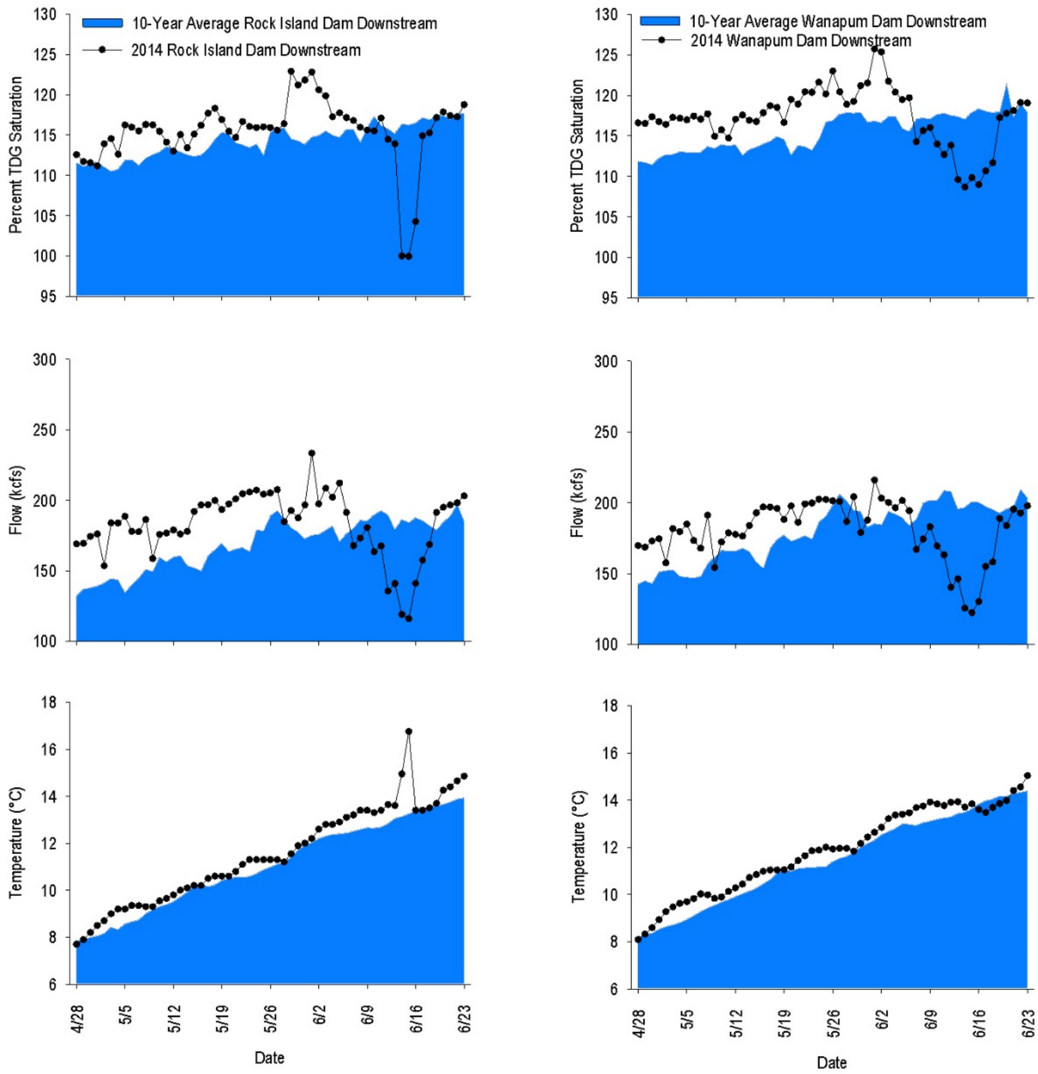



Figure 5. Daily median water quality values downstream of Rock Island and Wanapum dams are shown from 28 April – 23 June, 2014 along with the 10-year average which is depicted in blue (data source*: www.cbr.washington.edu/dart/dart.html* and *Grant PUD dam operations*).

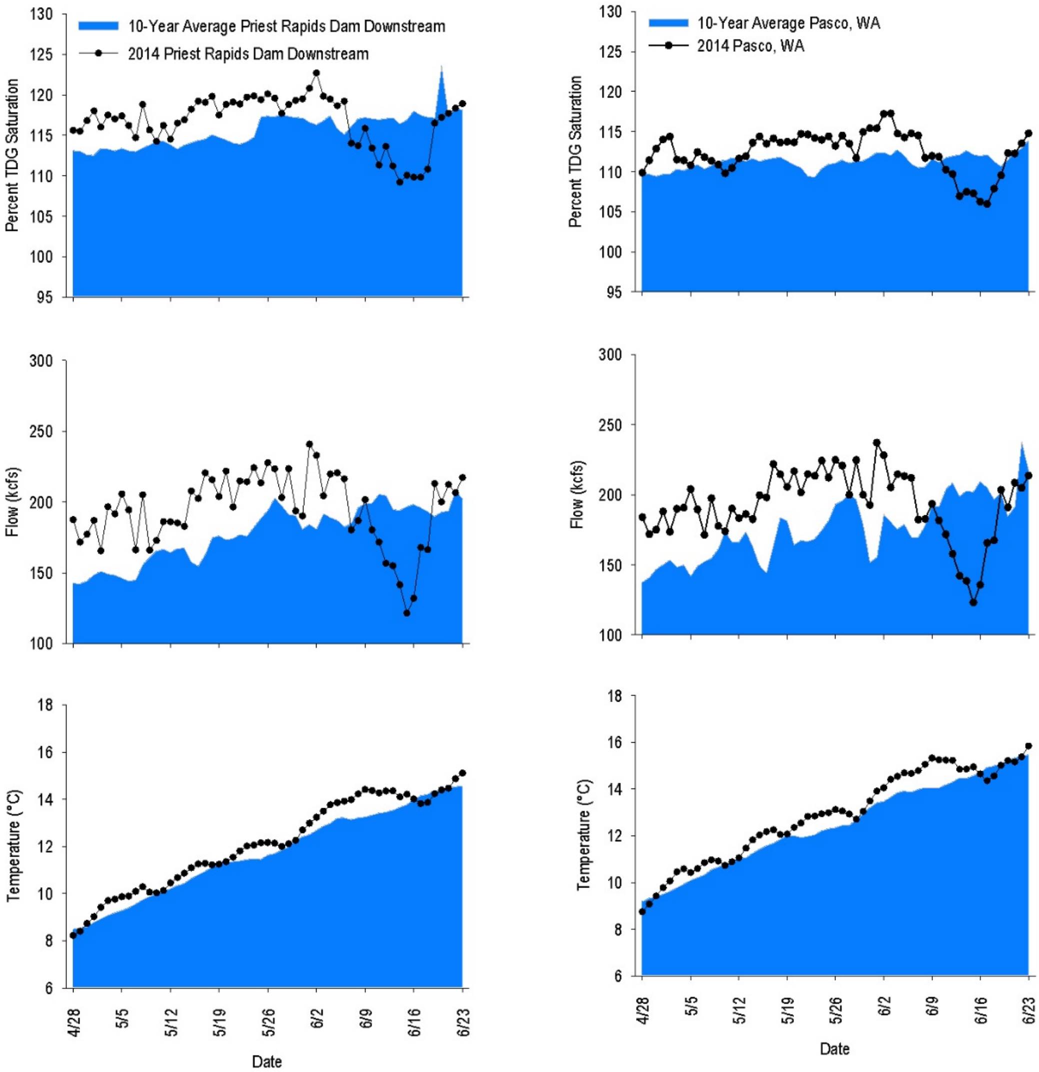



Figure 6. Daily median water quality values downstream of Priest Rapids Dam and at Pasco, WA (RM 330) are shown from 28 April – 23 June, 2014 along with the 10-year average which is depicted in blue. Flow data for Pasco, WA 10 year average is limited to data from 2006, 2010 and 2013 (*data source: www.cbr.washington.edu/dart/dart.html and Grant PUD dam operations*).

*Fish Characteristics*

A total of 1,720 juvenile steelhead and 1,716 yearling Chinook run-of-river smolts were tagged with JSATS transmitters and evaluated in the 2014 survival and behavioral studies. During the study, 14 tags were found to be inactive at the time of release and were excluded from survival data analysis (eight transmitters implanted in steelhead and six transmitters implanted in yearling Chinook salmon). Seven other fish excluded from the data included two holding mortalities (yearling Chinook salmon) released with active tags, three release process mortalities (one steelhead and two yearling Chinook salmon, one of which was released with an active tag), as well as two recapture mortalities (one steelhead and one yearling Chinook salmon).

Adipose clipped juvenile steelhead comprised 67% of the total steelhead tagged and released between 7-28 May 2014. The quantity of steelhead released varied by site with 399 released below Rock Island dam, 771 below Wanapum dam and 550 below Priest Rapids dam (Figure 1). Between 30 April and 24 May 2014, the vast majority of acoustic-tagged yearling Chinook salmon had been clipped at the adipose fin (94%). Yearling Chinook salmon release quantities also varied by site with 398 released below Rock Island dam, 769 below Wanapum dam, and 549 below Priest Rapids dam. Based on the 2014 Rock Island Dam run-timing smolt index (Columbia River DART website), all tagged steelhead were released between the 8th and 92nd percentile of the steelhead run-timing while Chinook salmon were released between the 12th and 89th percentile of the yearling Chinook salmon run-timing.

As analyzed by Skalski et al. 2014, the length, weight and condition factor distributions of fish released in the tailraces of Rock Island, Wanapum, and Priest Rapids dams were very comparable, suggesting no opportunity for any size bias to affect the survival estimates. Steelhead fork lengths ranged from 128-217 mm (mean length at 182.9 mm) and weight ranged from 21.5-88.0 g (mean weight at 57.0 g) (Appendix B, Figure B.1 and B.2). Yearling Chinook salmon fork lengths ranged from 108-200 mm (mean length at 143.7 mm) and weight ranged from 16.5-82.5 g (mean weight at 33.1 g) (Appendix B, Figure B.1 and B.2).

The average tag-burden for steelhead was 0.6% (range 0.4-1.5%) while the average yearling Chinook salmon tag burden was 1.1% (range 0.4-1.9%). The JSATS tags used in 2014 weighed an average of 0.32 g in air and were significantly lighter in weight than acoustic transmitters used in previous survival studies conducted in 2008-2010 where acoustic transmitters ranged from 0.75-1.50 g in air.

*Acoustic Battery Life Testing*

To determine tag life, 50 tags were randomly selected from three tag lots, activated, and monitored for battery failure. Tag life tags were deployed into a flow through tank supplied with ambient river water over the study period. Water conditions such as temperature and dissolved oxygen were monitored daily. The number of tags per release group followed a bell curve distribution and the average tag life was 23.7 days for lots 1 and 2 and 22.7 days for lot 3 (range 10.1-31.2 days).

*Data Collection*

All acoustic receivers were deployed and operational by 24 April 2014. Data collection commenced on 30 April 2014, after the first yearling Chinook salmon group was released below Rock Island Dam. The last tag detection, a steelhead, was recorded on 14 June 2014 at the Hanford arrays (RM 337). Over the study period, a total of 6,952,797 individual detections of acoustic tags were recorded on all detection arrays. The tag detection probabilities remained high at all detection arrays, ranging from 0.9873-1.000 for steelhead and 0.9769-1.000 for yearling Chinook salmon. A summary of tag detection probabilities by release group are shown in Table 1.

The majority of the deployed receivers successfully collected acoustic data for the duration of the study although there were exceptions. Fifteen of the 84 deployed receivers had mid-season disturbances in data- collection: six receivers became detached from river-bottom anchors; five receivers reached data storage capacity on internal SD cards and ceased writing new data, and three receivers malfunctioned. Of these fifteen, four where replaced immediately with supplemental receivers. The remaining eleven weren’t replaced due to sufficient overlap in detection coverage or late recognition of the issue (Appendix A, Table A.5).

A small portion of the 2014 PIT tagged steelhead and yearling Chinook salmon were also detected outside the Project study area by PIT tag readers at McNary (RM 292, 5.1% steelhead and 11.3% Chinook salmon), John Day (RM 216, 7.8% steelhead and 8.2% Chinook salmon), and Bonneville (RM 146, 6.4% steelhead and 7.4% Chinook salmon) dams as well as the Columbia River estuary experimental towing site (RM 19, 1.6% steelhead and 0.8% Chinook salmon) (Appendix A, Table A.7). Of the PIT-tagged steelhead and yearling Chinook salmon that were detected at downstream PIT arrays, 99.8% were detected passing through one or more of the Grant PUD acoustic detection arrays (0.2% of tagged steelhead and 0.1% of tagged Chinook salmon were not detected at any of the 2014 JSATS detection arrays).

Table 1. Array detection probabilities by species and release site at each of the acoustic tag detection arrays between Rock Island Dam (RM 453) and the Hanford Reach (RM 337).

| | Array Detection Probability Estimates (Standard Error) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Release Locations | Crescent Bar | Sunland Estates | Wanapum | Mattawa | Priest Rapids | Vernita Bridge | White Bluffs | Hanford |
| *Steelhead* | | | | | | | | |
| Rock Island Tailrace | 0.9873 (0.0056) | 1.000 (0.0000) | 1.000 (0.0000) | 1.000 (0.0000) | 1.000 (0.0000) | 0.9939 (0.0043) | 1.000 (0.0000) | 1.000 (0.0000) |
| Wanapum Tailrace | | | | 1.000 (0.0000) | 1.000 (0.0000) | 0.9971 (0.0020) | 1.000 (0.0000) | 1.000 (0.0000) |
| Priest Rapids Tailrace | | | | | | 0.9881 (0.0048) | 0.9959 (0.0029) | 0.9978 (0.0022) |
| *Yearling Chinook* | | | | | | | | |
| Rock Island Tailrace | 0.9769 (0.0076) | 1.000 (0.0000) | 1.000 (0.0000) | 0.9973 (0.0027) | 0.9972 (0.0028) | 0.9915 (0.0049) | 1.000 (0.0000) | 0.9940 (0.0042) |
| Wanapum Tailrace | | | | 1.000 (0.0000) | 1.000 (0.0000) | 0.9972 (0.0020) | 1.000 (0.0000) | 0.9971 (00.0021) |
| Priest Rapids Tailrace | | | | | | 0.9944 (0.0032) | 1.000 (0.0000) | 1.000 (0.0000) |

*Migration Rate*

In 2014, steelhead migration rates upstream of Wanapum Dam were markedly faster relative to historical rates, while downstream migrations more closely followed historical trends (Figure 7 and Figure 8). The cumulative median migration rate from the tailrace of Rock Island Dam to Wanapum Dam was 20.7 hr, a 55.5% decrease over the average median in 2006-2010/11[2]. Migration rates between Mattawa and Priest Rapids Dam also decreased within the Priest Rapids Reservoir, albeit less drastically (Δ-18.0% at 13.2 hr). Migration to in-river sites immediately below the dams varied; migration to Vernita Bridge decreased (Δ-14.3%, 1.8 hr), while Mattawa more closely followed historical trends (Δ-1.8% at 2.6 hr). In the lower reaches, median migration rates of 5.4 hr (Vernita Bridge to White Bluffs) and 8.5 hr (White Bluffs to the Hanford arrays) were recorded though no previous data exists for this area (Appendix C, Table. C.2).

In general, the migration rate of yearling Chinook salmon in 2014 was similar to the recorded median averages in 2006-2010 (Figure 7 and Figure 8). Migration from Wanapum Dam to Mattawa slightly increased by 4.8% at 3.3 hr, while migration from Priest Rapids Dam to Vernita Bridge did not appear to deviate (Δ0.0% at 2.0 hr). The only notable variation was between Priest Rapids Dam and Vernita Bridge where a 13.0% increase at 23.4 hr was documented. Median migration rates in the lowest reaches of the study were documented at 7.1 hr (Vernita Bridge to White Bluffs) and 19.2 hr (White Bluffs to the Hanford arrays). The timing of steelhead and yearling Chinook salmon arrival and passage appeared to be confounded with release timing; no additional trends in diel passage were exhibited in the data at Wanapum and Priest Rapids dams.

*Forebay Residence Times*

In 2014, forebay residence times were estimated using two methods; the first estimate was derived from applying the first and last detections from the BRZ and forebay[3] receivers *combined*, while the second was calculated using detections at the forebay receivers *alone*. The second method, in theory, is most similar to historical analyses although not equivalent due to differing acoustic technology and a notably less expansive array in 2014. Therefore for comparative purposes it can only be concluded that the BRZ method is likely to overestimate residence time while the forebay method is likely to underestimate.

Nonetheless, median forebay residence times in 2014 for both species at both dams were under 1 hour, regardless of the method of measuremet (Table 2). At Wanapum Dam, steelhead median forebay residence time was 28.5 min from the BRZ to forebay and 8.1 min in the immediate forebay area. Yearling Chinook salmon had a slightly shorter median residence time at Wanapum Dam; 20.3 min BRZ-forebay and 3.6 min in the immediate forebay. Median residence time at Priest Rapids Dam was longer than that at Wanapum Dam for both species; steelhead resided a median of 43.2 min within the BRZ to forebay area, and only 8.1 min in the immediate forebay. Furthermore, yearling Chinook salmon median residence time was a similar 42.8 min in the BRZ to forebay area and 3.6 min in the immediate forebay. Detailed median residence times by species, dam, and passage route are compiled in Appendix C; Table C.6 and C.7.

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[2] 2011 migration rate data was limited to steelhead between Wanapum and Priest Rapids dams, thus not all median averages were calculated with this data included.

[3] Forebay receivers were deployed either directly on the upstream face of the dam or within the immediate vicinity of the upstream face of the dam (see Appendix A for further details).

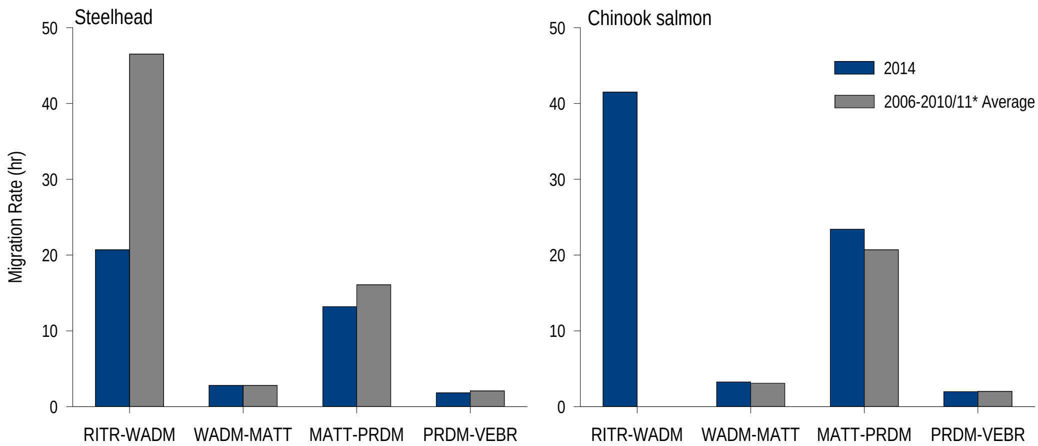


Figure 7. Steelhead and yearling Chinook salmon median migration rates compared to average median migration rates from 2006-2010/11 acoustic data. The asterisk indicates that the 2011 acoustic study solely recorded steelhead migration data between Wanapum and Priest Rapids dams, thus all other categories are void of this year's information. Further migration rate data are presented in Appendix C Table C.1, C.2.

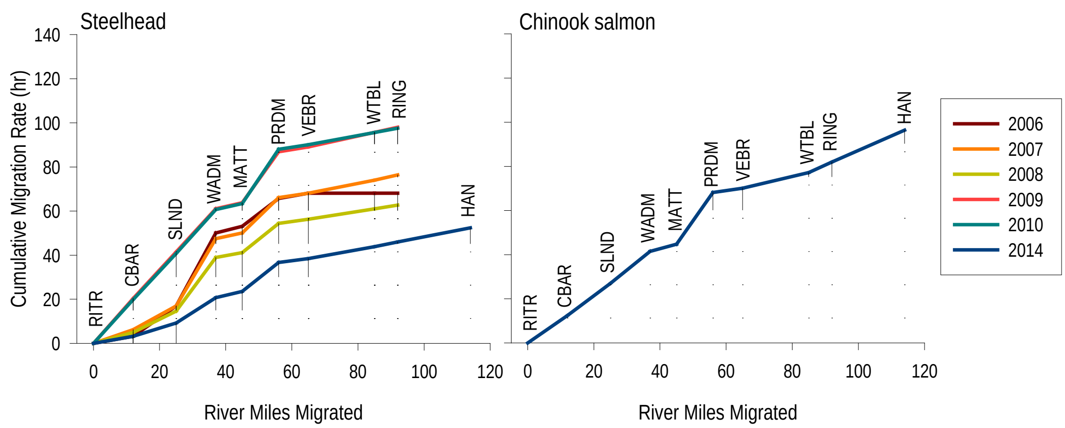


Figure 8. Cumulative median migration rates between each detection array by river mile for (left) steelhead and (right) yearling Chinook salmon. Steelhead data include relatable information from 2006-2010 and 2014 results; yearling Chinook salmon data include only 2014.

Table 2. Annual comparison of median forebay residences time at Wanapum and Priest Rapids dams (min) by species, steelhead and yearling Chinook salmon. Fish that were entrained in the gatewells, had an unknown passage location, or were last recorded with net upstream movement were excluded from this dataset.

| | | |
|---|---|---|
| **Wanapum Dam** | | |
| Steelhead | 2014[BRZ] | 28.5 |
| | 2014[Forebay] | 8.1 |
| | 2010 | 144.6 |
| | 2009 | 79.2 |
| | 2008 | 29.4 |
| | 2007 | 42.6 |
| | 2006 | 34.2 |
| Yearling Chinook salmon | 2014[BRZ] | 20.3 |
| | 2014[Forebay] | 3.6 |
| | 2008 | 14.4 |
| **Priest Rapids Dam** | | |
| Steelhead | 2014[BRZ] | 43.2 |
| | 2014[Forebay] | 8.1 |
| | 2010 | 90.0 |
| | 2009 | 57.6 |
| | 2008 | 14.4 |
| | 2007 | 20.4 |
| | 2006 | 20.4 |
| Yearling Chinook salmon | 2014[BRZ] | 42.8 |
| | 2014[Forebay] | 6.7 |
| | 2008 | 13.8 |
| | 2007 | 16.8 |
| | 2006 | 18.0 |

*Survival Analysis*

The survival estimates for steelhead and yearling Chinook salmon in 2014 were analyzed in Skalski et al (2014). The survival estimate of steelhead through the Wanapum Development was 0.9294 (0.0140) and through the Priest Rapids Development was 0.9613 (0.0098). The joint Wanapum-Priest Rapids Project survival of steelhead was 0.8934 (0.0162). Yearling Chinook salmon survival through the Wanapum Development was estimated at 0.9448 (0.0128) and through the Priest Rapids Development at 0.9612 (0.087), with a joint Wanapum-Priest Rapids Project survival of 0.9082 (0.0145). The survival estimates of steelhead in 2008, 2009, 2010 and 2014 are shown with standard errors in Figure 9.

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 Chinook salmon smolts through Wanapum and Priest Rapids dams is presented in a separate report (Skalski et al. 2014).

*Reach Survival*

Reach survival represents survival estimates per individual river segments between detection arrays; complete analysis is in Skalski et al (2014). Steelhead reach survival ranged from 0.9575 to 0.9986 and yearling Chinook salmon survival ranged from 0.9599 to 0.9951 (Table 3). Low standard errors were measured for both species; ranging from 0.0036 to 0.0103. Reach survival estimates were weighted by relative reach lengths to equate what proportion of fish failed to survive per river mile (RM). Steelhead mortality per RM peaked in the reaches proceeding Wanapum (0.326% per RM, WADM-MATT) and Priest Rapids dams (0.402% per RM, PRDM-VEBR). Steelhead also incurred higher mortality per RM in the reach directly above Wanapum dam (0.354% per RM, SLND-WADM). Similar to steelhead, yearling Chinook salmon exhibited the lowest survival by RM directly downstream of Wanapum (0.288% per RM, WADM-MATT) and Priest Rapids dams (0.446% per RM, PRDM-VEBR).

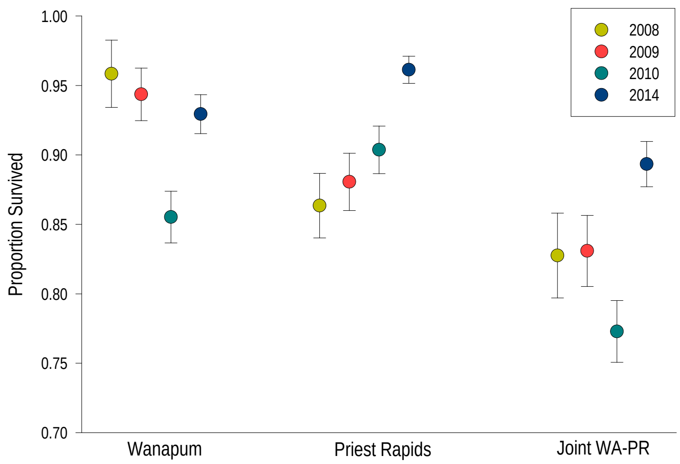


Figure 9. Comparative paired-release survival estimates of steelhead at the Wanapum Development (reservoir and dam), the Priest Rapids Development (reservoir and dam), and the Joint Wanapum-Priest Rapids Project (both developments combined).

Table 3. Survival estimates, adjusted by tagger effect and tag life (Skalski et al. 2014), are presented by reach and complemented with standard errors. Furthermore, reach survivals are weighted by total reach length (RM) for comparisons of relative percent losses per RM.

| | Steelhead | | | Yearling Chinook Salmon | | |
|---|---|---|---|---|---|---|
| *Reach* | *Survival* | *SE* | *% Loss by RM* | *Survival* | *SE* | *% Loss by RM* |
| RITR-CBAR | 0.9986 | 0.0049 | 0.012 | 0.9875 | 0.0060 | 0.104 |
| CBAR-SLND | 0.9957 | 0.0036 | 0.033 | 0.9933 | 0.0045 | 0.052 |
| SLND-WADM | 0.9575 | 0.0102 | 0.354 | 0.9877 | 0.0063 | 0.103 |
| WADM-MATT | 0.9739 | 0.0083 | 0.326 | 0.9770 | 0.0077 | 0.288 |
| MATT-PRDM | 0.9742 | 0.0086 | 0.235 | 0.9979 | 0.0039 | 0.019 |
| PRDM-VEBR | 0.9638 | 0.0101 | 0.402 | 0.9599 | 0.0103 | 0.446 |
| VEBR-WTBL | 0.9794 | 0.0078 | 0.103 | 0.9951 | 0.0041 | 0.024 |
| WTBL-HAN | 0.9765 | 0.0085 | 0.076 | 0.9887 | 0.0064 | 0.036 |

*Avian Predation*

Similar to previous survival studies, an annual investigation of avian predation with 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. Preliminary detection records from this research group tallied a total of 109 PIT tags, released during the spring 2014 Grant PUD survival study, were detected among a variety of avian colonies on the Columbia Plateau and main stem, Mid-Columbia River. A total of 101 steelhead and eight yearling Chinook salmon were detected at either Banks Lake, Potholes Reservoir, Island 20 (RM 332), Crescent Island (RM 317), Central Blalock Island (RM 274), or Little Miller Island (RM 205). Of the total PIT tags recovered, they comprised 5.9% of the total steelhead and 0.5% of the total yearling Chinook salmon that were released in the Project area.

In 2014, 12 PIT tags from steelhead that were released during the 2014 survival study were detected at the Caspian tern colony at Potholes Reservoir. Based on paired acoustic tag detection histories, all steelhead whose PIT tags were detected at the Caspian tern colony at Potholes Reservoir were consumed between release and the White Bluff detection array. This number appears to be a decrease in recovered steelhead PIT tags when compared to the 98 tags released and re-detected during the 2010 survival study (Timko et al 2011); representing a respective loss of 0.7% in 2014 and 5.0% in 2010. However, tag detection and deposition probabilities have not been applied to the raw data and are required to provide an appropriate estimate of predation (and consumption) of juvenile steelhead by Caspian terns that nested at Potholes Reservoir in 2014. A detailed analysis of predation by avian predators will be released in a separate report by Real Time Research (Evans et al. *in progress*).

*Dam Survival*

Based on acoustic tag detection histories, the Ricker survival estimates for steelhead and yearling Chinook salmon at Wanapum and Priest Rapids dams (commonly referred to as *concrete survival*) were calculated for treatment fish released above each dam paired with control fish released 0.5 km downstream of each dam. Table 4 lists steelhead and yearling Chinook salmon concrete survival estimates by year, with estimates remaining above 97% for both species at both dams.

Steelhead concrete survival at Priest Rapids Dam followed trends set by historical data with 2014 survival point estimates ranging between 97.8% and 98.5% (Table 4). On the other hand, at Wanapum Dam, variation in concrete survival is slightly more evident as estimates have marginally reduced from nearly 100% in 2008-2010 to 97.8% in 2014. Chinook salmon concrete survival estimates have not been calculated in recent years although 2014 estimates of 98.8% at Wanapum Dam and 97.1% for Priest Rapids Dam are similar to those calculated for steelhead in previous years at both dams.

*Passage Route Efficiency*

In 2014, the proportion of steelhead and yearling Chinook salmon that selected non-turbine passage routes through Wanapum Dam was lower than previous studies (55.2% and 35.0%, respectively) (Figure 10; Appendix D. Table D.1). In other words, the proportion of fish that selected the bypass or spillway at Wanapum Dam has decreased since 2008-2010 for steelhead and 2008 for Chinook salmon resulting in a lower non-turbine passage route efficiency (PRE) (Figure 12). At Wanapum Dam in 2014, the proportion of steelhead that passed through the WFB was 9.9%, a decrease of 67.4% compared to 2010 (PRE at the WFB in 2010 was 77.3%). Chinook salmon PRE at the WFB was 7.5%, representing a decrease from 29.5% passage estimates in 2008, the last year Chinook salmon PRE was estimated for Wanapum Dam.

At Priest Rapids Dam in 2014 higher PRE was documented through the powerhouse than the spillway for both study species; 30.9% of steelhead and 34.9% of Chinook salmon passed via the powerhouse. However, the majority of both species utilized the PRFB with 47.2% of steelhead and 38.1% of Chinook salmon selecting this route. Within the group that selected the PRFB, the majority passed through the spill-bay closest to the powerhouse (spill-bay 22) (Figure 11). In contrast, Chinook salmon PRE at the PRFB in 2014 was higher than previously recorded for the top-spill bypass in 2006 - 2008 when PRE ranged from 12.4% to 24.4%. A detailed list of passage percentages and annual comparisons from 2006-2014 can be referenced in Appendix D.

Table 4. Summary of dam (concrete) Ricker survival estimates by species at Wanapum and Priest Rapids dams. 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 0.5km downstream of the dam.

| | Ricker Survival Estimates | |
|---|---|---|
| Year | Wanapum | Priest Rapids |
| Steelhead | | |
| 2014 | 0.978 | 0.985 |
| 2010 | *1.013 | 0.997 |
| 2009 | *1.025 | 0.983 |
| 2008 | 0.995 | 0.952 |
| Yearling Chinook salmon | | |
| 2014 | 0.988 | 0.971 |

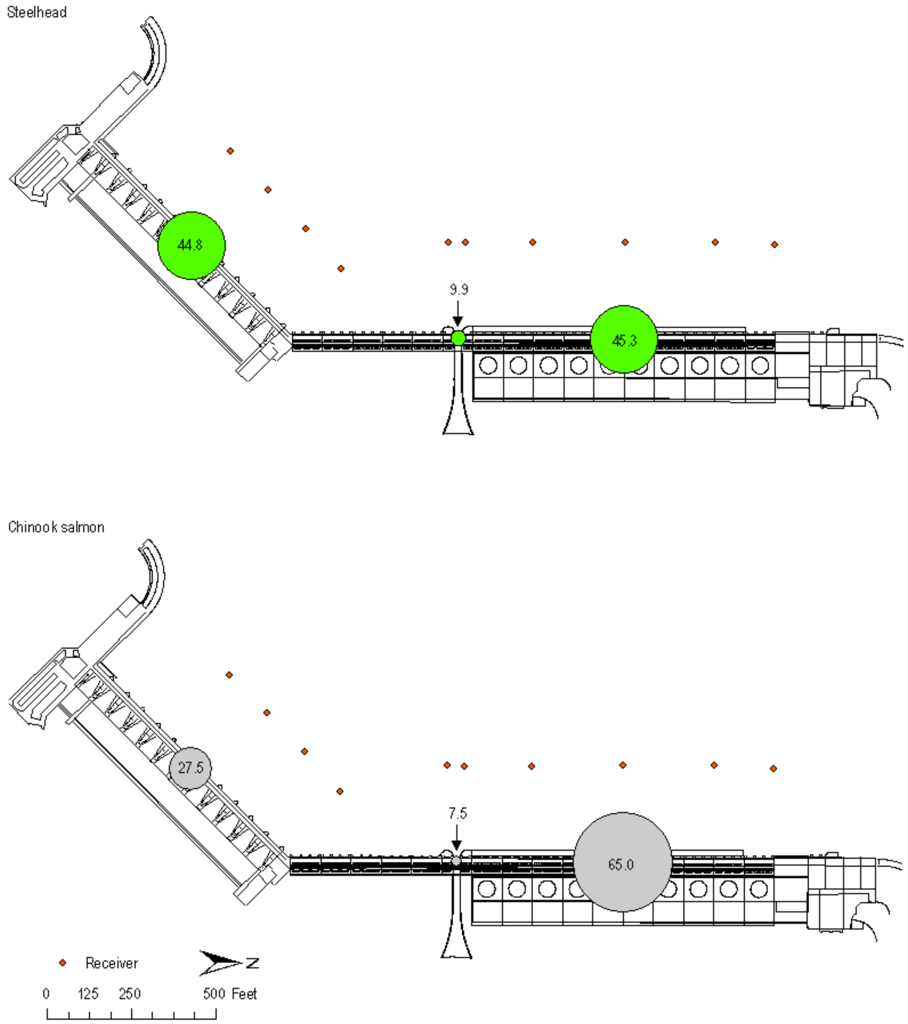


Figure 10. Passage percentages at Wanapum Dam in the spring of 2014; the top figure presents steelhead (green) and the bottom figure presents yearling Chinook salmon (gray). Detailed passage percentages shown by circles are proportional to percentages. Passage events that could not be identified are not depicted.

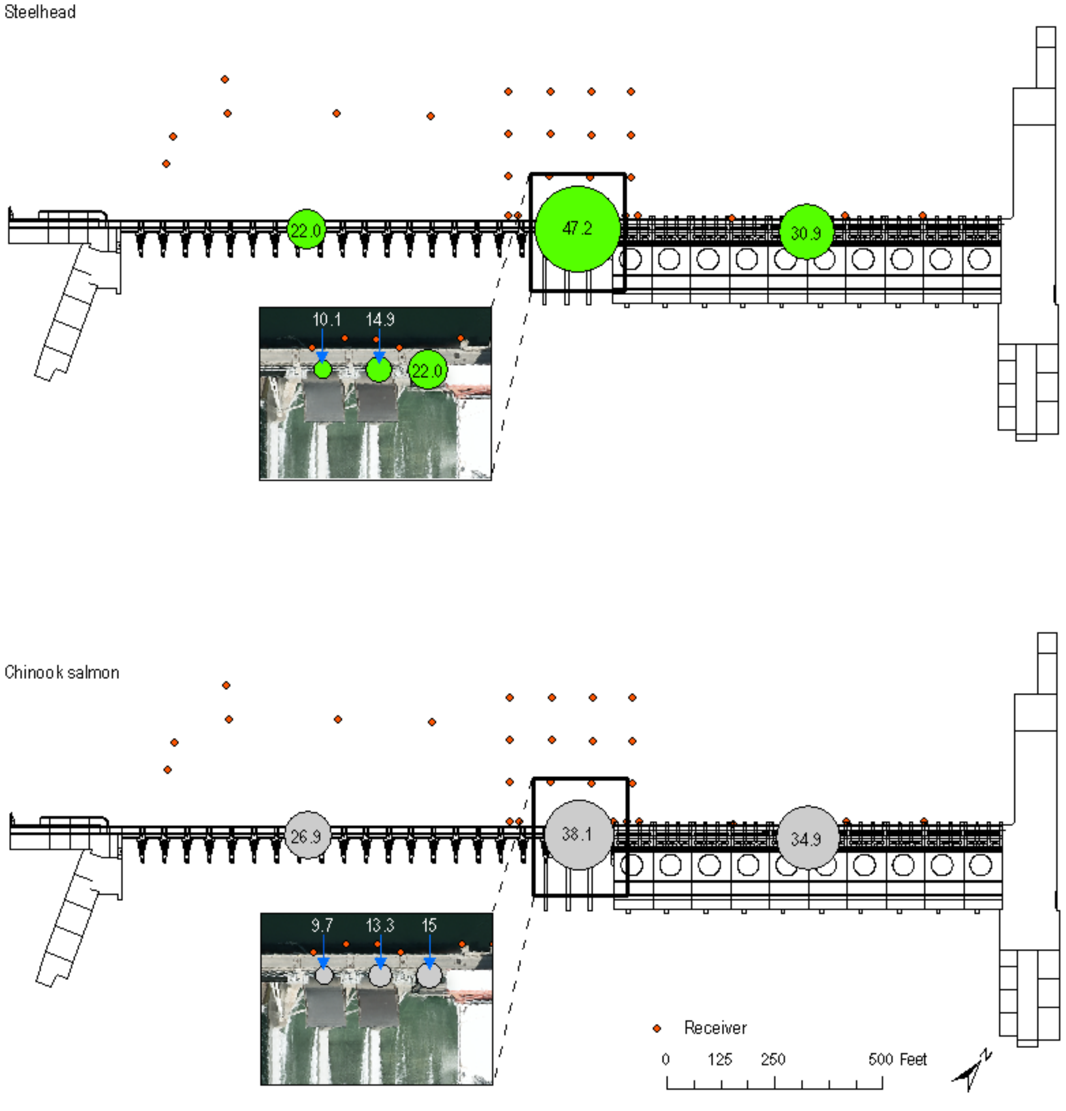


Figure 11. Passage percent at Priest Rapids Dam in 2014 for steelhead (top panel, green) and yearling Chinook salmon (bottom panel, gray) has been rounded to the nearest tenth. Detailed passage percentages are depicted as circles of diameter proportional to percentage. Passage events that could not be identified are not shown. Two fish of each species passed via the PRFB at unidentified bays and were excluded from the bay-specific analysis, 0.2% and 0.1% of steelhead and yearling Chinook salmon, respectively.

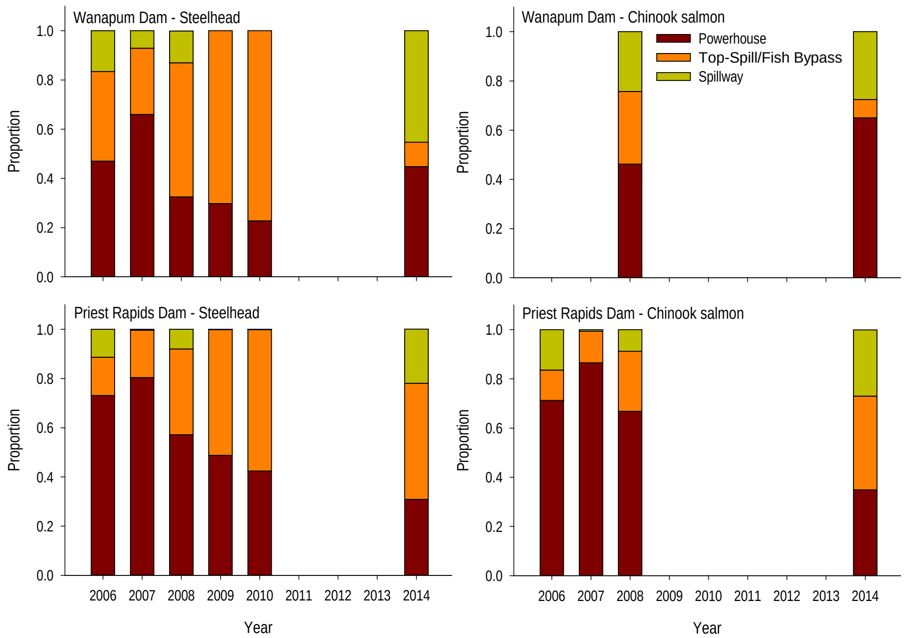


Figure 12. Historical passage proportion at Wanapum (top) and Priest Rapids dams (bottom) for steelhead (left) and Chinook salmon (right) by passage route: Powerhouse passage (maroon), top-spill/Fish Bypass passage (orange), and spillway (green). Data are representative of years when the given species were released.

*Relative Route-Specific Survival*

Similarly to the methods employed in previous passage studies, paired releases through a specified route were not conducted but acoustic-tagged steelhead and yearling Chinook salmon known to have successfully arrived and passed downstream of Wanapum and Priest Rapids dams were used to estimate route-specific relative survivals through each dam (Timko et al. 2010, 2011). At both dams survival was quantified as relative to fish that passed through the spillway, deemed a 'benign route', for comparative purposes and where results were significantly different from 1.0, p-values were <0.05. Steelhead that passed through the WFB had similar survival estimates as spillway fish, and steelhead that passed through the powerhouse at Wanapum Dam had nearly 5% lower survival estimates (Skalski et al. 2014). At Priest Rapids Dam, relative route-specific survival rates were significantly higher for steelhead that passed through the PRFB when compared to the spillway (Δ of 2.7%) and were significantly lower for powerhouse compared to the spillway (Δ of 3.6%) (Skalski et al. 2014).

Yearling Chinook salmon that passed via the WFB or the powerhouse did not experience significantly different survival rates than those that passed through the spillway. However, at Priest Rapids Dam yearling Chinook salmon that passed through the PRFB had significantly higher survival estimates than those that passed through the spillway (Δ of 1.8%) (Skalski et al. 2014). Conversely, yearling Chinook salmon that passed through the powerhouse decreased in survival by nearly 5% when compared to those that passed through the spillway.

Additional details on juvenile steelhead and yearling Chinook salmon relative-route specific survival can be referenced in a separate report by Skalski et al. (2014).

Based on acoustic tag detection histories, 100% of steelhead that migrated past Wanapum Dam through the WFB were detected downstream, compared to the 94.1% of steelhead that selected the powerhouse and 99.4% that selected the spillway (Table 5). Yearling Chinook salmon that passed via the WFB measured 96.3% detected, compared to 98.2% that selected the powerhouse and 97.0% that selected the spillway. However, it is noteworthy that due to low sample size at the WFB direct comparisons of these detection histories become less powerful. Downstream of Priest Rapids Dam, 99.8% of bypass route steelhead were detected, while 93.8% of powerhouse fish were detected and 97.0% of spillway fish were detected. Similarly, 99.8% of yearling Chinook salmon passing via the PRFB were detected, compared to 92.6% detected from the powerhouse and 98.0% detected from the spillway.

*Passage Proportions Relative to Migration Rates*

Downstream median migration rates of steelhead and yearling Chinook salmon were divided by passage route and then statistically analyzed with the Kruskal-Wallis ranked test of variance followed by a *post-hoc* Dunn's test ($P<0.05$). In general, in 2014, median migration rates for both species, through both dams, yielded a similar pattern. Powerhouse fish migrated downstream at the slowest rate, while fish that passed through the spillway and bypass routes migrated at comparable rates (Appendix C, Table C.3 and C.4).

Fish that passed through the powerhouse at Wanapum Dam (WADM-PRDM) migrated at a rate that was statistically slower than fish that passed through the spillway and WFB; fish that passed through the spillway and WFB had comparable migration rates that were not statistically different (Figure 13). Below Priest Rapids Dam (PRDM-HAN), steelhead that passed through the PRFB migrated downstream at a rate that was statistically faster than all other fish that passed through the dam at the powerhouse and spillway. Yearling Chinook salmon that passed through the powerhouse moved downstream at a rate that was statistically slower than fish that passed through the spillway.

*Passage Proportions Relative to Forebay Residence Times*

The median forebay residence times of steelhead and yearling Chinook salmon at Wanapum and Priest Rapids dams in 2014, defined as the first and last detections at the BRZ and forebay arrays, were grouped by route selection and analyzed statistically with a Kruskal-Wallis ranked test of variance followed by a Dunn's *post-hoc* analysis ($P<0.05$) (Figure 14).

In the Wanapum Dam forebay, steelhead and yearling Chinook salmon that selected the powerhouse for passage had statistically shorter residence times than fish that selected the spillway or WFB. Steelhead that passed through the WFB yielded comparable residence times to fish that passed at the spillway and were not statistically different. However, yearling

Table 5. Number of tags that passed at each dam by route with the corresponding percentage of tags which were detected downstream in 2014. The percentage of tags listed for all routes reflects concrete passage survival for all passage routes, including unknown passage locations and gatewell dipped fish; however, fish with upstream movement during last detection were excluded.

| | Wanapum Dam | | | | Priest Rapids Dam | | | |
|---|---|---|---|---|---|---|---|---|
| | Steelhead | | Yearling Chinook | | Steelhead | | Yearling Chinook | |
| Passage Route | n | % | n | % | n | % | n | % |
| All Routes | 377 | 97.1 | 382 | 97.9 | 1100 | 97.1 | 1120 | 96.9 |
| Bypass | 36 | 100.0 | 27 | 96.3 | 507 | 99.6 | 415 | 99.8 |
| Spillway | 164 | 99.4 | 99 | 97.0 | 236 | 97.0 | 293 | 98.0 |
| Powerhouse | 152 | 94.1 | 225 | 98.2 | 276 | 93.8 | 352 | 92.6 |

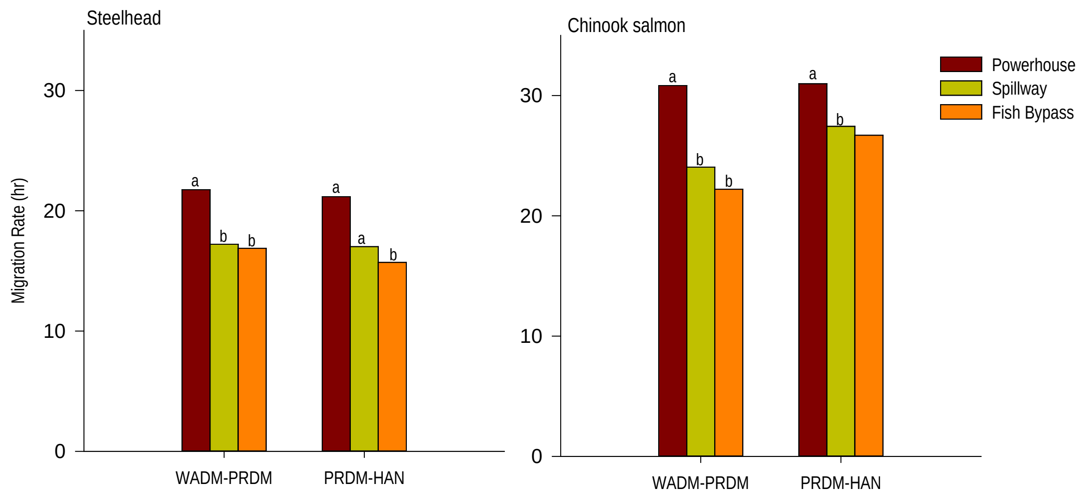


Figure 13. Median migration rates for steelhead (left) and yearling Chinook salmon (right) from Wanapum Dam to Priest Rapids Dam (WADM-PRDM) and Priest Rapids Dam to Hanford arrays (PRDM-HAN) separated by passage route (powerhouse, spillway or bypass). Letter labels above columns refer to which routes were statistical significant by reach, e.g. route “a” was statistically different than route “b” or “c” (significantly different from 1.0 where p-values were <0.05).

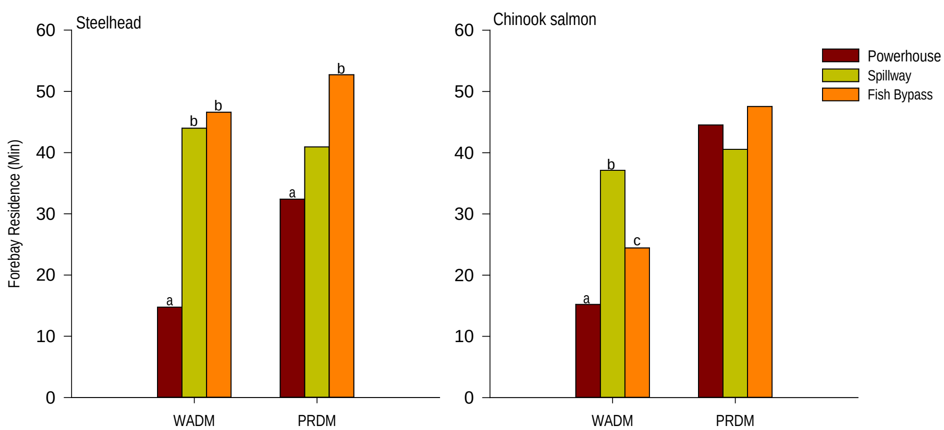


Figure 14. Median forebay residence times in minutes for steelhead and Chinook salmon at Wanapum and Priest Rapids dams separated by passage route (powerhouse, spillway or bypass). Letter labels above columns refer to which routes were statistical significant by reach, e.g. route “a” was statistically different than route “b” or “c” (significantly different from 1.0 where p-values were <0.05).

Chinook salmon that passed at the WFB had statistically shorter forebay residence times compared to those that passed through the spillway. At Priest Rapids Dam, the forebay residence times of steelhead were statistically shortest for fish that selected the powerhouse and longest for the fish that selected the PRFB for downstream passage. Yearling Chinook salmon had similar forebay residence times for all eventual routes; none of which were statistically significant.

At both dams, the hazard barrier is closer to the powerhouse than the spillway and is likely confounding these results. Yet, if milling is occurring directly upstream of the powerhouse at either dam, it is minimal as the total duration of time spent in the vicinity of the powerhouse is significantly shorter than observed in previous acoustic tag studies. For example, the average forebay residence times of steelhead that passed at the Wanapum Dam powerhouse in 2010 was more than 4 hr while in 2014 it was less than 15 min (Appendix C; Table C.6 and C.7).

*Passage Proportions Relative to Approach Position*

The approach position of each tagged fish was estimated at the hazard barrier, based on the acoustic receiver the tagged fish was nearest to as it entered the immediate forebay of each dam (first detection at Wanapum Dam on Figure 15 and Priest Rapids Dam on Figure 16). Tracking of fish movement in the forebay was not conducted at Wanapum Dam in 2014. The data in Figure 15 does not reflect movement pathways or assume that fish move in a linear pathway between the hazard barrier to the point of passage, in fact in previous studies we've seen schooling or milling behavior that is more prevelant by steelhead with prolonged residence times. Nonetheless, as fish approached Wanapum Dam, the highest proportion of steelhead and yearling Chinook salmon passed through the hazard barrier near the center of the reservoir, at the north eastern side of the dam which is near the end of the powerhouse (Figure 15). Fish that entered the forebay closest to the powerhouse were more likely to pass at the powerhouse. Conversely, fish that passed through the hazard barrier on the opposite side of the forebay appeared to be more likely to pass at the spillway. This trend was more pronounced for yearling Chinook salmon when compared to juvenile steelhead. However, fish that ultimately passed through the spillway and WFB were from detections of fish, especially steelhead, which entered the immediate forebay region of the dam in all approach positions (Figure 15).

At Priest Rapids Dam, similar trends were presented as those described at Wanapum Dam but were more pronounced. One interpretation of the data illustrated in Figure 16 is that fish were being collected at the PRFB that had entered the forebay from all locations, including the north, closest to the powerhouse (Figure 16). Yearling Chinook salmon seemed less likely to be captured at the PRFB than juvenile steelhead that entered the forebay from the north, also just upstream of the powerhouse.

*Priest Rapids Fish Bypass Passage Densities*

At Priest Rapids Dam, steelhead and yearling Chinook salmon were tracked in the immediate forebay area between turbine unit 2 and Spill Bay 16. Relative percent passage densities by species that selected the PRFB, i.e. per spatial bin, the proportion of fish that passed through the PRFB versus those that passed through the spillway or powerhouse, are shown in Figure 17. Normalized bin density plots per species depicting where PRFB route fish were more densely detected are also illustrated in Figure 18. For both species, fish that passed downstream through the PRFB were at the highest RPP directly upstream of the PRRB. Steelhead had higher relative percent passage (RPP) extending in front of the powerhouse than yearling Chinook salmon and both species had higher RPP that angled towards the spillway side (Figure 17). Steelhead also appeared to be more likely to be collected from directly upstream of the powerhouse than yearling Chinook salmon (Figure 18).

In previous tracking studies, fish that passed downstream of Priest Rapids Dam through the prototype bypass at Spill Bay 19 and 20 were at the highest RPP on the spillway side of the prototype bypass, within the 300 foot radius from the center of the prototype bypass entrance, and in front of the spillway bays between Spill Bay 6 and Spill Bay 18 (Timko et al. 2010, 2011). More specifically, in 2010, RPP for steelhead that passed through the prototype bypass were high (70-100%) in front of the powerhouse units. This trend is also exhibited in the 2014 RPP for steelhead.

The 2014 tracking results, illustrated in Figure 17 and Figure 18, demonstrate that steelhead passing downstream of the dam through the PRFB were likely being collected from the areas directly upstream of turbine units 1 and 2. The collection of fish at the PRFB from fish transiting across the spillway was marginally captured in the 2014 data set, and was likely a result of two things. First, tracking coverage at the spillway was decreased, and second, high spill volumes throughout the study between spill bays 1 and 18 likely collected and passed fish (an estimated 22% steelhead and 27% of yearling Chinook salmon).

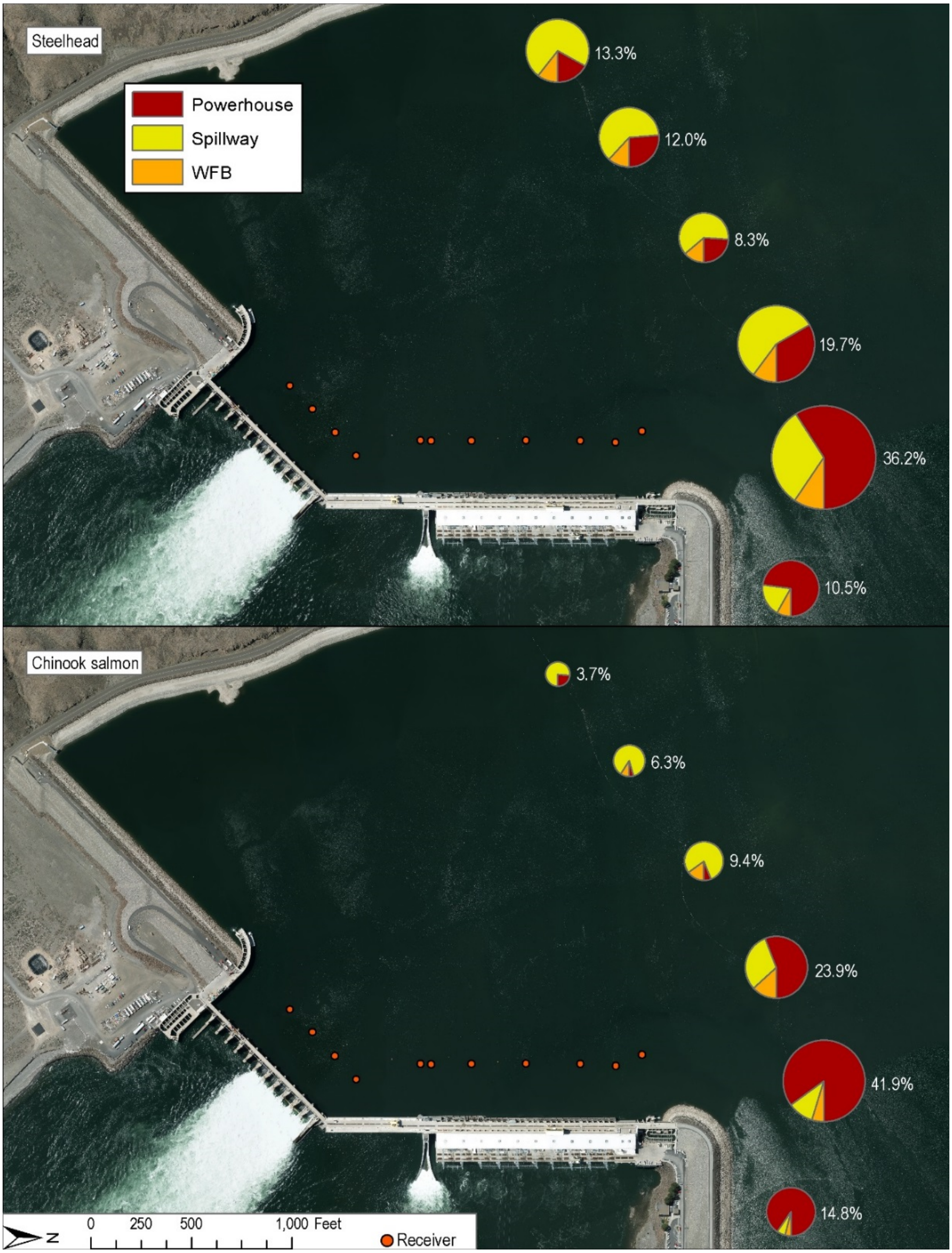


Figure 15. Proportion of juvenile steelhead (top) and yearling Chinook salmon (bottom) passing downstream at the hazard barrier of Wanapum Dam; the pie size is relative to the proportion of fish detected at each logger as fish entered the forebay (first detection). The pie composition indicates the relative passage route proportions (red = powerhouse, yellow = spillway, and orange = bypass) of fish detected in proximity to the closest receiver by species.

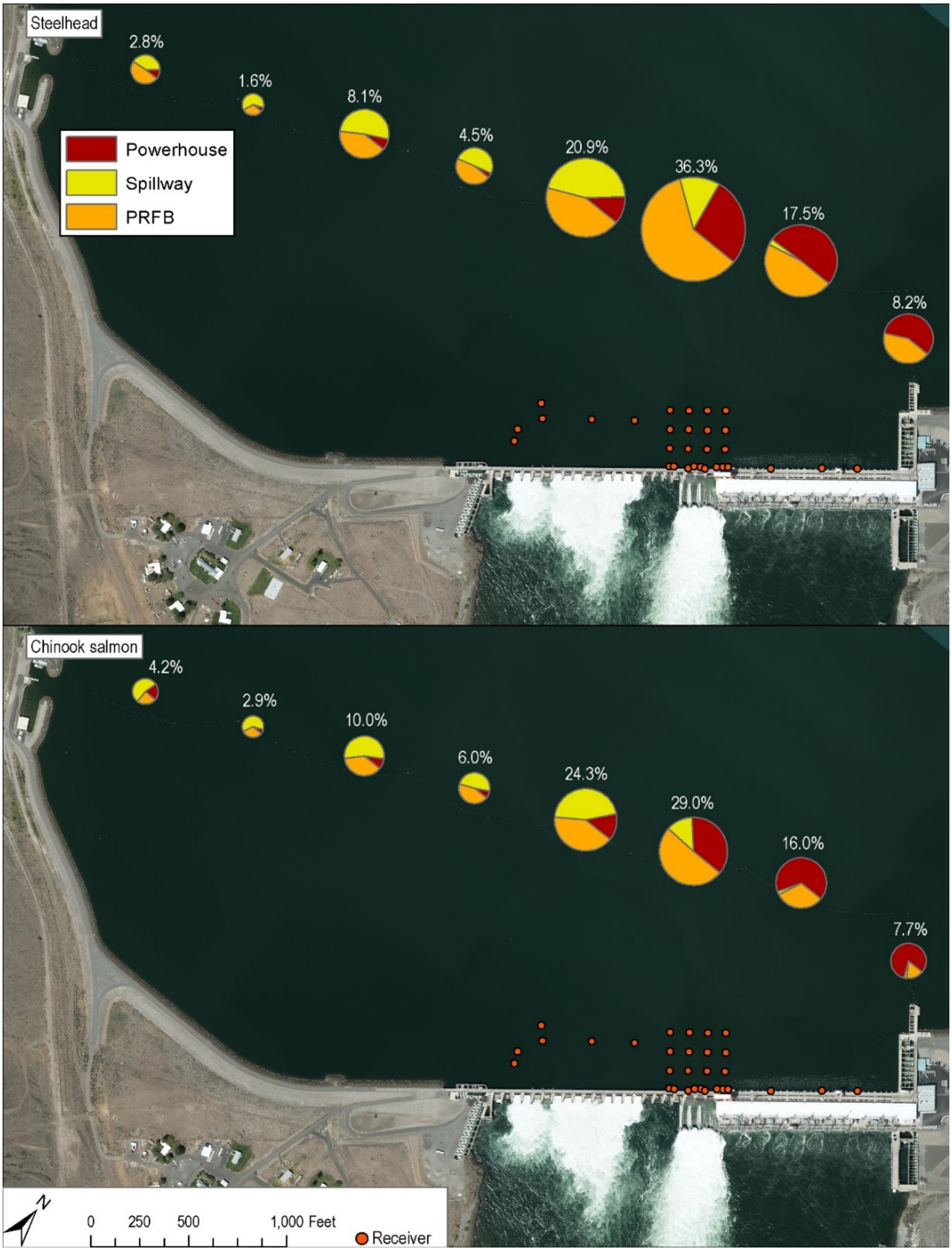


Figure 16. Proportion of juvenile steelhead (top) and yearling Chinook salmon (bottom) passing downstream at the hazard barrier of Priest Rapids Dam; the pie size is relative to the proportion of fish detected at each logger as fish entered the forebay (first detection). The pie composition indicates the relative passage route proportions (red = powerhouse, yellow = spillway, and orange = bypass) of fish detected in proximity to the closest receiver by species.

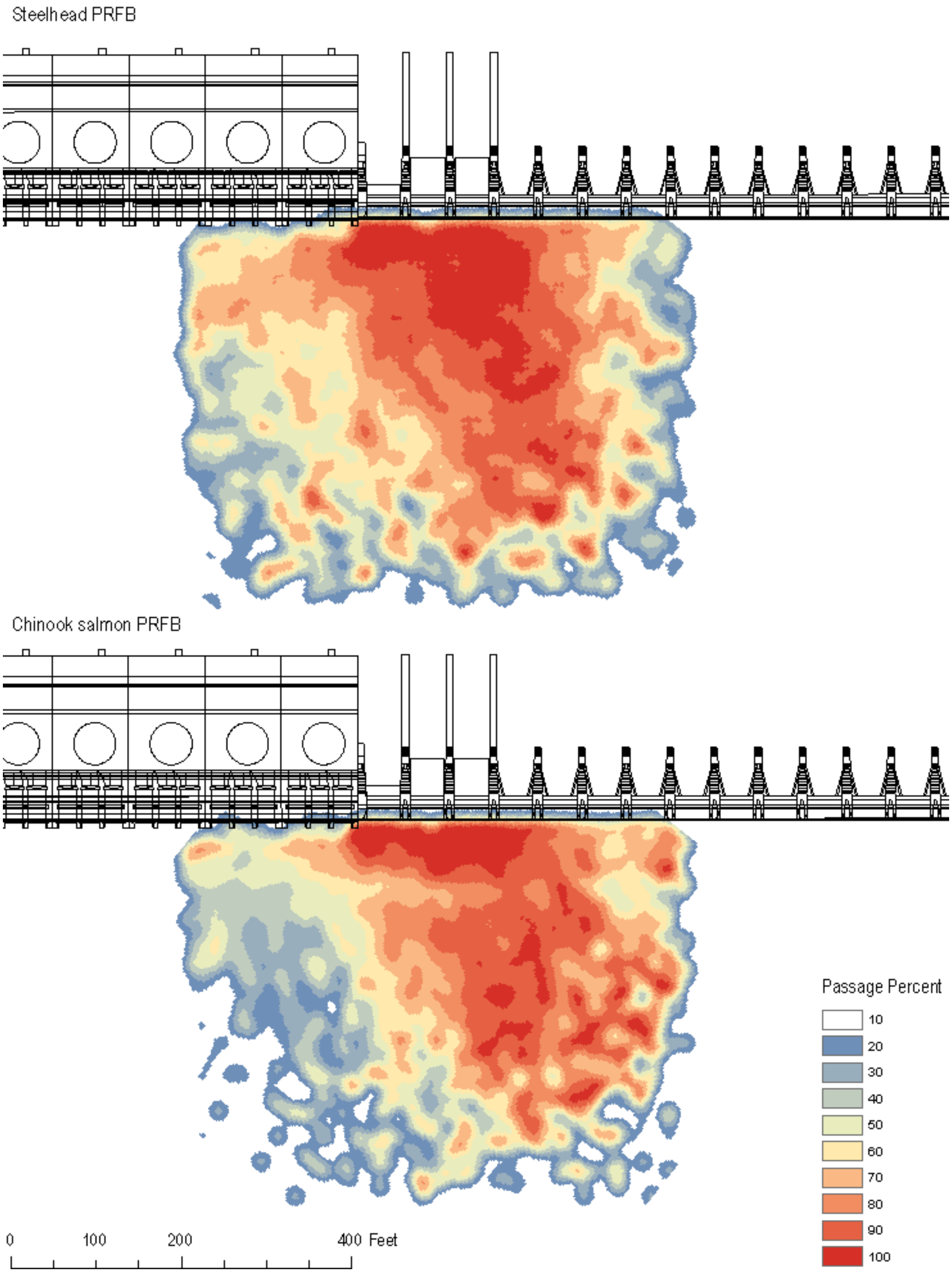


Figure 17. Relative passage percent locations of steelhead (top) and yearling Chinook salmon (bottom) that passed downstream through the Priest Rapids Fish Bypass (PRFB). RPP was calculated using the eventual passage route of each fish, which was based on total fish by species that entered each 10 ft x 10 ft bin and passed through the PRFB.

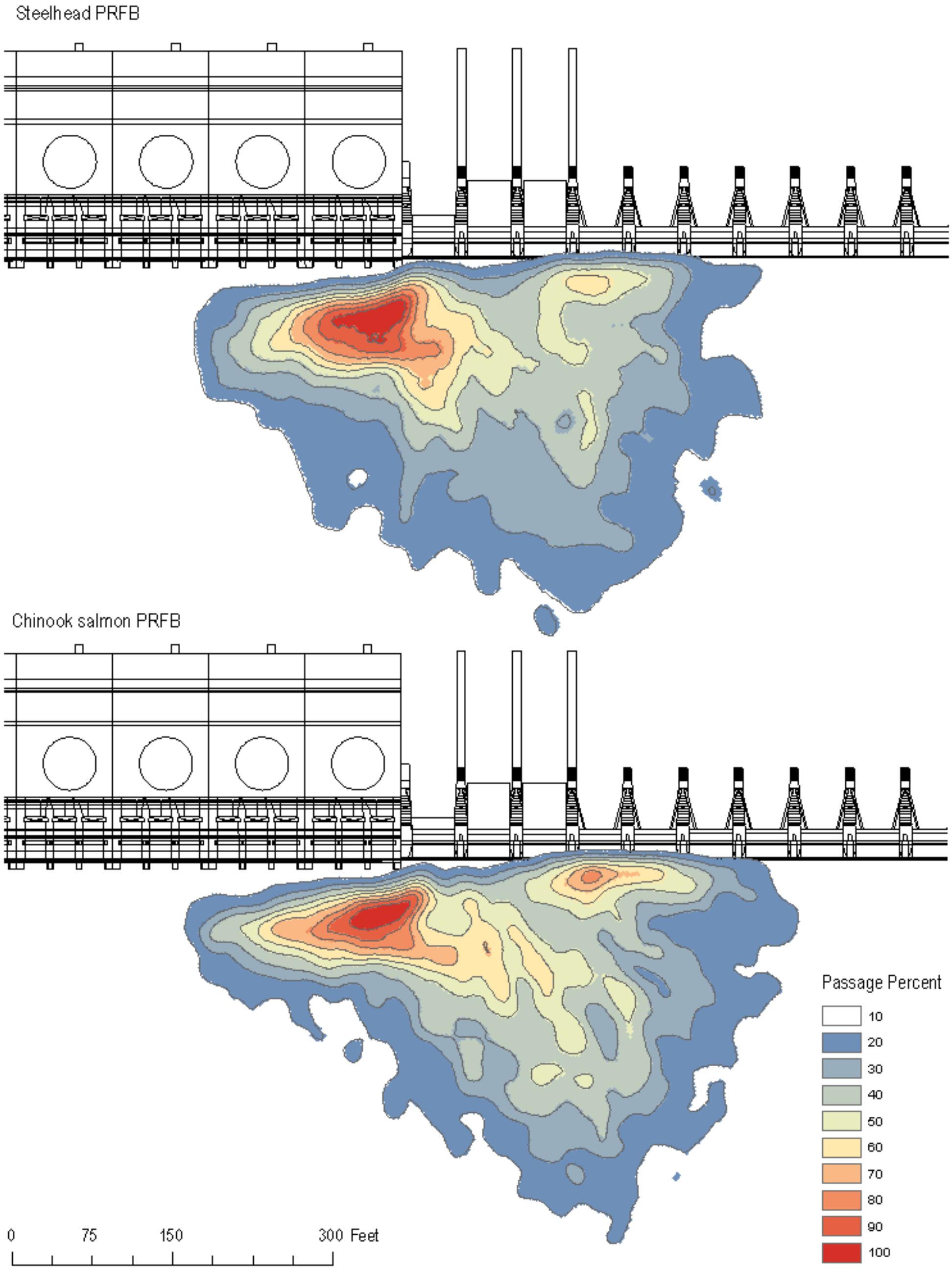


Figure 18. Normalized densities of steelhead (top) and yearling Chinook salmon (bottom) that passed downstream through the Priest Rapids Fish Bypass (PRFB) were created using a grid of 10 ft x 10 ft two-dimensional cells or bins in the forebay. Percentages were determined by the number of individual fish that entered each bin to illustrate where fish were in the forebay before passage selection occurred.

*Bypass Non-Selection*

Steelhead and yearling Chinook salmon that approached within 300 ft of the PRFB, but did not pass it, were termed “non-selection” fish. At the PRFB, non-selection steelhead and yearling Chinook salmon two-dimensional positions, shown in Figure 19, were evaluated for trends in forebay positions. For the most part, both species that did not select the PRFB but passed through the powerhouse were most heavily concentrated near the powerhouse, directly upstream of turbine Unit 1 and the upstream transition between the powerhouse and bypass structure. Conversely, the opposite seemed true for fish that chose to pass through the spillway instead of the PRFB.

*Zone Entrance Efficiency*

Zone entrance efficiency (ZEE) was measured as the ratio of fish which encounter the PRFB (to within 300 ft of the entrance) to the total population of fish approaching the dam. In 2014, nearly three quarters of all steelhead and 65% of all yearling Chinook salmon entered the PRFB zone of influence (Figure 20). ZEE in 2014 was 72.5% for steelhead and 65.2% for yearling Chinook salmon (Figure 21).

*Fish Collection Efficiency*

Fish collection efficiency (FCE) was measured as the ratio of fish that passed via the PRFB to the quantity of fish that entered the 300 ft zone of influence (i.e., how many fish passed through the PRFB after swimming within 300 ft of its entrance). In 2014, FCE was higher for steelhead (64%) than yearling Chinook salmon (57%) (Table 6); Figure 22). In 2014, there was greater than 95% collection efficiency at 50 ft from PRFB; both species had an estimated 98% with decreasing efficiency at greater distances. (Reference Appendix D; Table D.5 for FCE at incrementally further distances from the PRFB, starting at 50 ft to 300 ft upstream of the bypass).

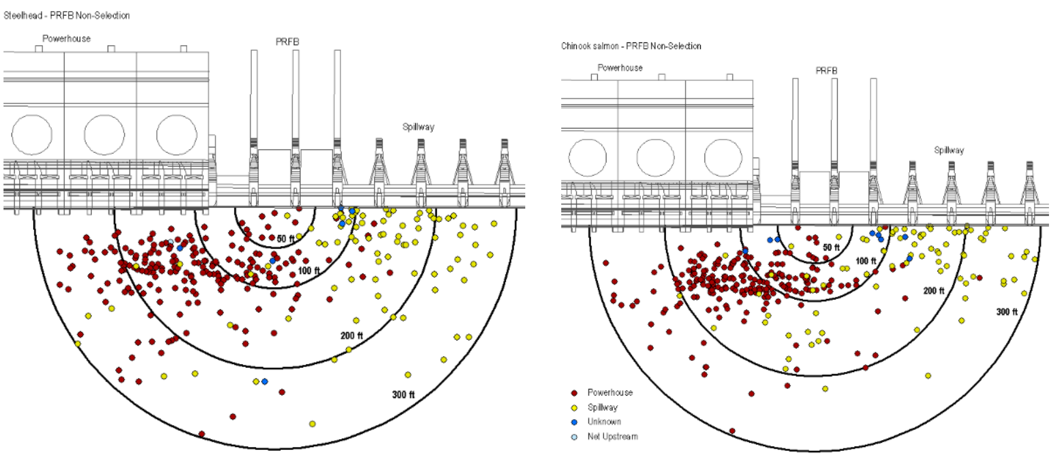


Figure 19. Juvenile steelhead (left) and yearling Chinook salmon (right) that entered the 300 ft radial zone of influence in front of the Priest Rapids Fish Bypass (PRFB) but were not captured are presented. Each point represents the closest estimated approach location to the PRFB in two-dimensions before non-selection occurred.

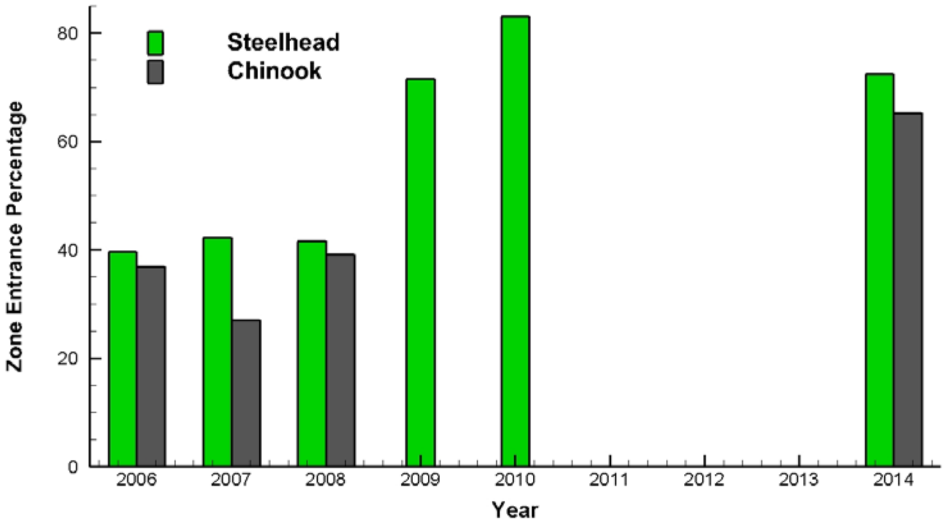


Figure 20. Percent of fish by species and year at Priest Rapids Dam that entered a 300 ft radius from the center of the bypass (PRFB) divided by the total number of fish that passed the dam (defined as zone entrance efficiency) in the 2006-2014 field studies. Behavioral studies were not conducted in 2011-2013 at Priest Rapids Dam; yearling Chinook salmon were not studied in 2009-2010.

Table 6. Priest Rapids Dam fish bypass (PRFB) 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 PRFB by species. The difference between the passage route efficiency (PRE) product (or the predicted PRE) and the proportion (or actual PRE) is likely due to the annual environmental and hydraulic variability between the two variables, ZEE and FCE.

| | | | | $PRE_{Bypass}$ | |
|---|---|---|---|---|---|
| Species | Year | ZEE | FCE | Product | Proportion |
| Steelhead | *Priest Rapids Dam Fish Bypass (PRFB)* | | | | |
| | 2014 | 0.73 | 0.64 | 0.47 | 0.47 |
| | Priest Rapids Dam Prototype Bulkhead Testing | | | | |
| | 2010 | 0.78 | 0.69 | 0.54 | 0.57 |
| | 2009 | 0.72 | 0.66 | 0.47 | 0.51 |
| | 2008 | 0.42 | 0.59 | 0.25 | 0.33 |
| | 2007 | 0.42 | 0.34 | 0.14 | 0.19 |
| | 2006 | 0.40 | 0.39 | 0.16 | 0.15 |
| Yearling Chinook Salmon | *Priest Rapids Dam Fish Bypass (PRFB)* | | | | |
| | 2014 | 0.65 | 0.57 | 0.37 | 0.38 |
| | *Priest Rapids Dam Prototype Bulkhead Testing* | | | | |
| | 2008 | 0.39 | 0.31 | 0.12 | 0.15 |
| | 2007 | 0.27 | 0.29 | 0.08 | 0.12 |
| | 2006 | 0.36 | 0.33 | 0.12 | 0.12 |

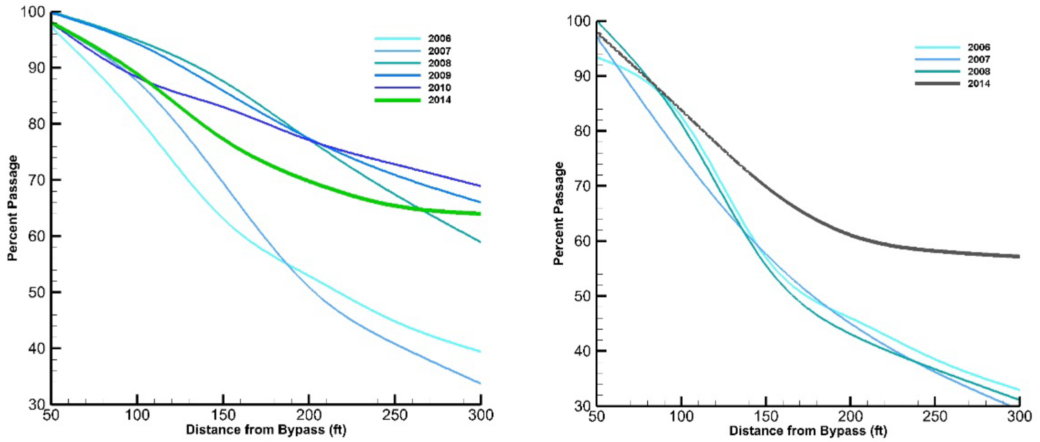


Figure 21. Percent passage of steelhead (left) and yearling Chinook salmon (right) through the Priest Rapids Dam fish bypass (PRFB) that were detected within 50, 100, 150, 200, 250, and 300 ft increments from the prototype bypass (steelhead 2006-2010, 2014; yearling Chinook salmon 2006-2008, 2014).

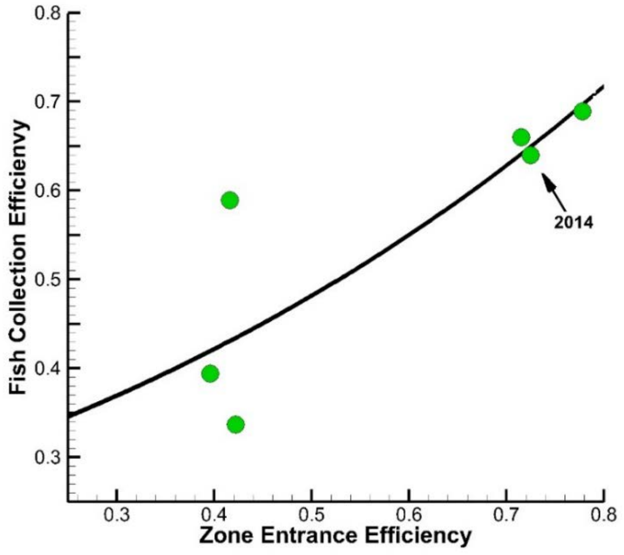


Figure 22. Steelhead fish collection efficiency (FCE) of the Priest Rapids Dam fish bypass in 2014 and at the prototype bypass in 2006-2010 are displayed by an exponential regression with zone entrance efficiency (ZEE). Each point represents steelhead (green) evaluated per year. Increased passage route 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 2014 and 2009. The exponential regression $R^2$ values of steelhead was 0.67.

## Discussion

The primary goals of this study were to estimate juvenile steelhead and yearling Chinook salmon survival and to examine behavioral passage trends through the Wanapum and Priest Rapids dams. JSATS acoustic technology was used to meet these goals by surgically implanting acoustic transmitters into fish and then collecting spatial data in a continuing series of detection arrays between Rock Island Dam (RM 453) and the Hanford Reach (RM 337). Distinct emphasis was placed on the behavior of steelhead and yearling Chinook salmon as they approached and passed downstream of Priest Rapids Dam at or near the newly constructed Priest Rapids Fish Bypass (PRFB) with additional 2/3D receivers arranged to three-dimensionally track study fish directly upstream of the PRFB.

For yearling Chinook salmon, survival standards were met after a series of PIT tag evaluation studies in 2003, 2004, and 2005; however, Grant PUD was required in 2014 to assess whether survival standards were being maintained. Yearling Chinook salmon that passed through the Project comfortably met the survival standards in 2014 (Skalski et al. 2014). Yearling Chinook salmon survival through the Project increased by 4.2% (90.8%) compared to the three-year Project survival average in 2003-2005 of 86.6%.

In 2014, juvenile steelhead BiOp and SSSA performance standards were met in two of the Project areas; survival standards were met through the Priest Rapids Development and the entire Project area but were not met in the Wanapum Development (Figure 23). The survival standard for steelhead of 93% through the Wanapum Development was narrowly missed by a margin of 0.06% (Skalski et al. 2014). Although, survival through the Wanapum Development increased slightly by 1.0% (from the three-year $\hat{S}$ average of 91.9% in 2008-2010 to $\hat{S}$ of 92.9% in 2014), the Priest Rapids Development and overall Project survival increased moderately at 7.9% and 8.3%, respectively (Figure 23). The estimated Priest Rapids Development survival in 2014 was similar to the survival estimates in 2011 when general survival and predation by fish and birds was investigated (2011 $\hat{S}$ of 97%; 2014 $\hat{S}$ of 96%).

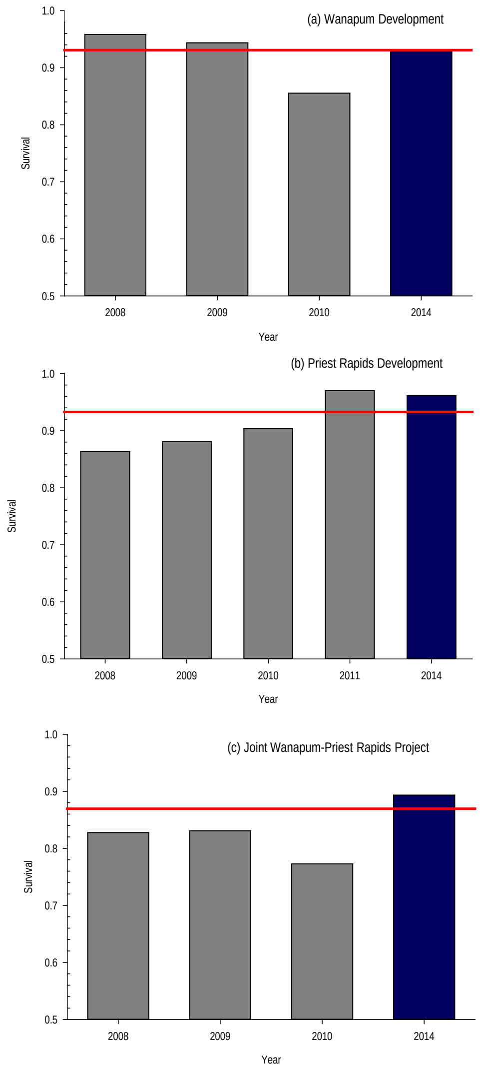


Figure 23. Survival of juvenile steelhead through the (a) Wanapum Development, (b) Priest Rapids Development, and (c) Joint Wanapum-Priest Rapids Project, 2006-2010 and 2014. The target performance standard for steelhead is 93% in each development and 86.5% in the Joint Wanapum-Priest Rapids Project (shown by red line). Steelhead survival was estimated in the Priest Rapids Development in 2011 and was similar to 2014 results.

The distinct increase in steelhead survival, predominantly through the Priest Rapids Development, was difficult to correlate to one, single variable. One possible variable was the increased regional effort to reduce avian predator populations. In comparison to previous years, the detections of Grant PUD study fish from 2014 at Potholes Reservoir has decreased. Although study fish were detected at the Potholes Reservoir nesting colony, the decrease in overall PIT tags detected could be a function of the decreased number of nesting breeding pairs in comparison to 2010. Evans et al. (*in progress*) are preparing a separate report of a retrospective analysis on avian predation in 2014 and we hope to gain further insights from their study contributions.

Juvenile salmon migration rates have also been well correlated with survival, as well as flow and spill, where increased survival was documented in years with faster migration (Anglea et al. 2005b; Faulkner et al. 2007; Muir et al. 2001; Thompson et al. 2012). In 2014, steelhead migration rates above Wanapum Dam were considerably faster than the 2006-2010 average (∆+55.5%). The faster migration rates were likely related to low forebay and reservoir elevations in the Wanapum Development that were 28 ft below the typical elevation, thus creating a more channelized river system. However, 2014 steelhead survival through the Wanapum Development deviated little from the 2008-2010 average, in fact the 2014 survival estimate of 92.9% was lower than that estimated in 2008 (95.8%) and 2009 (94.4%) (Figure 23). Downstream of Wanapum Dam, migration rates of steelhead and yearling Chinook salmon were more comparable to the 2008-2010/11 average, implying that changes in the environmental conditions that affected salmonid migration in 2014, were isolated to the Wanapum Reservoir.

Migrating juvenile salmonids with extended forebay residence times, *i.e.* ‘milling’ behavior, likely experienced an increase in predatory exposure and concurrent decreased survival estimates. When 2014 residence times were compared to historical times it yielded few definitive conclusions and was likely a result of changes in array structure and acoustic technology used. Nonetheless, upon extending the forebay to include BRZ loggers, both species were found to have resided in the forebay for less than one hour; thus milling behavior did not appear prevalent at either dam during the 2014 study.

It has been well established that passage through the powerhouse of hydroelectric dams can be harmful to migrating juvenile salmonids (Muir et al. 2001, Mighetto and Ebel 1994, Raymond 1979). In response, Grant PUD has constructed fish bypass structures at Wanapum and Priest Rapids dams that offer an additional non-powerhouse passage route. The 2014 migratory season marked the first year in which both bypass systems were in operation. In particular, 2014 was the inaugural operating season of the PRFB. Assessing each bypass’s efficiency was conducted through the examination of survival by passage route (route specific survival) weighted by the bypass’s ability to collect fish. Steelhead route specific survival through Wanapum Dam matched historical trends as fish that passed through the powerhouse were statistically measured at lower survival than fish that passed through the spillway or WFB. Yearling Chinook salmon deviated from hypothesized trends and showed no route specific improvements to survival; all routes yielded high survival at Wanapum Dam. Steelhead and yearling Chinook salmon that passed downstream of Priest Rapids Dam through the PRFB yielded statistically higher survival rates through the proceeding downstream reach than fish that passed through either the spillway or powerhouse. In addition to incurring the lowest survival at both dams, both species that passed through the powerhouse also had the slowest downstream migration rates relative to alternative passage routes.

Passage proportions at Wanapum Dam in 2014 were likely affected by low reservoir elevations. Only 10% of steelhead passed downstream through the WFB in 2014 compared to nearly 77% in 2010. Additionally in 2014, powerhouse route selection increased by 22% with the remaining 44% passing through the spillway; no steelhead passed through the spillway in 2010. It is reasonable to speculate that the changes in passage route proportions at Wanapum Dam may have negatively affected the estimated steelhead 2014 concrete survival. The 2014 steelhead concrete survival estimate was 97.8%, where 2009 and 2010 yielded virtually 100% survival with more steelhead passed through the WFB in previous years. Yearling Chinook salmon WFB collection decreased by 22% and powerhouse collection increased by 18% in 2014 relative to 2008, while spillway proportions remained similar (∆+3%). The ubiquitous decrease in 2014 WFB selection is a direct result of the Wanapum Reservoir drawdown that decreased the flow at the bypass to 80% below normal, which resulted in less attraction flow and ultimately decreased selection of that passage route.

Passage proportions of steelhead at Priest Rapids Dam match previous results more closely, though notable differences remain. The proportion of steelhead that passed through the powerhouse in 2014 decreased by 12% when compared to 2010. For comparison, yearling Chinook salmon passage at the powerhouse in 2014 also decreased noticeably compared to 2008 (Δ-33%). Yet in 2014 the PRFB collected 11% fewer steelhead relative to 2010 and 13% fewer yearling Chinook salmon relative to 2008. The confounding factor likely driving these changes in PRFB passage was the additional inadvertent spill in 2014. Less than 1% of 2010 steelhead passed through the spillway as it was sparsely operated, but in 2014, 22% of the steelhead passed through the spillway as it was operated during the majority of the study. The dam operations at each facility are dynamic from year to year, however the additional route for passage altered the anticipated Priest Rapids Dam passage dynamic, expressed predominantly by diminished PRFB selection than observed in previous years with a prototype bulkhead top-spill.

Further approach analysis corroborates with this hypothesis. Relative percent passage figures confirm that fish encountering the PRFB entrance from the spillway end are sufficiently attracted to pass at the PRFB. However, results from the normalized bin density figures confound this effect because a lower density of fish encountered the PRFB from the spillway, relative to the opposite side of the PRFB at the junction of the powerhouse. The normalized bin densities at Priest Rapids Dam also demonstrated that there was some attraction for fish to pass at the PRFB when they were in the forebay, directly upstream of turbine units 1 and 2. Based on the approach analysis from the BRZ, fish that entered the forebay near the spillway (south end of the BRZ) were more likely to have passed through the spillway and never encountered the PRFB entrance. Therefore, we suspect that if the spillway was closed in 2014, the PRFB would have likely collected a significant portion, if not all, of the steelhead that had entered the Priest Rapids Dam forebay at or near the spillway.

In summary, over the past several years, steelhead survival estimates in the Wanapum and Priest Rapids developments have failed to consistently meet BiOp and SSSA performance standards. In 2014, steelhead survival met nearly all performance standards; narrowly missing the mark at the Wanapum Development. Providing a quantitativly robust identification of a single factor that accounts for the increase in survival is convoluted, considering the ecological complexity of the Mid-Columbia River system, but several modifications to the river ecosystem suggest possible affects.

Grant PUD has put considerable effort into the management of piscivorous fish and birds, likely leading to decreased mortality from predation throughout the entire Project area. Additionally, the change in forebay elevation at Wanapum Dam has resulted in competing factors; faster migration rates that likely assisted in increasing survival, and lower WFB selection which may have led to an overall decreased Project survival. Another considerable change in Project operations in 2014 was the addition of the PRFB, allowing 2014 steelhead a safer alternative to powerhouse or spillway passage. The addition of this non-turbine route, however, did not considerably increase dam survival in 2014 relative to 2008-2010 results. Yet, it is feasible that less spill may increase PRFB selection in future years, and based on 2014 relative route-specific survival, increased passage at the PRFB would increase overall dam survival estimates similar to the WFB's effect on survival at Wanapum Dam in 2009-2010.

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Table C.7. Annual median forebay residence times at Priest Rapids Dam (in minutes) for steelhead and yearling Chinook salmon. The 2014 residence times were quantified in two ways: 1) BRZ Residence Time (BRZ), the time elapsed between the first detection at the BRZ and the last detection in the Wanapum forebay, and 2) Forebay Residence Time (Forebay), the time elapsed between the first and last detection on only those receivers in the immediate Priest Rapids forebay. The second approach is the most similar to historical measurements although not equivalent due to differing technology and array placement. Fish entrained in the gatewells, last detected with net upstream movement, or with unknown passage route were excluded from forebay residence time analyses. ........ C5

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# Appendix A

## Acoustic Array Positioning and System Detection Efficiency

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Table A.1. The 2014 receiver deployment configurations for Wanapum Dam. Table includes the array deployed at the Boat Restricted Zone (BRZ) and the array installed in the forebay. Unique system ID, unique receiver identification numbers, elevation, and position (NAD 83 HARN Washington State Plane South Feet) are provided. The forebay array also includes location relative to the dam (PH = powerhouse, WFB = Wanapum Fish Bypass, SP = spillway). Receivers that detached, leaked, or had SD card malfunctions are indicated by an asterisk. .................................A4

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| System ID | Number | Receiver Location | Northing | Easting | Elevation (ft) |
|---|---|---|---|---|---|
| Wanapum Dam BRZ | | | | | |
| W416_3A | 331 | BRZ | 562996.0 | 1770418.0 | 533.0 |
| W416_3B | 332 | BRZ | 563352.0 | 1770847.6 | 533.0 |
| W416_3C | 333 | BRZ | 563724.4 | 1771346.9 | 533.0 |
| W416_3D | 334 | BRZ | 564084.6 | 1771874.8 | 533.0 |
| W416_3E | 335 | BRZ | 564322.0 | 1772439.5 | 533.0 |
| W416_3F | 336 | BRZ | 564158.2 | 1773090.2 | 533.0 |
| Wanapum Dam Forebay | | | | | |
| W416_1A | 301 | SP | 561666.2 | 1772087.0 | 515.0 |
| W416_1B | 302 | SP | 561778.2 | 1772200.7 | 515.0 |
| W416_1C | 303 | SP | 561890.1 | 1772316.5 | 515.0 |
| W416_1D | 304 | SP | 561996.7 | 1772434.3 | 515.0 |
| W416_1E | 305 | WFB | 562315.5 | 1772356.7 | 510.0 |
| W416_1F | 306 | WFB | 562367.4 | 1772357.8 | 510.0 |
| W416_1G | 307 | PH | 562568.0 | 1772357.0 | 515.0 |
| W416_1H* | 308 | PH | 562840.2 | 1772354.8 | 515.0 |
| W416_1I | 309 | PH | 563110.9 | 1772355.9 | 515.0 |
| W416_1J* | 310A | PH | 563287.0 | 1772364.4 | 515.0 |
| W416_1J | 310B | PH | 563417.0 | 1772309.6 | 515.0 |

Table A.2. The 2014 receiver deployment configurations for Priest Rapids Dam. Table includes the array deployed at the Boat Restricted Zone (BRZ) and the array installed in the forebay. Unique system ID, unique receiver identification numbers, elevation, and position (NAD 83 HARN Washington State Plane South Feet) are provided. The forebay array also includes location relative to the dam (PH = powerhouse, PRFB = Priest Rapids Fish Bypass, SP = spillway). Receivers that detached, leaked, or had SD card malfunctions are indicated by an asterisk.

| System ID | Number | Receiver Location | Northing | Easting | Elevation (ft) |
|---|---|---|---|---|---|
| Priest Rapids Dam BRZ | | | | | |
| P397_4A | 531 | BRZ | 478452.6 | 1784995.4 | 475.0 |
| P397_4B | 532 | BRZ | 478658.8 | 1785536.5 | 475.0 |
| P397_4C | 533 | BRZ | 478900.6 | 1786073.0 | 475.0 |
| P397_4D | 534 | BRZ | 479126.5 | 1786614.2 | 475.0 |
| P397_4E | 535 | BRZ | 479358.6 | 1787158.4 | 475.0 |
| P397_4F | 536 | BRZ | 479579.3 | 1787688.0 | 475.0 |
| P397_4G | 537 | BRZ | 479800.0 | 1788217.7 | 475.0 |
| P397_4H | 538 | BRZ | 479835.3 | 1788895.1 | 475.0 |
| Priest Rapids Dam Forebay | | | | | |
| P397_1A* | 501A | SP | 478159.7 | 1787659.8 | 447.1 |
| P397_1AS | 501B | SP | 478218.5 | 1787635.2 | 455.0 |
| P397_1B* | 502A | SP | 478339.7 | 1787699.4 | 450.1 |
| P397_1BS | 502B | SP | 478397.1 | 1787645.1 | 455.0 |
| P397_1C | 503 | SP | 478496.5 | 1787898.6 | 444.1 |
| P397_1D | 504 | SP | 478628.5 | 1788072.7 | 441.1 |
| P397_1E* | 505 | SP | 478572.7 | 1788376.5 | 426.0 |
| P397_1F* | 506 | PRFB | 478637.4 | 1788458.1 | 425.5 |
| P397_1G | 507 | PRFB | 478664.5 | 1788505.4 | 436.6 |
| P397_1H | 508 | PRFB/PH | 478708.6 | 1788547.0 | 454.5 |
| P397_1I | 509 | PH | 478875.9 | 1788767.2 | 450.0 |
| P397_1J | 510 | PH | 479042.5 | 1788970.0 | 450.0 |
| P397_1K | 511 | PH | 479154.3 | 1789111.0 | 450.0 |

Table A.3. The 2014 receiver deployment configurations for Priest Rapids Dam 3D array. Unique system ID, unique receiver identification numbers, elevation, and position (NAD 83 HARN Washington State Plane South Feet) are provided. Location relative to the dam (PH = powerhouse, PRFB = Priest Rapids Fish Bypass, SP = spillway) is included. Receivers that detached, leaked, or had SD card malfunctions are indicated by an asterisk.

| System ID | Number | Receiver Location | Northing | Easting | Elevation (ft) |
|---|---|---|---|---|---|
| Priest Rapids 3D Array | | | | | |
| P397_1AA | 551 | SP | 478558.4 | 1788358.5 | 423.8 |
| P397_1AB | 552 | SP/PRFB | 478611.1 | 1788438.2 | 455.3 |
| P397_1AC* | 553 | PRFB | 478656.6 | 1788482.7 | 423.2 |
| P397_1AD | 554 | PRFB/PH | 478708.6 | 1788547.0 | 474.2 |
| P397_1AE* | 568 | PH | 478728.4 | 1788571.8 | 462.1 |
| P397_1AF | 555 | PH | 478745.1 | 1788592.9 | 476.0 |
| P397_2AA* | 556 | SP | 478630.3 | 1788301.8 | 476.0 |
| P397_2AB | 557 | SP/PRFB | 478688.6 | 1788376.5 | 455.0 |
| P397_2AC | 558 | PRFB | 478747.0 | 1788451.4 | 476.0 |
| P397_2AD | 559 | PH | 478804.2 | 1788524.4 | 410.0 |
| P397_2AE | 560 | SP | 478708.3 | 1788240.6 | 455.0 |
| P397_2AF | 561 | SP/PRFB | 478767.4 | 1788315.8 | 476.0 |
| P397_2AG | 562 | PRFB | 478824.7 | 1788391.7 | 455.0 |
| P397_2AH | 563 | PH | 478882.2 | 1788464.6 | 476.0 |
| P397_2AI | 564 | SP | 478785.0 | 1788180.1 | 476.0 |
| P397_2AJ | 565 | SP/PRFB | 478844.2 | 1788256.3 | 455.0 |
| P397_2AK | 566 | PRFB | 478902.7 | 1788330.0 | 476.0 |
| P397_2AL | 567 | PH | 478960.9 | 1788401.4 | 455.0 |

Table A.4. The 2014 receiver deployment configuration at each of the in-river detection sites (Crescent Bar, Sunland Estates, Mattawa, Vernita Bridge, White Bluffs, Hanford 1 and Hanford 2). Unique system ID, unique receiver identification numbers, and receiver position (NAD 83 Washington State Plane South Feet) are provided. All in-river receivers were attached to an acoustic release and deployed on the river bottom. Receivers that failed, intermittently or permanently, to collect data are indicated by an asterisk. Receiver 703R was installed as a replacement after the original receiver (703) broke free from its mount.

| System ID | Receiver | Northing | Easting |
|---|---|---|---|
| Crescent Bar | | | |
| W441_5A | 101 | 689415.4 | 1761800.6 |
| W441_5B | 102 | 689703.5 | 1761903.8 |
| W441_5C | 103 | 689991.7 | 1762003.8 |
| Sunland Estates | | | |
| W428_2A | 201 | 625132.5 | 1758901.5 |
| W428_2B | 202 | 625296.5 | 1759237.7 |
| W428_2C* | 203 | 625459.3 | 1759571.5 |
| W428_2D | 204 | 625620.9 | 1759902.9 |
| Mattawa | | | |
| P408_4A | 401 | 521626.1 | 1774599.8 |
| P408_4B | 402 | 521312.0 | 1774882.0 |
| P408_4C | 403 | 521001.9 | 1775122.8 |
| P408_4D | 404 | 520787.4 | 1775365.9 |
| Vernita Bridge | | | |
| M388_6A | 601 | 476247.4 | 1830873.7 |
| M388_6B* | 602 | 476498.6 | 1830768.2 |
| M388_6C | 603 | 476754.8 | 1830662.8 |
| M388_6D | 604 | 477032.7 | 1830545.5 |
| White Bluffs | | | |
| M368_5A | 701 | 489104.8 | 1902501.1 |
| M368_5B | 702 | 489243.8 | 1902684.2 |
| M368_5C* | 703 | 489382.7 | 1902867.4 |
| M368_5C | 703R | 489382.7 | 1902867.4 |
| M368_5D* | 704 | 489521.6 | 1903063.1 |
| Hanford 1 | | | |
| M339_0A | 801 | 352472.1 | 1952070.4 |
| M339_0B | 802 | 352323.5 | 1952550.7 |
| M339_0C | 803 | 352106.3 | 1953177.0 |
| M339_0D | 804 | 351933.0 | 1953736.3 |
| Hanford 2 | | | |
| M337_0A* | 901 | 343642.8 | 1953544.4 |
| M337_0B* | 902 | 343912.3 | 1953776.5 |
| M337_0C | 903 | 344119.5 | 1953965.6 |
| M337_0D | 904 | 344377.4 | 1954187.5 |

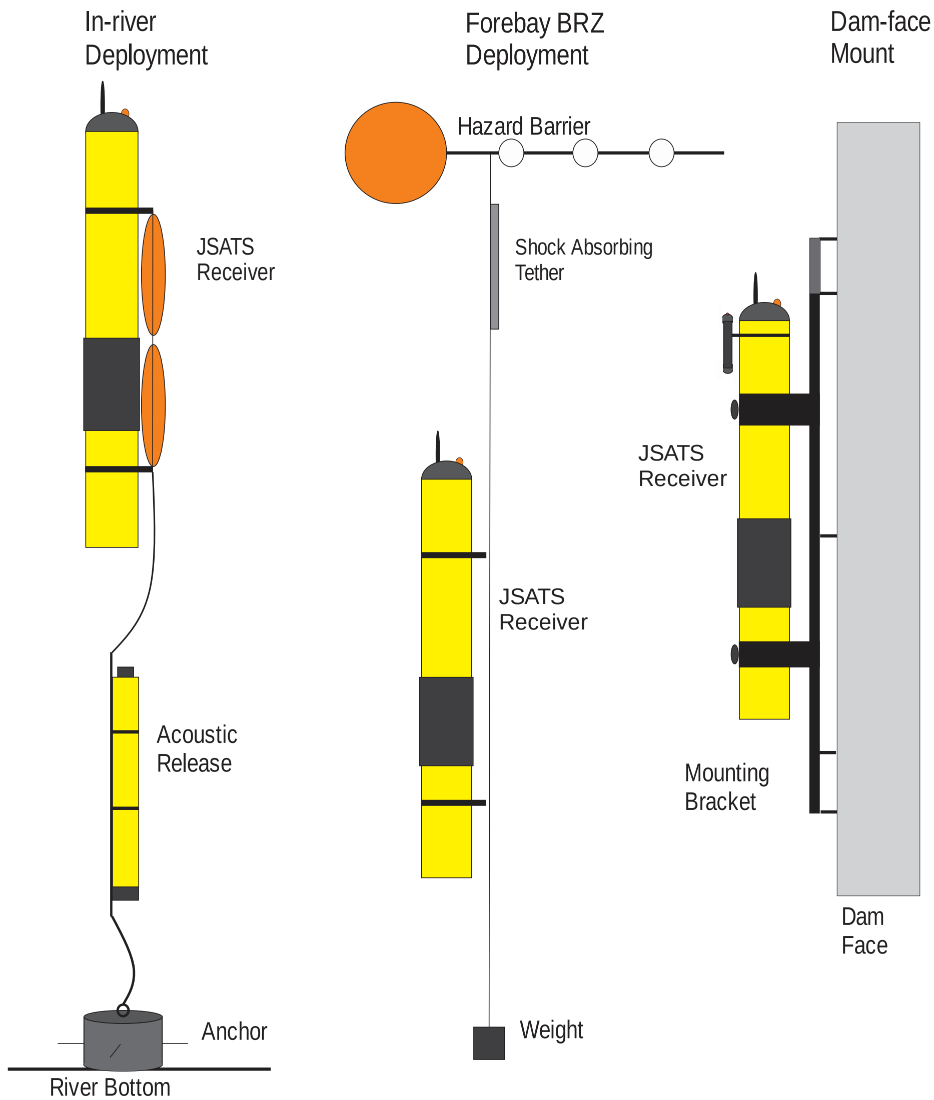


Figure A.1. Deployment schematic of in-river JSATS receivers fixed to the river bottom (left) with a concrete weight (approximately 75 lb.). Receivers were tethered to the release anchor assembly with 15' of 3/8" aircraft cable. Receivers attached to the hazard barrier of the BRZ at Wanapum and Priest Rapids dams (center) were suspended between large pelican clips attached to the pad-eye of hazard barrier crown buoys and 20 lb. lead weights. Shock absorbing tethers were affixed to 15' of 3/8" aircraft cable to reduce shock load to receivers during periods of heavy weather. Receivers attached to the face of Priest Rapids Dam (right) were attached via a metal bracket secured with rock bolts.

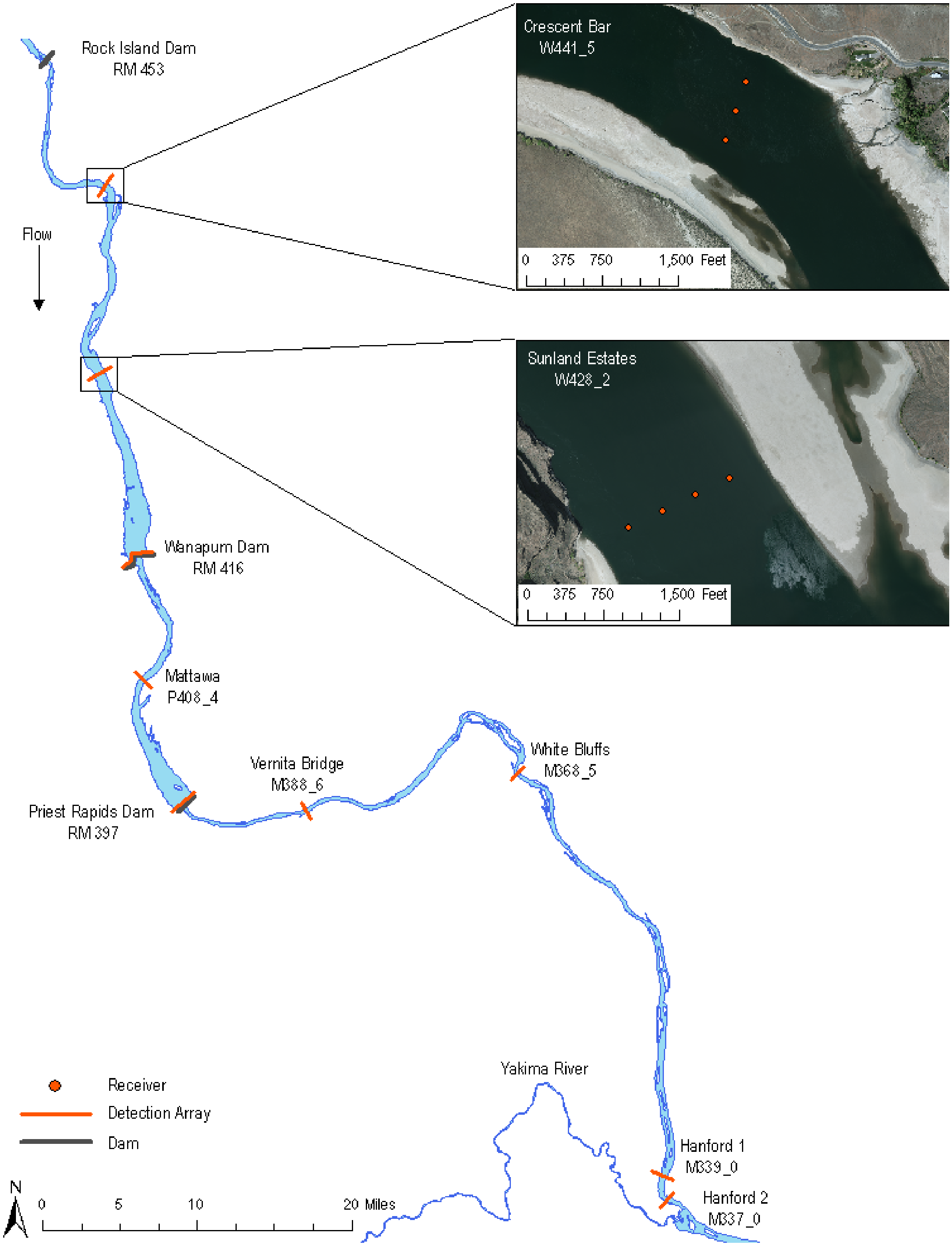


Figure A.2. Position of arrays deployed for the survival study including a detailed view of the cross-river detection arrays at Crescent Bar and Sunland Estates. Digital imagery courtesy of Grant PUD taken in March 2014.

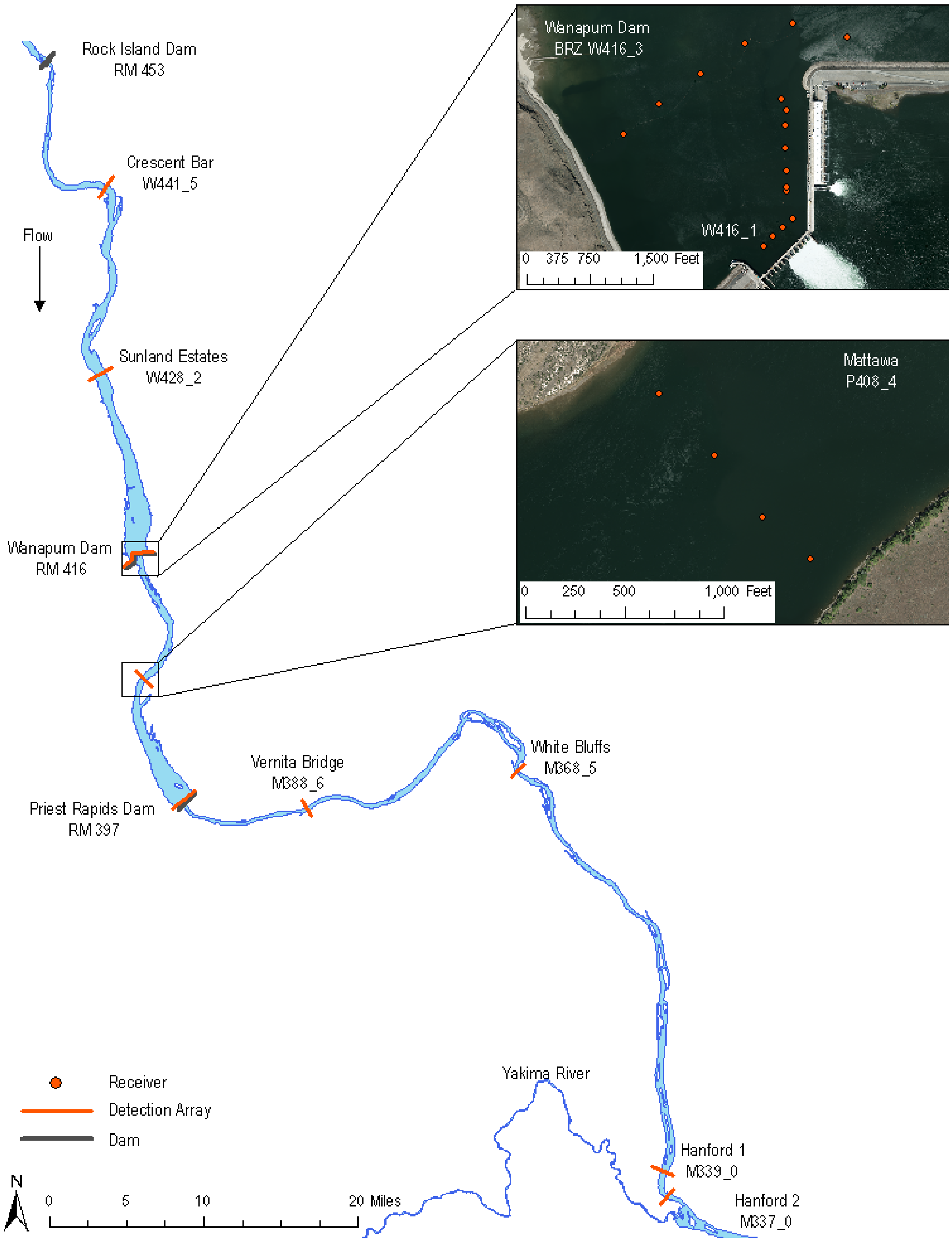


Figure A.3. Position of arrays deployed for the survival study including a detailed view of the detection array at Wanapum Dam and cross-river detection array at Mattawa. Digital imagery courtesy of Grant PUD taken in March 2014.

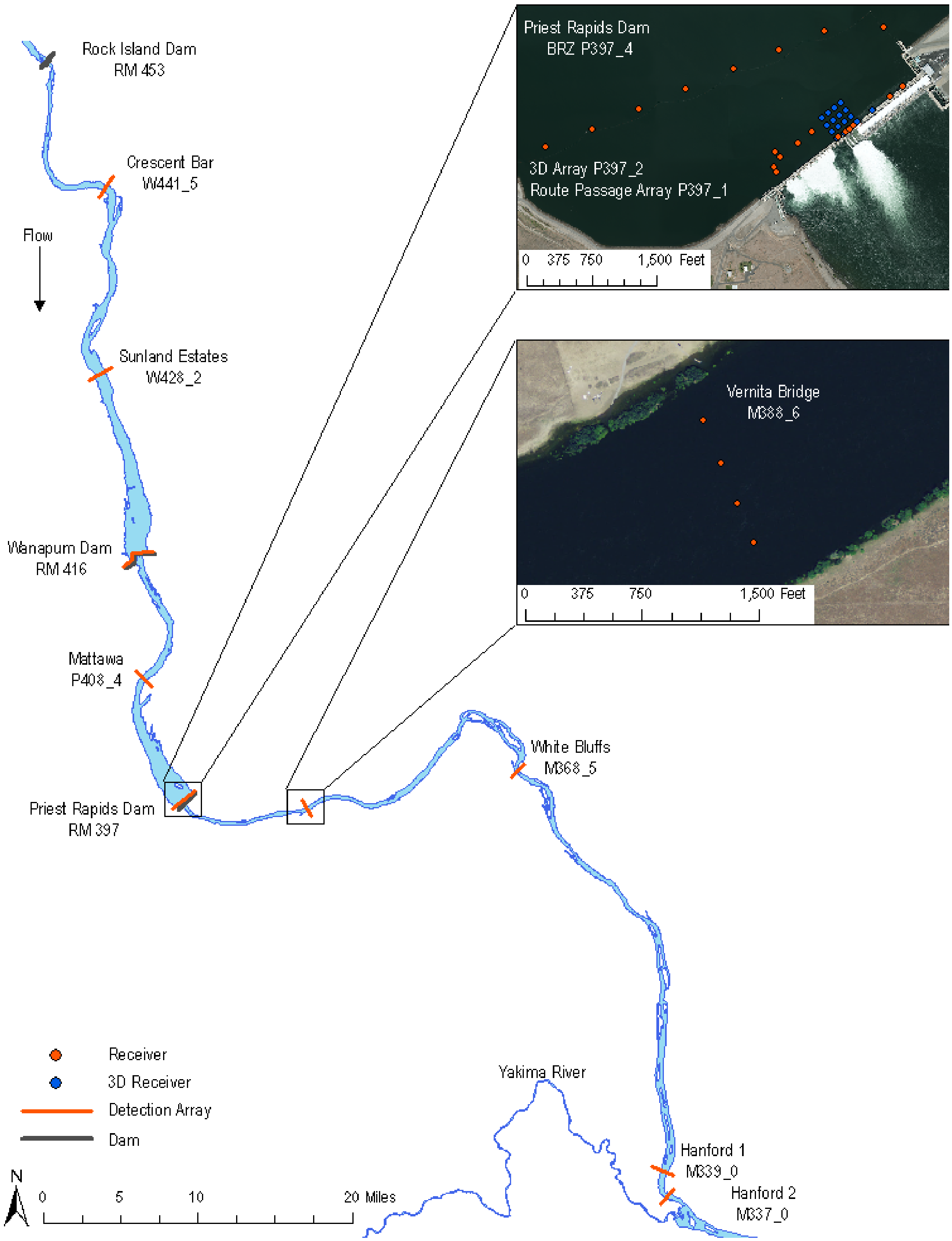


Figure A.4. Position of arrays deployed for the survival study including a detailed view of the detection array at Priest Rapids Dam and cross-river detection array at Vernita Bridge. Digital imagery of Priest Rapids Dam courtesy of Grant PUD taken in March 2014. Digital imagery of Vernita Bridge is the 2013 National Agriculture Imagery Program Mosaic for Benton County (http://datagateway.nrcs.usda.gov/gdgorder.aspx).

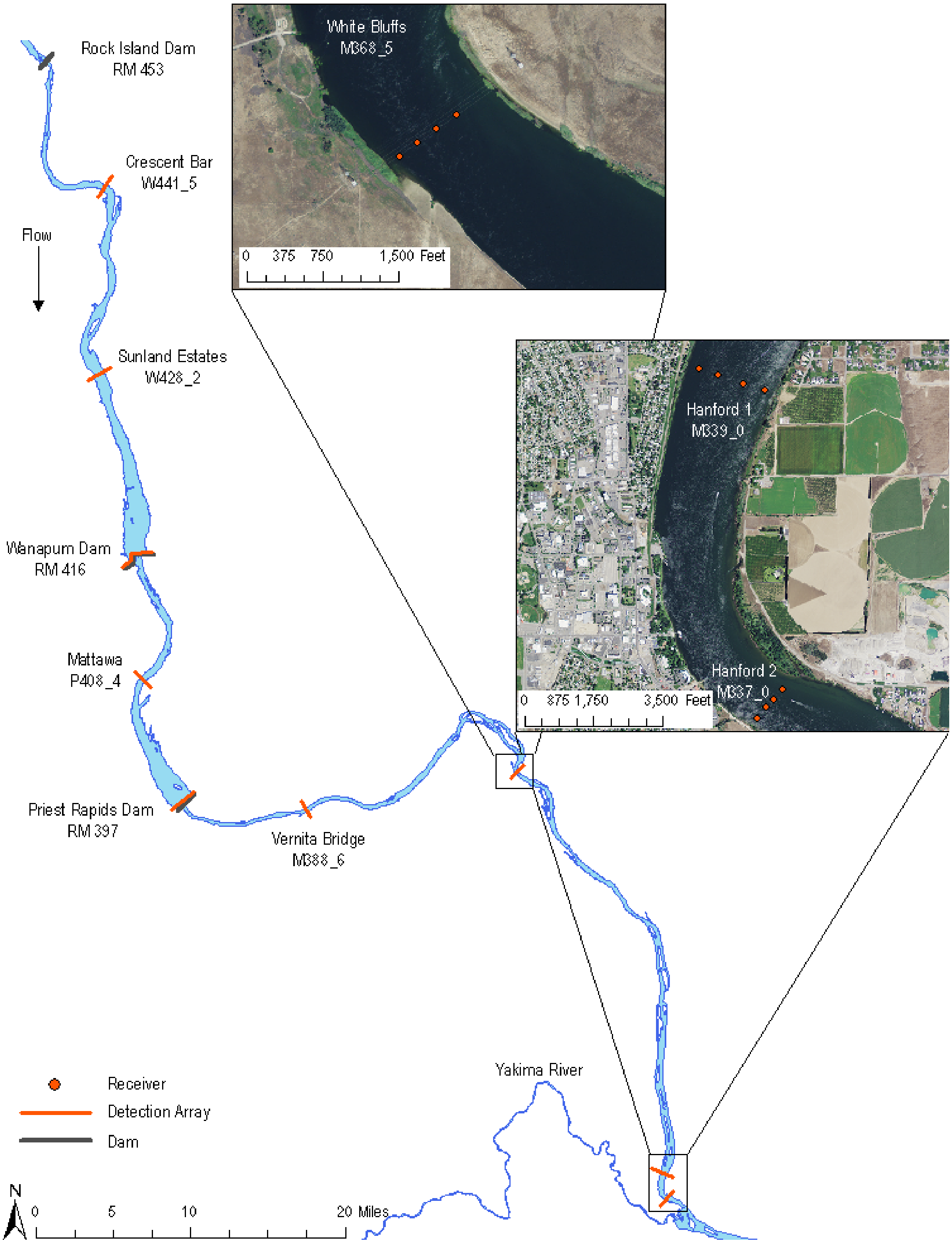


Figure A.5. Position of arrays deployed for the survival study including a detailed view of the cross-river detection array at White Bluffs, Hanford 1 and Hanford 2. Digital imagery is the 2013 National Agriculture Imagery Program Mosaic for Franklin County (http://datagateway.nrcs.usda.gov/gdgorder.aspx).

Table A.5. Summary of data collection failure events by detection array is listed with last valid detection date and time, and a brief explanation of lost data collection.

| Full SD Cards and Flooded Receivers | | | | | |
|---|---|---|---|---|---|
| Array | System ID | Number | Receiver Location | Last Detection | Comments |
| Priest Rapids FB | P397_1A | 501A | SP | 5/12/2014 3:20:38 AM | SD card full |
| Priest Rapids FB | P397_1B | 502A | SP | 5/29/2014 10:41:46 PM | SD card full |
| Priest Rapids FB | P397_1F | 506 | PRFB | | Flooded receiver |
| Priest Rapids 3D | P397_1AC | 553 | PRFB | 5/24/2014 2:41:48 AM | Flooded receiver |
| Priest Rapids 3D | P397_2AA | 556 | SP | | SD card full |
| **Failed Receivers or SD Cards** | | | | | |
| Array | System ID | Number | Receiver Location | Last Detection | Comments |
| Priest Rapids FB | P397_1D | 504 | SP | | Receiver malfunction |
| Priest Rapids FB | P397_1E | 505 | SP | 5/11/2014 5:32:59 AM | Receiver malfunction |
| Priest Rapids 3D | P397_1AE[1] | 568 | PH | | Power lost |
| Vernita Bridge | M388_6B | 602 | Vernita Bridge | Unknown | SD card unreadable |
| Hanford 2 | M337_0B | 902 | Hanford 2 | Unknown | SD card unreadable |
| **Damaged/Detached Receiver** | | | | | |
| Array | System ID | Number | Receiver Location | Last Detection | Comments |
| Sunland Estates | W428_2C | 203 | Sunland Estates | 5/27/2014 7:22:10 AM | Detached, not replaced |
| Wanapum FB | W416_1H | 308 | PH | 5/28/2014 7:09:34 AM | Detached, not replaced |
| Wanapum FB | W416_1J | 310A | PH | 5/13/2014 9:28:57 PM | Detached, replaced |
| Wanapum FB | W416_1J | 310B | PH | 5/28/2014 7:02:01 AM | Detached, not replaced |
| Vernita Bridge | M388_6B | 602 | Vernita Bridge | Unknown | Detached, not replaced |
| White Bluffs | M368_5C | 703 | White Bluffs | 6/3/2014 8:39:41 PM | Detached, replaced |
| White Bluffs | M368_5D | 704 | White Bluffs | 5/31/2014 11:44:44 AM | Detached, not replaced |
| Hanford 2 | M337_0A | 901 | Hanford 2 | 5/17/14 5:52:07 PM | Physical damage |

[1] Receiver was cabled to the surface and wrote data files to an external hard drive.

Table A.6. Total number of valid acoustic tag detections at each detection array deployed in the study area in 2014. First and last valid acoustic detection date and time are also listed.

| Detection Array | First Detection | Last Detection | Number of Detections |
|---|---|---|---|
| Crescent Bar | 4/30/14 1:16:21 PM | 5/27/14 5:27:00 PM | 35,003 |
| Sunland Estates | 4/30/14 8:41:18 PM | 5/27/14 10:41:55 PM | 163,396 |
| Wanapum BRZ | 5/1/14 8:45:16 PM | 5/28/14 7:04:11 AM | 174,183 |
| Wanapum Forebay | 5/1/14 9:05:07 PM | 5/28/14 7:12:49 AM | 215,728 |
| Mattawa | 5/1/14 11:55:02 PM | 6/4/14 9:18:24 PM | 236,059 |
| Priest Rapids BRZ | 5/2/14 10:47:00 PM | 6/1/14 11:14:15 PM | 1,112,135 |
| Priest Rapids 3D | 5/2/14 10:55:30 PM | 6/1/14 11:23:27 PM | 1,472,805 |
| Priest Rapids Forebay | 5/2/14 10:56:38 PM | 6/1/14 11:23:24 PM | 2,439,699 |
| Vernita Bridge | 5/3/14 4:04:31 AM | 6/3/14 4:09:09 PM | 214,399 |
| White Bluffs | 5/3/14 11:29:21 AM | 6/3/14 8:40:21 PM | 468,503 |
| Hanford 1 | 5/3/14 11:19:50 PM | 6/14/14 3:18:47 PM | 247,184 |
| Hanford 2 | 5/3/14 11:49:01 PM | 6/14/14 3:53:41 PM | 173,703 |
| | | Total Number of Detections: | 6,952,797 |

Table A.7. The 2014 PIT tag quantities of steelhead and yearling Chinook salmon detected downstream of the study area including 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 detected was reported by PTAGIS (http://www.ptagis.org/).

| Species | Release Site | McNary | John Day | Bonneville | Estuary | Total Detected |
|---|---|---|---|---|---|---|
| Steelhead | Rock Island | 15 | 34 | 26 | 7 | 82 |
| | Wanapum | 43 | 44 | 41 | 13 | 141 |
| | Priest Rapids | 31 | 57 | 44 | 8 | 140 |
| Yearling Chinook salmon | Rock Island | 38 | 31 | 30 | 6 | 105 |
| | Wanapum | 81 | 61 | 66 | 3 | 211 |
| | Priest Rapids | 77 | 50 | 32 | 4 | 163 |

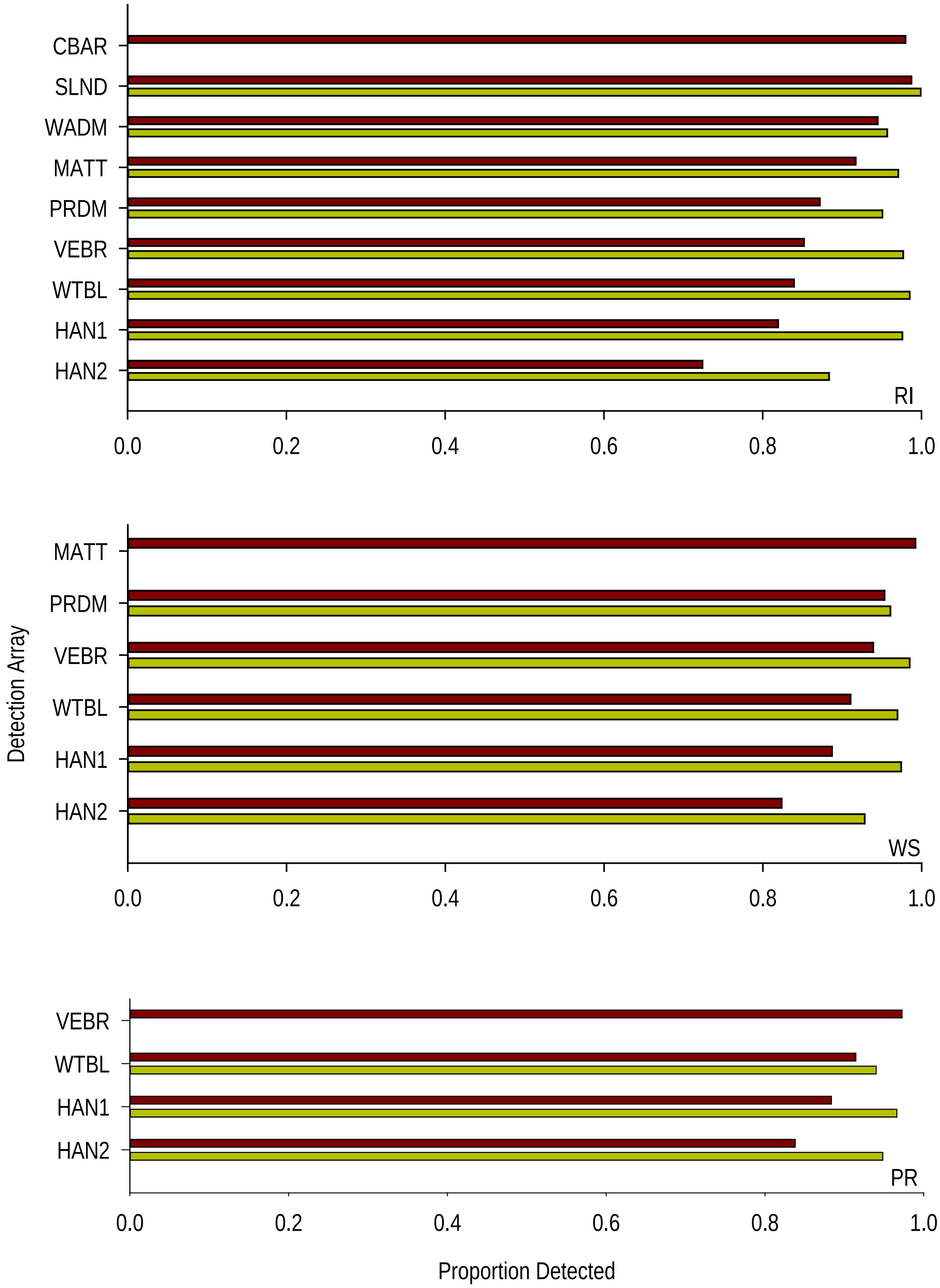


Figure A.6. The 2014 absolute detection rate of steelhead by release group (RI = Rock Island, WS = Wanapum, and PR = Priest Rapids dams). Red bars present the calculation from total released in the tailrace of each dam to each detection array, and the yellow bars present the proportion detected between arrays—the positive detection at the upstream array to the positive detection at the nearest downstream array.

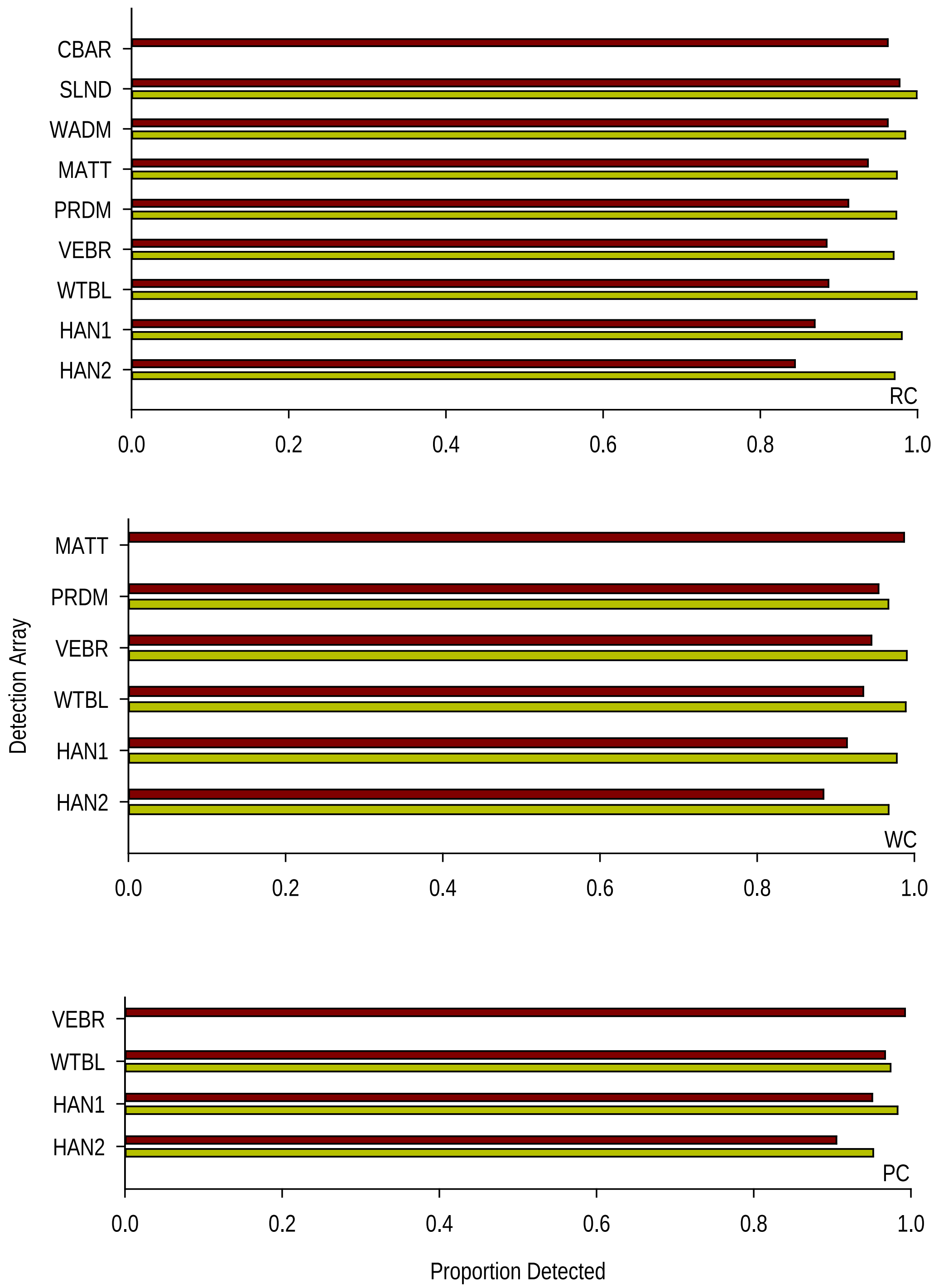


Figure A.7. The 2014 absolute detection rate of yearling Chinook salmon by release group (RC = Rock Island, WC = Wanapum, and PC = Priest Rapids dams). Red bars present the calculation from total released in the tailrace of each dam to each detection array, and the yellow bars present the proportion detected between arrays—the positive detection at the upstream array to the positive detection at the nearest downstream array.

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# Appendix B

## Fish Handling and Release Characteristics

## List of Tables

Table B.1. The quantity of steelhead and yearling Chinook salmon that were collected, tagged, and released by release groups during the spring of 2014. RCO5, WC05, and PC05 were not successfully released on May 4. RI=399, WS=771, PR=550, RC=398, WC=769, and PC=549........................................................B2

## List of Figures

Figure B.1. Size distribution of tagged (a) steelhead (n=1,720, green) and (b) yearling Chinook salmon (n=1,716, gray) released for the 2014 Grant PUD survival and behavioral analyses. .........................................................B3

Figure B.2. Relative frequency of length and weight of tagged steelhead (shown in green, n=1,720) and yearling Chinook salmon (shown in grey, n=1,716) released in the 2014 Grant PUD survival and behavioral analyses. The fork length in millimeters of (a) steelhead and (c) yearling Chinook salmon as well as the weight in grams of (b) steelhead and (d) yearling Chinook salmon are shown above. The average steelhead fork length was 182.9 mm (range 128.0-217.0 mm) and weight was 57.0 g (range 21.5-88.0 g). The average yearling Chinook salmon fork length was 143.7 mm (range 108.0-200.0 mm) and weight was 33.1 g (range 16.5-82.5 g)...........................................................................................................................B4

Table B.1. The quantity of steelhead and yearling Chinook salmon that were collected, tagged, and released by release groups during the spring of 2014. RCO5, WC05, and PC05 were not successfully released on May 4. RI=399, WS=771, PR=550, RC=398, WC=769, and PC=549.

| Release Groups and Number of Fish Released | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steelhead | | | | | | Chinook salmon | | | | | | Date | | |
| RI | $n_{RI}$ | WS | $n_{WS}$ | PR | $n_{PR}$ | RC | $n_{RC}$ | WC | $n_{WC}$ | PC | $n_{PC}$ | Collection | Surgery | Release |
| | | | | | | CH RC01 | 18 | | | | | 28-Apr | 29-Apr | 30-Apr |
| | | | | | | CH RC02 | 18 | | | | | 29-Apr | 30-Apr | 1-May |
| | | | | | | CH RC03 | 18 | CH WC01 | 27 | | | 30-Apr | 1-May | 2-May |
| | | | | | | CH RC04 | 18 | CH WC02 | 31 | CH PC01 | 19 | 1-May | 2-May | 3-May |
| | | | | | | | | CH WC03 | 32 | CH PC02 | 20 | 2-May | 3-May | 4-May |
| | | | | | | CH RC06 | 18 | CH WC04 | 33 | CH PC03 | 22 | 3-May | 4-May | 5-May |
| | | | | | | CH RC07 | 18 | | | CH PC04 | 23 | 4-May | 5-May | 6-May |
| ST RI01 | 20 | | | | | CH RC08 | 19 | CH WC06 | 34 | | | 5-May | 6-May | 7-May |
| ST RI02 | 20 | | | | | CH RC09 | 17 | CH WC07 | 35 | CH PC06 | 24 | 6-May | 7-May | 8-May |
| ST RI03 | 20 | ST WS01 | 29 | | | CH RC10 | 20 | CH WC08 | 40 | CH PC07 | 25 | 7-May | 8-May | 9-May |
| ST RI04 | 20 | ST WS02 | 32 | ST PR01 | 22 | CH RC11 | 20 | CH WC09 | 41 | CH PC08 | 28 | 8-May | 9-May | 10-May |
| ST RI05 | 20 | ST WS03 | 34 | ST PR02 | 23 | CH RC12 | 20 | CH WC10 | 43 | CH PC09 | 28 | 9-May | 10-May | 11-May |
| ST RI06 | 20 | ST WS04 | 35 | ST PR03 | 23 | CH RC13 | 20 | CH WC11 | 44 | CH PC10 | 31 | 10-May | 11-May | 12-May |
| ST RI07 | 21 | ST WS05 | 37 | ST PR04 | 25 | CH RC14 | 20 | CH WC12 | 43 | CH PC11 | 32 | 11-May | 12-May | 13-May |
| ST RI08 | 21 | ST WS06 | 40 | ST PR05 | 26 | CH RC15 | 20 | CH WC13 | 43 | CH PC12 | 32 | 12-May | 13-May | 14-May |
| ST RI09 | 21 | ST WS07 | 42 | ST PR06 | 27 | CH RC16 | 20 | CH WC14 | 40 | CH PC13 | 31 | 13-May | 14-May | 15-May |
| ST RI10 | 22 | ST WS08 | 45 | ST PR07 | 28 | CH RC17 | 19 | CH WC15 | 39 | CH PC14 | 30 | 14-May | 15-May | 16-May |
| | | | | | | | | | | | | 15-May | 16-May | 17-May |
| ST RI11/12 | 44 | ST WS09/10 | 99 | ST PR08/09 | 63 | CH RC18/19 | 38 | CH WC16/17 | 75 | CH PC15/16 | 57 | 16-May | 17-May | 18-May |
| ST RI13 | 22 | ST WS11 | 53 | ST PR10 | 33 | CH RC20 | 19 | CH WC18 | 36 | CH PC17 | 27 | 17-May | 18-May | 19-May |
| ST RI14 | 22 | ST WS12 | 49 | ST PR11 | 35 | CH RC21 | 19 | CH WC19 | 35 | CH PC18 | 27 | 18-May | 19-May | 20-May |
| ST RI15 | 22 | ST WS13 | 45 | ST PR12 | 35 | CH RC22 | 19 | CH WC20 | 33 | CH PC19 | 25 | 19-May | 20-May | 21-May |
| ST RI16 | 22 | ST WS14 | 42 | ST PR13 | 33 | | | CH WC21 | 31 | CH PC20 | 23 | 20-May | 21-May | 22-May |
| ST RI17 | 21 | ST WS15 | 43 | ST PR14 | 32 | | | CH WC22 | 34 | CH PC21 | 24 | 21-May | 22-May | 23-May |
| ST RI18 | 20 | ST WS16 | 42 | ST PR15 | 32 | | | | | CH PC22 | 21 | 22-May | 23-May | 24-May |
| ST RI19 | 21 | ST WS17 | 38 | ST PR16 | 31 | | | | | | | 23-May | 24-May | 25-May |
| | | ST WS18 | 34 | ST PR17 | 29 | | | | | | | 24-May | 25-May | 26-May |
| | | ST WS19 | 32 | ST PR18 | 27 | | | | | | | 25-May | 26-May | 27-May |
| | | | | ST PR19 | 26 | | | | | | | 26-May | 27-May | 28-May |

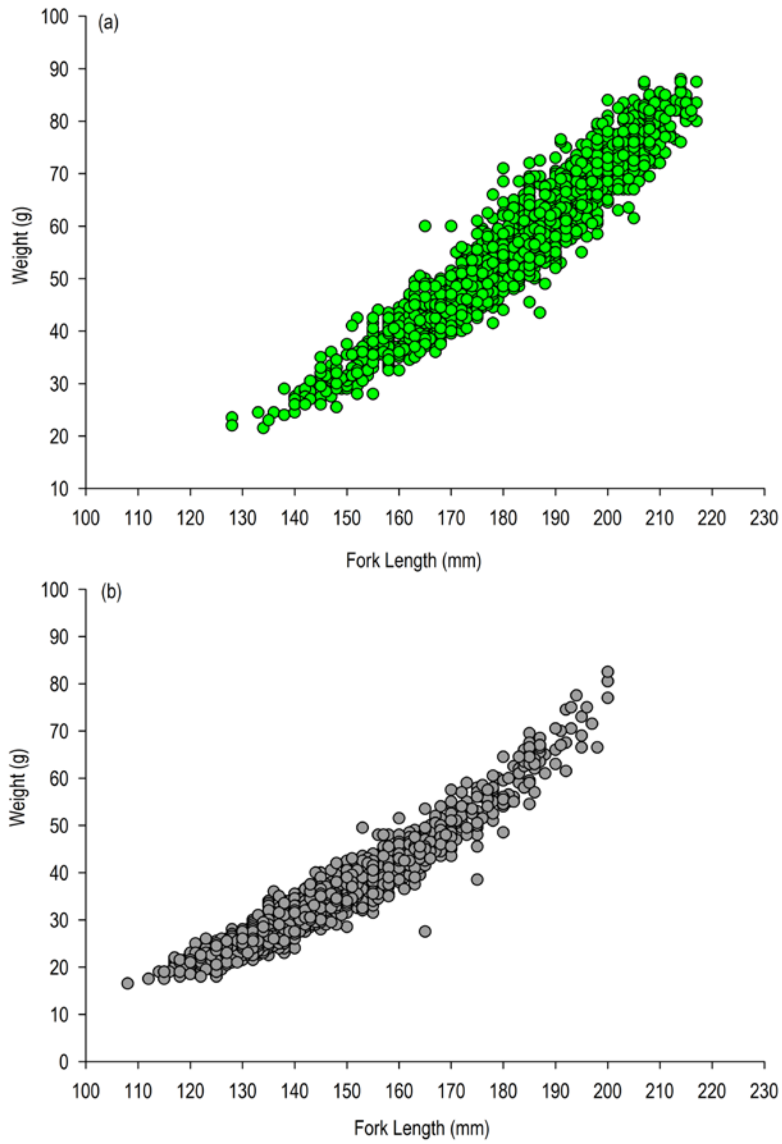


Figure B.1. Size distribution of tagged (a) steelhead (n=1,720, green) and (b) yearling Chinook salmon (n=1,716, gray) released for the 2014 Grant PUD survival and behavioral analyses.

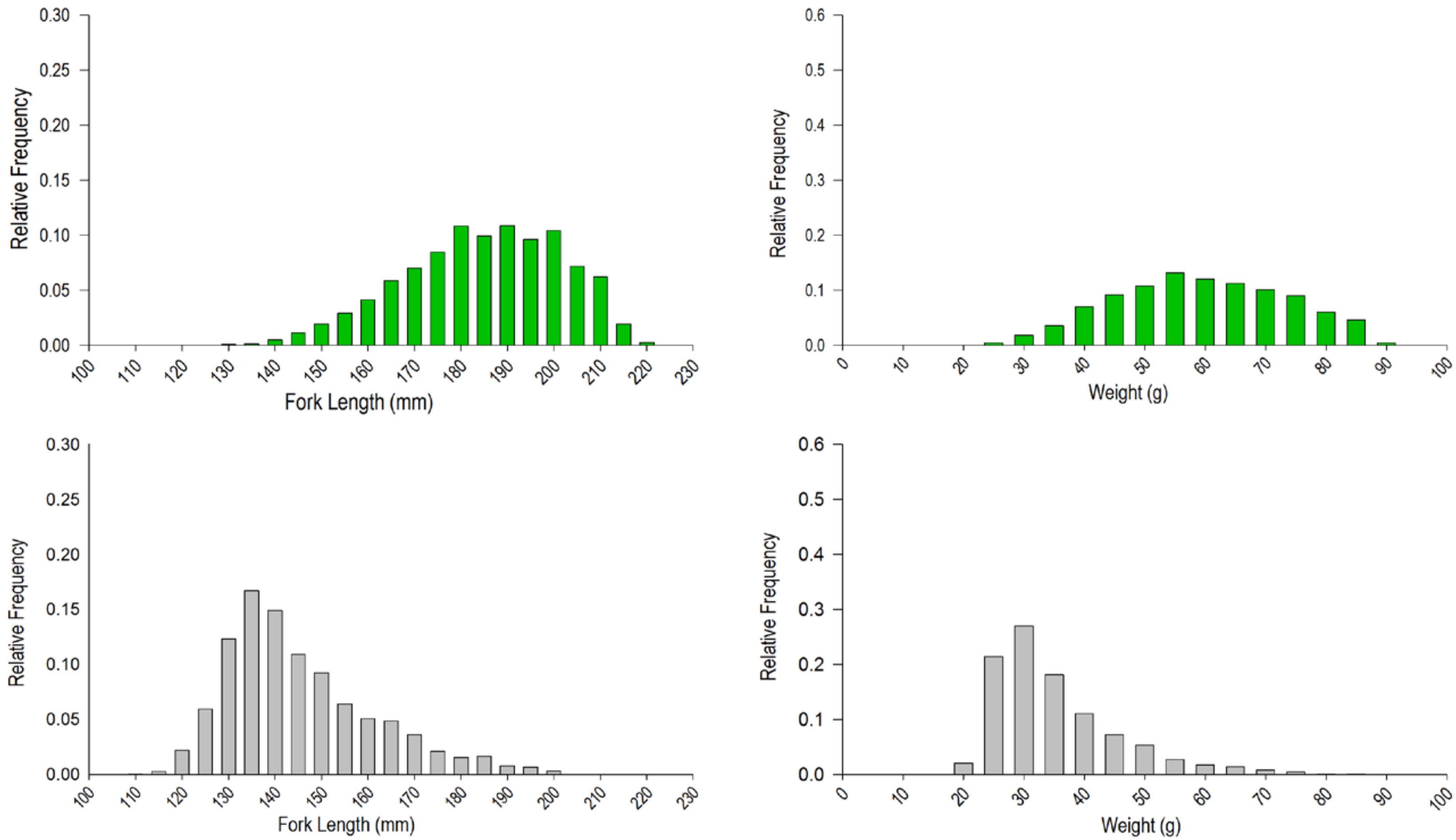


Figure B.2. Relative frequency of length and weight of tagged steelhead (shown in green, n=1,720) and yearling Chinook salmon (shown in grey, n=1,716) released in the 2014 Grant PUD survival and behavioral analyses. The fork length in millimeters of (a) steelhead and (c) yearling Chinook salmon as well as the weight in grams of (b) steelhead and (d) yearling Chinook salmon are shown above. The average steelhead fork length was 182.9 mm (range 128.0-217.0 mm) and weight was 57.0 g (range 21.5-88.0 g). The average yearling Chinook salmon fork length was 143.7 mm (range 108.0-200.0 mm) and weight was 33.1 g (range 16.5-82.5 g).

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# Appendix C

## Migration Rates and Forebay Residence Times

# List of Tables

Table C.1. Summary of 2014 median migration rates (measured in hours) for all release groups listed by species (steelhead and yearling Chinook salmon) and independent reach. Median travel times were measured from either the time of release (in the tailrace of each dam) or last detection at the previous array, to the first detection at the next downstream array. Cumulative travel times, measured from the time of release to first detection at a given array, are indicated in parenthesis. Fish entrained in the gatewells were not included in this measurement. ....C2

Table C.2. Annual median migration rates (measured in hours) for all release groups listed by species, reach and study year. Median travel times were measured from either the time of release or last detection at the previous array to the first detection at the next downstream detection array. Yearling Chinook salmon travel data from 2009-2010 were sourced from Chelan County PUD memorandum 2012 (O'Connor 2012 Memo), while all steelhead and remaining yearling Chinook salmon data were taken from 2006-2011 GCPUD acoustic survival reports (Timko; Sullivan; Thompson et al. 2006-2012). Fish entrained in the gatewells were not included in this analysis. ....C3

Table C.3. Annual median migration rates (measured in hours) of steelhead and yearling Chinook salmon from Wanapum Dam to each detection array by passage route. Yearling Chinook salmon were not monitored at Wanapum Dam during 2006-2011 acoustic studies. Furthermore, there were no steelhead detected passing through the Wanapum Dam spillway in 2009 or 2010. ....C3

Table C.4. Annual median migration rates (measured in hours) of steelhead and yearling Chinook salmon (referenced below as Chinook) from Priest Rapids Dam to each detection array are presented by passage route. There was only one steelhead detected passing through the Priest Rapids Dam spillway in 2009 and 2010 and there is no yearling Chinook salmon passage data available for 2009 or 2010. ....C4

Table C.5. Annual comparison of median residence times (in minutes) for steelhead and yearling Chinook salmon at Crescent Bar, Sunland, Mattawa, Vernita Bridge, White Bluffs, and Hanford detection arrays. Data in these locations was not collected for Chinook salmon in previous years, while steelhead data was collected in only a subset of these locations in 2008-2010. ....C4

Table C.6. Annual median forebay residence times at Wanapum Dam (in minutes) for steelhead and yearling Chinook salmon. The 2014 residence times were quantified in two ways: 1) BRZ Residence Time (BRZ), the time elapsed between the first detection at the BRZ and the last detection in the Wanapum forebay, and 2) Forebay Residence Time (Forebay), the time elapsed between the first and last detection on only those receivers in the immediate Wanapum forebay. The second approach is the most similar to historical measurements although not equivalent due to differing technology and array placement. Fish entrained in the gatewells, last detected with net upstream movement, or with unknown passage route were excluded from forebay residence time analyses. ....C5

Table C.7. Annual median forebay residence times at Priest Rapids Dam (in minutes) for steelhead and yearling Chinook salmon. The 2014 residence times were quantified in two ways: 1) BRZ Residence Time (BRZ), the time elapsed between the first detection at the BRZ and the last detection in the Wanapum forebay, and 2) Forebay Residence Time (Forebay), the time elapsed between the first and last detection on only those receivers in the immediate Priest Rapids forebay. The second approach is the most similar to historical measurements although not equivalent due to differing technology and array placement. Fish entrained in the gatewells, last detected with net upstream movement, or with unknown passage route were excluded from forebay residence time analyses. ....C5

Table C.1. Summary of 2014 median migration rates (measured in hours) for all release groups listed by species (steelhead and yearling Chinook salmon) and independent reach. Median travel times were measured from either the time of release (in the tailrace of each dam) or last detection at the previous array, to the first detection at the next downstream array. Cumulative travel times, measured from the time of release to first detection at a given array, are indicated in parenthesis. Fish entrained in the gatewells were not included in this measurement.

| | | Detection Arrays | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Release Site | CBAR | SNLD | WADM | MATT | PRDM | VEBR | WTBL | HAN |
| Steelhead | Rock Island Dam | 3.2 | 6.0 (9.2) | 11.5 (20.7) | 2.5 (23.2) | 13.7 (36.9) | 1.8 (38.7) | 4.4 (43.1) | 8.0 (51.1) |
| | Wanapum Dam | | | | 3.0 | 12.7 (15.7) | 1.8 (17.5) | 4.4 (21.9) | 8.7 (30.6) |
| | Priest Rapids Dam | | | | | | 1.9 | 7.4 (9.3) | 8.7 (18.0) |
| Yearling Chinook salmon | Rock Island Dam | 5.0 | 12.0 (17.0) | 24.5 (41.5) | 2.9 (44.4) | 20.4 (64.8) | 1.9 (66.7) | 5.2 (71.9) | 17.2 (89.1) |
| | Wanapum Dam | | | | 3.6 | 26.4 (30.0) | 1.9 (31.9) | 5.9 (37.8) | 19.7 (57.5) |
| | Priest Rapids Dam | | | | | | 2.1 | 10.2 (12.3) | 20.7 (33.0) |

Table C.2. Annual median migration rates (measured in hours) for all release groups listed by species, reach and study year. Median travel times were measured from either the time of release or last detection at the previous array to the first detection at the next downstream detection array. Yearling Chinook salmon travel data from 2009-2010 were sourced from Chelan County PUD memorandum 2012 (O'Connor 2012 Memo), while all steelhead and remaining yearling Chinook salmon data were taken from 2006-2011 GCPUD acoustic survival reports (Timko; Sullivan; Thompson et al. 2006-2012). Fish entrained in the gatewells were not included in this analysis.

| Species | Year | WADM | MATT | PRDM | VEBR | WTBL | HAN |
|---|---|---|---|---|---|---|---|
| Steelhead | 2014 | 20.7 | 2.8 | 13.2 | 1.8 | 5.4 | 8.5 |
| | 2011 | | 3.6 | 9.8 | | | |
| | 2010 | 60.7 | 2.7 | 24.6 | 2.1 | | |
| | 2009 | 61.1 | 2.7 | 23.1 | 2.2 | | |
| | 2008 | 39 | 2.2 | 13.2 | 1.9 | | |
| | 2007 | 47.5 | 2.6 | 16 | 2 | | |
| | 2006 | 50.1 | 3 | 12.6 | 2.4 | | |
| Yearling Chinook salmon | 2014 | 41.5 | 3.3 | 23.4 | 2.0 | 7.1 | 19.2 |
| | 2010 | | 2.9 | 21.1 | 2.2 | | |
| | 2009 | | 3.1 | 24.2 | 2.2 | | |
| | 2008 | | 2.1 | 17.1 | 1.9 | | |
| | 2007 | | 4 | 24 | 1.9 | | |
| | 2006 | | 3.2 | 14.4 | 1.9 | | |

Table C.3. Annual median migration rates (measured in hours) of steelhead and yearling Chinook salmon from Wanapum Dam to each detection array by passage route. Yearling Chinook salmon were not monitored at Wanapum Dam during 2006-2011 acoustic studies. Furthermore, there were no steelhead detected passing through the Wanapum Dam spillway in 2009 or 2010.

| | | Powerhouse | | WFB | | Spillway | |
|---|---|---|---|---|---|---|---|
| Species | Year | MATT | PRDM | MATT | PRDM | MATT | PRDM |
| Steelhead | 2014 | 2.8 | 16.1 | 2.4 | 11.6 | 2.2 | 14.7 |
| | 2010 | 3 | 24.5 | 2.4 | 25 | | |
| | 2009 | 3.2 | 23 | 2.5 | 22.1 | | |
| | 2008 | 2.5 | 15.6 | 2.1 | 13.9 | 2.1 | 9.1 |
| | 2007 | 2.8 | 16.2 | | | 2.3 | 16.9 |
| Yearling Chinook salmon | 2014 | 3.1 | 23.4 | 3.1 | 15.0 | 2.5 | 19.6 |
| | 2008 | 2.3 | 18.5 | 2.2 | 18.2 | 1.8 | 12.7 |

Table C.4. Annual median migration rates (measured in hours) of steelhead and yearling Chinook salmon (referenced below as Chinook) from Priest Rapids Dam to each detection array are presented by passage route. There was only one steelhead detected passing through the Priest Rapids Dam spillway in 2009 and 2010 and there is no yearling Chinook salmon passage data available for 2009 or 2010.

| | | Powerhouse | | | | PRFB | | | | Spillway | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Year | VEBR | RING | WTBL | HAN | VEBR | RING | WTBL | HAN | VEBR | RING | WTBL | HAN |
| Steelhead | 2014 | 1.9 | | 4.5 | 8.6 | 1.7 | | 4.4 | 8.3 | 1.9 | | 4.4 | 8.9 |
| | 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 | | |
| Chinook | 2014 | 2.0 | | 5.4 | 20.4 | 1.9 | | 5.7 | 18.7 | 2.0 | | 5.3 | 17.9 |
| | 2008 | 1.9 | 6.8 | | | 1.9 | 6.8 | | | 1.8 | 6.3 | | |

Table C.5. Annual comparison of median residence times (in minutes) for steelhead and yearling Chinook salmon at Crescent Bar, Sunland, Mattawa, Vernita Bridge, White Bluffs, and Hanford detection arrays. Data in these locations was not collected for yearling Chinook salmon in previous years, while steelhead data was collected in only a subset of these locations in 2008-2010.

| Species | Year | CBAR | SLND | MATT | VEBR | WTBL | HAN |
|---|---|---|---|---|---|---|---|
| Steelhead | 2014 | 84 | 372 | 180 | 102 | 156 | 174 |
| | 2010 | | | 180 | 216 | | |
| | 2009 | | | 288 | 288 | | |
| | 2008 | | | 324 | 180 | | |
| Yearling Chinook salmon | 2014 | 90 | 468 | 216 | 120 | 174 | 192 |

Table C.6. Annual median forebay residence times at Wanapum Dam (in minutes) for steelhead and yearling Chinook salmon. The 2014 residence times were quantified in two ways: 1) BRZ Residence Time (BRZ), the time elapsed between the first detection at the BRZ and the last detection in the Wanapum forebay, and 2) Forebay Residence Time (Forebay), the time elapsed between the first and last detection on only those receivers in the immediate Wanapum forebay. The second approach is the most similar to historical measurements although not equivalent due to differing technology and array placement. Fish entrained in the gatewells, last detected with net upstream movement, or with unknown passage route were excluded from forebay residence time analyses.

| Species | Year | All Routes | Powerhouse | Bypass | Spillway |
|---|---|---|---|---|---|
| Steelhead | 2014[BRZ] | 28.5 | 14.8 | 46.6 | 44.0 |
| | 2014[Forebay] | 8.1 | 3.0 | 15.6 | 20.4 |
| | 2010 | 144.6 | 289.2 | 121.8 | |
| | 2009 | 80.4 | 43.8 | 87.0 | |
| | 2008 | 30.0 | 10.2 | 58.2 | 18.0 |
| | 2007 | 29.4 | 27.0 | | 61.2 |
| | 2006 | 26.4 | 22.8 | | 49.8 |
| Yearling Chinook salmon | 2014[BRZ] | 20.3 | 15.2 | 24.4 | 37.1 |
| | 2014[Forebay] | 3.6 | 1.8 | 9.0 | 12.0 |
| | 2008 | 0.2 | 14.4 | 14.4 | 14.4 |

Table C.7. Annual median forebay residence times at Priest Rapids Dam (in minutes) for steelhead and yearling Chinook salmon. The 2014 residence times were quantified in two ways: 1) BRZ Residence Time (BRZ), the time elapsed between the first detection at the BRZ and the last detection in the Wanapum forebay, and 2) Forebay Residence Time (Forebay), the time elapsed between the first and last detection on only those receivers in the immediate Priest Rapids forebay. The second approach is the most similar to historical measurements although not equivalent due to differing technology and array placement. Fish entrained in the gatewells, last detected with net upstream movement, or with unknown passage route were excluded from forebay residence time analyses.

| Species | Year | All Routes | Powerhouse | Bypass/Top-Spill | Spillway |
|---|---|---|---|---|---|
| Steelhead | 2014[BRZ] | 43.2 | 32.4 | 52.7 | 40.9 |
| | 2014[Forebay] | 8.1 | 7.8 | 12.6 | 6.0 |
| | 2010 | 91.8 | 52.8 | 147.0 | 21,322.8[2] |
| | 2009 | 57.6 | 45.6 | 42.6 | 44.4 |
| | 2008 | 14.4 | 13.2 | 13.2 | 10.2 |
| | 2007 | 20.4 | 19.8 | 22.2 | 9.6 |
| | 2006 | 19.8 | 19.8 | 40.8 | 7.8 |
| Yearling Chinook salmon | 2014[BRZ] | 42.8 | 44.5 | 47.5 | 40.6 |
| | 2014[Forebay] | 6.7 | 8.4 | 7.8 | 4.2 |
| | 2008 | 13.8 | 12.6 | 15.6 | 13.8 |
| | 2007 | 16.8 | 16.2 | 21.0 | 9.0 |
| | 2006 | 18.0 | 19.2 | 30.6 | 9.0 |

[2]In 2010, one acoustic-tagged steelhead was last detected at the spillway after spending 14.8 days in the forebay (tag code 4566.21, release group WS14), first detected on 5/25/2010 7:56:35 – 6/9/2010 3:19:28. The tag was detected downstream at Vernita Bridge (6/9/2010 5:36:46 am) and Ringold (6/9/2010 11:52:02). Migration rates between sites fit typical egress for juvenile steelhead and did not exhibit typical predation suspected detection histories; the tagged fish is an outlier but could not excluded from the data set.

# Appendix D

## *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, (2006-2010 and 2014). Zone entrance efficiency (ZEE) at the Wanapum Dam Fish Bypass (WFB) and Priest Rapids Dam Fish Bypass (PRFB) are shown in Table F.3. Fish collection efficiency (FCE) at Wanapum Dam and Priest Rapids Dam are listed in Tables F.4 and F.5, respectively (2006-2010 and 2014). All tables have data segregated by species.

# List of Tables

Table D.1. The passage route efficiencies (PRE) of downstream migrant steelhead through Wanapum Dam in 2014 are shown below with 2006-2010 results for comparison (*from* Timko et al. 2011). At each dam, powerhouse passage includes fish that were entrained in the gatewells. Passage events that could not be identified or fish last detected with upstream movement were not included in PRE estimates. In 2006-2007, a prototype fish bypass was used for surface passage of smolts at the sluiceway along with a top-spill bulkhead at Spill Bay 12. ........ D2

Table D.2. The passage route efficiencies (PRE) of downstream migrant steelhead through Priest Rapids Dam in 2014 are shown below with 2006-2010 results for comparison (*from* Timko et al. 2011). At each dam, powerhouse passage includes fish that were entrained in the gatewells. Passage events that could not be identified or fish last detected with upstream movement were not included in PRE estimates. ........ D3

Table D.3. The passage route efficiencies (PRE) of downstream migrant yearling Chinook salmon through Wanapum and Priest Rapids dams in 2014 are shown below with 2006-2010 results for comparison (*from* Sullivan et al. 2009). At each dam, powerhouse passage includes fish that were entrained in the gatewells. Passage events that could not be identified or fish last detected with upstream movement were not included in PRE estimates. ........ D4

Table D.4. The percent zone of entrance efficiency (ZEE) of the Priest Rapids Dam Fish Bypass (2014) and top-spill configuration (2006-2010) for steelhead and yearling Chinook salmon. ........ D5

Table D.5. Fish collection efficiency (FCE) of steelhead and yearling Chinook salmon smolts at the Priest Rapids Dam Fish bypass (2014) and 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). ........ D5

Table D.1. The passage route efficiencies (PRE) of downstream migrant steelhead through Wanapum Dam in 2014 are shown below with 2006-2010 results for comparison (*from* Timko et al. 2011) [3]. At each dam, powerhouse passage includes fish that were entrained in the gatewells. Passage events that could not be identified or fish last detected with upstream movement were not included in PRE estimates. In 2006-2007, a prototype fish bypass was used for surface passage of smolts at the sluiceway along with a top-spill bulkhead at Spill Bay 12.

| Year | Passage Route | $n_i$ | $n_{total}$ | $PRE_i$ |
|---|---|---|---|---|
| *Wanapum Dam* | | | | |
| 2014 | Powerhouse | 162 | 362 | 44.8% |
| | Fish Bypass | 36 | 362 | 9.9% |
| | Spillway | 164 | 362 | 45.3% |
| | *Non-Turbine Passage* | *200* | | *55.2%* |
| 2010 | Powerhouse | 128 | 563 | 22.7% |
| | Fish Bypass | 435 | 563 | 77.3% |
| | Spillway | 0 | 563 | 0.0% |
| 2009 | Powerhouse | 218 | 731 | 29.8% |
| | Fish Bypass | 513 | 731 | 70.2% |
| | Spillway | 0 | 731 | 0.0% |
| 2008 | Powerhouse | 179 | 550 | 32.5% |
| | Fish Bypass | 300 | 550 | 54.5% |
| | Spillway | 71 | 550 | 12.9% |
| 2007 | Powerhouse | 749 | 1135 | 66.0% |
| | Top-Spill (SB12)/Sluiceway | 305 | 1135 | 26.9% |
| | Spillway | 81 | 1135 | 7.1% |
| 2006 | Powerhouse | 150 | 319 | 47.0% |
| | Top-Spill (SB12)/Sluiceway | 116 | 319 | 36.4% |
| | Spillway | 53 | 319 | 16.6% |

[3] Analysis has been refined thus numbers reported in this table differ slightly than reported in prior years (Timko et al. 2011).

Table D.2. The passage route efficiencies (PRE) of downstream migrant steelhead through Priest Rapids Dam in 2014 are shown below with 2006-2010 results for comparison (*from* Timko et al. 2011)[4]. At each dam, powerhouse passage includes fish that were entrained in the gatewells. Passage events that could not be identified or fish last detected with upstream movement were not included in PRE estimates.

| Year | Passage Route | $n_i$ | $n_{total}$ | $PRE_i$ |
|---|---|---|---|---|
| *Priest Rapids Dam* | | | | |
| 2014 | Powerhouse | 332 | 1075 | 30.9% |
| | Fish Bypass | 507 | 1075 | 47.2% |
| | *Spillway* | 236 | 1075 | 22.0% |
| | *Non-Turbine Passage* | *743* | | *69.1%* |
| 2010 | Powerhouse | 469 | 1105 | 42.4% |
| | Top-Spill Prototype Bypass | 635 | 1105 | 57.5% |
| | Spillway | 1 | 1105 | 0.1% |
| 2009 | Powerhouse | 612 | 1254 | 48.8% |
| | Top-Spill Prototype Bypass | 641 | 1254 | 51.1% |
| | Spillway | 1 | 1254 | 0.1% |
| 2008 | Powerhouse | 607 | 1062 | 57.2% |
| | Top-Spill Prototype Bypass | 370 | 1062 | 34.8% |
| | Spillway | 85 | 1062 | 8.0% |
| 2007 | Powerhouse | 785 | 976 | 80.4% |
| | Top-Spill Prototype Bypass | 187 | 976 | 19.2% |
| | Spillway | 4 | 976 | 0.4% |
| 2006 | Powerhouse | 446 | 610 | 73.1% |
| | Top-Spill Prototype Bypass | 95 | 610 | 15.6% |
| | Spillway | 69 | 610 | 11.3% |

[4] Analysis has been refined thus numbers reported in this table differ slightly than reported in prior years (Timko et al. 2011).

Table D.3. The passage route efficiencies (PRE) of downstream migrant yearling Chinook salmon through Wanapum and Priest Rapids dams in 2014 are shown below with 2006-2010 results for comparison (*from* Sullivan et al. 2009)[5]. At each dam, powerhouse passage includes fish that were entrained in the gatewells. Passage events that could not be identified or fish last detected with upstream movement were not included in PRE estimates.

| Year | Passage Route | $n_i$ | $n_{total}$ | $PRE_i$ |
|---|---|---|---|---|
| *Wanapum Dam* | | | | |
| 2014 | Powerhouse | 234 | 361 | 65.0% |
| | Fish Bypass | 27 | 361 | 7.5% |
| | Spillway | 99 | 361 | 27.5% |
| | *Non-Turbine Passage* | *126* | | *35.0%* |
| 2008 | Powerhouse | 455 | 984 | 46.2% |
| | Fish Bypass | 290 | 984 | 29.5% |
| | Spillway | 239 | 984 | 24.3% |
| *Priest Rapids Dam* | | | | |
| 2014 | Powerhouse | 380 | 1088 | 34.9% |
| | Fish Bypass | 415 | 1088 | 38.1% |
| | Spillway | 293 | 1088 | 26.9% |
| | *Non-Turbine Passage* | *708* | | *65.1%* |
| 2008 | Powerhouse | 600 | 898 | 66.8% |
| | Top-Spill Prototype Bypass | 219 | 898 | 24.4% |
| | Spillway | 79 | 898 | 8.8% |
| 2007 | Powerhouse | 738 | 853 | 86.5% |
| | Top-Spill Prototype Bypass | 110 | 853 | 12.9% |
| | Spillway | 5 | 853 | 0.6% |
| 2006 | Powerhouse | 326 | 458 | 71.2% |
| | Top-Spill Prototype Bypass | 57 | 458 | 12.4% |
| | Spillway | 75 | 458 | 16.4% |

[5] Analysis has been refined thus numbers reported in this table differ slightly than reported in prior years (Sullivan et al.2009; Timko et al. 2010, 2011).

Table D.4. The percent zone of entrance efficiency (ZEE) of the Priest Rapids Dam Fish Bypass (2014) and top-spill configuration (2006-2010) for steelhead and yearling Chinook salmon.

| Year | Steelhead | Yearling Chinook salmon |
|---|---|---|
| 2014 | 72.50% | 65.20% |
| 2010 | 77.80% | |
| 2009 | 71.50% | |
| 2008 | 41.60% | 39.10% |
| 2007 | 42.20% | 27.10% |
| 2006 | 39.60% | 36.90% |

Table D.5. Fish collection efficiency (FCE) of steelhead and yearling Chinook salmon smolts at the Priest Rapids Dam Fish bypass (2014) and 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) | 2014 | 2010 | 2009 | 2008 | 2007 | 2006 |
|---|---|---|---|---|---|---|
| Steelhead | | | | | | |
| 50 | 98.1% | 98.0% | 99.8% | 100.0% | 97.9% | 97.3% |
| 100 | 88.9% | 88.3% | 94.3% | 94.9% | 87.6% | 81.3% |
| 150 | 77.3% | 83.0% | 85.9% | 87.6% | 69.5% | 63.1% |
| 200 | 69.8% | 77.1% | 77.4% | 77.2% | 50.9% | 52.9% |
| 250 | 65.4% | 72.8% | 70.9% | 67.4% | 40.8% | 44.8% |
| 300 | 64.0% | 68.9% | 66.0% | 58.9% | 33.7% | 39.4% |
| Yearling Chinook salmon | | | | | | |
| 50 | | | | 100.0% | 97.1% | 93.4% |
| 100 | | | | 81.3% | 75.6% | 82.6% |
| 150 | | | | 55.6% | 57.6% | 57.0% |
| 200 | | | | 43.1% | 45.0% | 46.0% |
| 250 | | | | 36.7% | 36.2% | 38.5% |
| 300 | | | | 31.1% | 29.3% | 32.9% |

**Project Title:** **Evaluation of Foraging Behavior, Dispersal, and Predation on ESA-listed Salmonids from the Upper Columbia River by Caspian Terns Displaced from Managed Colonies in the Columbia Plateau Region**

**Date Submitted:** November 17, 2014

**Project Sponsors:** Oregon State University (OSU), U.S. Geological Survey-Oregon Cooperative Fish and Wildlife Research Unit (USGS), and Real Time Research, Inc. (RTR)

**Project Leaders:** Daniel D. Roby, OSU and USGS (daniel.roby@oregonstate.edu)
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**Project Liaison:** Curtis Dotson, Public Utility District No. 2 of Grant County, Washington (cdotson@gcpud.org)

**Project Type:** Avian predation research, monitoring, and evaluation

**Project Duration:** February 1, 2015 – January 31, 2016, with the option to extend project duration if deemed necessary

**Project Cost**
**Year 1 (CY13):** **$457,465**
**Year 2 (CY14):** **$834,223**
**Year 3 (CY15):** **$1,244,000 (estimate)**

**Location:** Research would be conducted at Goose Island in Potholes Reservoir, WA and Crescent Island in McNary Reservoir, WA; these two Caspian tern colonies are slated for management activities in 2015. Research and monitoring will also be conducted at un-managed bird colonies that pose a potential risk to the survival of juvenile salmonids originating from the upper Columbia River, with emphasis on impacts on smolt survival in the vicinity of the Wanapum-Priest Rapids Project. Tagging and release of juvenile steelhead and yearling Chinook salmon to evaluate impacts of predation by Caspian terns and other piscivorous colonial waterbirds will be conducted at Rock Island Dam, WA. Dispersal of Caspian terns from the Goose Island and Crescent Island colonies will be evaluated via satellite telemetry and resighting of banded birds, and will include investigations of dispersal to other locations along the mid-Columbia River, elsewhere in the Columbia Plateau region, as well as outside the Columbia River Basin.

**Short Description:** In Year 3 of this study, we propose to evaluate the efficacy of implemented management actions for reducing avian predation on juvenile salmonids in the Columbia Plateau region. Specifically, this study is designed to evaluate dispersal of and changes in predation rates by Caspian terns (*Hydroprogne caspia*) dissuaded from nesting on Goose Island in Potholes Reservoir, WA (the second year of dissuasion activities) and on Crescent Island in McNary Reservoir, WA (the first year of dissuasion activities). These management actions are part of a management plan to reduce the impact of avian predation on survival of juvenile salmonids (*Oncorhynchus* spp.) from the upper Columbia River. Research and monitoring is focused on Caspian tern predation on two populations of salmonids that are listed under the Endangered Species Act: Upper Columbia River steelhead trout (*O. mykiss*) and Upper Columbia River Chinook salmon (*O. tshawytscha*).

The Goose Island and Crescent Island colonies are the two largest Caspian tern breeding colonies in the Columbia Plateau region; together they comprised 84% of all breeding pairs of Caspian terns in the region during 2014. Caspian terns nesting at Goose Island regularly commute to the mid-Columbia River to consume juvenile salmonids. Losses of Upper Columbia River steelhead and yearling Chinook to predation by Goose Island terns have been substantial, averaging 15.7% and 2.5%, respectively, of available smolts during 2008-2013. In 2014, efforts to dissuade Caspian terns from nesting on Goose Island were partially successful, causing a ca. 60% decline in colony size compared to the average colony size prior to management (ca. 400 nesting pairs during 2008-2013). Tern predation rates on juvenile steelhead and yearling Chinook salmon were also substantially lower in 2014 (ca. 81% and ca. 88% lower, respectively), compared with pre-management estimates during 2008-2013. Data from Caspian terns outfitted with satellite-tracked telemetry tags (satellite tags) at Goose Island in April 2014 indicated that most terns that associated with the Goose Island colony early in the 2014 breeding season remained in the vicinity of Goose Island for, on average, 54% of the smolt outmigration period. Satellite telemetry data also indicated that Caspian terns from Goose Island prospected for nest sites primarily at active colonies elsewhere in the Columbia Plateau region.

In 2014, predation rates on Upper Columbia River steelhead (3.4%; 95% c.i. = 2.4 - 4.9%) by Caspian terns nesting at Crescent Island were higher than average annual predation rates (ca. 2.3%), consistent with compensation for reduced predation by Goose Island terns and a somewhat greater than average number of Caspian terns nesting at Crescent Island in 2014. Of the 198 banded Caspian terns seen at Goose Island in 2013 and resighted in 2014, 26 were confirmed to have nested on Crescent Island in 2014, indicating substantial movement of Caspian terns from the Goose Island colony to the Crescent Island colony. The higher predation rates on Upper Columbia salmonids by Crescent Island Caspian terns in 2014 partially offset the benefits achieved by a smaller Caspian tern colony at Goose Island in 2014. Recoveries of acoustic-tagged (JSATS) fish released by Grant County PUD into the Wanapum-Priest Rapids Project – tags that provide information on where (spatially) and when (temporally) fish are depredated – indicate that Caspian terns nesting on both Goose Island and Crescent Island commuted to the Wanapum-Priest Rapids Project to forage on salmonids in 2014, further demonstrating connectivity between the two nesting sites and between the foraging areas used on the mid-Columbia River by terns from the two sites.

As part of the management effort led by the U.S. Army Corps of Engineers (USACE) and the Bureau of Reclamation (BOR), resource managers are planning to reduce the impacts of Caspian terns that have nested on both Goose Island in Potholes Reservoir (Phase I of the Inland Avian Predation Management Plan) and Crescent Island in McNary Reservoir (Phase II of Inland Avian Predation Management Plan). In 2015, Caspian terns will continue to be dissuaded from nesting on Goose Island via habitat modification (installation of stakes, ropes, and flagging to deter nesting) and human hazing during the nesting season, with dissuasion efforts expanded into the adjacent nesting area used for nesting by Caspian terns in 2014 (a small rocky islet dubbed "Northwest Rocks"). While dissuasion was effective in preventing Caspian terns from nesting in 2014 where they had previously nested on Goose Island, it is uncertain how terns will respond if dissuasion is installed on the entirety of Goose Island and on the surrounding rocky islets, including Northwest Rocks, in 2015. Some Caspian terns with high fidelity to the Goose Island colony may persist in nesting attempts at Goose Island or prospect for nesting opportunities elsewhere in Potholes Reservoir. If hundreds of Caspian terns continue to nest on or near Goose Island, or if dissuaded terns remain in the area and forage on juvenile salmonids in the mid-Columbia River, smolt mortality due to Caspian tern predation may still have a significant impact on survival of out-migrating juvenile salmonids.

Efforts to dissuade Caspian terns from nesting on Crescent Island in McNary Reservoir will also be implemented in 2015, with the objective of significantly reducing the size of the tern colony there. It is unknown how effective dissuasion techniques at Crescent Island may be in reducing the impact of Caspian terns on smolt survival in the mid-Columbia River, as this is the first year of attempts to manage the Crescent Island tern colony. Part of this uncertainty relates to where Caspian terns that are successfully dissuaded from nesting on Crescent Island might choose to nest or forage. As with the Goose Island Caspian tern colony, if hundreds of Caspian terns continue to nest on Crescent Island, or if Caspian terns dissuaded from nesting on Crescent Island remain in the area, predation by Crescent Island terns may still significantly impact the survival of juvenile salmonids in the mid-Columbia River, including those populations from the Upper Columbia River. Given the high degree of connectivity between the Caspian tern colonies at Goose Island and Crescent Island, effective dissuasion at one site may induce more terns to prospect for nesting opportunities at the other site. If terns are effectively dissuaded from nesting at both sites, hundreds of pairs of Caspian terns may be prospecting for alternative nest sites elsewhere within the Columbia Plateau region.

As part of Year 3 of this study, we propose to investigate the outcome of management initiatives directed at Caspian terns nesting on Goose and Crescent islands. At these managed tern colony sites we propose to collect data on (1) habitat use by prospecting Caspian terns in response to dissuasion activities, (2) colony size and nesting success of any Caspian terns that continue to nest on either island, and (3) stock-specific predation rates on salmonid smolts by any Caspian terns that remain at or near either colony during the 2015 breeding season. To assess dispersal patterns and foraging locations of Caspian terns dissuaded from nesting on Goose Island or Crescent Island, terns prospecting at both colony sites would be tracked using satellite telemetry throughout the 2015 nesting season. To supplement data from satellite-tagged Caspian terns, re-sighting efforts for Caspian terns banded with field-readable leg bands would be conducted at Goose Island, Crescent Island, and other Caspian tern colonies in the Columbia Plateau region, as well as throughout the Pacific Northwest. These data would provide valuable information on colony connectivity in the region and identification of colony sites where managed Caspian terns from the Goose Island or Crescent Island colonies relocate to nest. To evaluate stock-specific predation rates on ESA-listed steelhead and yearling Chinook smolts by Caspian terns from managed colonies, a representative sample of smolts would be PIT-tagged at Rock Island Dam throughout the duration of the 2015 out-migration. Recoveries of smolt PIT tags on managed Caspian tern colonies, and at other un-managed bird colonies within foraging range of the Wanapum-Priest Rapids Project, would be used to assess the impact of avian predation on survival of juvenile salmonids. Total mortality of steelhead and yearling Chinook smolts in the Wanapum-Priest Rapids Project and the proportion of that mortality that is due to predation by Caspian terns and other piscivorous colonial waterbirds would be compared to evaluate whether Caspian tern management activities result in commensurate increases in smolt survival. In summary, results from this proposed study in 2015 would help determine the efficacy of on-going (Goose Island) and newly implemented (Crescent Island) management efforts developed by resource managers to reduce Caspian tern predation on juvenile salmonids in the mid-Columbia River.

This research proposal assumes that there would be no cost-sharing from the federal action agencies (i.e., USACE – Walla Walla District, Bureau of Reclamation) to accomplish the RM&E described in this proposal for 2015. If cost-sharing does occur, it will likely reduce the scope and cost of the work proposed here. Regardless of the extent of cost-sharing, the work proposed here would need to be closely coordinated with the federal action agencies charged with implementing any management initiatives at the Goose Island and Crescent Island colonies in 2015 so that the RM&E proposed here does not restrict, inhibit, or in any way compromise the implementation and/or evaluation of management actions at the Caspian tern colonies on Goose Island and Crescent Island.

**Project Background:** Avian predation is a factor limiting the recovery of some salmonid populations from the Columbia River basin that are listed under the U.S. Endangered Species Act (Collis et al. 2002; Lyons et al. 2011; Evans et al. 2012). Caspian terns, double-crested cormorants (*Phalacrocorax auritus)*, American white pelicans (*Pelecanus erythrorhynchos*), and several species of gulls (*Larus* spp*.)* have all been identified as predators of anadromous juvenile salmonids in the Columbia Plateau region. Of these avian predators, Caspian terns have been determined to have the highest per capita (per bird) impacts on survival of juvenile salmonids, especially steelhead, a salmonid species known to be particularly susceptible to tern predation (Collis et al. 2001; Antolos et al. 2005; Evans et al. 2012). Predation by other avian predators, however, can be substantial due to the large size (number of breeding individuals) of these colonies in the Columbia River Basin (thousands of adults; Adkins et al., In press; Hostetter et al., In press).

Caspian terns are colonial fish-eating waterbirds that nest along coastlines, in estuaries, and at inland sites on major rivers and lakes (Cuthbert et al. 1999). The breeding season for Caspian terns is generally from April to July (Cuthbert et al. 1999). Caspian terns are considered strictly piscivorous and forage by plunge-diving into the water to capture fish near the surface. Records of Caspian terns nesting in southeastern Washington in the Columbia Plateau region date back to 1929 (Kitchin 1930), when a small nesting colony of Caspian terns was observed on Moses Lake, Washington. Recently, Adkins et al. (In press) reported five different Caspian tern colonies in the Columbia Plateau region during 2004-2009, ranging in size from an average of six breeding pairs at Sprague Lake, Washington to an average of over 400 breeding pairs on Crescent Island in the McNary Dam Reservoir.

The two largest Caspian tern colonies in the Columbia Plateau region are located on Goose Island in Potholes Reservoir, WA, with an average colony size of 404 breeding pairs during 2008-2013, and on Crescent Island in McNary Reservoir, with an average of 391 breeding pairs during 2008-2013 (BRNW 2013). Caspian terns nesting on Goose Island are known to commute at least 30 km from Potholes Reservoir to the mid-Columbia River to consume anadromous juvenile salmonids (Maranto et al. 2010). Since 2008 and prior to recent tern management activities on Goose Island, estimated predation rates (number consumed/number available) on ESA-listed steelhead and Chinook salmon from the Upper Columbia River populations have averaged 15.7% and 2.5%, respectively, with predation rates as high as 20% in some years (Evans et al. 2012; BRNW 2013). Lyons et al. (2011) estimated that the annual population growth rate (λ) of Upper Columbia steelhead would be increased by 4.2% for hatchery-raised smolts and 3.2% for wild smolts, if predation by Caspian terns nesting at the Goose Island colony was eliminated and compensatory mortality did not occur.

Survival standards for juvenile salmonids established under the 2004 Biological Opinion for the Wanapum-Priest Rapids Project (Wanapum and Priest Rapids dams and reservoirs) require at least 93% survival for juvenile salmonids through each hydropower development (one dam and associated reservoir; NMFS 2004). To evaluate whether these standards were met, Grant County Public Utility District (GPUD) No. 2 conducted salmonid survival studies during 2008-2010 and again in 2014 within the Wanapum-Priest Rapids Project. Survival studies utilized double-tagged (acoustic tag and passive integrated transponder [PIT] tag) smolts to track fish behavior (travel times and routes) and estimate survival (Timko et al. 2011). Results indicated that survival standards for steelhead were not being met in the Priest Rapids development during 2008-2010 and in the Wanapum development in 2010 (Thompson et al. 2012). Estimates of predation rates by Goose Island Caspian terns on steelhead smolts tagged and released by the GPUD during these years ranged from 12.8% to 20.8% of available steelhead smolts below Rock Island Dam (Evans et al. 2013), indicating that predation by Caspian terns was a substantial source of smolt mortality within the Priest Rapids Project. Comparisons between total steelhead mortality and mortality caused by Caspian tern predation indicated that between 37% and 85% of all steelhead mortality in the Wanapum-Priest Rapids Project during 2008-2010 was attributable to predation by Caspian terns from Goose Island colony (Evans et al. 2013).

Resource management agencies are now implementing a management plan aimed at reducing the impacts of Caspian terns that nest in the Columbia Plateau region (i.e., colonies on Goose and Crescent islands) on the survival of ESA-listed salmonids, in particular, steelhead smolts originating from the upper Columbia River and lower Snake River. In 2014, the USACE and BOR began implementation of Phase I of the Inland Avian Predation Management Plan (USACE 2014) by reducing nesting habitat and actively discouraging Caspian terns from nesting on Goose Island in Potholes Reservoir. Proposed management initiatives are focused on reducing Caspian tern predation on Columbia Basin salmonids without adversely affecting the Caspian tern population in western North America. Achieving these objectives will require (1) redistribution of Caspian terns from breeding colony sites in the Columbia Plateau region to multiple dispersed colony sites elsewhere within their breeding range (USFWS 2005; Collis et al. 2012) and (2) identifying specific sites on the mid-Columbia River where Caspian tern predation pressure on smolts is high and implementing measures (i.e., adaptive management) to protect smolts at those locales. Additionally, actions taken as part of the Inland Avian Predation Management Plan are best considered in the context of Caspian tern management at the large breeding colony on East Sand Island in the Columbia River estuary and elsewhere in the Pacific Region. Actions taken on East Sand Island and elsewhere have the potential to cause changes in colony size and impacts from Caspian tern predation for colonies in the Columbia Plateau region. Efforts to better understand colony connectivity, dispersal, foraging locations, and impacts on survival of salmonid stocks (predation rates) by Caspian terns from managed colonies would be instrumental in determining the efficacy of management actions in 2015 and beyond.

In addition to the results discussed above, this project has provided novel findings of relevance to the enhancement of Upper Columbia River steelhead trout and Chinook salmon populations. For instance, predation on PIT-tagged steelhead released from Rock Island Dam by gulls nesting on Crescent Island (5.6%; 95% c.i. = 3.4 - 8.7%) was greater than that of Caspian terns nesting on Crescent Island (2.8%; 95% c.i. = 2.2 - 3.5%) in 2013. Caspian terns nesting on Twinning Island in Banks Lake consumed an estimated 1.1% (95% c.i. = 0.4 - 2.7%) of tagged steelhead released below Rock Island Dam in 2014, including predation of JSATS-tagged steelhead within the Wanapum-Priest Rapids Project. Cumulative impacts from un-managed bird colonies can also be substantial, with upwards of 15% and 5% of steelhead and yearling Chinook, respectively, released below Rock Island Dam consumed by birds nesting at un-managed colonies in the Columbia Plateau region during previous years (BRNW 2012 and 2013). These results indicate that concerns over avian predation in the Columbia Plateau region are not limited to Caspian terns nesting on Goose and Crescent islands; impacts from Caspian terns nesting at other colonies (e.g., Twinning Island in Banks Lake) and from other colonial waterbird species are comparable to or even greater than those documented for Caspian terns nesting on Goose and Crescent islands (USACE 2014; Hostetter et al., In press).

In 2014, tracking of Caspian terns outfitted with satellite telemetry tags was demonstrated to be an effective technique for assessing the efficacy of tern management efforts. Prior to active dissuasion activities at Goose Island, a sample of Caspian terns (n = 28) was captured and outfitted with satellite tags to track their individual responses to dissuasion. Tags were programed on a 28-hour cycle, with an on-period of 6 hours and an off-period of 22 hours. Preliminary results indicate that a majority of tagged Caspian terns remained in the Columbia Plateau region throughout the smolt outmigration period (April – May). On average, satellite-tagged terns were present in the Columbia Plateau region during 90% of periods when the tag was on (range: 6 – 100%, with 14 individuals present during 100% of periods when tag was on). At a smaller scale, on average, tagged terns were present in the foraging area of Caspian terns nesting at Goose Island (characterized using Global Positioning System [GPS] tags deployed on terns nesting at Goose Island in 2013) during 58% of periods when the tag was on during the smolt out-migration period (range = 6 – 100%). Most satellite-tagged terns visited several active or historical Caspian tern colony sites within the Pacific Region during the breeding season; however, extended associations with alternative colonies (i.e. potential nesting attempts) occurred primarily at just four other colonies in the Columbia Plateau region (Banks Lake, Sprague Lake, Crescent Island, and the Blalock Islands). In addition to these observations, satellite-tracking of tagged Caspian terns demonstrated that this technique can be used to identify foraging hotspots on the mid-Columbia River in near real-time, including foraging hotspots in the Wanapum-Priest Rapids Project. Satellite-tracking is also a technique that can identify incipient Caspian tern nesting efforts in new or unmonitored colony sites as they occur (in near real-time).

**Project Tasks:** The work proposed here is part of a comprehensive project to evaluate avian predation and management efficacy throughout the Columbia River basin. The research, monitoring, and evaluation proposed here would be a continuation of work funded by the PRCC during 2013-2014, along with funding from other sources (U.S. Army Corps of Engineers, Bonneville Power Administration, and Bureau of Reclamation). Collectively our research group would evaluate Caspian tern nesting ecology, dispersal patterns, and impacts of tern predation on smolts at numerous breeding colonies both within and outside the Columbia River basin. Studies at other Caspian tern colonies provide the cost-sharing needed to fully implement the work proposed as part of this study (e.g., colony connectivity and movement rates of individual Caspian terns to and from the Columbia Plateau region). Increased management activity (Phase II) and new research tasks that are described above require an increase in the proposed budget for funding from the PRCC to conduct avian predation studies in 2015, compared to 2013 and 2014.

The proposed tasks for Year 3 of this study (CY15) are:

**Task 1: Monitor effects of Caspian tern management activities at the Goose Island and Crescent Island colonies.**

*Description*: We would assist the action agencies (Bureau of Reclamation and Corps of Engineers) in deploying passive dissuasion materials (pier blocks, wooden stakes, polypropylene rope, and surveyor's flagging, willow plantings, or others as directed by the action agencies) on the Caspian tern colonies at Goose Island and Crescent Island and nearby areas prior to the onset of the 2015 nesting season. At Goose Island in 2014, a 2.39-acre area was covered with passive dissuasion materials, including all areas where Caspian terns had historically nested on Goose Island, plus buffers around these former nesting areas. In 2015, this effort will be expanded to include the 2014 nesting area (Northwest Rocks) and any other area necessary to prevent Caspian tern nesting on or immediately adjacent to Goose Island. At the request of the action agencies, we would purchase any additional necessary passive dissuasion materials and transport these materials to Goose Island prior to the 2015 nesting season, with the assistance and cooperation of the action agencies. Our group would also provide personnel to assist the action agencies in erecting the passive dissuasion prior to the onset of nesting by gulls and terns on the island. If directed by the action agencies, we would assist with the deployment of passive dissuasion materials on the Caspian tern colony at Crescent Island and in surrounding areas.

In addition to assisting with deployment of passive dissuasion materials on the Goose Island Caspian tern colony, colony monitors would maintain the passive dissuasion materials as needed and would supplement the passive dissuasion with active dissuasion (human hazing), if needed to prevent nesting by Caspian terns. This active dissuasion would cease as soon as a Caspian tern egg, or a California or ring-billed gull egg, is laid in an area where active dissuasion is being used. In 2014, Caspian tern hazing activities on Goose Island were eventually constrained by gulls laying eggs, but Caspian terns laid only three eggs on the main Goose Island, all of which were quickly collected under permit. If directed by the action agencies, we would advise and assist any hazing efforts implemented at Crescent Island.

Regular visits to the Caspian tern colony on Goose Island during passive and active dissuasion and throughout the breeding season would be used to assess Caspian tern colony size (number of breeding pairs), seasonal colony attendance (number of adult terns on-colony), nesting habitat use, and nesting success (number of young terns raised per breeding pair; for detailed methods, see Roby et al. 2012). High-resolution aerial photography of the Goose Island tern colony during late incubation would be used to determine nesting habitat use, peak colony size, and peak nesting density. These measures would be compared to data from breeding seasons prior to management (2010-2013) to assess changes in these metrics post-management. We would conduct similar efforts at Crescent Island, as directed by the action agencies.

In addition to the above-mentioned standard measures of colony performance, we would record and map the distribution and timing of tern loafing and nest initiation on Goose Island to determine where on the island passive dissuasion techniques are ineffective. Behavioral interactions between Caspian terns, ring-billed gulls, and California gulls (two nesting gull species not targeted for management on Goose Island or Crescent Island) that might influence the behavior and distribution of nesting Caspian terns would also be noted. We would conduct similar efforts at Crescent Island, as directed by the action agencies.

To measure Caspian tern movement rates and colony connectivity, we would re-sight Caspian terns that were previously banded at the Goose Island and Crescent Island colonies with field-readable plastic leg bands at other breeding colonies (e.g., East Sand Island in the Columbia River estuary, Crescent Island on the mid-Columbia River, Goose Island in Potholes Reservoir, and other Columbia Plateau colonies, as appropriate). These data would be important for determining where Caspian terns displaced from the Goose Island and Crescent Island colonies are recruiting back into the breeding population. These data could also determine to what extent Caspian terns displaced from either Goose Island, Crescent Island, or East Sand Island, all colonies where active tern management is on-going, relocate to other colonies in the Columbia Plateau region and, therefore, continue to pose a threat to survival of ESA-listed juvenile salmonids in the mid-Columbia River.

The effects of dissuasion on the diet and foraging behavior of Caspian terns from the Goose Island and/or Crescent Island colony would be determined by quantifying the taxonomic composition of the tern diet, if feasible. Diet composition would be measured by direct observation of adults as they return to the colony with fish in their bills (i.e., bill-load observations). Prey items would be identified to the taxonomic level of family, genus, or species depending on individual characteristics of each fish (see Antolos et al. 2005). If a sizable Caspian tern colony persists at Goose Island despite dissuasion efforts, estimates of the numbers of salmonid smolts consumed and consumption of other fish species of conservation concern (e.g., lamprey) would be calculated using a bioenergetics modeling approach (Roby et al. 2003; Antolos et al. 2005). The bioenergetics model relies on measurements of a number of input variables, including (1) the numbers of fish-eating waterbirds present (adults and chicks), (2) the waterbirds' daily energy requirements, (3) the waterbirds' diet composition, and (4) the energy content of smolts and the other prey types consumed. Many of these input variables vary across the season, so accurate estimates of smolt consumption rely on data collected throughout the period when birds are nesting (April through July).

Diet composition and prey consumption data collected in 2015 would be compared to results from 2010-2013. Comparisons of diet composition and smolt consumption data collected in 2015 with those data from 2010-2013 can also be used to evaluate the efficacy of other Caspian tern management initiatives in the region. Specifically, might management actions implemented to reduce Caspian tern predation on juvenile salmonids in the Columbia River estuary increase the number of ESA-listed salmonids consumed by Caspian terns in the Columbia Plateau region?

**Task 2: Determine dispersal patterns (spatial and temporal) of Caspian terns in relation to management activities on the Goose Island and Crescent Island colonies.**

*Description*: To track Caspian tern dispersal patterns in response to nesting dissuasion, solar-charging satellite telemetry tags (Microwave Telemetry, Inc., Columbia, MD) would be affixed to up to 28 Caspian terns captured on the Goose Island colony site and an additional 28 terns captured on the Crescent Island colony site during the nest initiation period (April). A sufficient number of new satellite tags would be deployed at Goose Island to restore a sample size of 28 individuals with a history of nesting there, depending on how many tags deployed in 2014 were still functional and providing data. (As of 11/17/2014, 24 of 28 tags deployed in 2014 were still providing location data.) These new satellite tags would be programmed to collect location data at a moderate frequency during both daytime and nighttime periods (e.g., a duty cycle consisting of 6 hours on, 22 hours off). Daytime locations would indicate general regions where terns are foraging (e.g., specific areas on the mid-Columbia River). Nighttime locations would indicate where terns are roosting or nesting (e.g., colony sites that displaced terns have dispersed to). Tags that transmit location data to the Argos satellite network allow the tracking of birds that remain within the Columbia Plateau region, as well as those individuals that leave the region. All location data are transmitted to satellites for electronic delivery to researchers within a few days of collection. No recapture and handling of the tagged terns is required following initial capture and tag deployment.

Terns would be captured at the Goose Island and Crescent Island colony sites using a compressed air-powered net launcher, noose mats, or other trapping techniques in a small section of each former colony area temporarily left open to facilitate trapping of prospecting adult terns. Once the capture and tagging effort is complete, the capture area would be closed off using dissuasion materials similar to those used elsewhere on the island (e.g., ropes and flagging). This technique was used successfully at Goose Island in 2014 to capture and satellite – tag 28 Caspian terns over a 9-day period ending on April 11$^{th}$. Terns were quickly dissuaded from the capture area following completion of capture efforts and no terns initiated nests (i.e. no tern eggs were laid) in the capture area.

All Caspian terns affixed with satellite tags, and any surplus handled during the capture effort, would be fitted with field-readable leg bands to allow ready identification of individuals using binoculars and spotting scopes. Terns banded in 2014, along with cohorts banded in previous years, offer an additional opportunity to determine dispersal patterns of Caspian terns leaving the Goose Island colony. Research crews conducting work at other Caspian tern colonies on the Columbia River (Crescent Island in the mid-Columbia River, East Sand Island in the estuary) and tern colonies outside the Columbia River basin (Malheur National Wildlife Refuge [Oregon], Upper Klamath Basin [Oregon and California], and others) would be able to document dispersal to these alternative colonies, if it occurs.

Site visits would be conducted at locations along the mid-Columbia River, and across the Columbia Plateau region where terns are frequently observed, to assess tern behavior (i.e., foraging, loafing, or nesting) and to survey for additional (un-tagged) terns. Such information would be important for identifying potential foraging hotspots or incipient alternative nesting sites.

**Task 3: Determine changes in predation rates on salmonid smolts by Caspian terns in relation to management activities on Goose and Crescent islands.**

*Description*: The methods of Evans et al. (2012) and Hostetter et al. (In press) would be used to calculate predation rates on salmonid species (Chinook, coho, sockeye, and steelhead) and ESA-listed populations (DPS/ESUs; where adequate sample sizes allow), based on recoveries of salmonid Passive Integrated Transponder (PIT) tags on the Goose Island and Crescent Island tern colonies in 2015. The detection of smolt PIT tags on Caspian tern colonies, along with release and in-river interrogation data from fish passing Rock Island Dam (the upper-most foraging range for Goose Island terns foraging on the Columbia River), would be used to estimate predation rates and to evaluate the relative susceptibility of various salmonid species, stocks, run-types, and rearing-types (hatchery, wild) to Caspian tern predation in 2015. Species- and stock-specific predation rates on salmonids by Caspian terns in 2015 would be compared to results from previous years (2008-2013 [pre-management] and 2014 [management of Goose Island only]) to document changes, with the goal of determining the efficacy of tern management activities in reducing predation on juvenile salmonids.

To increase the precision of predation rate estimates, and to minimize potential biases resulting from small sample sizes, predation rate estimates should be calculated from large releases of PIT-tagged fish (Evans et al. 2012). These fish should be randomly-selected for tagging (e.g., tagged regardless of their condition, origin, and size) and tagged in concert with, and in proportion to, the run at-large to ensure that the tagged sample is representative of the entire smolt population (tagged and untagged) passing through the Wanapum-Priest Rapids Project. To ensure that an adequate sample size and a representative sample of PIT-tagged steelhead and yearling Chinook salmon are available for this study in 2015, we propose to continue to PIT-tag about 7,000 run-of-river juvenile steelhead and 5,500 run-of-river yearling Chinook salmon at Rock Island Dam in 2015. These sample sizes would result in estimates of predation rates with a precision of approximately ± 3% for steelhead and ± 1% for Chinook salmon per bird colony (see BRNW 2013 for details).

The intentional tagging of steelhead and yearling Chinook salmon at Rock Island Dam provides data to evaluate not only Caspian tern predation rates associated with the Goose Island and Crescent Island colonies, but also predation associated with other Caspian tern colonies and colonies of other piscivorous waterbirds (e.g., double-crested cormorants, California gulls, ring-billed gulls, and American white pelicans) nesting in the Columbia Plateau region and elsewhere on the lower Columbia River (e.g., Columbia River estuary). For instance, PIT tags implanted in steelhead and yearling Chinook at Rock Island Dam in 2014 were recovered on 14 different bird colonies, ranging from Caspian terns nesting on Twinning Island on Banks Lake, WA to double-crested cormorants nesting on East Sand Island in the Columbia River estuary. These data can then be used to evaluate cumulative impacts of avian predation on smolts throughout their freshwater out-migration, data needed to document mortality factors both within and outside of the Wanapum-Priest Rapids Project (see Task 5 for details about evaluating impacts from un-managed bird colonies).

**Task 4. Determine changes in total reservoir-specific mortality within the Wanapum-Priest Rapids Project in relation to Caspian tern management activities on Goose and Crescent islands.**

In addition to calculating species and stock-specific predation rates on juvenile salmonids by Caspian terns, an overall measure of smolt mortality in the Wanapum-Priest Rapids Project may be paramount for documenting the efficacy of Caspian tern management to increase smolt survival. For example, reductions in the numbers of Caspian terns nesting on Goose Island and Crescent Island should result in commensurate increases in smolt survival, if displaced terns relocate to and forage in out-of-basin locations following dissuasion. To address this critical question and to document where (spatially) and when (temporally) within the Wanapum-Priest Rapids Project steelhead and yearling Chinook are depredated by terns, we propose to again collaborate with researchers conducting Juvenile Salmonid Acoustic Telemetry System (JSATS) survival studies on steelhead and yearling Chinook smolts in 2015. Specifically, we would compare estimates of total mortality of steelhead and yearling Chinook smolts (1-survival) derived from JSATS-tagged fish to estimates of smolt mortality attributable to Caspian terns. Because JSATS-tagged fish are also PIT-tagged (i.e., double tagged), we can estimate the location within the Wanapum-Priest Rapids Project where JSATS-tagged steelhead and yearling Chinook are depredated, based on tags subsequently recovered from bird colonies (see Evans et al. 2013 for details).

The methods of Evans et al. (2013) would be used to calculate reservoir-specific (Wanapum and Priest Rapids) and Project-specific predation rates by terns nesting at managed colonies (Goose Island and Crescent Island) based on releases and recoveries of JSATS-tagged steelhead and yearling Chinook, as part of the 2015 Grant County Public Utility District survival study. The methods of Timko et al. (2011) would be used to estimate total steelhead and yearling Chinook mortality in these same reaches. Reservoir- and project-specific estimates of Caspian tern predation rates and total mortality from 2015 would be compared to similar datasets and analyses conducted during 2014 (Phase I management) and 2008-2010 (pre-management conditions).

*NOTE: Methods of estimating avian predation rates rely on large samples from a single-release/recapture model (Evans et al. 2012), while JSATS-based survival estimates use smaller numbers of fish and a paired-release model (Timko et al. 2011). Although these differences do* *not preclude calculating avian predation rates on JSATS-tagged fish, the number of JSATS-tagged fish available is often too small to generate precise estimates. For example, only ~ 1,000 JSATS-tagged fish are needed to generate precise survival estimates, but > 5,000 tagged fish are needed to generate precise avian predation rates. As such, proposed releases of JSATS-tagged fish in 2015 are inadequate for precise estimates of avian predation rates, but are critical to determining where (spatially) and when (temporally) predation events occurs within the Wanapum-Priest Rapids Project. Consequently, Task 3 (PIT-tagging at Rock Island Dam) and Task 4 (JSATS-tagging by GPUD) are complementary, not duplicative, efforts.*

**Task 5. Determine changes in colony size, colony connectivity, and predation rates (if warranted) at un-managed piscivorous waterbird colonies within foraging distance of the Priest Rapids Project.**

Periodic aerial and ground-based surveys (a total of ca. 6 – 8 surveys, as needed) of un-managed piscivorous waterbird colonies on islands between John Day and Rocky Reach reservoirs and surrounding areas (nesting sites within foraging distance of the mid-Columbia River) would be conducted to determine the size of bird colonies. Surveys would also be conducted at any new or incipient Caspian tern colonies that may have formed, or otherwise unmonitored existing colonies that may have grown as a result of efforts to dissuade terns from nesting at Goose Island and Crescent Island in 2015.

The two managed Caspian tern colonies in the Columbia Plateau region (Crescent Island and Goose Island-Potholes) have served as the nest sites for about 90% of the Caspian terns nesting in the region. Thus, with the advent of Phase II of the Inland Avian Predation Management Plan in 2015, the vast majority of Caspian terns with a history of nesting in the Columbia Plateau region will be displaced from their former breeding sites and will be prospecting for other nesting habitat. While it is likely that many of these prospecting Caspian terns will attempt to nest at other sites with a history of Caspian tern nesting (e.g., the Blalock Islands, Badger Island, Twinning Island, Harper Island), some new nesting areas may also develop. New Caspian tern colonies are likely to form on sites with a history of gull nesting (e.g., Island 20), but completely new colony sites are also possible. For example, Caspian terns nested for the first time on Northwest Rocks next to Goose Island in 2014, likely because suitable nesting habitat on Goose Island was not longer available to Caspian terns with a history of nesting there. Caspian terns also prospected for nest sites at other small islands in Potholes Reservoir, islands with no previous history of gull or tern nesting. Finding, identifying, and monitoring these incipient Caspian tern colony sites would be a major task as part of the proposed project. This effort is crucial for obtaining an accurate picture of the impacts of Caspian tern predation on smolt survival in the mid-Columbia River during 2015, a year of major, but unpredictable, change in the distribution of nesting Caspian terns within the Columbia Plateau region.

The same survey and counting protocols used for Caspian terns and described in Task 1 would be used at un-managed colonies. Counts in 2015 would then be compared to counts in previous years to determine changes in colony size and the region-wide breeding population. Where feasible, resighting of banded Caspian terns would be conducted to assess dispersal from the colonies on Goose and Crescent islands. A portion of these colonies – those within foraging distance of the Wanapum-Priest Rapids Project – would also be scanned for salmonid PIT tags to determine predation rates using methods described under Task 3. Based on preliminary data collected in 2014, existing un-managed bird colonies that pose a potential risk to smolt survival in and around the Wanapum-Priest Rapids project include Caspian terns nesting on islands in Banks Lake, gulls nesting on Island 20 in the Hanford Reach, and gulls nesting on Crescent Island in McNary Reservoir. Finally, JSATS-tagged fish detected on un-managed bird colonies would be used to determine where (spatially) and when (temporally) predation events occurred within the Wanapum-Priest Rapids Project in 2015. Analogous to Task 4, data from other species of avian predators may be essential for evaluating the overall impact of avian predation on smolt survival in 2015.

**Permitting:** All permits needed to conduct this work would be acquired (i.e., for island access: Temporary Use Permits from BOR and USFWS; for steelhead and yearling Chinook tagging: Scientific Collection Permit from WDFW and Take Authorization Letter from NOAA Fisheries; for Caspian tern banding and tagging: Scientific Collection Permit from WDFW and Bird Banding Permit from USGS-Bird Banding Lab).

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| **Key Personnel:** | Grant County PUD | Curtis Dotson, *Project Liaison* |
| | USGS-ORCFWRU/OSU | Daniel D. Roby, *Principal Investigator* |
| | OSU | Donald E. Lyons, *Lead Wildlife Biologist* |
| | RTR | Ken Collis, *Co-Principal Investigator* |
| | RTR | Allen F. Evans, *Lead Fisheries Biologist* |

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| **Schedule (Year 3):** | January-February | Submit required research permits applications |
| | Early January | Order equipment (i.e., satellite tags) |
| | February | Hire field personnel, install passive dissuasion materials |
| | Late March | Begin colony monitoring at Goose and Crescent islands |
| | Early April | Begin PIT-tagging of fish at Rock Island Dam |
| | April | Satellite-tagging of terns on Goose and Crescent islands |
| | August | Complete field work, including PIT tag recovery |
| | Late January | Submit draft annual report |
| | Late February | Submit final annual report |

**Deliverables:** Project results would be made available in a variety of formats. Research results would be presented in (1) a Final Annual Report, (2) weekly summary reports during the field season provided on the project webpage (www.birdresearchnw.org), and (3) presentations at regional planning meetings and other professional meetings, as needed or requested.

- **Estimated Project Cost:** Below is a provisional estimate of the costs for the work described above, separated by task. Costs for each task are not independent from the costs of the other tasks, because some tasks rely on the successful completion of another task. For example, we cannot accomplish Task 2 (dispersal patterns) without completing Task 1 (colony monitoring), and we cannot complete Task 4 (tern predation as a proportion of total smolt mortality) without completing Task 3 (fish PIT-tagging and estimates of tern predation rates).

| Task | Description | Estimated Cost |
|---|---|---|
| 1 | Monitor effects of Caspian tern management activities at the breeding colonies on Goose Island and Crescent Island. | $377,000 |
| 2 | Determine dispersal patterns (spatial and temporal) of Caspian terns in relation to management activities on Goose and Crescent islands. | $412,000 |
| 3 | Determine changes in predation rates by Caspian terns in relation to management activities on Goose and Crescent islands. | $224,000 |
| 4 | Determine changes in total reservoir-specific mortality within the Wanapum-Priest Rapids Project (based on JSATS tags) in relation to Caspian tern management activities on Goose and Crescent islands. | $26,000 |
| 5 | Determine changes in colony size and smolt predation rates (if warranted) at un-managed piscivorous waterbird colonies within foraging distance of the Wanapum-Priest Rapids Project. | $205,000 |
| | **ESTIMATED TOTAL COST** | **$1,244,000** |

Detailed, line item-by-line item budgets, are available upon request.

- **Project Cost-sharing:** The U.S. Army Corps of Engineers is funding the construction and monitoring of alternative Caspian tern colony sites in Don Edwards National Wildlife Refuge in San Francisco Bay in compensation for the dissuasion of Caspian terns nesting at Goose Island-Potholes and Crescent Island in the Columbia Plateau region. The implementation of Phase II of the Inland Avian Predation Management Plan (management to reduce or eliminate the Crescent Island Caspian tern colony) was contingent on completion of these alternative Caspian tern colony sites. The installation of dissuasion to discourage Caspian terns from nesting on Goose Island-Potholes is funded jointly by the USACE-Walla Walla District and the Bureau of Reclamation. The installation of dissuasion to discourage Caspian terns from nesting on Crescent Island is funded by the USACE-Walla Walla District.

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# Survival of Acoustic-Tagged Steelhead and Yearling Chinook Salmon Smolts through the Wanapum – Priest Rapids Project in 2014

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# Executive Summary

## Study Objective

The objectives of the 2014 steelhead and yearling Chinook salmon acoustic-tag studies were to estimate passage survival through the Wanapum Development (one dam and reservoir), Priest Rapids Development (one dam and reservoir), and the Wanapum – Priest Rapids Project (both dams and reservoirs).

## Tag Release Methods

Tag releases of run-of-river steelhead and yearling Chinook salmon smolts were performed at Rock Island, Wanapum, and Priest Rapids tailraces. The paired release-recapture methods of Burnham et al. (1987) were used to estimate passage survival through the Wanapum Development, the Priest Rapids Development, and the Wanapum – Priest Rapids Project. All fish were tagged with the Lotek *Model L-AMT-1.421* acoustic transmitter and a Biomark *Model* BIOMARK *HPT12* PIT tag. Release sizes were 398, 771, and 550 steelhead at Rock Island, Wanapum, and Priest Rapids tailraces, respectively. For yearling Chinook salmon, the release sizes were 398, 768, and 549, respectively.

## Results

### Steelhead

Passage survival for the Wanapum Development was estimated to be $\hat{S}_{\text{WAN}}$ = 0.9294 ($\widehat{SE}$ = 0.0140). Passage survival at Priest Rapids Development was estimated at $\hat{S}_{\text{PR}}$ = 0.9613 ($\widehat{SE}$ = 0.0098). Passage through the Wanapum – Priest Rapids Project was estimated at $\hat{S}_{\text{W-PR}}$ = 0.8934 ($\widehat{SE}$ = 0.0162).

### Yearling Chinook Salmon

Passage survival through the Wanapum Development was estimated to be $\hat{S}_{\text{WAN}}$ = 0.9448 ($\widehat{SE}$ = 0.0128). Passage survival at the Priest Rapids Development was estimated to be $\hat{S}_{\text{PR}}$ = 0.9612 ($\widehat{SE}$ = 0.0087). Survival through the Wanapum – Priest Rapids Project was estimated at $\hat{S}_{\text{W-PR}}$ = 0.9082 ($\widehat{SE}$ = 0.0145).

This report conforms to the guidelines of the Peven et al. (2005) survival studies recommendations.

## Study Summary Sheet 1

| | | | |
|---|---|---|---|
| Year: 2014 | | | |
| Study site(s): Rock Island, Wanapum, and Priest Rapids tailrace release sites | | | |
| Objective of study: Estimate survival (one dam and reservoir) at Wanapum and Priest Rapids developments | | | |
| State hypothesis, if applicable: N/A | | | |
| Fish<br>• Species-race: Steelhead<br>• Source: Wanapum and Priest Rapids gatewells | | | |
| Size (median & range)<br>• Weight (g): 59.0, 22.0–85.5 (Rock Island); 56.5, 21.5–87.5 (Wanapum); 55.5, 23.0–88.0 (Priest Rapids)<br>• Length (mm): 185, 128–215 (Rock Island); 184, 134–217 (Wanapum); 184, 128–217 (Priest Rapids) | | | |
| Tags (Type/model/weight)<br>• PIT Tag: *Biomark, Model* BIOMARK *HPT12*, 12.5 mm, 134.2 kHz, 0.115 g in air<br>• Acoustic tag: *Lotek Wireless*, Model *L-AMT-1.421*, 11.1 mm x 5.5 mm x 3.7 mm, 3-sec burst rate, 0.32 g in air | | | |
| Implant procedure<br>• Surgical: Yes<br>• Injected: No | | | |
| Survival estimate (per species or objective) | | | |
| • Type: | <u>Wanapum Development</u> | <u>Priest Rapids Development</u> | <u>Wanapum – Priest Rapids Project</u> |
| • Value & SE: | 0.9294 (0.0140) | 0.9613 (0.0098) | 0.8934 (0.0162) |
| • Sample sizes: | 398 (RI) | 771 (WAN) | 550 (PR) |
| • Analytical model: Paired release-recapture model | | | |
| Hypothesis test and results (if applicable): N/A | | | |
| Characteristics of estimate<br>• Effects reflected (direct, total, etc.): Total survival<br>• Absolute or relative: Absolute | | | |
| Environmental/operating conditions | | | |
| • Type: Development | <u>Wanapum</u> | | <u>Priest Rapids</u> |
| • Discharge (kcfs; median, range): | 188.5, 162.5–203.7 | | 198.1, 171.3–224.8 |
| Unique study characteristics: N/A | | | |

**Study Summary Sheet 2**

| | | | |
|---|---|---|---|
| Year: 2014 | | | |
| Study site(s): Rock Island, Wanapum, and Priest Rapids tailrace release sites | | | |
| Objective of study: Estimate survival at Wanapum and Priest Rapids developments | | | |
| State hypothesis, if applicable: N/A | | | |
| Fish<br>• Species-race: Yearling Chinook salmon<br>• Source: Wanapum and Priest Rapids gatewells | | | |
| Size (median & range)<br>• Weight (g): 31.0, 16.5–77.0 (Rock Island); 30.0, 18.0–82.5 (Wanapum); 30.0, 17.5–80.5 (Priest Rapids)<br>• Length (mm): 142, 108–200 (Rock Island); 140, 114–200 (Wanapum); 140, 115–200 (Priest Rapids) | | | |
| Tags<br>• PIT Tag: *Biomark*, *Model* BIOMARK *HPT12*, 12.5 mm, 134.2 kHz, 0.115 g in air<br>• Acoustic tag: *Lotek Wireless*, Model *L-AMT-1.421*, 11.1 mm x 5.5 mm x 3.7 mm, 3-sec burst rate, 0.32 g in air | | | |
| Implant procedure<br>• Surgical: Yes<br>• Injected: No | | | |
| Survival estimate (per species or objective) | | | |
| • Type: | <u>Wanapum Development</u> | <u>Priest Rapids Development</u> | <u>Wanapum – Priest Rapids Project</u> |
| • Value & SE: | 0.9448 (0.0128) | 0.9612 (0.0087) | 0.9082 (0.0145) |
| • Sample sizes: | 398 (RI) | 768 (WAN) | 549 (PR) |
| • Analytical model: Paired release-recapture model | | | |
| Hypothesis test and results (if applicable): N/A | | | |
| Characteristics of estimate<br>• Effects reflected (direct, total, etc.): Total survival<br>• Absolute or relative: Absolute | | | |
| Environmental/operating conditions | | | |
| • Type: Development | <u>Wanapum</u> | | <u>Priest Rapids</u> |
| • Discharge (kcfs; median, range): | 181.4, 158.2–203.7 | | 198.1, 171.3–224.8 |
| Unique study characteristics: N/A | | | |

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# 1.0 Introduction

The objectives of the 2014 acoustic-tagged steelhead and yearling Chinook salmon smolt survival studies at the Wanapum – Priest Rapids Project were six-fold:

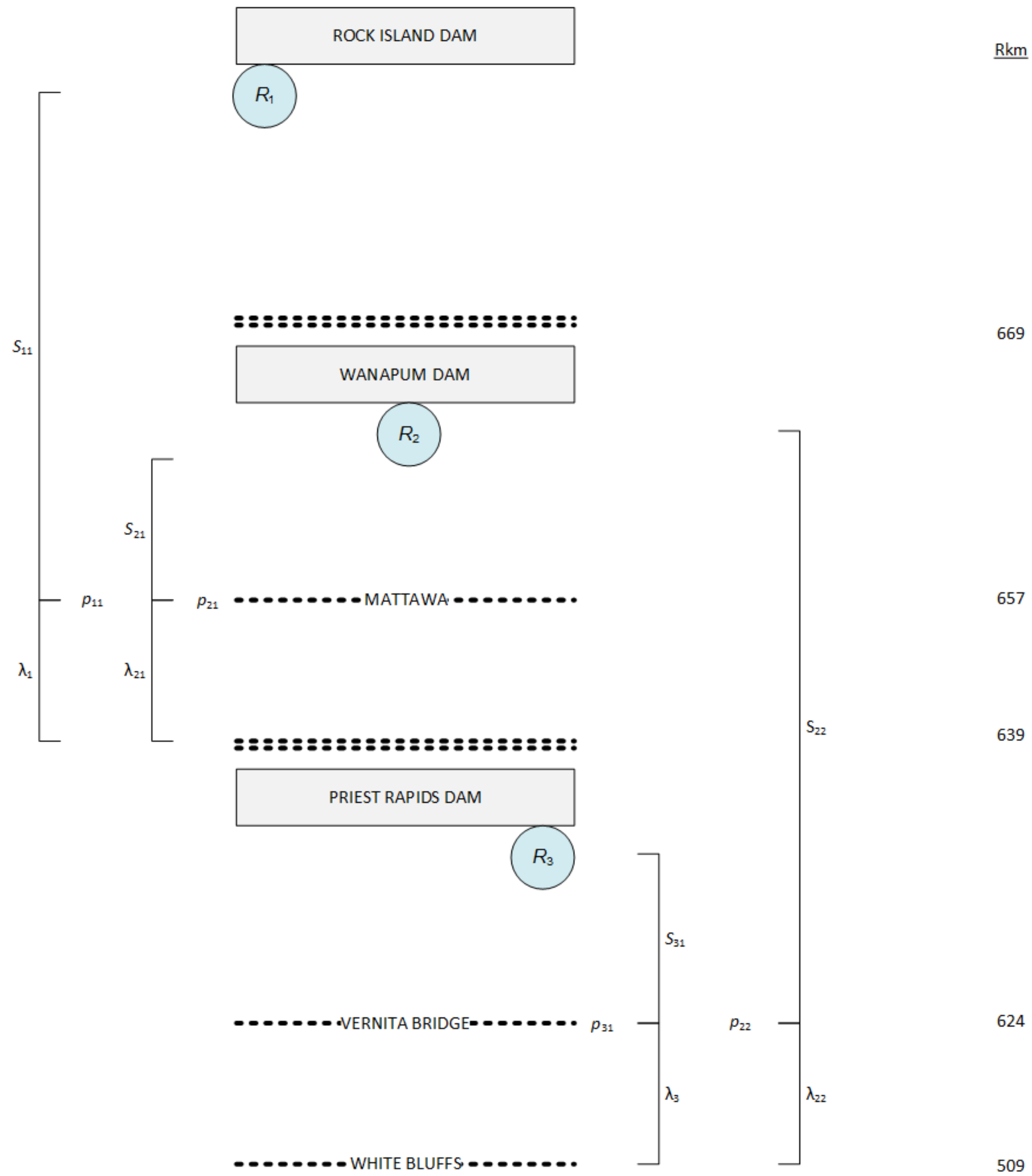
a. Estimate steelhead smolt passage survival through the Wanapum Development (one reservoir and dam).
b. Estimate steelhead smolt passage survival through the Priest Rapids Development (one reservoir and dam).
c. Estimate steelhead smolt passage survival through the Wanapum – Priest Rapids Project (both dams and reservoirs).
d. Estimate yearling Chinook salmon smolt passage survival through the Wanapum Development.
e. Estimate yearling Chinook salmon smolt passage survival through the Priest Rapids Development.
f. Estimate yearling Chinook salmon smolt passage survival through the Wanapum – Priest Rapids Project.

This report summarizes the results of these studies for 2014.

# 2.0 Methods

## 2.1 Acoustic-Tag Handling, Tagging, and Release Procedures

The steelhead and yearling Chinook salmon handling, tagging, and release procedures used in 2014 followed the methods described in Skalski et al. (2007, 2009a, 2009b, 2010). Fish were acquired at the Wanapum and Priest Rapids gatewells, tagged onshore at Wanapum Dam with a minimum 24-hour recovery period, and released by helicopter at the designated release sites. Each replicate had tags activated at the same time. Fish at Wanapum were released 48 hours later than the Rock Island releases, and at Priest Rapids 1 day after that. Releases at Rock Island and Wanapum tailraces were used to estimate passage survival through the Wanapum Development (Figure 2.1). Releases at Wanapum and Priest Rapids tailraces were used to estimate project survival through the Priest Rapids Development (Figure 2.1). Passage survival through the Wanapum – Priest Rapids Project was based on the product of the Wanapum and Priest Rapid survival estimates. Table 2.1 summarizes the number of tags released per location in performing the 2014 release-recapture survival study. Between 7–28 May 2014, 18 replicate releases of steelhead were performed. Release sizes range from 20–99 smolts, with a mean of 31.9 smolts per release per site. Between 30 April and 24 May 2014, 20 replicate releases of yearling Chinook salmon were performed, ranging from 17–75 smolts per release, with a mean of 28.6 smolts per release, per site. The survival estimates were based on pooling the data from the replicate releases over time. Both steelhead and yearling Chinook salmon smolts were tagged with the *Biomark, Model BIOMARK HPT12* and *Lotek Wireless, Model L-AMT-1.421*.




Project survival estimate: $\hat{S}_{\mathrm{WAN}} = \dfrac{\hat{S}_{11}}{\hat{S}_{21}}; \hat{S}_{\mathrm{PR}} = \dfrac{\hat{S}_{22}}{\hat{S}_{31}}$

**Figure 2.1.** Schematic of the paired release-recapture design used to estimate passage survival at the Wanapum and Priest Rapids developments based on releases $R_1$, $R_2$, and $R_3$.

**Table 2.1.** Summary of the number of fish tagged and ultimately used in the survival analyses in 2014.

| Location | Steelhead | Yearling Chinook Salmon |
|---|---|---|
| Rock Island tailrace ($R_1$) | 398 | 398 |
| Wanapum tailrace ($R_2$) | 771 (766)* | 768 (765)* |
| Priest Rapids tailrace ($R_3$) | 550 | 549 |

*Censoring occurred for $R_2$ fish at Priest Rapids because of subsequent upstream travel reminiscent of predation.

A total of 20 replicate releases (i.e., $R_1$, $R_2$, and $R_3$) of yearling Chinook salmon were performed over the period 30 April – 24 May 2014. Over the period 7–28 May, a total of 18 replicate release were performed with steelhead smolts. Due to weather conditions on 17 May 2014, no releases were performed. Instead, those releases were conducted on 18 May, along with the planned releases for that day.

A routine part of the acoustic-tag survival analysis was an analysis to check for the presence of tag-lot and/or tagger effects. In 2014, three tag lots were used for all releases. Tag-lot effects were evaluated with separate tag-life curves and tests of equality based on the Komogorov-Smirnov test of homogeneity. For tagger effects, reach survivals were calculated for the fish tagged by each staff member by release group (i.e., $R_1$, $R_2$, and $R_3$) to test for homogeneity of survival estimates. If significant heterogeneity ($P < 0.05$) was found, the reach survival estimates were examined to identify any consistent pattern of depressed survival estimates across release groups and across reaches. An additional source of information was the tag failure rate during the 48-hour holding period between tag activation and fish release.

## 2.2 Detection Locations

Hydrophone arrays across the Columbia River at Mattawa and Priest Rapids Dam forebay were used as terminal detection arrays in estimating passage survival at the Wanapum Development (reservoir and dam) (Figure 2.1). The cross-river hydrophone arrays at Vernita Bridge and White Bluffs served as the terminal arrays used in estimating survival at the Priest Rapids Development (reservoir and dam) (Figure 2.1). Survival through the Wanapum – Priest Rapids Project (Appendix A, Figure A.2.2) was estimated as the product of the individual survival estimates.

## 2.3 Statistical Methods

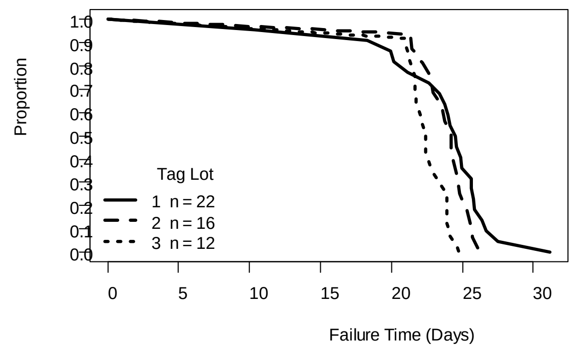
### 2.3.1 Survival Estimates

The paired release-recapture methods of Burnham et al. (1987) were used to analyze the acoustic-tag survival investigations (Appendix A). Survival estimates were based on the pooled capture histories of the replicate releases over the season.

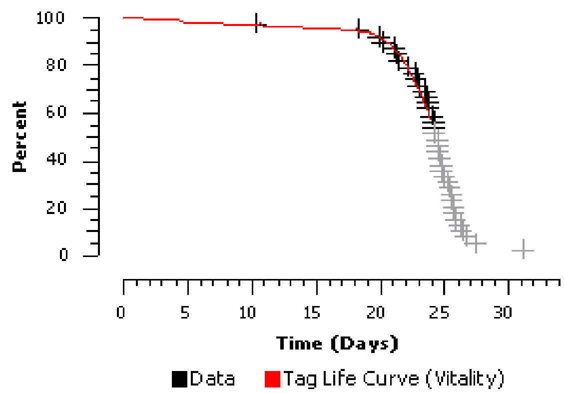
### 2.3.2 Tag-Life Corrections

The steelhead and yearling Chinook salmon smolts were tagged using the same three lots of *Lotek Wireless, Model L-AMT-1.421* acoustic tags. Consequently, a single systematic sample of $n = 50$ tags was used to characterize the tag-life curve for both species. All tags in the failure-time study were continuously monitored in river water until failure. Sample sizes for the three individual lots were $n = 22$, 16, and 12 (Figure 2.2a). Based on pair-wise tests of homogeneity using the Kolmogorov-Smirnov test, lots 1 and 2 were found to share the same tag-life process but both were different from tag lot 3. The four-parameter vitality model of Li and Anderson (2009) was fit to the pooled tag-life curve of lots 1 and 2 (Figure 2.2b). These tags had a mean tag life of 23.7 days. A three-parameter Weibull model was fit to lot 3 with an expected tag life of 22.7 days (Figure 2.2c). Separate tag life adjustments were made for fish tagged with lots 1–2 or 3.

a. Empirical tag-life curves for lots 1, 2, and 3




b. Vitality curve fit to lots 1 and 2 pooled




c. Weibull curve fit to lot 3

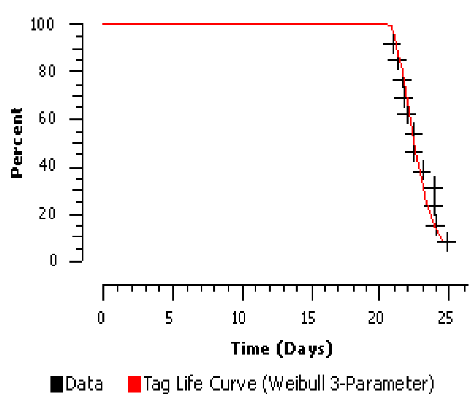



**Figure 2.2.** Acoustic-tag failure times by a) tag lot and fitted tag-life curves for b) tag lots 1–2 and c) tag lot 3.

## 3.0 Results

Using run-of-river fish (ROR) collected at the Wanapum and Priest Rapids gatewells, juvenile passage survival for steelhead and yearling Chinook salmon smolts was estimated at the Wanapum and Priest Rapids developments. Results for steelhead are presented first, followed by that of the yearling Chinook salmon.

### 3.1 Steelhead Survival Estimates

For each survival estimate, a summary of the study results is presented, followed by the supporting tables and figures.

#### 3.1.1 Wanapum Development

*Tagger Effects.* Three different staff tagged all of the fish in the survival study. The tagging study was designed and conducted such that each tagger contributed equally to the upstream (treatment) and downstream (control) release locations. Although the numbers of fish tagged by each individual were not the same, the proportions were homogeneous between the Rock Island and Wanapum tailrace locations $\left(P\left(\chi_4^2 \geq 1.4633\right) = 0.8331\right)$ (Table 3.1). The balanced tagger design was implemented with the hope that if any small tagger effects went unnoticed, they might cancel when calculating project passage survival as a ratio of upstream to downstream reach survivals. No significant heterogeneity ($P < 0.05$) was detected in fish survival for fish tagged by different staff (Table 3.2). Therefore, all tagged fish, regardless of tagger, were used in the survival analysis.

*Downstream Mixing.* Arrival timing of the Rock Island ($R_1$) and Wanapum ($R_2$) tailrace releases to Mattawa and Priest Rapids forebay was offset with the $R_2$ release arriving approximately two days after the peak of the $R_1$ arrivals (Figure 3.1).

*Size Distributions.* The length, weight, and condition factor distributions for the Rock Island and Wanapum tailrace releases were very similar, suggesting no opportunity for size bias to affect the survival estimates (Figure 3.2).

*Tag-Life Correction.* Graphical comparison of the tag-life curve with the cumulative arrival distributions indicates the vast majority of fish finished the study before tag failure became an appreciable problem (Figure 3.3). The probability a tag was active when arriving at the detection locations was estimated to be >0.986 in all cases (Table 3.3).

*Wanapum Development Passage Survival Estimate.* The detection histories of the Rock Island and Wanapum tailrace releases to Mattawa and Priest Rapids forebay were used as the basis of the paired release-recapture analysis (Table 3.4). Separate Cormack (1964) – Jolly (1965) – Seber (1965) estimates of reach survival for the two release groups after adjustment for tag life produced a passage survival estimate at Wanapum Development (reservoir and dam) of $\hat{S}_{\text{WAN}}$ = 0.9246/0.9949 = 0.9294 ($\widehat{\text{SE}}$ = 0.0140) (Table 3.5).

**Table 3.1.** Numbers of steelhead salmon tagged at each release site by tagger used in estimating survival through the Wanapum and Priest Rapids developments $\left(P\left(\chi_4^2 \geq 1.4633\right) = 0.8331\right)$.

| Release site | Tagger A | Tagger B | Tagger C | Total tags per site |
|---|---|---|---|---|
| Rock Island tailrace ($R_1$) | 92 | 157 | 149 | 398 |
| Wanapum tailrace ($R_2$) | 155 | 315 | 301 | 771 |
| Priest Rapids tailrace ($R_3$) | 115 | 221 | 214 | 550 |
| Total tags | 362 | 693 | 664 | |

**Table 3.2.** Cormack-Jolly-Seber estimates of reach survival (not adjusted for tag life) for steelhead smolts by tagger for releases at (a) Rock Island, (b) Wanapum, and (c) Priest Rapids tailraces and associated *P*-values for tests of homogeneous survival.

a. Rock Island tailrace ($R_1$)

| | $R_1$ to Crescent Bar | | Crescent Bar to Sunland Estates | | Sunland Estates to Wanapum | | Wanapum to Mattawa | | Mattawa to Priest Rapids | | Priest Rapids to Vernita Bridge | | Vernita Bridge to White Bluffs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tagger | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE |
| A | 0.9789 | 0.0151 | 0.9886 | 0.0113 | 0.9444 | 0.0241 | 0.9524 | 0.0232 | 0.9500 | 0.0244 | 0.9872 | 0.0131 | 0.9730 | 0.0189 |
| B | 1.0001 | 0.0001 | 0.9935 | 0.0064 | 0.9359 | 0.0196 | 0.9658 | 0.0151 | 0.9787 | 0.0122 | 0.9703 | 0.0147 | 0.9767 | 0.0133 |
| C | 0.9933 | 0.0067 | 1.0000 | 0.0000 | 0.9865 | 0.0095 | 0.9932 | 0.0068 | 0.9793 | 0.0118 | 0.9429 | 0.0196 | 0.9848 | 0.0106 |
| *P*-value | 0.2731 | | 0.5618 | | 0.1249 | | 0.2032 | | 0.3845 | | 0.1428 | | 0.8425 | |

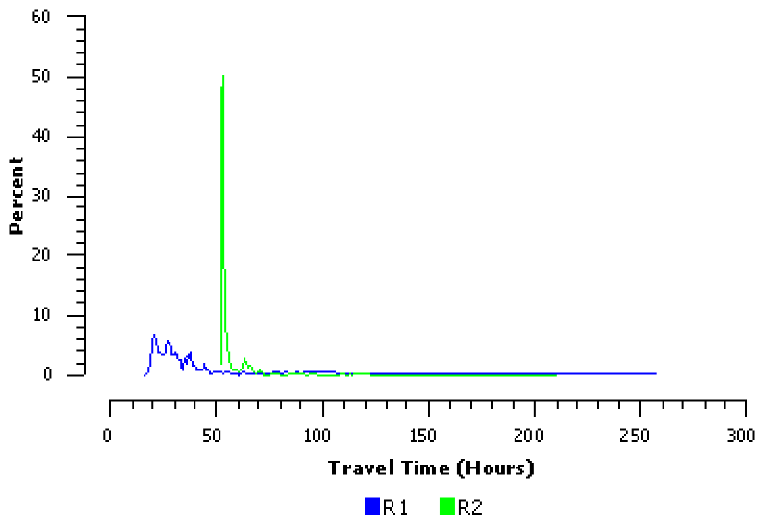
b. Wanapum tailrace ($R_2$)

| | $R_2$ to Mattawa | | Mattawa to Priest Rapids | | Priest Rapids to Vernita Bridge | | Vernita Bridge to White Bluffs | |
|---|---|---|---|---|---|---|---|---|
| Tagger | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE |
| A | 1.0000 | 0.0000 | 0.9806 | 0.0111 | 0.9741 | 0.0131 | 0.9586 | 0.0165 |
| B | 0.9905 | 0.0055 | 0.9744 | 0.0089 | 0.9700 | 0.0098 | 0.9622 | 0.0112 |
| C | 0.9900 | 0.0057 | 0.9799 | 0.0081 | 0.9795 | 0.0083 | 0.9790 | 0.0085 |
| *P*-value | 0.2195 | | 0.8772 | | 0.8187 | | 0.4692 | |

c. Priest Rapids tailrace ($R_3$)

| | $R_3$ to Vernita Bridge | | Vernita Bridge to White Bluffs | |
|---|---|---|---|---|
| Tagger | Estimate | SE | Estimate | SE |
| A | 0.9913 | 0.0087 | 0.9211 | 0.0253 |
| B | 0.9737 | 0.0110 | 0.9158 | 0.0191 |
| C | 0.9915 | 0.0066 | 0.9567 | 0.0141 |
| *P*-value | 0.2684 | | 0.2900 | |

a. Arrival distributions at Mattawa (rkm 657)




b. Arrival distributions at Priest Rapids forebay (rkm 639)

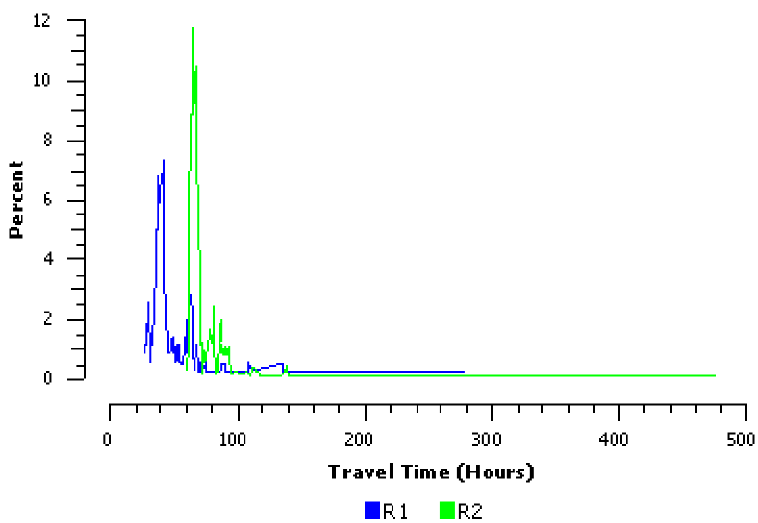
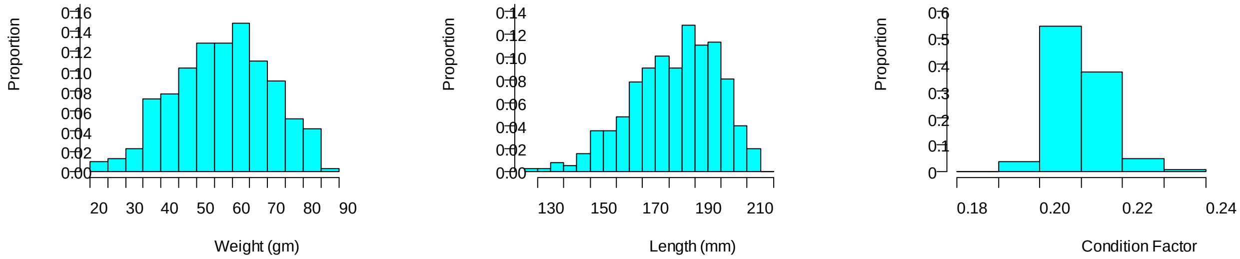


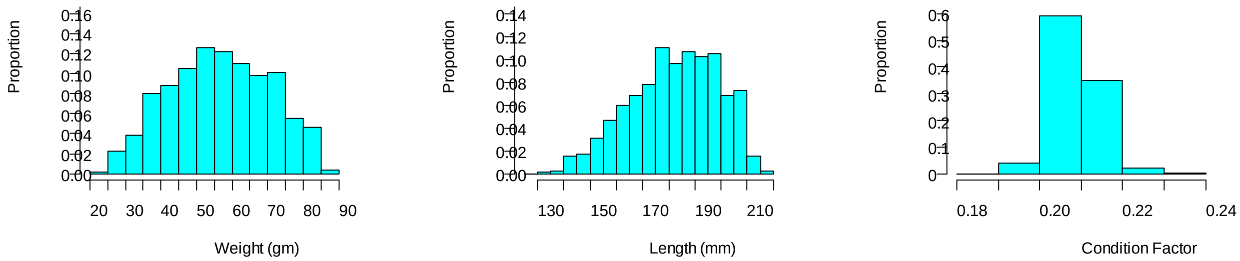

**Figure 3.1.** Arrival distribution plots for steelhead smolts from Rock Island tailrace ($R_1$) and Priest Rapids tailrace ($R_2$) releases at (a) Mattawa (rkm 657) and (b) Priest Rapids forebay (rkm 639). Times are relative to the Rock Island tailrace release group ($R_1$).

<u>Weight (gm)</u> <u>Fork Length (mm)</u> <u>Condition Factor</u>

a. Rock Island tailrace ( $R_1$)




b. Wanapum tailrace ($R_2$)




c. Priest Rapids tailrace ($R_3$)

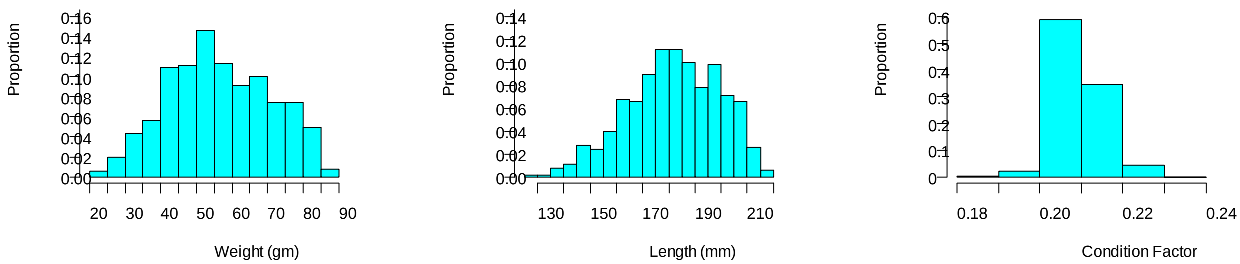
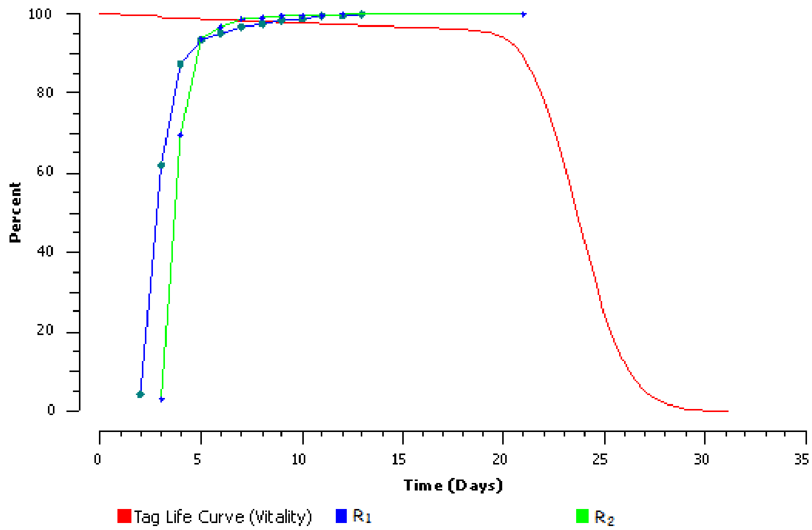



**Figure 3.2.** Distributions of weight (g), length (mm), and condition factor for steelhead smolts used in the 2014 acoustic-tag survival study for (a) Rock Island tailrace ($R_1$), (b) Wanapum tailrace ($R_2$), and Priest Rapids tailrace ($R_3$) releases.

a. Arrival distributions at Priest Rapids forebay vs. tag-life curve of tag lots 1–2




b. Arrival distributions at Priest Rapids forebay vs. tag-life curve of tag lot 3

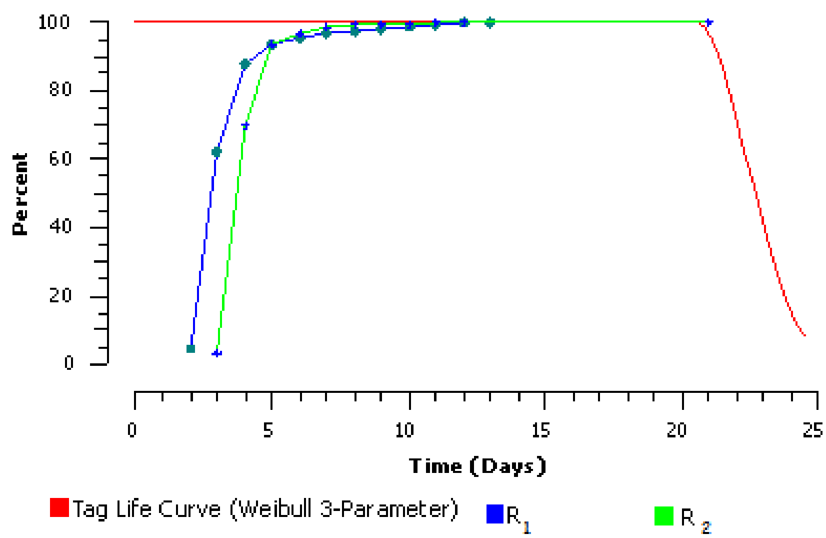



**Figure 3.3**. Tag-life curves vs. timing of downstream detections of steelhead smolts at (a) Mattawa and (b) Priest Rapids forebay for releases from Rock Island ($R_1$) and Wanapum ($R_2$) tailraces for tag lots 1–2 and tag lot 3. Plots illustrate that the vast majority of smolts finished the study before tag failure became appreciable.

**Table 3.3.** Estimated probabilities of an acoustic tag being active when a steelhead smolt arrived at Mattawa or Priest Rapids forebay for releases from Rock Island ($R_1$) and Wanapum ($R_2$) tailraces by tag lot. Standard errors in parentheses.

| Release location | Tag lot | Detection locations | |
|---|---|---|---|
| | | Mattawa | Priest Rapids |
| Rock Island tailrace ($R_1$) | 1–2 | 0.9909 (0.0033) | 0.9893 (0.0039) |
| | 3 | 1.0000 (0.0000) | 1.0000 (0.0000) |
| Wanapum tailrace ($R_2$) | 1–2 | 0.9889 (0.0041) | 0.9868 (0.0047) |
| | 3 | 1.0000 (nan) | 1.0000 (0.0001) |

**Table 3.4.** Capture histories of the Rock Island ($R_1$) and Wanapum ($R_2$) tailrace releases of steelhead at Mattawa and Priest Rapids forebay in 2014. A 1 denotes detection; 0, nondetection.

| Release location | Detection history | | | | Total |
|---|---|---|---|---|---|
| | 11 | 01 | 10 | 00 | |
| Rock Island tailrace ($R_1$) | 356 | 0 | 10 | 32 | 398 |
| Wanapum tailrace ($R_2$) | 748 | 0 | 17 | 6 | 771 |

**Table 3.5.** Survival and detection probabilities estimated by the Cormack-Jolly-Seber model adjusted for tag life used in estimating survival through the Wanapum Development for steelhead smolts in 2014.

| Release site | $\hat{S}$ release to Mattawa | $\hat{\lambda}^*$ |
|---|---|---|
| Rock Island tailrace ($R_1$) | 0.9246 (0.0138) | 0.9741 (0.0085) |
| Wanapum tailrace ($R_2$) | 0.9949 (0.0029) | 0.9798 (0.0054) |
| | Detection probability at Mattawa | |
| Rock Island tailrace ($R_1$) | 1.0000 (<0.0001) | |
| Wanapum tailrace ($R_2$) | 1.0000 (<0.0001) | |

*Joint probability of surviving from Mattawa to Priest Rapids forebay and being detected at Priest Rapids forebay

### 3.1.2 Priest Rapids Development

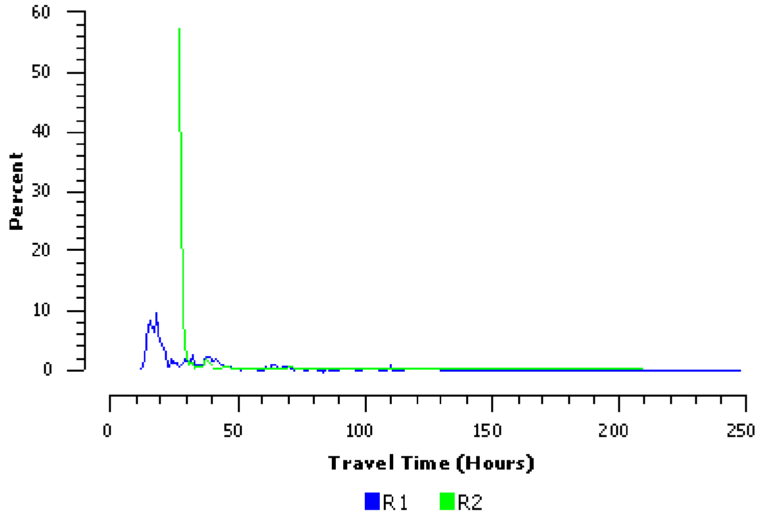
*Downstream Mixing.* Timing plots indicate the Priest Rapids tailrace release ($R_2$) arrived approximately 25 hours after the arrival of the Wanapum tailrace release ($R_2$) at Vernita Bridge and White Bluffs (Figure 3.4).

*Size Distribution.* The length, weight, and condition factor distributions for the Wanapum and Priest Rapids tailrace releases were very comparable (Figure 3.2), suggesting no opportunity for any size bias to affect the survival estimates.

*Tag-Life Corrections.* The same tag survivorship curves used for steelhead passage survival estimates at the Wanapum Development (Figure 2.2) were also used in the survival analysis at Priest Rapids. Comparison of the tag-life curves with the cumulative travel time curves for the Wanapum ($R_2$) and Priest Rapids ($R_3$) tailrace releases indicates the vast majority of fish finished the study before tag failure became appreciable (Figure 3.5). In all cases, the probability a tag was still active was >0.984 (Table 3.6).

*Priest Rapids Development Passage Survival Estimate.* Detection histories at Vernita Bridge and White Bluffs were the basis of the survival analysis (Table 3.7). Reach survivals, adjusted for tag life, used in the paired-release model are reported in Table 3.8. Passage survival at the Priest Rapids Development (reservoir and dam) for steelhead in 2014 was estimated to be $\hat{S}_{\text{PR}} = 0.9512/0.9895 = 0.9613$ ($\widehat{\text{SE}} = 0.0098$).

a. Arrival distributions at Vernita Bridge




b. Arrival distributions at White Bluffs

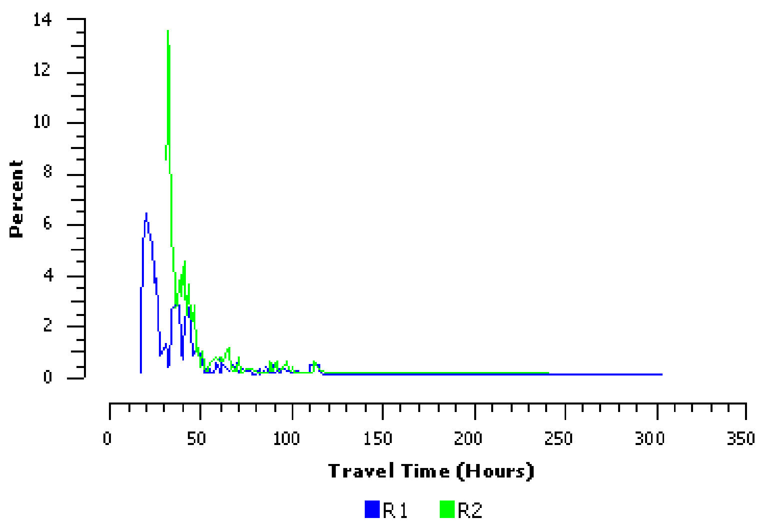
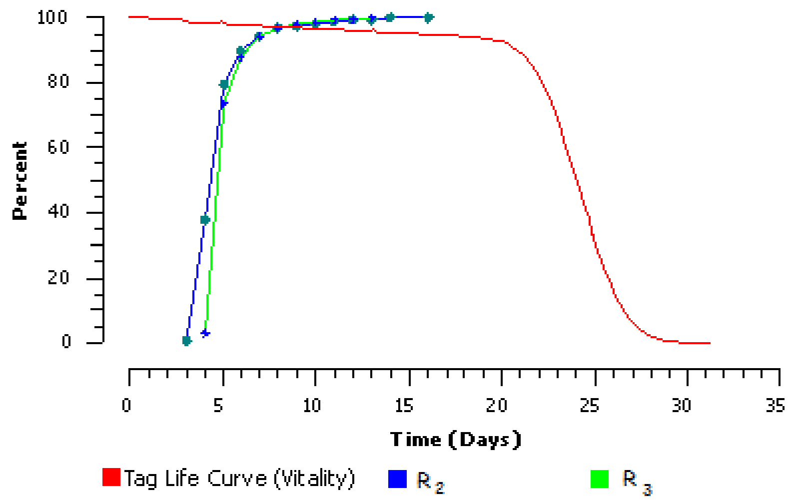



**Figure 3.4.** Arrival distribution plots for steelhead smolts from Wanapum tailrace ($R_2$) and Priest Rapids tailrace ($R_3$) releases at (a) Vernita Bridge (rkm 624) and (b) White Bluffs (rkm 509) detection arrays. Times are relative to the Wanapum tailrace release group ($R_2$).

a. Arrival distributions at White Bluffs vs. tag-life curve of tag lots 1–2




b. Arrival distributions at White Bluffs vs. tag-life curve of tag lot 3

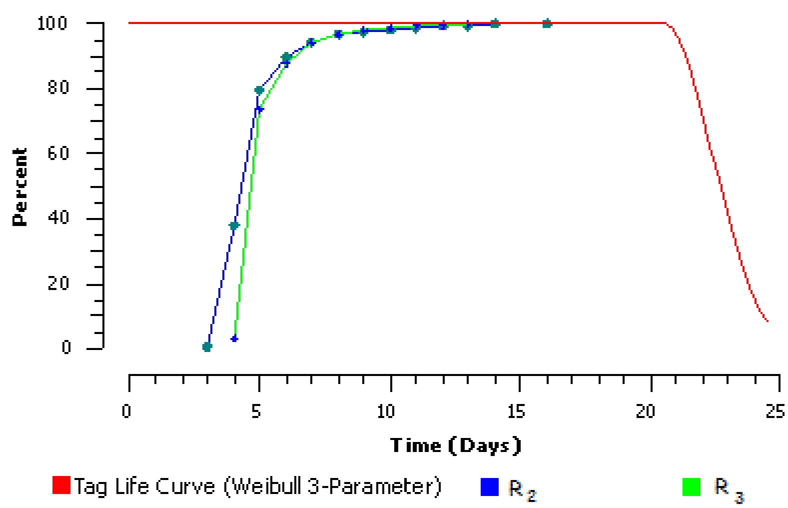



**Figure 3.5.** Tag-life curves vs. timing of downstream detections of steelhead smolts at White Bluffs for releases $R_2$ and $R_3$ for (a) tag lots 1–2 and b) tag lot 3. Plots illustrate that the vast majority of smolts finished the study before tag failure became appreciable.

**Table 3.6.** Estimated probabilities of an acoustic tag being active when a steelhead smolt arrived at Vernita Bridge or White Bluffs after release from Wanapum and Priest Rapids tailraces by tag lots. Standard errors in parentheses.

| | | Detection locations | |
|---|---|---|---|
| Release location | Tag lot | Vernita Bridge | White Bluffs |
| Wanapum tailrace ($R_2$) | 1–2 | 0.9859 (0.0056) | 0.9851 (0.0059) |
| | 3 | 1.0000 (0.0000) | 1.0000 (0.0000) |
| Priest Rapids tailrace ($R_3$) | 1–2 | 0.9862 (0.0055) | 0.9845 (0.0061) |
| | 3 | 1.0000 (nan) | 1.0000 (0.0000) |

**Table 3.7.** Capture histories of the Wanapum ($R_2$) and Priest Rapids ($R_3$) tailrace releases of steelhead at Vernita Bridge and White Bluffs in 2014. A 1 denotes detection; 0, nondetection.

| | Detection history | | | | |
|---|---|---|---|---|---|
| Release | 11 | 01 | 10 | 00 | Total |
| Wanapum tailrace ($R_2$) | 699 | 2 | 23 | 42 | 766 |
| Priest Rapids tailrace ($R_3$) | 498 | 5 | 37 | 10 | 550 |

**Table 3.8.** Survival and detection probabilities estimated by the Cormack-Jolly-Seber model, adjusted for tag life, used in estimating survival through the Priest Rapids Development for steelhead smolts in 2014.

| Release site | $\hat{S}$ Release to Vernita Bridge | $\hat{\lambda}^*$ |
|---|---|---|
| Wanapum tailrace ($R_2$) | 0.9512 (0.0084) | 0.9687 (0.0065) |
| Priest Rapids tailrace ($R_3$) | 0.9895 (0.0055) | 0.9319 (0.0110) |
| | Detection probability at Vernita Bridge | |
| Wanapum tailrace ($R_2$) | 0.9971 (0.0020) | |
| Priest Rapids tailrace ($R_3$) | 0.9901 (0.0044) | |

*Joint probability of surviving from Vernita Bridge to White Bluffs and being detected at White Bluffs

### 3.1.1 Wanapum – Priest Rapids Project

*Wanapum – Priest Rapids Project Passage Survival.* The estimate of steelhead smolt survival through the Wanapum – Priest Rapids Project was calculated as the product of the individual Wanapum and Priest Rapids survival estimates. This product produces the joint survival estimate of

$$\hat{S}_{\text{WAN-PR}} = (0.9294)(0.9613) = 0.8934\left(\widehat{\text{SE}} = 0.0162\right).$$

## 3.2 Yearling Chinook Salmon Survival Estimates

For each survival estimate, a summary of study results is presented, followed by the supporting figures and tables.

### 3.2.1 Wanapum Development

*Tagger Effects.* The numbers of yearling Chinook salmon smolts tagged by the staff were homogeneous across the Rock Island, Wanapum, and Priest Rapids release groups $\left(P\left(\chi_4^3 \geq 0.8938\right) = 0.9254\right)$ (Table 3.9). While there was some small evidence of heterogeneity in survivals for smolts tagged by different personnel (Table 3.10), no consistent pattern was discernible that would preclude any of the fish from the subsequent survival analysis.

*Downstream Mixing.* Arrival timing of the Rock Island ($R_1$) and Wanapum ($R_2$) tailrace releases to the downstream detection arrays at Mattawa and Priest Rapids was very similar (Figure 3.6). Timing was nearly coincident, with the arrival distribution of the upstream Rock Island release much more spread out.

*Size Distributions.* The length, weight, and condition factor distributions for the upstream (treatment) Rock Island and downstream (control) Wanapum tailrace releases were very similar (Figure 3.7). Results suggest no reason to suspect size bias in the subsequent project survival estimates.

*Tag-Life Correction.* Comparison of the tag-life curve with that of the cumulative travel time curves indicates almost all fish finished the study before tag failure became an appreciable concern (Figure 3.8). In all cases, the probability of a tag remaining active at the end of the survival study was >0.983 (Table 3.11).

*Wanapum Development Passage Survival.* Capture histories to Mattawa and Priest Rapids forebay (Table 3.12) for the Rock Island and Wanapum tailrace releases were used to estimate passage survival through the Wanapum Development. The ratio of the tag-life-corrected Cormack-Jolly-Seber estimates of survival to Mattawa were used to estimate survival (Table 3.13). Passage survival through the Wanapum Development (one reservoir and dam) was estimated to be $\hat{S}_{\text{WAN}}$ = 0.9448/1.0000 = 0.9448 ($\widehat{\text{SE}}$ = 0.0128).

**Table 3.9.** Numbers of yearling Chinook salmon tagged at each release site by taggers used in estimating passage survival through the Wanapum and Priest Rapids developments $\left(P\left(\chi_4^2 \geq 0.8938\right) = 0.9254\right)$.

| Release locations | Tagger A | Tagger B | Tagger C | Total tags per site |
|---|---|---|---|---|
| Rock Island tailrace ($R_1$) | 112 | 162 | 124 | 398 |
| Wanapum tailrace ($R_2$) | 226 | 295 | 247 | 768 |
| Priest Rapids tailrace ($R_3$) | 152 | 219 | 178 | 549 |
| Total tags | 490 | 676 | 549 | |

**Table 3.10.** Cormack-Jolly-Seber estimates of reach survival (not adjusted for tag life) for yearling Chinook salmon smolts by tagger for releases at (a) Rock Island, (b) Wanapum, and (c) Priest Rapids tailraces and associated *P*-values.

a. Rock Island tailrace ($R_1$)

| | $R_1$ to Crescent Bar | | Crescent Bar to Sunland Estates | | Sunland Estates to Wanapum | | Wanapum to Mattawa | | Mattawa to Priest Rapids | | Priest Rapids to Vernita Bridge | | Vernita Bridge to White Bluffs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tagger | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE |
| A | 0.9889 | 0.0080 | 0.9882 | 0.0083 | 0.9767 | 0.0115 | 0.9881 | 0.0084 | 0.9942 | 0.0061 | 0.9573 | 0.0158 | 1.0000 | 0.0000 |
| B | 0.9934 | 0.0066 | 1.0000 | 0.0000 | 0.9933 | 0.0066 | 0.9732 | 0.0132 | 0.9931 | 0.0069 | 0.9719 | 0.0139 | 0.9854 | 0.0102 |
| C | 0.9580 | 0.0239 | 0.9851 | 0.0148 | 0.9851 | 0.0148 | 0.9545 | 0.0256 | 1.0000 | 0.0000 | 0.9365 | 0.0307 | 1.0000 | 0.0000 |
| *P*-value | 0.1927 | | 0.5248 | | 0.5935 | | 0.3903 | | 0.6120 | | 0.5035 | | 0.1314 | |

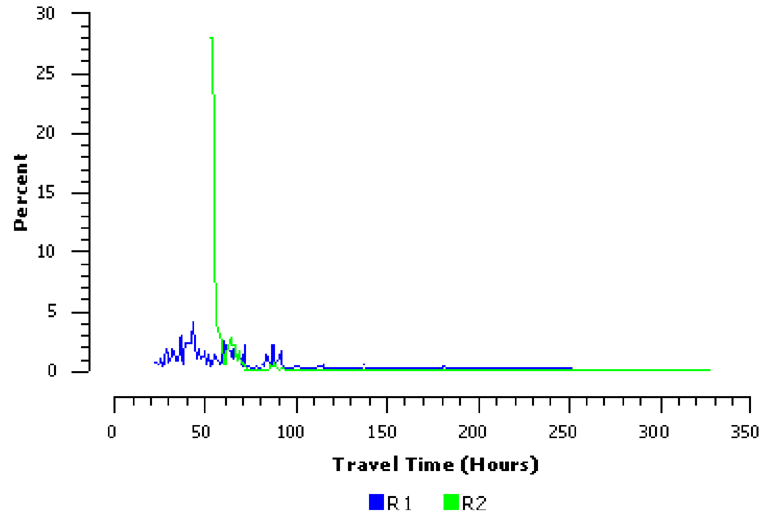
b. Wanapum tailrace ($R_2$)

| | $R_2$ to Mattawa | | Mattawa to Priest Rapids | | Priest Rapids to Vernita Bridge | | Vernita Bridge to White Bluffs | |
|---|---|---|---|---|---|---|---|---|
| Tagger | Estimate | SE | Estimate | SE | Estimate | SE | Estimate | SE |
| A | 0.9825 | 0.0071 | 0.9881 | 0.0059 | 0.9727 | 0.0090 | 0.9844 | 0.0069 |
| B | 0.9896 | 0.0060 | 0.9790 | 0.0085 | 0.9965 | 0.0036 | 0.9819 | 0.0080 |
| C | 1.0000 | 0.0000 | 0.9854 | 0.0102 | 0.9407 | 0.0203 | 1.0000 | 0.0000 |
| *P*-value | 0.1628 | | 0.7352 | | 0.0096 | | 0.1794 | |

c. Priest Rapids tailrace ($R_3$)

| | $R_3$ to Vernita Bridge | | Vernita Bridge to White Bluffs | |
|---|---|---|---|---|
| Tagger | Estimate | SE | Estimate | SE |
| A | 1.0003 | 0.0002 | 0.9706 | 0.0110 |
| B | 1.0000 | 0.0000 | 0.9679 | 0.0119 |
| C | 0.9894 | 0.0109 | 0.9663 | 0.0191 |
| *P*-value | 0.3821 | | 0.9777 | |

a. Arrival distributions at Mattawa (rkm 657)




b. Arrival distributions at Priest Rapids forebay (rkm 639)

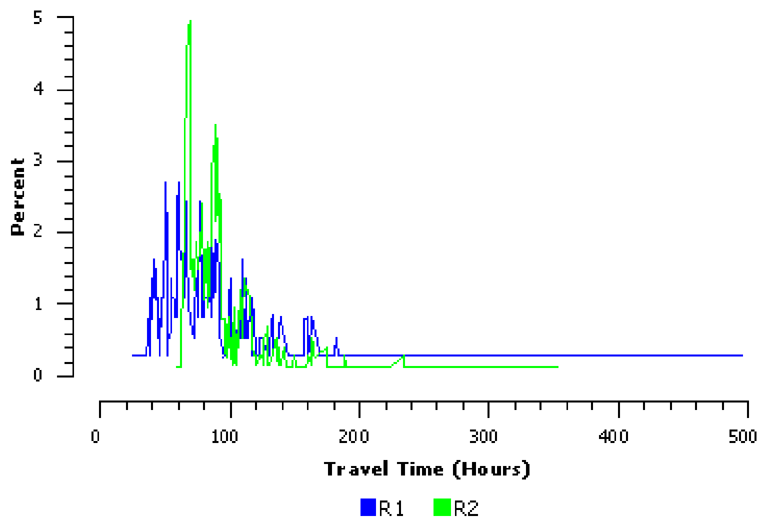



**Figure 3.6.** Arrival distribution plots for releases from Rock Island ($R_1$) and Wanapum ($R_2$) of yearling Chinook salmon smolts at (a) Mattawa (rkm 657) and (b) Priest Rapids forebay (rkm 639) detection arrays. Times are relative to the Rock Island tailrace release ($R_1$).

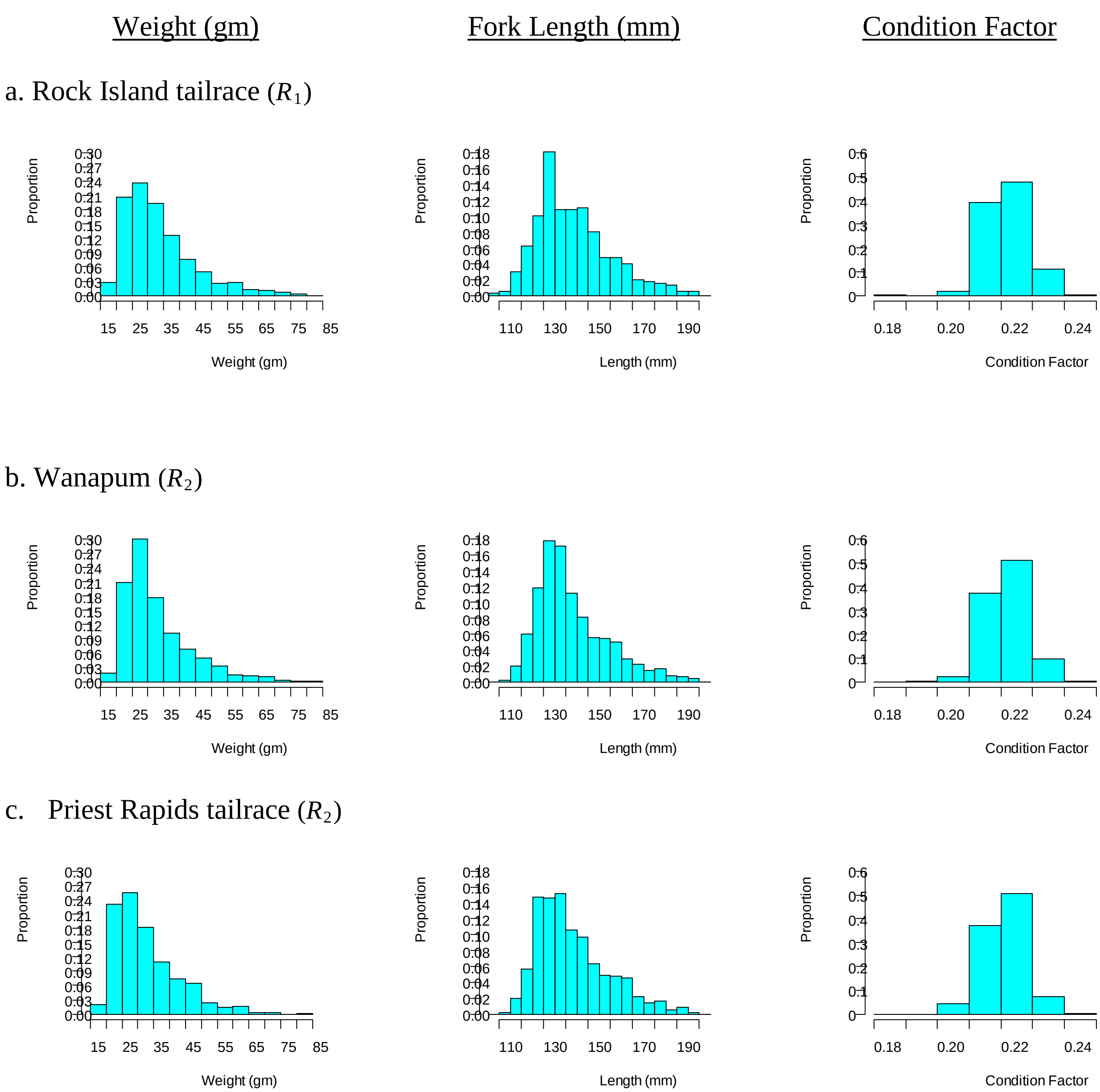
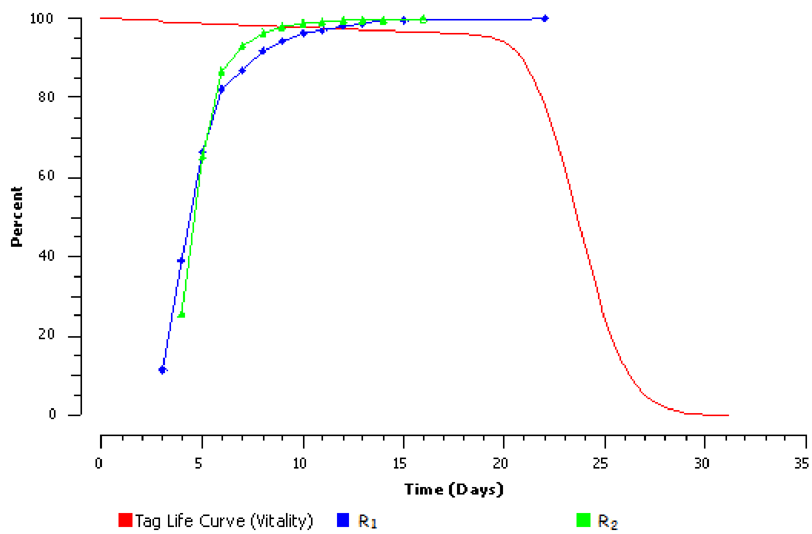



**Figure 3.7.** Distributions of weight (g), length (mm), and condition factor for yearling Chinook salmon smolts used in the 2014 acoustic-tag survival study for (a) Rock Island ($R_1$), (b) Wanapum ($R_2$), and (c) Priest Rapids ($R_3$) tailrace releases.

a. Arrival distributions at Priest Rapids for releases $R_1$ and $R_2$ vs. tag-life curve of tag lots 1–2




b. Arrival distributions at Priest Rapids for releases $R_1$ and $R_2$ vs. tag-life curve tag lot 3

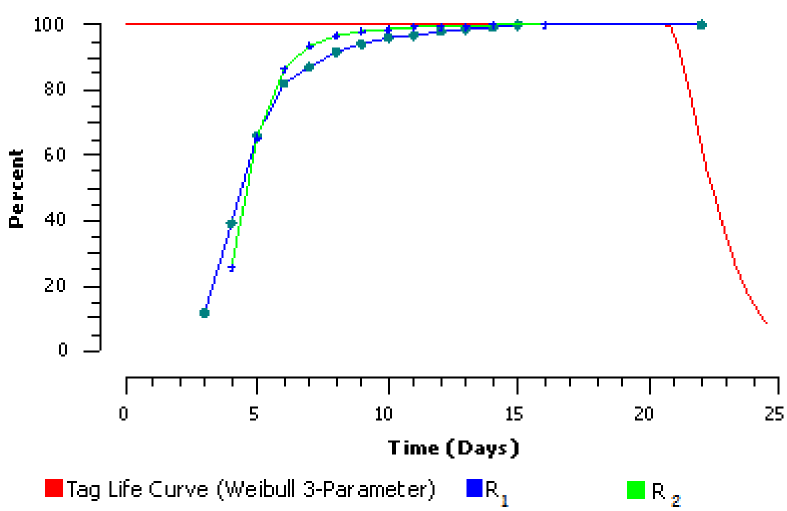



**Figure 3.8.** Tag-life curves vs. timing of downstream detections of yearling Chinook salmon smolts at Priest Rapids forebay (rkm 639) for releases from Rock Island ($R_1$) and Wanapum ($R_2$) tailraces for (a) tag lots 1–2 and (b) tag lot 3. Plots illustrate the vast majority of smolts finished the study before tag failure became apparent.

**Table 3.11.** Estimated probabilities of an acoustic tag being active when a yearling Chinook salmon smolt arrived at Mattawa or Priest Rapids forebay after release from Rock Island ($R_1$) and Wanapum ($R_2$) tailraces. Standard errors in parentheses.

| | | Detection locations | |
|---|---|---|---|
| Release location | Tag lot | Mattawa | Priest Rapids |
| Rock Island tailrace ($R_1$) | 1–2 | 0.9873 (0.0047) | 0.9834 (0.0059) |
| | 3 | 1.0000 (0.0000) | 1.0000 (0.0000) |
| Wanapum tailrace ($R_2$) | 1–2 | 0.9883 (0.0044) | 0.9844 (0.0058) |
| | 3 | 1.0000 (nan) | 1.0000 (0.0000) |

**Table 3.12.** Capture histories of the Wanapum ($R_1$) and Priest Rapids ($R_2$) tailrace releases of yearling Chinook salmon smolts at Mattawa and Priest Rapids in 2014. A 1 denotes detection; 0, nondetection.

| | Detection history | | | | |
|---|---|---|---|---|---|
| Release | 11 | 01 | 10 | 00 | Total |
| Rock Island tailrace ($R_1$) | 371 | 0 | 2 | 25 | 398 |
| Wanapum tailrace ($R_2$) | 747 | 0 | 12 | 9 | 768 |

**Table 3.13.** Survival and detection probabilities estimated by the Cormack-Jolly-Seber model adjusted for tag life used in estimating passage survival through the Wanapum Development (one reservoir and dam) for yearling Chinook salmon smolts in 2014.

| Release site | $\hat{S}$ Release to Mattawa | $\hat{\lambda}^*$ |
|---|---|---|
| Rock Island tailrace ($R_1$) | 0.9448 (0.0124) | 0.9986 (0.0038) |
| Wanapum tailrace ($R_2$) | 1.0000 (0.0054) | 0.9873 (0.0045) |
| | Detection probability at Mattawa | |
| Rock Island tailrace ($R_1$) | 1.0000 (<0.0001) | |
| Wanapum tailrace ($R_2$) | 1.0000 (<0.0001) | |

*Joint probability of surviving from Mattawa to Priest Rapids and being detected at Priest Rapids.

### 3.2.2 Priest Rapids Development

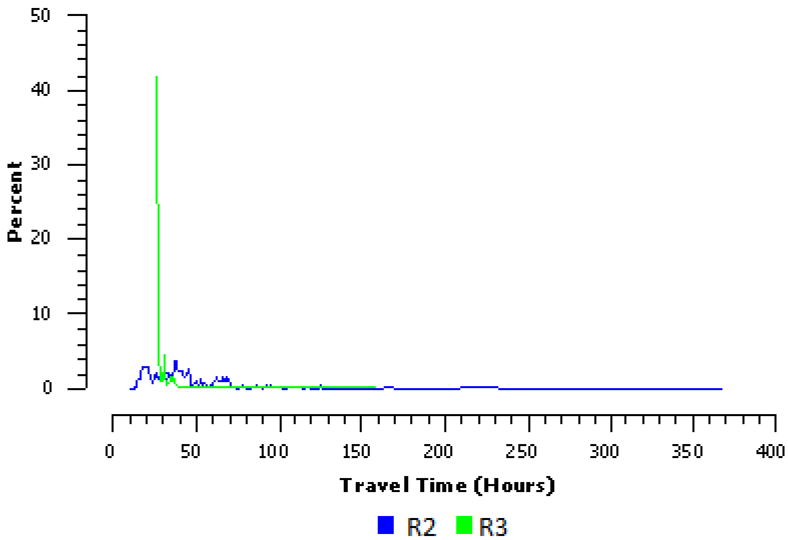
*Downstream Mixing.* The arrival distributions of upstream ($R_2$) and downstream ($R_3$) releases overlapped at Vernita Bridge and White Bluffs, with common modes (Figure 3.9).

*Size Distributions.* The length, weight, and condition factor distributions for the upstream Wanapum and downstream Priest Rapids tailrace releases were very similar, suggesting no source for size bias to influence survival estimates (Figure 3.7).

*Tag-Life Corrections.* Comparison of the tag-life curves with the cumulative arrival timing distributions of the Wanapum and Priest Rapids tailrace releases to the downstream detection sites at Vernita Bridge and White Bluffs indicates all fish completed the study before tag failure became an appreciable concern (Figure 3.10). In all cases, the probability of a tag being active when arriving at a detection location was >0.982 (Table 3.14).

*Priest Rapids Development Passage Survival.* Tag-life-corrected, Cormack-Jolly-Seber estimates of reach survival were based on capture histories of the Wanapum and Priest Rapids tailrace releases to Vernita Bridge and White Bluffs (Table 3.15). Passage survival through the Priest Rapids Development (one reservoir and dam) was estimated to be $\hat{S}_{\mathrm{PR}}$ = 0.9596/0.9983 = 0.9612 ($\widehat{SE}$ = 0.0087) (Table 3.16).

a. Arrival distributions at Vernita Bridge (rkm 624)




b. Arrival distributions at White Bluffs (rkm 509)

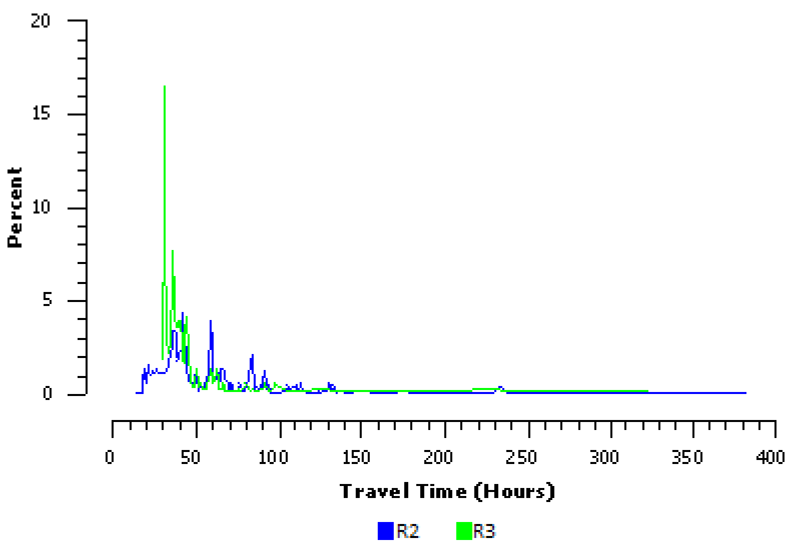
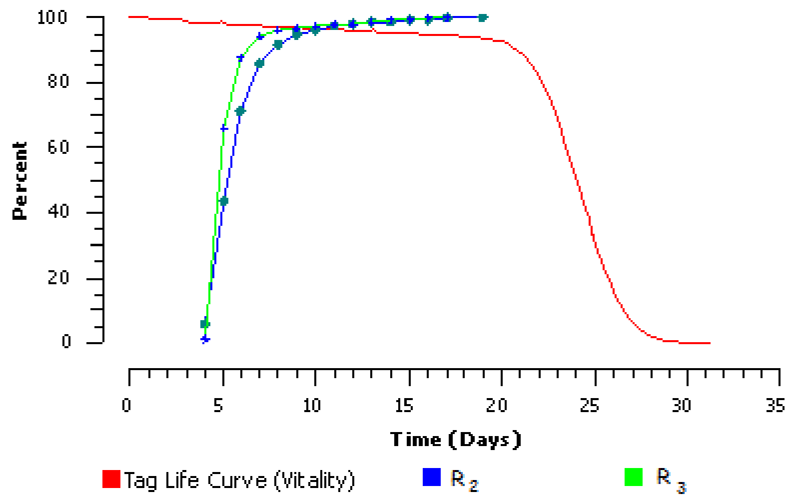



**Figure 3.9.** Arrival distribution plots for releases of yearling Chinook salmon smolts from Wanapum ($R_2$) and Priest Rapids ($R_3$) tailraces at (a) Vernita Bridge (rkm 624) and (b) White Bluffs (rkm 509) detection arrays. Time starts at Wanapum tailrace release.

a. Arrival distributions for releases $R_2$ and $R_3$ vs. tag-life curve of tag lots 1–2




b. Arrival distributions for releases $R_2$ and $R_3$ vs. tag-life curve of tag lot 3

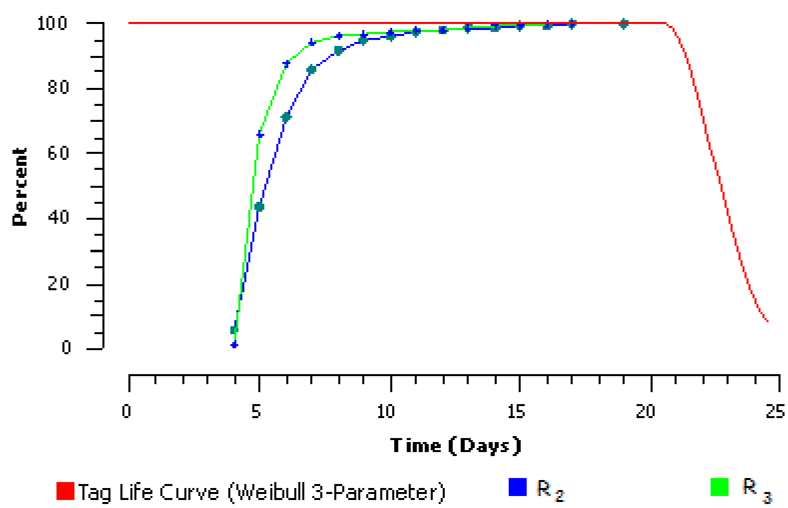



**Figure 3.10.** Tag-life curves vs. timing of downstream detections of yearling Chinook salmon smolts at White Bluffs for releases from Wanapum ($R_2$) and Priest Rapids ($R_3$) tailraces for (a) tag lots 1–2 and (b) tag lot 3. Plots illustrate the vast majority of smolts finished the study before tag failure became apparent.

**Table 3.14.** Estimated probabilities of an acoustic tag being active when a yearling Chinook salmon smolt arrived at Vernita Bridge or White Bluffs for releases from Wanapum ($R_2$) and Priest Rapids ($R_3$) tailraces by tag lot. Standard errors in parentheses.

| | | Detection locations | |
|---|---|---|---|
| Release location | Tag lot | Vernita Bridge | White Bluffs |
| Wanapum tailrace ($R_2$) | 1 & 2 | 0.9837 (0.0056) | 0.9822 (0.0061) |
| | 3 | 1.0000 (0.0000) | 1.0000 (0.0000) |
| Priest Rapids tailrace ($R_3$) | 1 & 2 | 0.9862 (0.0047) | 0.9938 (0.0056) |
| | 3 | 1.0000 (nan) | 1.0000 (0.0000) |

**Table 3.15.** Capture histories used to estimate yearling Chinook salmon survival through the Priest Rapids Development based on releases from Wanapum ($R_2$) and Priest Rapids ($R_3$) tailraces. A 1 denotes detection; 0, nondetection.

| | Detection history | | | | |
|---|---|---|---|---|---|
| Release | 11 | 01 | 10 | 00 | Total |
| Wanapum tailrace ($R_2$) | 714 | 2 | 10 | 39 | 765 |
| Priest Rapids tailrace ($R_3$) | 528 | 3 | 17 | 1 | 549 |

**Table 3.16.** Survival and detection probabilities estimated by the Cormack-Jolly-Seber model, adjusted for tag life, used in estimating passage survival through the Priest Rapids Development (one reservoir and dam) for yearling Chinook salmon smolts in 2014.

| Release site | $\hat{S}$ Release to Vernita Bridge | $\hat{\lambda}^*$ |
|---|---|---|
| Wanapum tailrace ($R_2$) | 0.9596 (0.0085) | 0.9877 (0.0043) |
| Priest Rapids tailrace ($R_3$) | 0.9983 (0.0018) | 0.9707 (0.0075) |
| | Detection probability at Vernita Bridge | |
| Wanapum tailrace ($R_2$) | 0.9972 (0.0020) | |
| Priest Rapids tailrace ($R_3$) | 0.9944 (0.0032) | |

*Joint probability of surviving from Vernita Bridge to White Bluffs and being detected at White Bluffs

### 3.2.3 Wanapum – Priest Rapids Project

*Wanapum – Priest Rapids Project Passage Survival.* Using the product of the individual survival estimates through Wanapum and Priest Rapids, the survival through the Wanapum – Priest Rapids project is estimated to be

$$\hat{S}_{\text{WAN-PR}} = (0.9448)(0.9612) = 0.9082\left(\widehat{\text{SE}} = 0.0145\right).$$

## 3.3 Fish Passage

### 3.3.1 Routes of Passage

The arrays in front of the dams were used to obtain routes of passage for the fish entering Wanapum and Priest Rapids dams. The near perfect detection probabilities allowed estimates of route-specific passage proportions based on the binomial sampling model.

At Wanapum Dam, powerhouse plus gatewell passage was the dominant route of passage for yearling Chinook salmon (65.0%, $\widehat{\text{SE}}$ = 2.5%). For steelhead, passage proportions were nearly equal between the spillway (45.3%, $\widehat{\text{SE}}$ = 2.6%) and powerhouse 44.8%, $\widehat{\text{SE}}$ = 2.6%) (Table 3.17).

Passage at Priest Rapids Dam was more evenly distributed between top spill, spillway, and powerhouse (plus gatewell). For both yearling Chinook salmon and steelhead, top spill was the major route of passage at 38.1%, $\widehat{\text{SE}}$ = 1.5% and 47.2%, $\widehat{\text{SE}}$ = 1.5%, respectively (Table 3.17).

### 3.3.2 Fish Passage Efficiency (FPE)

Fish passage efficiency (FPE) is defined as the proportion (i.e., fraction) of fish that pass through the dam by non-turbine routes. In the case of these studies, turbine routes include both powerhouse plus gatewell. The FPEs at Wanapum were $\widehat{\text{FPE}}$ = 0.3500 ($\widehat{\text{SE}}$ = 0.0251) and $\widehat{\text{FPE}}$ = 0.5525 ($\widehat{\text{SE}}$ = 0.0261) for yearling Chinook salmon and steelhead, respectively. The FPE for yearling Chinook salmon at Priest Rapids Dam was estimated to be $\widehat{\text{FPE}}$ = 0.6520 ($\widehat{\text{SE}}$ = 0.0144). For steelhead at Priest Rapids Dam, the FPE was estimated to be $\widehat{\text{FPE}}$ = 0.6920 ($\widehat{\text{SE}}$ = 0.0141).

**Table 3.17.** Route-specific passage proportions (standard error in parentheses) at (a) Wanapum and (b) Priest Rapids dams for yearling Chinook salmon and steelhead.

a. Wanapum Dam

| Stock | Fish Bypass | Spillway | Powerhouse + Gatewell |
|---|---|---|---|
| Yearling Chinook salmon | 0.0750 (0.0139) | 0.2750 (0.0235) | 0.6500 (0.0251) |
| Steelhead | 0.0994 (0.0157) | 0.4530 (0.0262) | 0.4475 (0.0261) |

b. Priest Rapids Dam

| Stock | Top Spill | Spillway | Powerhouse + Gatewell |
|---|---|---|---|
| Yearling Chinook salmon | 0.3814 (0.0147) | 0.2693 (0.0134) | 0.3493 (0.0145) |
| Steelhead | 0.4716 (0.0152) | 0.2195 (0.0126) | 0.3088 (0.0141) |

### 3.3.3 Route-Specific Relative Survivals

The tag-release design did not permit the estimation of absolute survivals through the passage routes at Wanapum and Priest Rapids dams. Instead, relative survivals were calculated, expressing survival through one route relative to that of survival through the spillway. The spillway was selected as the route of reference, because it is common to both dams and expected to be the most benign route.

At Wanapum Dam, survival through the powerhouse and bypass were not appreciably or significantly different from the spillway for yearling Chinook salmon ($P > 0.05$). However, for steelhead, powerhouse passage was significantly different and lower than survival through the spillway ($P < 0.05$) (Table 3.18).

At Priest Rapids, passage through the top spill was significantly different and higher than through the spillway for both yearling Chinook salmon and steelhead ($P < 0.05$). Powerhouse passage had significantly lower survival than through the spillway for both fish stock ($P < 0.05$) (Table 3.18).

**Table 3.18.** Route-specific relative survival compared to the spillway at (a) Wanapum and (b) Priest Rapids dams for yearling Chinook salmon and steelhead in 2014. Routes of passage denoted as spillway (Spill), powerhouse (PH), bypass (BYP), and top spill (TS). Standard errors in parentheses.

a. Wanapum Dam

| Stock | $S_{PH/}S_{Spill}$ | $S_{BYP/}S_{Spill}$ |
|---|---|---|
| Yearling Chinook salmon | 1.0048 (0.0208) | 0.9931 (0.0414) |
| Steelhead | 0.9502 (0.0190)* | 1.0061 (0.0062) |

b. Priest Rapids Dam

| Stock | $S_{PH/}S_{Spill}$ | $S_{TS/}S_{Spill}$ |
|---|---|---|
| Yearling Chinook salmon | 0.9501 (0.0156)* | 1.0184 (0.0089)* |
| Steelhead | 0.9636 (0.0179)* | 1.0265 (0.0120)* |

* Significantly different from 1 at $P < 0.05$

## 4.0 Discussion and Summary

### *Study Conduct*

The 2014 steelhead and yearling Chinook salmon smolt survival studies at Wanapum and Priest Rapids developments were conducted with few issues. Tag releases were performed between 7–28 May for steelhead and 30 April – 24 May 2014 for yearling Chinook salmon. Analysis found tagger effort was reasonably balanced across release locations, and there was little evidence to suggest that fish tagged by different staff had differential effects on reach survival. There was good downstream mixing among the three releases of yearling Chinook salmon. For steelhead, arrival timing between release groups was offset by 25–51 hours. Tag-life corrections were relatively small; in all cases, the probability of a tag being active at a downstream detection site was ≥0.982.

### *Study Performance*

Four development-specific survival estimates were produced in 2014 (i.e., 2 species × 2 developments). In all four cases, estimated standard errors were ≤0.0140 (requirements specify SE ≤ 0.025). In three of the four cases, development passage survival (i.e., reservoir and dam) estimates meet requirements of $\hat{S} \geq 0.93$ (i.e., steelhead, $\hat{S}_{PR} = 0.9613$; yearling Chinook salmon, $\hat{S}_{WAN} = 0.9448$; and yearling Chinook salmon, $\hat{S}_{PR} = 0.9612$). For steelhead at Wanapum, $\hat{S}_{WAN} = 0.9294$, missing the benchmark by 0.0006.

The Wanapum – Priest Rapids Project has a survival standard of $0.93^2 = 0.8649$. In 2014, both the yearling Chinook salmon ($\hat{S}_{W\text{-}PR} = 0.9082$, $\widehat{SE} = 0.0145$) and steelhead ($\hat{S}_{W\text{-}PR} = 0.8934$, $\widehat{SE} = 0.0162$) met that project standard despite the slightly lower-than-standard survival estimate for steelhead through the Wanapum Development.

### *Cross-Year Comparison*

Survival estimates have been generated at the Grant PUD hydroprojects since 2008 (Table 4.1). For steelhead, passage survival in 2014 was the highest among four years of historical data at the Priest Rapids Development. At the Wanapum Development, steelhead survival in 2014 was the third highest of four years of estimates. Overall, 2014 had the highest Wanapum – Priest Rapids Project survival in four years of investigation.

The 2014 yearling Chinook salmon study was the first of its kind at Wanapum/Priest Rapids using acoustic telemetry. No comparison to other migration years is therefore possible (Table 4.1). However, in 2003, 2004, and 2005, paired release-recapture studies were performed with PIT tags, and survival estimates were 0.8663 (0.0442), 0.8640 (0.0309), and 0.8685 (0.0214) with a three-year average of 0.8663 (Anglea et al. 2004, 2005a, 2005b).

Average flow during the steelhead tagging study (7–28 May) at Wanapum Dam was 187.3 kcfs. Figure 4.1 plots flow patterns (7 – 28 May 2014) for the 20-year period 1995–2014 at Wanapum Dam. The 2014 flows were the sixth highest in the last 20 years. Average flow during the yearling Chinook salmon tagging study (30 April – 24 May 2014) at Wanapum Dam was 182.1 kcfs.

Average flows over the course of the yearling Chinook salmon and study at Priest Rapids (30 April – 28 May) was 195.4 kcfs. Comparison of the 2014 flows to flow patterns over the last 20 years (30 April – 28 May) at Priest Rapids Dam indicates 2014 was the fifth highest flow year (Figure 4.2).

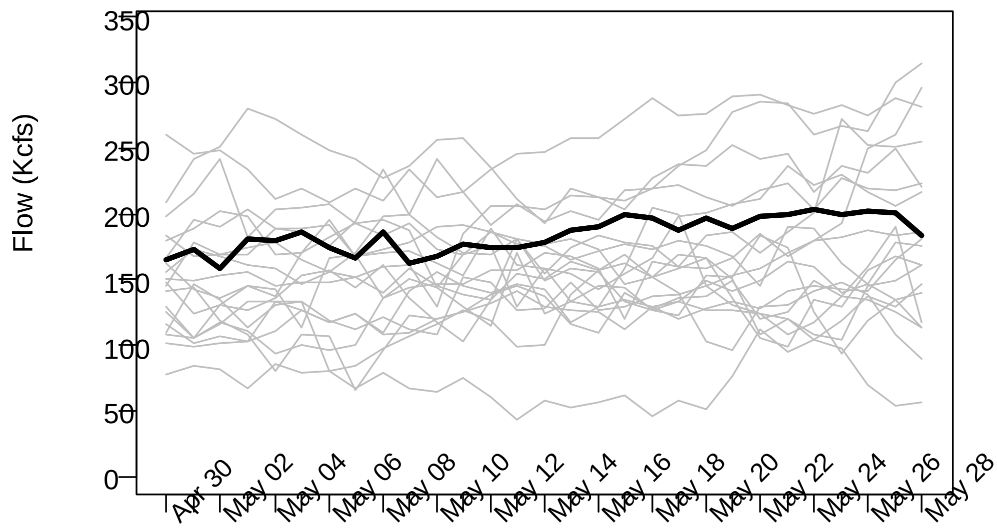



**Figure 4.1.** Flow at Wanapum Dam for the years 1995–2014 from 30 April – 28 May. The darker black line is the flow observed in 2014.

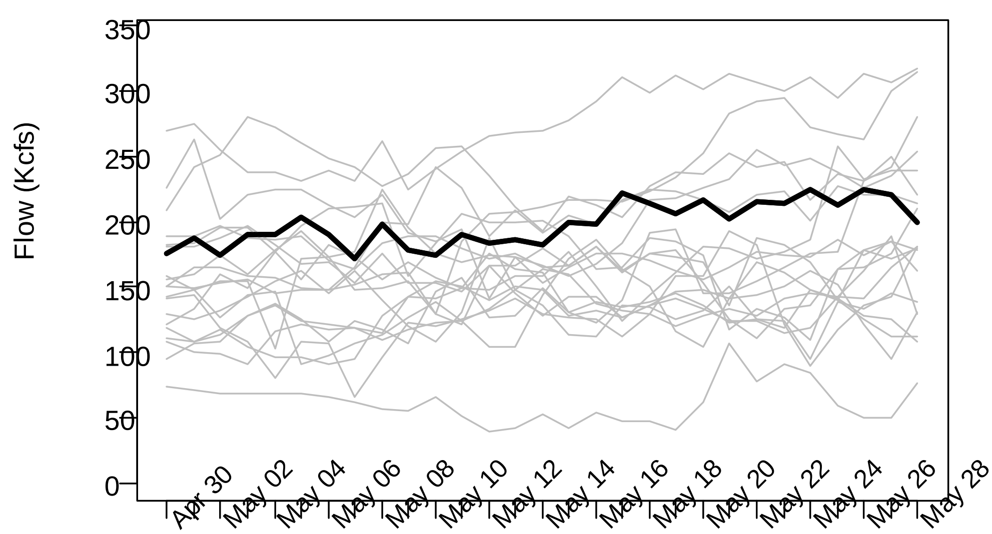



**Figure 4.2.** Flow at Priest Rapids Dam for the years 1995–2014 from 30 April – 28 May. The darker black line is the flow observed in 2014.

**Table 4.1.** Summary of survival studies at Wanapum and Priest Rapids developments, 2008–2014. Survival estimates and associated standard errors are presented by species, year, and location.

| Species | Project | Year | $\hat{S}$ | SE |
|---|---|---|---|---|
| Steelhead | Wanapum Development | 2008 | 0.9584 | 0.0242 |
| | | 2009 | 0.9436 | 0.0189 |
| | | 2010 | 0.8553 | 0.0186 |
| | | 2014 | 0.9294 | 0.0140 |
| | Priest Rapids Development | 2008 | 0.8635 | 0.0232 |
| | | 2009 | 0.8806 | 0.0206 |
| | | 2010 | 0.9037 | 0.0171 |
| | | 2014 | 0.9613 | 0.0098 |
| | Wanapum – Priest Project* | 2008 | 0.8276 | 0.0305 |
| | | 2009 | 0.8309 | 0.0256 |
| | | 2010 | 0.7729 | 0.0223 |
| | | 2014 | 0.8934 | 0.0162 |
| Sockeye salmon | Wanapum Development | 2009 | 0.9726 | 0.0093 |
| | | 2010 | 0.9408 | 0.0138 |
| | Priest Rapids Development | 2009 | 0.9460 | 0.0114 |
| | | 2010 | 0.9688 | 0.0139 |
| | Wanapum – Priest Project* | 2009 | 0.9210 | 0.0142 |
| | | 2010 | 0.9114 | 0.0187 |
| Yearling Chinook salmon | Wanapum Development | 2014 | 0.9448 | 0.0128 |
| | Priest Rapids Development | 2014 | 0.9612 | 0.0087 |
| | Wanapum – Priest Project* | 2014 | 0.9082 | 0.0145 |

*Based on product of individual development survival estimates

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# Appendix A:

# Statistical Methods

**1.0 Objectives**

In 2014, steelhead and yearling Chinook salmon smolts were acoustically tagged for the following objectives:

1. Estimate project passage survival through the Wanapum Development (one reservoir and dam).
2. Estimate project passage survival through the Priest Rapids Development (one reservoir and dam).
3. Estimate passage survival through the Wanapum – Priest Rapids Project (both reservoirs and dams).

These three objectives were accomplished using three release locations (Rock Island, Wanapum, and Priest Rapids tailraces) at the Project.

**2.0 Tag Release-Recapture Design**

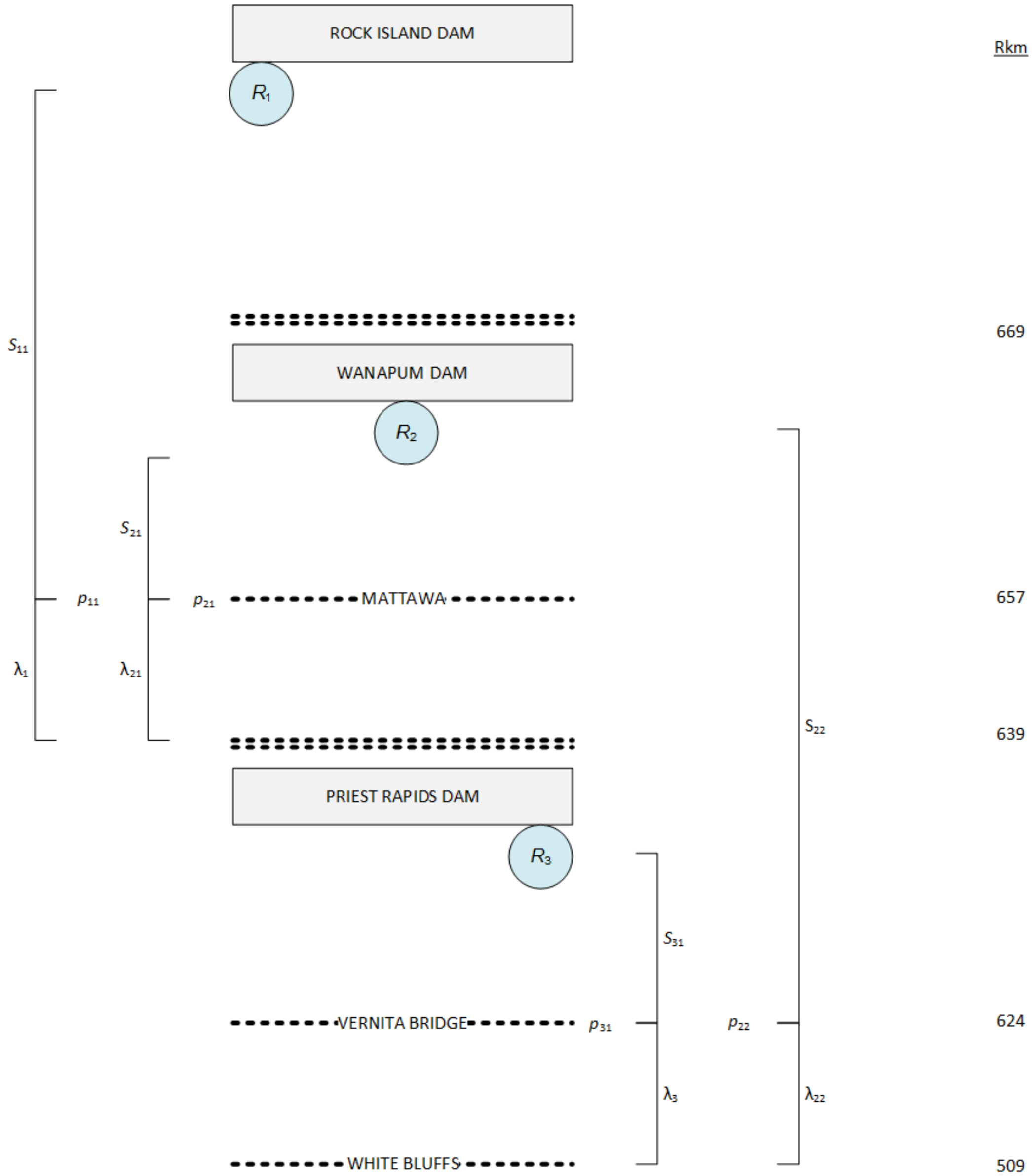
Paired release-recapture models were used to estimate passage survivals at the Wanapum and Priest Rapids developments (Fig. A.2.1). Releases from the Rock Island (treatment) and Wanapum (control) tailraces were used to estimate passage survival through the Wanapum Development. Releases from the Wanapum (treatment) and Priest Rapids (control) tailraces were used to estimate passage survival through the Priest Rapids Development (Fig. A.2.1). In turn, passage survival through the Wanapum – Priest Rapids Project was estimated by the product of the individual development survival estimates and from the paired releases at Rock Island (treatment) and Priest Rapids (control) tailraces (Fig. A.2.2).

**3.0 Development Passage Survival Estimates**

**3.1 Passage Survival at Wanapum Development**

In estimating Wanapum Development passage survival, the fully parameterized release-recapture model can be written as follows:

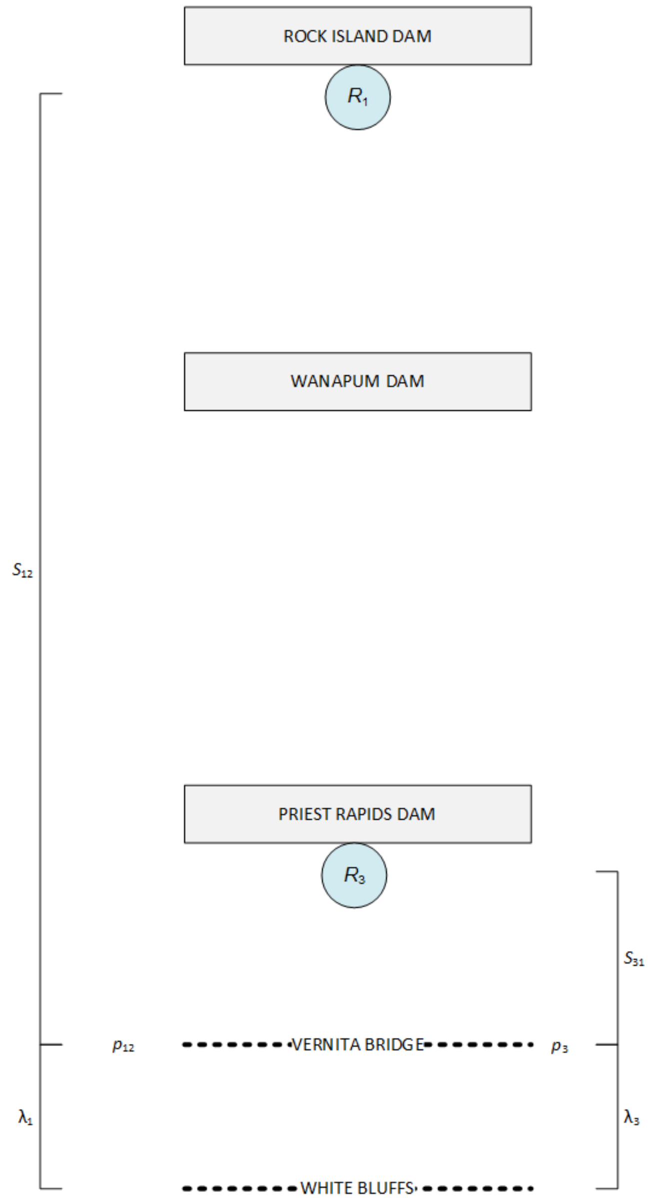
$$\begin{aligned} L = & \binom{R_1}{\underset{\sim}{n}} \left(S_{11} p_{11} \lambda_1\right)^{n_{11}} \left(S_{11}\left(1-p_{11}\right)\lambda_1\right)^{n_{01}} \left(S_{11} p_{11}\left(1-\lambda_1\right)\right)^{n_{10}} \\ & \cdot \left(\left(1-S_{11}\right)+S_{11}\left(1-p_{11}\right)\left(1-\lambda_1\right)\right)^{n_{00}} \\ & \cdot \binom{R_2}{\underset{\sim}{m}} \left(S_{21} p_{21} \lambda_2\right)^{m_{11}} \left(S_{21}\left(1-p_{21}\right)\lambda_2\right)^{m_{01}} \left(S_{21} p_{21}\left(1-\lambda_2\right)\right)^{m_{10}} \\ & \cdot \left(\left(1-S_{21}\right)+S_{21}\left(1-p_{21}\right)\left(1-\lambda_2\right)\right)^{m_{00}} \end{aligned} \tag{1}$$




Passage Survivals:

$$\hat{S}_{\text{WAN}} = \frac{\hat{S}_{11}}{\hat{S}_{21}} \qquad \text{and} \qquad \hat{S}_{\text{PR}} = \frac{\hat{S}_{22}}{\hat{S}_{31}}$$

Figure A.2.1. Schematic of paired releases used to estimate passage survival (reservoir and dam) at Wanapum and Priest Rapids developments.




Survival through Wanapum – Priest Rapids Project estimated by:

$$\hat{S}_{\text{Wan/PR}} = \frac{\hat{S}_{12}}{\hat{S}_{31}}$$

Figure A.2.2. Schematic of the paired releases used to estimate passage survival through the Wanapum – Priest Rapids Project.

where $\underset{\sim}{n}$ and $\underset{\sim}{m}$ are the vectors of counts associated with the downstream capture histories of releases $R_1$ and $R_2$, respectively (Figure A.2.1).

In the case of potential tag failure, additional parameters need to be added to the above model (1) based on methods of Townsend et al. (2006). Table A.3.1 presents the expected probabilities of occurrence for each of the possible capture histories under tag failure where:

$L_{11}$ = probability a tag from release $R_1$ survives the first reach,

$P\left(L_{12} \middle| L_{11}\right)$ = conditional probability a tag from release $R_1$ survives the second reach given its survival to the first reach,

$L_{12}$ = probability a tag from release $R_1$ survives both reach 1 and reach 2,

$L_{21}$ = probability a tag from release $R_2$ survives the first reach,

$P\left(L_{22} \middle| L_{21}\right)$ = conditional probability a tag from release $R_2$ survives the second reach conditional on its surviving the first reach,

$L_{22}$ = probability a tag from release $R_2$ survives both reach 1 and reach 2.

The joint likelihood can be expressed as

$$L = L\left(S_{11}, p_{11}, \lambda_1 \middle| R_1, \underset{\sim}{n}, \underset{\sim}{L}_1\right) \cdot L\left(S_{21}, p_{21}, \lambda_2 \middle| R_2, \underset{\sim}{m}, \underset{\sim}{L}_2\right). \quad (2)$$

The estimates of survival from likelihood model (2) should be more accurate for it takes into account possible tag failure and tag-life probabilities less than one.

The estimates of the survival and capture parameters in likelihood model (2) were calculated, treating the estimates of tag life (i.e., $\hat{L}_{11}$, $\hat{L}_{12}$, $\hat{L}_{21}$, and $\hat{L}_{22}$) as known constants. However, to calculate a realistic variance estimator for the survival parameters, the error in the estimation of the tag-life probabilities must be incorporated into an overall variance calculation. The variance of the survival estimates was calculated using the total variance formula

$$\text{Var}\left(\hat{S}_{WAN}\right) = \text{Var}_{\hat{\underset{\sim}{L}}}\left[E\left(\hat{S}_{WAN} \middle| \hat{\underset{\sim}{L}}\right)\right] + E_{\hat{\underset{\sim}{L}}}\left[\text{Var}\left(\hat{S}_{WAN} \middle| \hat{\underset{\sim}{L}}\right)\right]. \quad (3)$$

The above variance was therefore estimated in stages using the expression

$$\text{Var}\left(\hat{S}_{WAN}\right) = s^2_{\hat{S}_{WAN}|\hat{\underset{\sim}{L}}} + \text{Var}\left(\hat{S}_{WAN} \middle| \hat{\underset{\sim}{L}}\right). \quad (4)$$

Table A.3.1. Detection histories and expected probabilities of occurrences for releases $R_1$ and $R_2$ for the acoustic-tag study.

| Release | Detection History | Expected Probabilities |
|---|---|---|
| $R_1$ | 11 | $S_{11}L_{11}p_{11}P\left(L_{12}\middle|L_{11}\right)\lambda_1 = S_{11}p_{11}L_{12}\lambda_1$ |
| | 01 | $S_{11}L_{11}\left(1-p_{11}\right)P\left(L_{12}\middle|L_{11}\right)\lambda_1 = S_{11}\left(1-p_{11}\right)L_{12}\lambda_1$ |
| | 10 | $S_{11}L_{11}p_{11}\left[1-P\left(L_{12}\middle|L_{11}\right)\lambda_1\right] = S_{11}p_{11}\left(L_{11}-L_{12}\lambda_1\right)$ |
| | 00 | $\left(1-S_{11}\right)+S_{11}\left[\left(1-L_{11}\right)+L_{11}\left(1-p_{11}\right)-L_{12}\left(1-p_{11}\right)\lambda_1\right]$ |
| $R_2$ | 11 | $S_{21}p_{21}P\left(L_{22}\middle|L_{21}\right)\lambda_2 = S_{21}p_{21}L_{22}\lambda_2$ |
| | 01 | $S_{21}L_{21}\left(1-p_{21}\right)P\left(L_{22}\middle|L_{21}\right)\lambda_2 = S_{21}\left(1-p_{21}\right)L_{22}\lambda_2$ |
| | 10 | $S_{21}p_{21}\left[1-P\left(L_{22}\middle|L_{21}\right)\lambda_2\right] = S_{21}p_{21}\left(L_{21}-L_{22}\lambda_2\right)$ |
| | 00 | $\left(1-S_{21}\right)+S_{21}\left[\left(1-L_{21}\right)+L_{21}\left(1-p_{21}\right)-L_{22}\left(1-p_{21}\right)\lambda_2\right]$ |

The second term in Eq. (4) was derived from the maximum likelihood model (2) conditioning on the tag-life probabilities (i.e., $\hat{\underset{\sim}{L}}$ ). The first variance component in Eq. (4) was calculated using bootstrap resampling techniques (Efron and Tibshirani 1993). Alternative estimates of $\hat{\underset{\sim}{L}}$ were computed by bootstrapping both the observed tag-life data and travel-time data. For each estimated vector of tag-life parameters, survival was estimated using likelihood model (2). One thousand bootstrap estimates of the tag-life parameters were calculated along with the corresponding conditional maximum likelihood estimates of survival. The first variance component in Eq. (4) was then estimated by the quantity

$$s^2_{\hat{S}_{WAN}|\hat{\underset{\sim}{L}}} = \frac{\sum_{b=1}^{1000}\left(\hat{S}_b - \bar{\hat{S}}\right)^2}{(1000-1)}$$

where $\hat{S}_b$ = the *b*th bootstrap estimate of survival $(b = 1, \ldots, 1000)$,

$$\bar{\hat{S}} = \frac{\sum_{b=1}^{1000}\hat{S}_b}{1000}.$$

Use of Eqs. (4) and (5) also permits examining the contribution of the sampling error in the tag-life parameters to the overall variance in survival estimates.

Tag Life. In 2014, 50 Lotek *Model L-AMT-1.421* acoustic tags were used to characterize tag life from systematically sampling tags used in the steelhead and yearling Chinook salmon study. The tags were initiated and continually monitored in ambient river water until they failed. The failure times (or tag lives) were recorded for each of the 50 tags. The failure-time data were fit to the four-parameter vitality distribution (Li and Anderson 2009) for tag lots 1–2, where the cumulative function is of the form

$$F(t) = \left(\Phi\left(\frac{1-rt}{\sqrt{u^2+s^2t}}\right) - e^{\left(\frac{2u^2r^2}{s^4}+\frac{2r}{s^2}\right)} \times \Phi\left(-\frac{\frac{2u^2r}{s^2}+1+rt}{\sqrt{u^2+s^2t}}\right)\right) \times e^{(-kt)}. \quad (5)$$

Maximum likelihood estimation was used to calculate the parameters of the tagging model.

For tag lot 3, the tag-life data were fit to a three-parameter Weibull distribution (Elandt-Johnson and Johnson 1980:62) with scale $(\lambda)$, shape $(\beta)$, and shift $(\gamma)$ parameters and with a probability density function of the form

$$f(t) = \frac{\beta}{\lambda}\left(\frac{t-\gamma}{\lambda}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\lambda}\right)^{\beta}},$$

with survivorship function

$$S(t) = e^{-\left(\frac{t-\gamma}{\lambda}\right)^{\beta}},$$

cumulative density function

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\lambda}\right)^{\beta}}.$$

Tests Within a Release. The detection design for 2014 (Fig. A.2.1) did not permit calculation of Burnham et al. (1987) Tests 2 and 3. Furthermore, because smolts are not physically rehandled during detection, there was no reason to believe upstream detection would have an effect on downstream survival and detection processes.

Tests of Mixing. For the estimates of development and project survival to be valid, the detection data need to conform to the assumptions of statistical model (1). One assumption is the downstream mixing of release groups. Chi-square R × C contingency tables can be used to test the assumption of homogeneous arrival distributions for the various paired-releases. The chi-square contingency table tests of homogeneity are of the form:

| | | Release | |
|---|---|---|---|
| | | $R_1$ | $R_2$ |
| Arrival Date | 1 | | |
| | 2 | | |
| | ⋮ | | |
| | $D$ | | |

However, these tests are very sensitive at the sample sizes used in the tagging study. Instead, visual inspection of the arrival distributions was used to assess adequate mixing.

### 3.2 Passage Survival through the Priest Rapids Development

Using the paired releases $R_2$ and $R_3$ depicted in Fig. A.2.1, passage survival through the Priest Rapids Development (one reservoir and dam) was estimated analogous to the methods described in Section 3.1. Downstream detection sites for this analysis were Vernita Bridge and White Bluffs.

### 3.3 Passage Survival through the Wanapum – Priest Rapids Project

Using the paired releases $R_1$ and $R_3$ depicted in Fig. A.2.2, passage survival through the Wanapum – Priest Rapids Project (both dams and reservoirs) can be estimated. Downstream detection sites for this analysis were Vernita Bridge and White Bluffs. This survival estimate was compared to the estimate calculated as the product of the individual Wanapum and Priest Rapids development passage survival estimates, i.e. $\hat{S}_{\text{WAN-PR}} = \hat{S}_{\text{WAN}} \cdot \hat{S}_{\text{PR}}$. If assumptions are satisfied, these estimates shall be similar. Managers often prefer the product method because of the consistency between the individual development estimates and the project estimate.

## 4.0 Literature Cited

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Phone: 208.321.0363
Fax: 208.321.0364

# Memorandum

**To:** Denny Rohr

**From:** Tracy Hillman

**Date:** 17 November 2014

**Re:** FCWG Meeting Progress Report

The Fall Chinook Working Group (FCWG) met at Grant PUD in Ephrata, WA, on Tuesday, 4 November from 10:00 am to 12:00 pm.

## Wanapum Dam Issues

- Grant PUD gave a brief update on the status of Wanapum Dam. The update described the ongoing cleaning of aquatic vegetation and other debris from the pump screens, the status of installation of tendons in the monolith piers, and the planned removal of the Fishway Exit Passage Systems from the dam. The plan is to remove the exit passage systems in the dry before the anticipated pool raise occurs later this year.
- A total of 15 tendons have to be installed before the pool can be raised to 558-562 feet. Currently, 13 tendon holes have been drilled and sheathed. The pool will be refilled at a rate of three feet per day with monitoring occurring as the pool is refilled.

## Final Report and Implementation Feasibility Study/Implementation Feasibility Plan

- Consistent with the 401 reporting requirements, Grant PUD is preparing a final report for Ecology that includes the investigation of reasonable and feasible measures to avoid, reduce, or mitigate for adverse effects (Implementation Feasibility Study; IFS) and a plan to implement approved measures (Implementation Feasibility Plan; IFP). Grant PUD provided an overview of the information contained within the report. Members had no concerns or comments on the layout of the report. A draft of the final report will be available for review by 12 November. The FCWG will have 90 days to review the report. The final report will be submitted to Ecology and FERC in April 2015.

## Hanford Reach Working Group Updates

- Protection flows started on 15 October with reverse load factoring. Fall Chinook spawning below the 50 kcfs level began on 22 October; spawning above the 50 kcfs level began on 29 October. The critical flow elevation will be determined following the 23 November survey.
- The FCWG/HRWG is reviewing the 2013-2014 Hanford Reach Protection Program Draft Report. Comments are due to Grant PUD by 28 November.
- The FCWG/HRWG is reviewing the 2013-2014 Priests Rapids Hatchery M&E Report. Comments are due to Grant PUD by 21 November.
- Using hook-and-line, volunteers captured 305 untagged fall Chinook in the Hanford Reach on 24-26 October. Three fish died, resulting in a total of 302 untagged Chinook for the hatchery program. The goal was to collect 500 untagged Chinook.

## 2014 Return-Year Studies and Funding Opportunities

- The Alaska Department of Fish and Game is funding a study to evaluate the effects of redd superimposition on fall Chinook salmon in the Hanford Reach. The study focuses on numbers of eggs dislodged from redds during spawning.
- Proposals by Mainstem Fish Research and Pacific Northwest National Laboratory were developed to investigate predation in the McNary reservoir and the effect of superimposition on emergence timing. The proposals were submitted to the Northern Fund. Ecosystem Insights and WDFW developed a proposal to analyze otoliths to investigate limiting factors. The proposal will be submitted through the LOA process.

## Next Steps

The FCWG will next meet on Tuesday, 2 December 2014 at Grant PUD in Ephrata, WA.

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# Priest Rapids Coordinating Committee Meeting

Wednesday, November 19, 2014
9:00 am – 1:00 pm
SeaTac Radisson Hotel

Audio: 1-800-977-8002   Bridge: 45582544
Webinar Instructions:
https://grantpud.webex.com/grantpud/j.php?MTID=m3050f8f5182b6caafb34510f58f0210e

## PRCC Members

Scott Carlon, Justin Yeager (Alt), NMFS
Bob Rose, YN
Jeff Korth, C. Andonaegui (Alt), P. Verhey, (Alt), WDFW
Curt Dotson, Tom Dresser (Alt), GCPUD
Jim Craig, USFWS
Kirk Truscott, CCT
Tom Skiles, CTUIR
Denny Rohr, Facilitator

## Meeting Agenda

I. Welcome and Introductions

II. Meeting Minutes Approval:

   A. Affirmation of B. Rose approval of September 24, 2014 meeting minutes

   B. Approval of October 29, 2014 meeting minutes

III. Agenda Review

IV. Action Items Review – from October 29, 2014 Meeting

V. Presentation: Avian Studies Reports – Dan Roby, Oregon State University; Allen Evans, Real Time Research (C. Dotson)

VI. Review/Discussion of 2014 Survival/Behavioral Studies Draft Reports – (C. Dotson)

VII. Update of Wanapum Dam Activities (T. Dresser)

VIII. SOA 2014–04, Affirmation of Schedule Change for Sockeye Survival Studies (C. Dotson)

IX. Potpourri (D. Rohr)

X. Updates

A. Inland Avian Predation Activities (C. Dotson)

B. Priest Rapids Bypass Operation (C. Dotson, T. Dresser)

C. Hatchery Activities (T. Dresser)

    a. Carlton Acclimation Facility

    b. Nason Creek Acclimation Facility

    c. PR Hatchery Modifications

    d. Penticton Hatchery

D. Hatchery Permits (Section 10 for Summer Chinook and Section 7 Consultation for Bull Trout) (T. Dresser)

E. NNI Funded Projects

    a. Real Time Research Avian Study (C. Dotson)

       ** Including "Comprehensive Assessment of Total Smolt Mortality in Relation to Avian Predation on the Mid- and Lower Columbia River: Spatial and Temporal Analysis of Reservoir-Specific Smolt Losses"

    b. Supplementary Tags and Tagging for Assessment of Predation Losses of Subyearling Chinook Salmon in the lower Hanford Reach and Upper McNary Reservoir (C. Dotson)

    c. Upper Columbia Fish Screen Monitoring Program Phase I Contract Extension (J. Korth)

    d. Upper Columbia Fish Screen Monitoring Program Phase II – (J. Korth)

    e. Lower Wenatchee Instream Flow Enhancement Project Phase II – (J. Korth)

    f. Mid-Columbia River Intake Screen and Diversion Assessment (T. Dresser)

    g. Methow Valley Irrigation District (MVID) Instream Flow Improvement Project (T. Dresser)

F. Committee Reports (D. Rohr)

G. NNI and Habitat Funds Report (D. Rohr)

H. Other

XI. Review of Next Month's Agenda Topics (D. Rohr)

XII. Next Meeting – November 19, 2014, SeaTac Radisson Hotel (D. Rohr)

# Priest Rapids Coordinating Committee Meeting

Wednesday, November 19, 2014
9:00 am – 1:00 pm
SeaTac Radisson Hotel

## PRCC Members

Scott Carlon, Justin Yeager (Alt), NMFS
Bob Rose, YN
Jeff Korth, C. Andonaegui (Alt), P. Verhey (Alt), WDFW
Curt Dotson, Tom Dresser (Alt), GCPUD
Jim Craig, USFWS
Kirk Truscott, CCT
Tom Skiles, CTUIR
Denny Rohr, Facilitator

## Attendees

Scott Carlon, NMFS
Bob Rose, YN (Via phone)
Leah Sullivan, Blue Leaf Environmental
Dan Roby, Oregon State University
Tom Dresser, GCPUD (Via phone)
Denny Rohr, Facilitator
Jeff Korth, WDFW
Jim Craig, USFWS
Allen Evans, Real Time Research
Curt Dotson, GCPUD
Debbie Williams, GCPUD (Via phone)

## Distributed Items:

1. November 19, 2014 Agenda
2. Evaluation of Foraging Behavior, Dispersal, and Predation on ESA-listed Salmonids from the Upper Columbia River by Caspian Terns Displace from Managed Colonies in the Columbia Plateau Region (PPT presentation)
3. Behavior and Survival Analysis of Juvenile Steelhead and Yearling Chinook Salmon through the Priest Rapids Project in 2014
4. PRFF and FCWG committee reports
5. Survival of Acoustic-Tagged Steelhead and Yearling Chinook Salmon Smolts through the Wanapum – Priest Rapids Project in 2014
6. SOA 2014-04, Change Sockeye Survival Study from year 2016 to 2015
7. Wanapum Reservoir Press Release – November 18, 2014

## Decision Summary:

1. PRCC members affirmed SOA 2014-04, Sockeye Survival Study, dated 10/29/2014, subject to Truscott and Skiles approval.

Action Items:

1. Williams to distribute October 29, 2014 meeting minutes for comment.
2. Dotson will send the Avian Studies Report PowerPoint to Rohr for distribution.
3. Committee Members to review 2015 Avian Foraging proposal prior to the December 16th PRCC meeting. Dotson will have OSU separate costs of Crescent Island and Goose Island, as it relates to satellite tagging of terns.
4. Carlon will talk to Gary Fredricks, NMFS, regarding how much money the action agencies are willing to fund for avian studies and management.
5. Dotson will send 2014 Survival/Behavioral Studies Draft Report CD's to Truscott, Rose and Skiles. A 30 day comment period was agreed upon with comments due on December 19th.
6. Rohr will discuss changing the December PRCC meeting to the afternoon of December 16, 2014, via conference call, with Mike Schiewe, HCP Coordinating Committee Chair.

# Final Meeting Minutes

I. Welcome and Introductions

II. Meeting Minutes Affirmation and Approval:

   A. September 24, 2014 – Affirmed by Rose via email to Rohr.

   B. October 29, 2014 – **Williams will distribute minutes for comment.** Send comments to Williams and approval to Rohr.

III. Agenda Review – Dotson added the 2015 Avian Foraging proposal from OSU/Real Time Research to the agenda.

IV. Action Items Review – October 29, 2014 Meeting – Complete

V. Presentation: Avian Studies Reports – Dan Roby, USGS/Oregon State University and Allen Evans, Real Time Research (RTR) – Dan Roby, USGS/OSU, and Allen Evans, RTR, presented a PowerPoint (attached) summarizing results of the "2014 Evaluation of foraging behavior, colony connectivity, and predation on ESA-listed salmonids from the upper Columbia River by Caspian terns nesting on Goose Island, Potholes Reservoir." Dissuasion efforts of Caspian terns worked extremely well on Goose Island, with predation rates on yearling Chinook and steelhead being drastically reduced due to dissuasion efforts. **Dotson will send the PowerPoint presentation to Rohr for distribution. Additional information can be located at** www.birdresearchnw.org.

VI. 2015 Avian Research Proposal – Dan Roby, USGS/OSU presented Year 3 of the proposal "Evaluation of Foraging Behavior, Dispersal, and Predation on ESA-listed Salmonids from the Upper Columbia River by Caspian Terns Displaced from Managed Colonies in the Columbia Plateau Region" to PRCC members. Research funded by the No Net Impact (NNI) fund provides hard data to avian management groups responsible for avian management in the Columbia Plateau. PRCC members commented that the Priest Rapids Project should be the focus of any NNI funded projects and that the PRCC shouldn't be responsible for avian management outside of the Project. After a short discussion of the proposal, PRCC members asked that costs for Goose Island and Crescent Island be identified and listed separately. If possible, Dotson asked that PRCC members send any questions they may have to him prior to the December 3rd Inland Avian Management meeting in Walla Walla as he will be able to discuss PRCC questions with Roby and Evans at that time. PRCC members will review the proposal prior to the December 16th PRCC meeting. Carlon will talk to Gary Fredricks, NMFS, regarding how much money the action agencies are willing to fund for avian studies and management. Future discussion topic: Responsibility of PRCC for Caspian Terns that are pushed to Crescent Island and the sustainability of funding this project long term.

VII. Review/Discussion of 2014 Survival/Behavioral Studies Draft Reports – Dotson distributed CD's that will provide the reports in Word format. A 30 day comment period was agreed upon with comments due by December 19th. Dotson will send CD's to Truscott, Rose and Skiles.

VIII. Update of Wanapum Dam Activities – Dresser reported that on November 18th, a press release (attached) was sent out outlining Grant PUD's plan to start refilling Wanapum Reservoir between November 24th and December 11th based on river flows and structural-integrity measurements. The partial refill will take six to 18 days to reach a target forebay elevation of 562', with an operating range of 4'. The refill plan is still under review by FERC and the Board of Consultants, which met today.

The Wanapum right bank spiral chute and supporting structure was removed on November 17th and the left bank spiral chute and supporting structure was removed on November 18th. Removal of the left bank infrastructure is expected to take about 1 week. As soon as that is completed, crews will move to the right bank and begin removal of all infrastructure installed during the draw down. At this time, it is expected that there will be a 2 week outage window during which time both fishways will be dewatered. Infrastructure removed from the left bank will be saved in the very slim chance that it would be needed again.

IX. SOA 2014-04, Change of Sockeye Survival Study from year 2016 to 2015 – During last month's PRCC meeting, members approved moving the year 2016 sockeye study to 2015. This SOA captures that move for the administrative record. PRCC members affirmed SOA 2014-04, dated 10/29/2014, subject to Truscott and Skiles approval.

X. Potpourri – Adult spill for fallback ended on November 15th at Wanapum and Priest Rapids dams.

XI. Updates

A. Inland Avian Predation Activities (Goose Island / NW Rocks Follow Up) (C. Dotson) – The Army Corp of Engineers (Walla Walla District) will hold an avian predation workshop in Walla Walla on 12/3/2014.

B. Priest Rapids Bypass Operation (C. Dotson) – No update.

C. Hatchery Activities (C. Dotson, J. Korth)

1. Carlton Acclimation Facility – 181,000 2013 smolts will be transferred to Dryden for acclimation.

2. Nason Creek Acclimation Facility –Tangle nets were used to collect 27 natural origin fish for Nason Creek broodstock. Hatchery origin fish were collected at Tumwater. There are currently 45,000 BY 2013 juvenile Nason Creek spring Chinook acclimating at the Nason Creek Facility. Dedication of the facility took place on November 13th, with a public open house to follow. Dresser noted that all members of the public were very supportive of the program.

3. White River – Dresser reported that there are no more ESA listed spring Chinook adults at the Little White Salmon National Fish Hatchery and that approximately 75,000 juveniles (BY 2013) on station will be transferred to the White River in March for acclimation and eventual release in May 2015.

4. PR Hatchery Modifications – Dresser reported that modifications made to the adult trap worked very well, but there are still additional modifications that may be needed to accommodate the large number of returning fish. There are approximately 25 items that still need to be addressed in 2015. Dresser said that there are concerns of steelhead getting into the volunteer trap that needs to be addressed. A question concerning drains in the incubation room was also raised. Dresser indicated that there may be a work-around/process to address drain issues in the incubation room. BY 2014 broodstock collection goals were met and real-time otolith readings and adult mating strategies was implemented at the PRH this year.

5. Penticton Hatchery – 2.6 million eggs were collected for BY 2014. Juveniles will be released into Skaha Lake in 2015.

D. Hatchery Permits (Section 10 for Summer Chinook and Section 7 Consultation for Bull Trout – Dresser reported that on November 25, 2014, Grant, Douglas and Chelan PUD's will be meeting with NOAA to discuss inconsistencies in the draft Section 10's that had been developed for the USFWS and PUD's program as it relates to the Methow monitoring and evaluation programs.

E. NNI Funded Projects

1. Real Time Research Avian Study (C. Dotson) – See Item V above. Report will be complete in January.

   ** Including "Comprehensive Assessment of Total Smolt Mortality in Relation to Avian Predation on the Mid- and Lower Columbia River: Spatial and Temporal Analysis of Reservoir-Specific Smolt Losses"

2. Supplementary Tags and Tagging for Assessment of Predation Losses of Subyearling Chinook Salmon in the lower Hanford Reach and Upper McNary Reservoir (C. Dotson) – Battelle is analyzing data; a draft report will be forthcoming in December.

3. Upper Columbia Fish Screen Monitoring Program Phase I Contract Extension (J. Korth) – No update provided.

4. Upper Columbia Fish Screen Monitoring Program Phase II – (J. Korth) – No update provided.

5. Lower Wenatchee Instream Flow Enhancement Project Phase II – (J. Korth) – No update provided.
6. Mid-Columbia River Intake Screen and Diversion Assessment – Korth reported that divers intend to be in the water by the end of this week. WDFW and Grant PUD will coordinate pool raise information regarding the Wanapum reservoir.
7. Methow Valley Irrigation District (MVID) Instream Flow Improvement Project (T. Dresser) – No update

F. Committee Reports (D. Rohr) – Distributed via email.

G. NNI and Habitat Funds Report (D. Rohr) – Rohr will distribute upon receipt.

XII. Review of Next Month's Agenda Topics (D. Rohr) – Review of avian project proposal; review of draft juvenile survival/behavior study document.

XIII. Next Meeting – December 17, 2014, SeaTac Radisson Hotel. Rohr will discuss changing the December PRCC meeting to the afternoon of December 16, 2014, via conference call, with Mike Schiewe, HCP Coordinating Committee Chair.

# PRCC-HCP Briefing

**November 3, 2014**

Grant County
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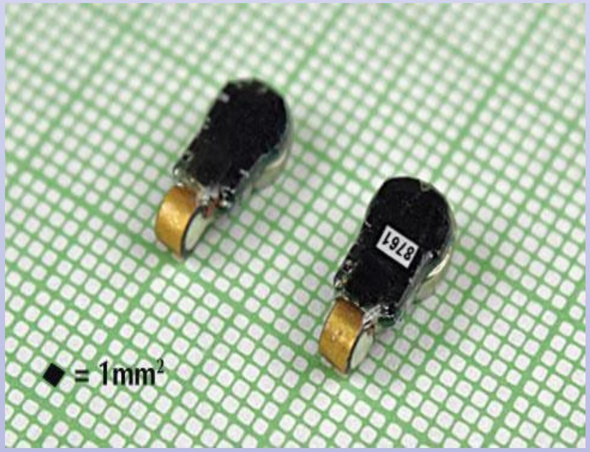
# Steelhead and Yearling Chinook Acoustic Tag Study

LOTEK *Model L-AMT-1.421*

acoustic transmitters



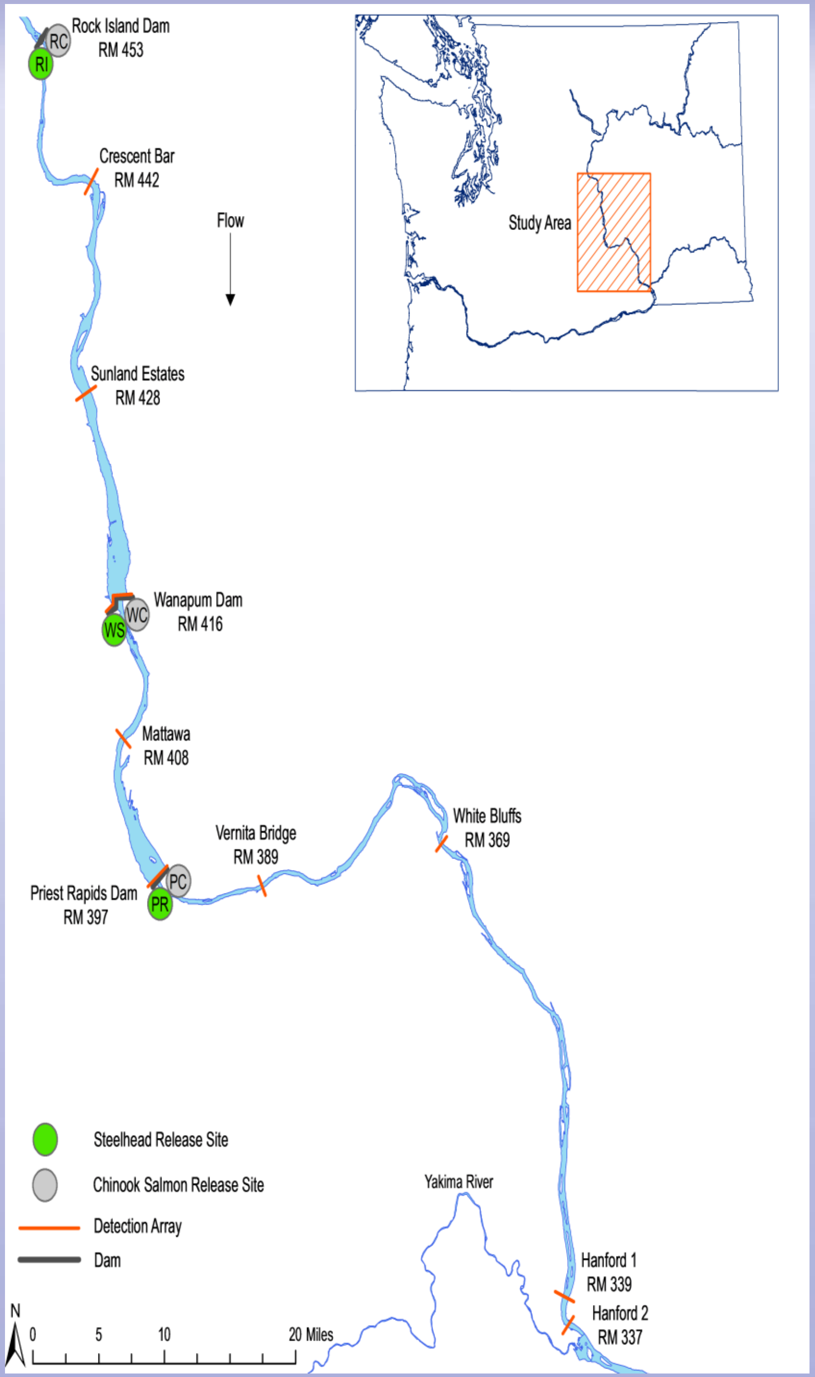


*Biomark HDX12*
12 mm PIT tags

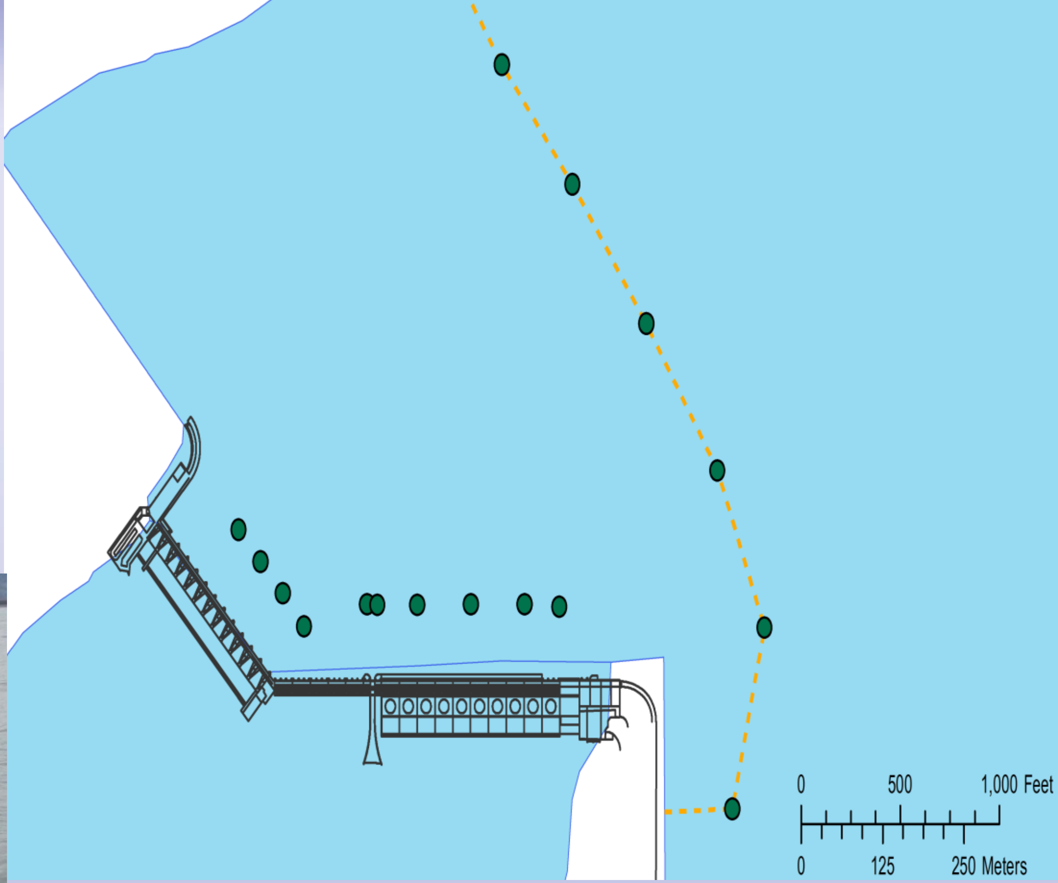
*Teknologic*
Autonomous
Receivers

# Project Overview

- Release Dates and Quantities
  - Steelhead (May 7-28)
    - Rock Island: 399
    - Wanapum: 771
    - Priest Rapids: 550
  - Yearling Chinook (Apr 30 – May 24)
    - Rock Island: 398
    - Wanapum: 769
    - Priest Rapids: 549



# Wanapum Dam

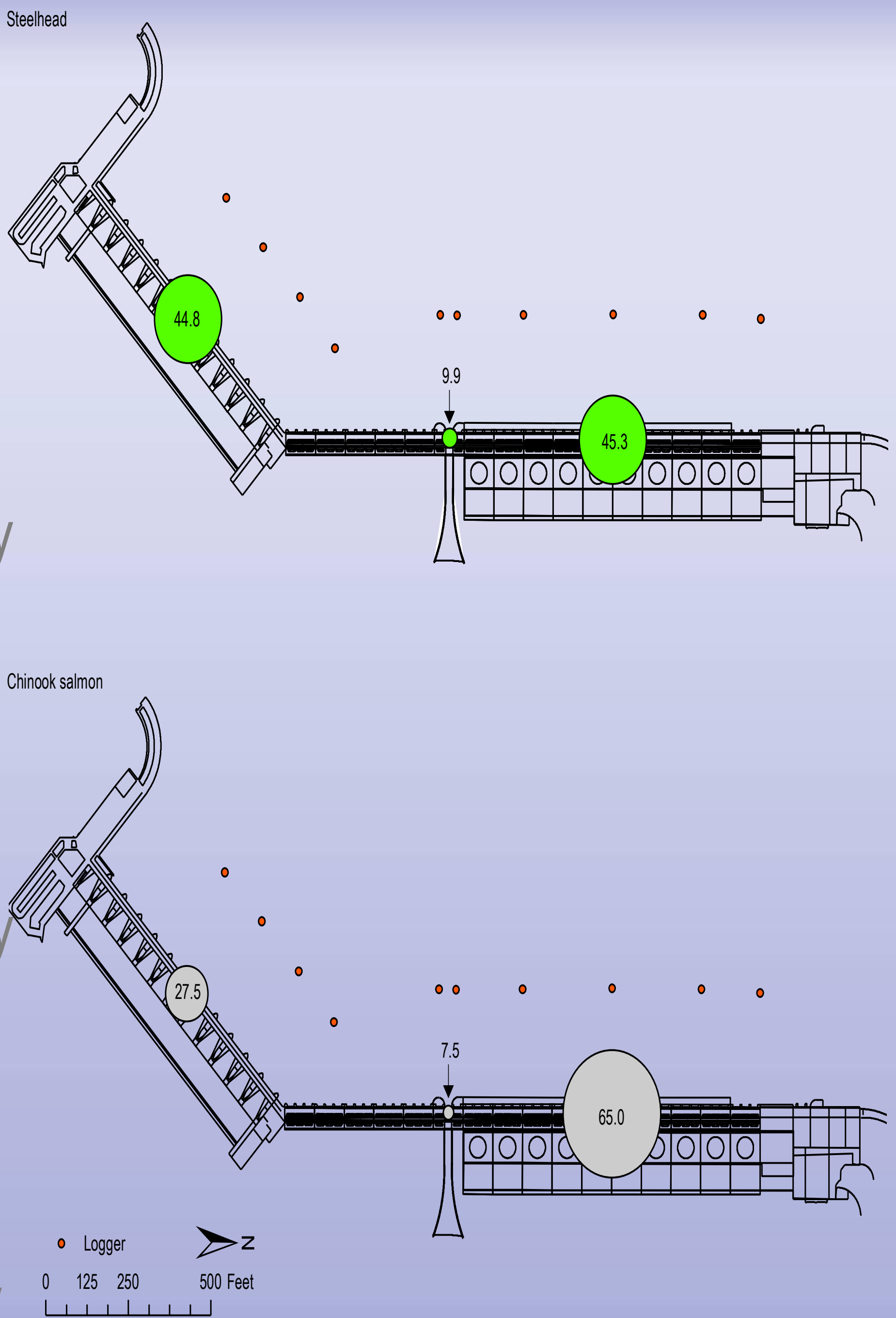



- Receivers for 0/1 and passage route determination
  - ✓ 6 BRZ (Boat Restricted Zone)
  - ✓ 10 dam

# Passage Route Selection

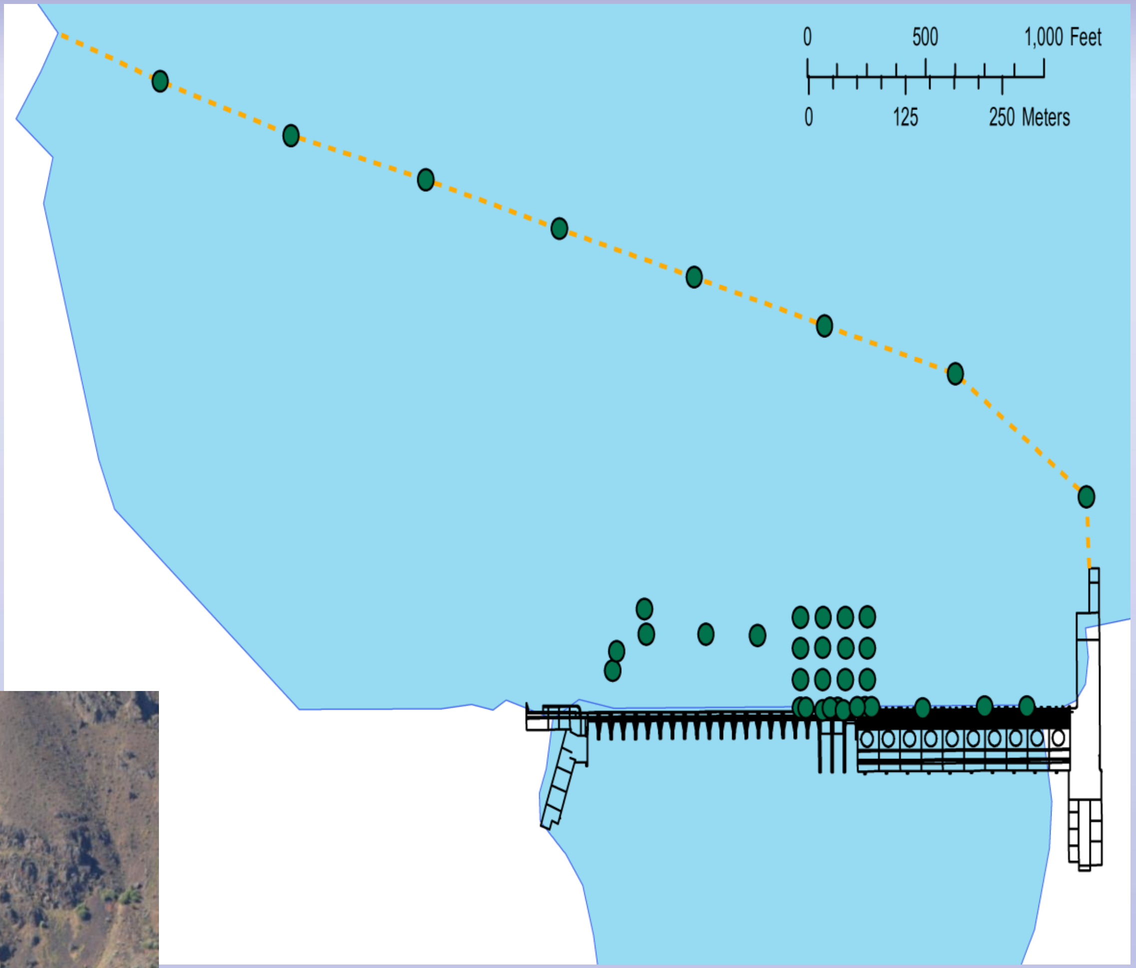
Wanapum Dam

- Steelhead: Non-Turbine FPE 55%
  - 9.9% bypass, 44.8% spillway
  - 45.3% powerhouse
- Yearling Chinook: Non-Turbine FPE 35%
  - 7.5% bypass, 27.5% spillway
  - 65.0% powerhouse




**FPE = Fish Passage Efficiency**

# Priest Rapids Dam

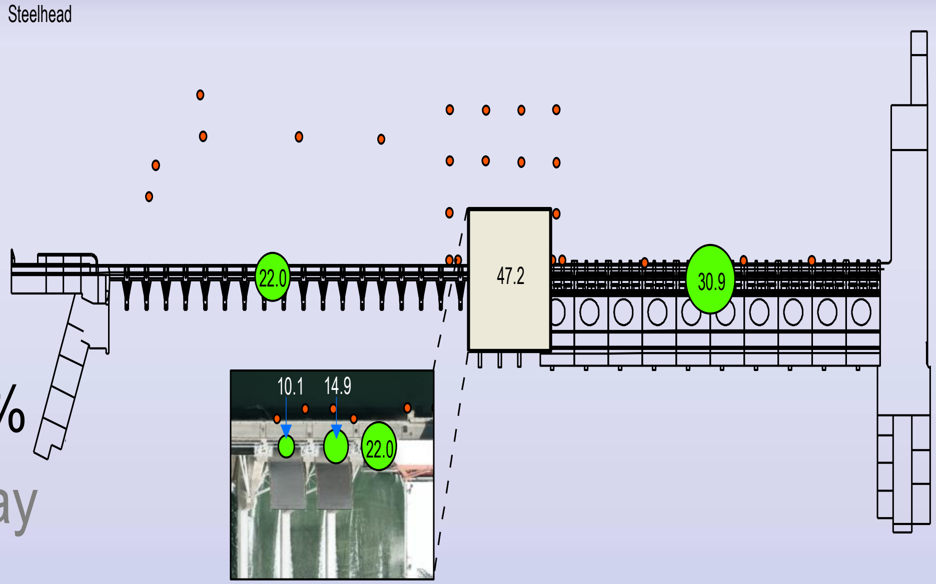



- Receivers for 0/1, passage route determination, and 3D tracking at top-spill
  - ✓ 8 BRZ (Boat Restricted Zone)
  - ✓ 28 dam

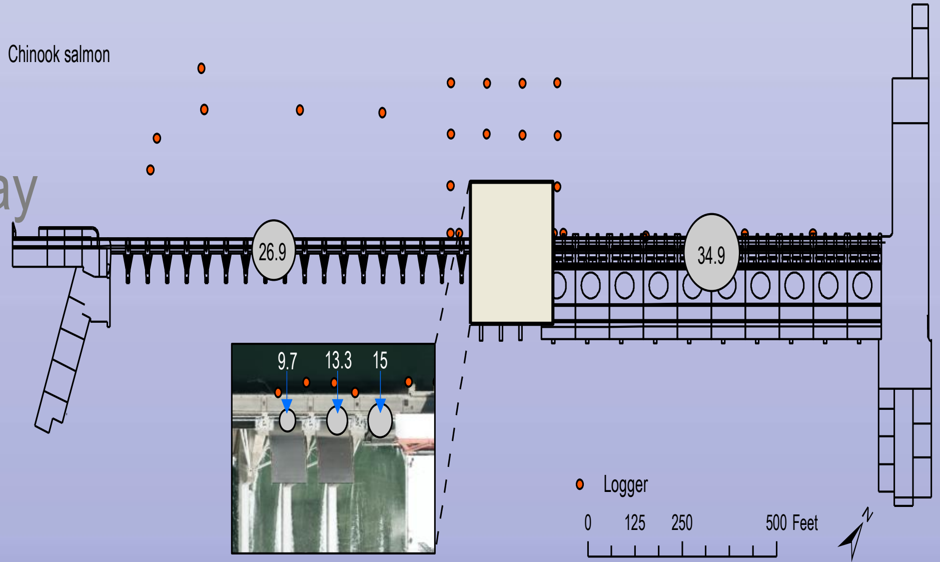
# Passage Route Selection

Priest Rapids Dam

- Steelhead: Non-Turbine FPE 69%
  - 47.2% top-spill, 22.0% spillway
  - 30.9% powerhouse




- Yearling Chinook: Non-Turbine FPE 65%
  - 38.1% top-spill, 26.9% spillway
  - 34.9% powerhouse




FPE = Fish Passage Efficiency

# Passage Survival by Dam

| Species | Year | Wanapum | Priest Rapids |
|---|---|---|---|
| Steelhead | | | |
| | 2014 | 0.978 | 0.985 |
| Yearling Chinook | | | |
| | 2014 | 0.988 | 0.971 |

*Point estimates are based on proportions of fish detected downstream at one or more locations that passed at each dam.*

# Survival Summary

| Project | Yearling Chinook salmon | Steelhead |
|---|---|---|
| Wanapum | 0.9448 (0.0128) | 0.9294 (0.0140) |
| Priest Rapids | 0.9612 (0.0087) | 0.9613 (0.0098) |
| Wanapum – Priest Rapids | 0.9082 (0.0148) | 0.8934 (0.0163) |

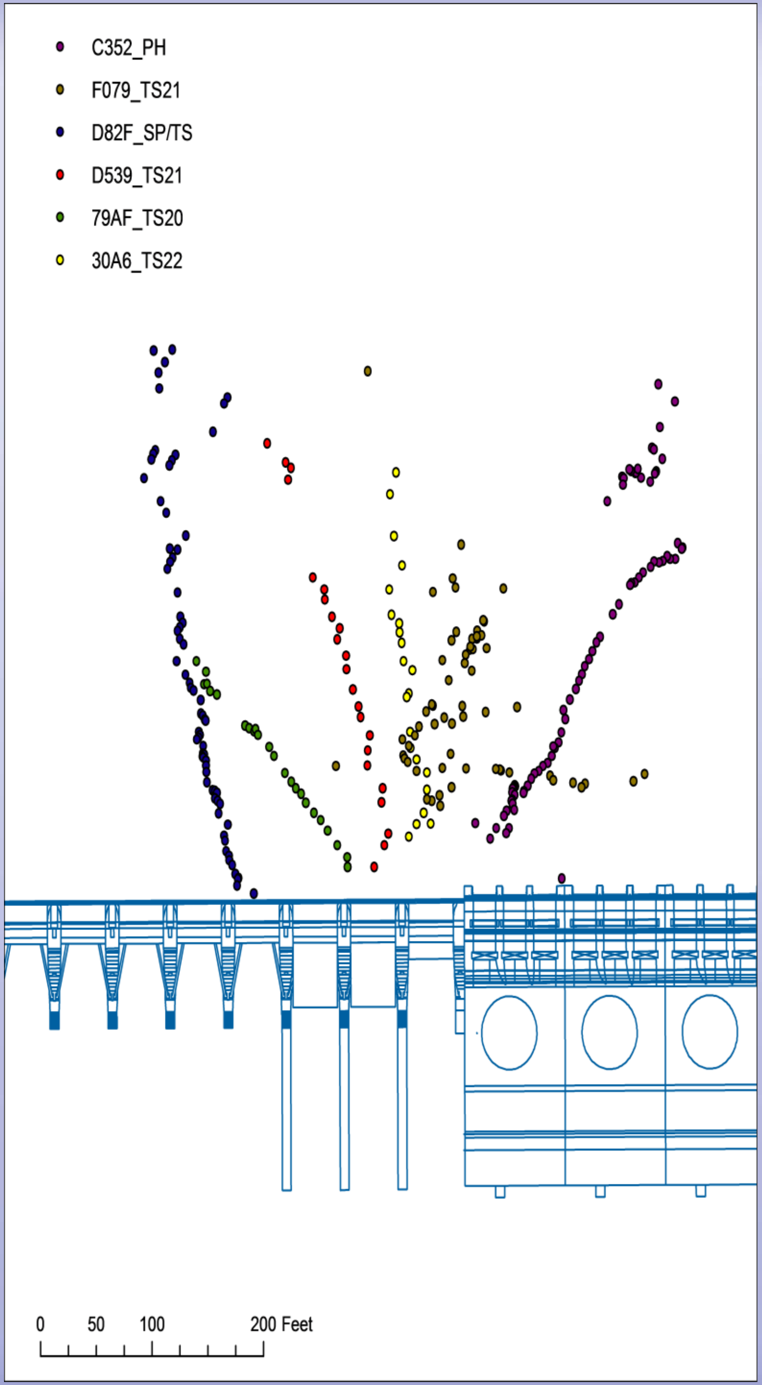
Survival standard: $\hat{S} \geq 0.93$ and $\widehat{\text{SE}} \leq 0.025$

# Survival by Passage Route

| | Wanapum | | Priest Rapids | |
|---|---|---|---|---|
| Passage Route | Qty Passed | Detected Downstream | Qty Passed | Detected Downstream |
| **Steelhead** | | | | |
| WFB/PRFB | 36 | 1.000 | 507 | 0.996 |
| Spillway | 164 | 0.994 | 236 | 0.970 |
| Powerhouse | 152 | 0.941 | 276 | 0.938 |
| **Yearling Chinook** | | | | |
| WFB/PRFB | 27 | 0.963 | 415 | 0.998 |
| Spillway | 99 | 0.970 | 293 | 0.980 |
| Powerhouse | 225 | 0.982 | 352 | 0.926 |

# 3D Positions

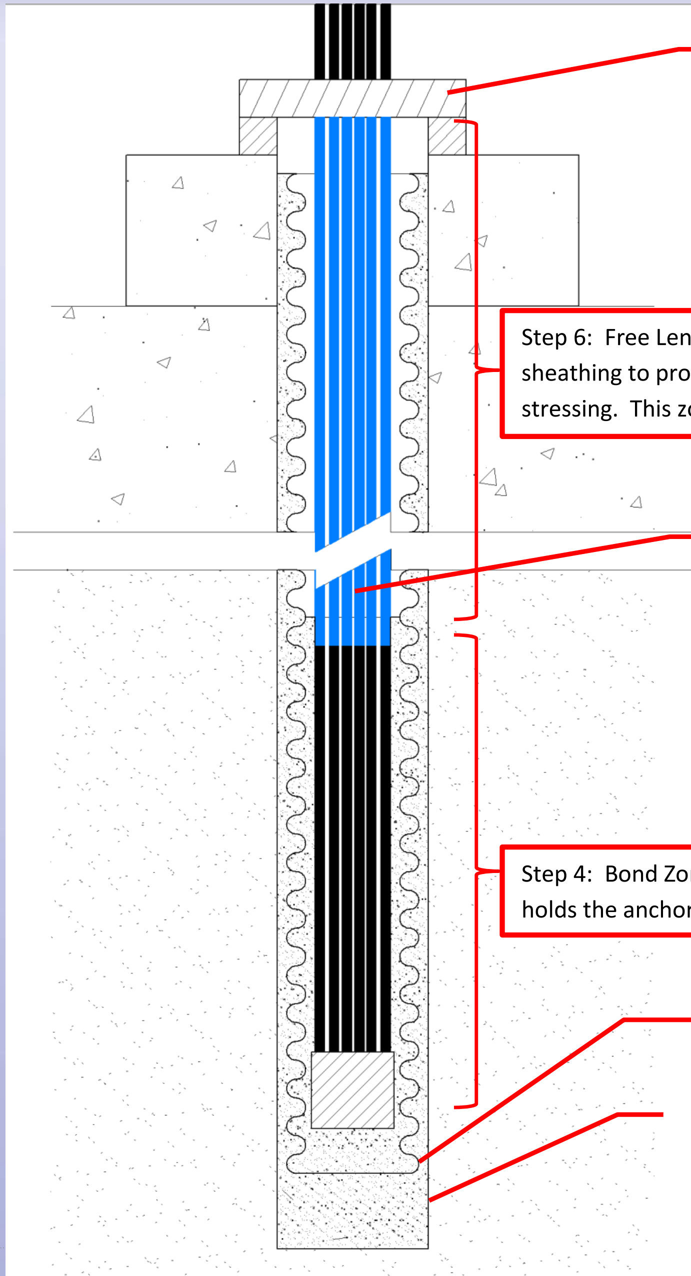
*in progress*



**In preparation for an anticipated pool raise during 4th Quarter 2014, Grant PUD will remove the Wanapum Fishway Exit Passage System from the Wanapum Left Bank Fishway on November 17th, 2014.**

# Construction status

- 34 of 35 required - 4” pilot holes completed;
- 15 of 35 - 16” full sized holes completed (6 in progress);
- 10 of 35 - 10” sheaths installed and grouted;
- 11 of 35 tendon installation and tensioning in progress;



Step 5: Anchor Head and Wedge Plate – Tendon is stressed/tensioned and strands are clamped/wedge to hold tension (see photos)

Step 6: Free Length – Wire strands are encapsulated with plastic sheathing to protect from corrosion and allow for stretching during stressing. This zone is grouted after tendon is stressed.

Step 3: 61-Strand Tendon Anchor – Install 250 foot long (approximate) tendon into corrugated sheath (see photo)

Step 4: Bond Zone – Bare wires grouted into sheath prior to stressing. This holds the anchor into the rock formation.

Step 2: 10” Diameter Corrugated Sheath – Grouted into hole

Step 1: 16” Diameter Bore Hole – Drilled through spillway structure and into bedrock (see photo)

# Refill Plan

- As of 11/3/2014, Grant PUD has completed 13 of the 15 tendon holes required for the pool raise (562’) to the full diameter and the full depth.

- Grant PUD has completed 13 of the 15 sheaths required for the pool raise (562’).

- Key elements of the plan
  - Refill elevation 558’-562’
  - Total refill maximum of 3’ over a 24 hour period
  - Data collection and analysis collected along the way
  - Likely, 2 to 3 weeks to reach 561.5’

# PRCC-HCP Briefing

**November 17, 2014**

Grant County
PUBLIC UTILITY DISTRICT
*Excellence in Service and Leadership*

# Wanapum Refill

- Grant PUD is very close to initiating a partial refill of Wanapum Reservoir.  Pending FERC & BOC approval of Grant PUD's refill plan, raising of the reservoir could begin as early as Saturday November 22nd.

- There is still considerable spillway repair work left before the refill can begin. Therefore, while November 22nd is within the realm of possibility, it is a very optimistic date.

- Grant PUD is relatively confident that the refill will begin sometime between November 22nd and December 11th.

- Key elements of the plan
    - ✓ Refill elevation 558'-562'
    - ✓ Total refill maximum of 3' over a 24 hour period
    - ✓ Data collection and analysis collected along the way

- Duration of the refill is expected to range from 6 to 18 calendar days but could take longer pending river conditions.

- After the intermediate pool raise is complete (558' – 562'), Wanapum Dam fish ladders will be functional without the modifications that were put into place during the drawdown operational level.

# Wanapum Fishway Exit Passage System Removal

Right-Bank fishway

- Spiral Chute and all supporting structures would be removed on Nov 17th.

- Chain falls would be attached off the bottom end of the flume to make sure it does not float once pool comes up.

Left-Bank Exit Passage Structure

- Pumps and AWS turned off on Nov 18th and FW crews would sweep fish to tailrace.

- All pumps, water supply pipes, weir box, lamprey passage measures, flume, spiral chute and all supporting structures would be removed beginning on Nov 18th (1 week).

- Bulk-headed off at ladder exit.  Left-bank fishway would remain down from Nov 18th – Dec 31, 2014 for regularly scheduled ladder O&M

Grant County PUBLIC UTILITY DISTRICT

# Wanapum Right-Bank Fishway Exit Passage System Removal

**As re-fill occurs**

- When pool hits ~554' (end of wooden flume is ~553.5') the process of pulling all items out of right-bank would begin. The pumps would be turned off, ladder sweep and divers will go in and begin to remove flume, water supply pipes, pumps and support structures.
- A major concern as it relates to the flume, is if it were to buckle with uplifting pressure and/or wave action, sharp fiberglass edges could be exposed.
- Once everything attached to the outside of the weir box is removed. A bulkhead will be placed on the outside of the fishway exit and the process to remove the weir box and lamprey passage measures, etc. would begin.
- 2 weeks has been built into the schedule for removal. The 2 week timeframe maybe necessary over concern that the right bank weir box may be extremely difficult getting it out as it was very difficult going in (tight-fit) and demobilization includes in-water work.
- Once all structures are removed, bulkhead would be removed and right bank ladder would be fully operational and be able to be maintained in criteria.

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# Memorandum

**To:** Denny Rohr

**From:** Tracy Hillman

**Date:** 17 November 2014

**Re:** PRFF Meeting Progress Report

The Priest Rapids Fish Forum (PRFF) met at Grant PUD Natural Resources Office in Wenatchee, WA, on Wednesday, 5 November 2014, from 9:00 am to 12:00 pm.

## Wanapum Dam Issues

- Grant PUD provided an update on issues at Wanapum Dam. The update described the results from the steelhead and yearling Chinook salmon survival studies conducted in 2014, ongoing cleaning of aquatic vegetation from the pump screens, the planned removal of the Fishway Exit Passage Systems from the dam, and the status of installation of tendons in the monolith piers.
- At Wanapum, survival of yearling Chinook was about 94% and survival of steelhead was about 93%. Approximately 55% of the steelhead and 35% of the yearling Chinook passed Wanapum Dam through non-turbine passage routes (spillway and bypass). At Priest Rapids, survival of both yearling Chinook and steelhead was about 96%. About 69% of the steelhead and 65% of the yearling Chinook passed through non-turbine routes at Priest Rapids Dam.
- Grant PUD described the planned removal of the Fishway Exit Passage Systems from Wanapum dam. The plan is to remove the exit passage systems in the dry before the anticipated pool raise occurs later this year. Removal work will begin on 17 November. It is projected that both ladders will be dewatered at the same time for no longer than 2 - 3 weeks during mid-December.
- A total of 15 tendons have to be installed before the pool can be raised to 558-562 feet. Currently, 13 tendon holes have been drilled and sheathed. The pool will be refilled at a rate of three feet per day with monitoring occurring as the pool is refilled.

## White Sturgeon Updates

- Juvenile sturgeon rearing at Marion Drain and at WDFW facilities from the 2014 brood year are doing well.
- Grant PUD, in coordination with Golder and Chelan PUD, will evaluate the feasibility and application of using the Ecopath/Ecosim model as a way to estimate sturgeon carrying capacity within the project area. This information may be used to determine how many juvenile sturgeon will be released into the project area annually.
- Grant PUD is considering funding one or two boats to collect white sturgeon broodstock downstream from McNary Dam in 2015.
- Golder shared results on length frequency distributions of CRITFC and wild white sturgeon within the project area.

## Pacific Lamprey Updates

- The PRFF received a draft NNI Concept Paper prepared by the Yakama Nation, Umatillas, WDFW, Colville Tribes, and WDFW. The purpose of the Concept Paper is to develop a five-year action plan for Pacific lamprey. To that end, the Concept Paper provides context and meaning of NNI, and clarity in its application. The paper identifies nine tasks, which are linked to Grant PUD's Pacific Lamprey Management Plan, NNI, and/or adaptive management requirements. The PRFF will review the draft Concept Paper and discuss it during the next meeting.
- A total of 139 unique PIT-tagged adult lamprey have been detected at Priest Rapids Dam. These fish were tagged downstream in the Columbia River. About 91% of the tagged fish passed Priest Rapids Dam. A total of 118 unique tags were detected at Wanapum Dam. About 61% of these passed the dam. There are currently 14 tagged lamprey in the Left Bank Ladder at Wanapum Dam.
- The PRFF will tour the adult fish ladders in January or February.
- USFWS explained that local experts met to fill out templates for the Pacific Lamprey Regional Implementation Planning process. Templates for all Upper Columbia areas have been completed.

## Aquatic Invasive Species

- Grant PUD reported that they will provide the PRFF with a draft report later this month on their assessment of benthic organisms stranded in Wanapum Reservoir due to water level reductions. They noted that most macroinvertebrates were found below the ordinary low-water mark. Rare species such as ashy pebblesnails, floater mussels, and pearlshell mussels were found in Wanapum reservoir. No invasive species were found.

## Next Steps

The next meeting of the PRFF will be on Wednesday, 3 December 2014 at Grant PUD in Wenatchee, WA.

| | |
|---|---|
| **From:** | Tom Skiles |
| **To:** | Alyssa Buck; Debbie Williams; Denny Rohr; Jim_L_Craig@fws.gov; Tom Dresser; carmen.andonaegui@dfw.wa.gov; Curtis Dotson; jeff.korth@dfw.wa.gov; justin.yeager@noaa.gov; kirk.truscott@colvilletribes.com; melissarohr76@gmail.com; Orlene Hahn; patrick.verhey@dfw.wa.gov; rosb@yakamafish-nsn.gov; scott.carlon@noaa.gov |
| **Subject:** | Re: Fwd: Wanapum Future Unit Bypass |
| **Date:** | Monday, May 18, 2015 2:14:54 PM |
| **Attachments:** | ATT00001<br>ATT00002 |

I just had a helpful conversation with Curt about this and he suggested that I take a look at the 1-hr time step data and account for the change in flow operations, which occur at 10am every third day, not at midnight. Making that adjustment may change these histograms quite a bit.

As well, he also explained the operational relationship between forebay elevation and spill.

Standby…


Tom D. Skiles

Fish Passage Specialist

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>>> Denny Rohr <drohr5@aol.com> 5/18/2015 2:01 PM >>>

PRCC:

Please see information and analysis below from Tom S regarding the WFB testing. This subject is an agenda item and will be discussed at our May 27th PRCC meeting, and including Tom's information below. Please contact Tom directly with questions and/or comments, and let me know if there is anything I can do to help as well.

Thanks for sending, Tom.

--Denny


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-----Original Message-----
From: Tom Skiles <skit@critfc.org>
To: Denny Rohr <drohr5@aol.com>
Cc: Brent Hall <brenthall@ctuir.org>; Carl Merkle <carlmerkle@ctuir.org>; Mike Matylewich <MATM@critfc.org>
Sent: Mon, May 18, 2015 1:09 pm
Subject: Wanapum Future Unit Bypass

Hi Denny,
Can you share this with the PRCC?

Hi Folks-

I decided to check-in and see how Grant was doing with their Wanapum Future Unit Bypass spill test (see the two figures below). I took a look at COE data and summarized it in two figures (actually, I sliced it and diced it in a bunch of different ways). The figures below are very similar. The upper figure has histogram bars for turbine generation flow (light blue) and the one below does not. The red bars represent the three-day blocks that the WFUB should be at 15kcfs and the darker blue bars are the three-day blocks at 20kcfs or above. As you can see, there is a lot of variation, which perhaps illustrates the challenge that Grant has hitting the agreed upon flow targets. There are some caveats with these figures (e.g. these are daily averages), but I hope they serve to inform the committee, to a lesser or greater degree.

Please provide comments, questions, and criticisms.

Tom D. Skiles

Fish Passage Specialist

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PNNL-23719

Pacific Northwest NATIONAL LABORATORY

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# Survival of Wild Hanford Reach and Priest Rapids Hatchery Fall Chinook Salmon Juveniles in the Columbia River: Predation Implications

## October 2014


RA Harnish
ED Green
KA Deters
KD Ham
Z Deng
H Li
B Rayamajhi
KW Jung
GA McMichael



U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

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# Abstract

The population of fall Chinook salmon that inhabits the Hanford Reach comprises the majority of the Columbia Upriver Bright (URB) stock and is one of the most productive Chinook salmon stocks in the Pacific Northwest. Recent studies indicated that much of the high productivity of the population may be attributed to very high survival during early freshwater life stages within the Hanford Reach. However, some evidence suggests significant mortality of smolts occurs over a short period of time and distance as they migrate from the Hanford Reach to McNary Dam. Large populations of piscivorous fishes and birds inhabit the Columbia River and may be responsible for this mortality. We implanted 200 wild Hanford Reach and 200 Priest Rapids Hatchery (PRH) URB fall Chinook salmon with acoustic transmitters and estimated their survival through multiple reaches of the Columbia River to identify mortality "hot spots" and to help classify the putative source(s) of mortality.

Acoustic-tagged wild Hanford Reach fall Chinook salmon had an estimated survival probability of 0.50 from release to McNary Dam. This estimate is considerably higher than was observed in 2014 for the group of wild Hanford Reach fall Chinook salmon juveniles implanted with passive integrated transponders (PIT-only; $S = 0.34$). The large discrepancy between survival estimates derived from acoustic-tagged versus PIT-only groups is likely a result of the difference in fish size between groups. We attempted to minimize the effect of the transmitter on the performance of implanted fish by only tagging fish that measured ≥80 mm FL; whereas, fish as small as 60 mm FL were implanted with PIT tags. As we demonstrated, survival of these fish is strongly, positively correlated with fish length. Therefore, we expect that the survival of the overall population of juvenile wild Hanford Reach fall Chinook salmon through the study area was substantially lower than it was for acoustic-tagged fish. However, we believe that the relative losses of tagged fish by reach were representative of the overall population.

Acoustic-tagged PRH smolts also had an estimated survival probability of 0.50 from release to McNary Dam; albeit over a longer reach than was traversed by the wild group. This estimate is substantially lower than what was observed for PIT-only PRH smolts in 2014 ($S = 0.66$). The difference in survival between groups of acoustic-tagged and PIT-only PRH fall Chinook salmon juveniles may have been the result of a reduction in performance of acoustic-tagged fish caused by the tagging procedure or presence of the tag, and/or a result of acoustic transmitter loss (i.e., tag shedding). Although results from a 60-day laboratory study conducted at PNNL found a very high rate of fish survival (99.2%) and tag retention (100%) of 126 fish implanted with the same transmitter and surgical technique, we observed relatively high post-tagging, pre-release mortality for the group of PRH fall Chinook salmon we implanted with acoustic transmitters for the in-river survival evaluation described in this report.

Because reaches differed in length, survival is better compared among reaches on a per-kilometer basis to identify potential mortality "hot spots". Survival-per-kilometer ($S_{km}$) was generally lower in the transition area between the Hanford Reach and McNary Reservoir, within McNary Reservoir, and in the upper half of John Day Reservoir (down to Crow Butte) than in reaches located downstream of Crow Butte. The lowest $S_{km}$ was observed in the immediate forebay of McNary Dam for both wild and hatchery fish. As expected, travel rates were fastest in flowing reaches (i.e., Hanford Reach and dam tailraces) and slowest through reservoirs. We observed a significant, positive relationship between the probability of survival to McNary Dam and fish length.

Data from this study and others indicate much of the mortality incurred by URB fall Chinook salmon juveniles between Priest Rapids and Bonneville dams can likely be attributed to predation from resident piscivorous fish. Analyzing 8 years of data, we observed no significant relationship between the survival of PIT-only wild Hanford Reach fall Chinook salmon to McNary Dam and the size of the primary avian predator nesting colonies located in McNary Reservoir. We also did not observe mortality "hot spots" in the reaches of the Columbia River that contain the largest colonies of predaceous waterbirds. Instead, we observed relatively consistent mortality rates between release and Crow Butte, which is more indicative of predation from piscivorous fish, which are more widely distributed than avian predators. In addition, results of studies conducted to assess avian predation rates have consistently estimated very low predation rates (<2%) on subyearling fall Chinook salmon upstream of Bonneville Dam. Alternatively, predation rates estimated for piscivorous fish suggest they may be consuming 17% of the juvenile salmon that enter John Day Reservoir during June, July, and August, when most salmon smolts entering the reservoir are subyearling fall Chinook salmon.

Our study confirmed that the loss rates of juvenile URB fall Chinook salmon from the Hanford Reach were high in areas where habitat has been influenced by hydropower development and native and non-native predatory fish species. Whereas our study had some limitations due to 1) the size of fish we were able to tag, 2) the potential for a tag or tagging effect on fish performance, and 3) possible tag loss, we believe that the relative loss rates are representative for the wild Hanford Reach and Priest Rapids Hatchery portions of the URB stock. Much of the mortality appears to be concentrated in the river/reservoir transition area where large predator-rich tributaries enter as well as in the immediate dam forebays where travel rates of outmigrating smolts are slowed. Additional work to document how the predation rates we observed in the larger size classes of juvenile URB fall Chinook salmon relate to the overall population, as well as efforts to determine the potential effectiveness of management actions intended to reduce the populations and/or productivity of piscivorous fish species will provide the information necessary to enable managers to design and implement strategies to improve the freshwater survival of this important stock.

# Acknowledgments

We sincerely appreciate the cooperation of Jeff Fryer and the CRITFC crew, including Bobby Begay, for providing us with wild Hanford Reach fall Chinook salmon to tag and for sharing their holding tanks and tagging location with us. Similarly, we would like to thank Glen Pearson and Mike Lewis of WDFW and the Grant County Public Utility District (Grant PUD) for providing us with PRH smolts to tag and access to the outflow channel for installation of the cabled JSATS array. We thank PNNL staff Zachary Booth, Sam Cartmell, Tao Fu, Xinya Li, Bo Liu, Terence Lozano, Jun Lu, Jayson Martinez, Jason Reynolds, Spencer Sandquist, Jie Xiao, and Yong Yuan, as well as John Stephenson for transmitter development, tag life results, and/or the installation and monitoring of the cabled JSATS array at PRH. We thank James Hughes and the North Bonneville PNNL crew, including Mark Weiland and others who conducted the JSATS studies at McNary and John Day dams for the Corps of Engineers in 2014. These people deployed, serviced, maintained, and downloaded autonomous and cabled acoustic telemetry receiver arrays downstream of rkm 524. Thanks to Jina Kim for assistance with data management, processing, and validation. We would also like to thank Ricardo Walker, Megan Nims, Bryan Jones, and Stephanie Liss for assisting with transmitter implantation and Scott Titzler, Bob Mueller, Brian Bellgraph, and Kyle Larson for servicing autonomous acoustic telemetry receivers. We thank John Clark (ADFG, PSC) for providing study review, insight, and support. Finally, we would like to thank the Pacific Salmon Commission and Grant PUD for funding this effort and the U.S. Army Corps of Engineers for funding the performance standard evaluations at McNary and John Day dams, which were conducted in parallel to this study and provided much additional data.

# Acronyms and Abbreviations

| | |
|---|---|
| AABM | Aggregate Abundance Based Management |
| ATLAS | Acoustic Tag Life Adjusted Survival |
| CJS | Cormack-Jolly-Seber |
| CR | Columbia River |
| CRITFC | Columbia River Inter-Tribal Fish Commission |
| DOE | Department of Energy |
| FCRPS | Federal Columbia River Power System |
| FL | fork length |
| HR | Hanford Reach |
| HRFCPPA | Hanford Reach Fall Chinook Protection Program Agreement |
| JBS | juvenile bypass systems |
| JDA | John Day |
| JSATS | Juvenile Salmon Acoustic Telemetry System |
| MCN | McNary |
| NPM | northern pikeminnow |
| ODFW | Oregon Department of Fish and Wildlife |
| PIT | passive integrated transponder |
| PNNL | Pacific Northwest National Laboratory |
| PRD | Priest Rapids Dam |
| PRH | Priest Rapids Hatchery |
| PRI | pulse rate interval |
| SMB | smallmouth bass |
| TDA | The Dalles |
| URB | Upriver Bright |
| VBSA | Vernita Bar Settlement Agreement |
| WAL | walleye |
| WDFW | Washington State Department of Fish and Wildlife |

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# 1.0 Introduction

The population of fall Chinook salmon *Oncorhynchus tshawytscha* that inhabits the Hanford Reach comprises the majority of the Columbia River Upriver Bright (URB) stock and is one of the most productive Chinook salmon stocks in the Pacific Northwest (Peters et al. 1999; Langness and Reidinger 2003; Harnish et al. 2012, 2013). As such, it is able to sustain high rates of harvest and therefore has great economic and cultural importance to native peoples and commercial and recreational fishers. The URB stock is a far north-migrating stock and is an important contributor to all three Aggregate Abundance Based Management (AABM) fisheries and a primary contributor to Columbia River fisheries.

Recent studies have indicated that much of the high productivity of the population may be attributed to very high survival during early freshwater life stages. In fact, results from a cohort reconstruction indicated that nearly two-thirds (65%) of the broods from 1975 through 2004 that displayed above-average egg-to-presmolt survival also had above-average adult/spawner production. Thus, Hanford Reach fall Chinook salmon brood year strength appears to be largely determined by interannual variation in freshwater survival, indicating the importance of the freshwater life phase to the overall productivity of the population. Enactment of operational constraints to limit discharge fluctuations downstream of Priest Rapids Dam have resulted in increased productivity and egg-to-pre-smolt survival rates. Harnish et al. (2014) observed a 217% increase in egg-to-pre-smolt productivity (Ricker $\alpha$) that corresponded with constraints enacted by the Vernita Bar Settlement Agreement (VBSA), which limited redd dewatering, and an additional 130% increase that coincided with enactment of the interim Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA) in 1999, which limited stranding and entrapment of juveniles. Additionally, the average egg-to-pre-smolt survival probability estimate increased from 0.30 during the pre-VBSA period (brood years [BY] 1975–1983) to 0.36 during the period of the VBSA (BY 1984–1998) to 0.42 during the HRFCPPA period (BY 1999–2004[1]). In addition, a study conducted in 2012 estimated the egg-to-fry survival of fall Chinook salmon to be 71% in the Hanford Reach (Oldenburg et al. 2012). The survival rates discovered during these studies for the Hanford Reach population are much higher than those reported for other populations of Chinook salmon. From 215 published and unpublished estimates for wild or naturally rearing populations of Chinook salmon, Quinn (2005) calculated a mean egg-to-fry survival of 38% and a mean egg-to-smolt survival of 10%.

Although egg-to-pre-smolt survival has been found to be very high for the Hanford Reach fall Chinook salmon population, survival from pre-smolt to age-3 adult equivalent averaged just 0.29% for BY 1986–2004. Some evidence suggests significant mortality of smolts occurs over a short period of time and distance as they emigrate from the Hanford Reach to McNary Dam. Survival from release in the Hanford Reach to McNary Dam has averaged just 37% since 1995 for PIT-tagged wild fall Chinook salmon juveniles (Fish Passage Center 2013). Annual losses of this magnitude represent an obvious bottleneck to production.

Large populations of piscivorous fishes, such as smallmouth bass *Micropterus dolomieu*, northern pikeminnow *Ptychocheilus oregonensis*, walleye *Sander vitreus*, and channel catfish *Ictalurus punctatus* inhabit the Columbia River along with nesting colonies of avian predators, such as terns, cormorants,

[1] The Priest Rapids Project is currently operated under the HRFCPPA. The productivity analysis conducted by Harnish et al. (2012, 2013) included BY 1975–2004.

gulls, and pelicans.  The objective of this study was to estimate survival of acoustic-tagged Hanford Reach fall Chinook salmon juveniles through multiple reaches of the Columbia River to identify mortality "hot spots" and help to classify the putative source(s) of mortality (i.e., fish or birds).

# 2.0 Materials and Methods

## 2.1 Fish Collection, Tagging, and Release

### 2.1.1 Fish Collection and Holding

*Wild Hanford Reach fall Chinook salmon*

Wild fall Chinook salmon juveniles were collected from multiple locations in the Hanford Reach during the first week of June 2014 by Columbia River Inter-Tribal Fish Commission (CRITFC) personnel using stick and beach seines (4.8 mm mesh size). Seining was conducted in sections of the river with moderate velocity and 0.3 m to 1.4 m depth that were primarily located upstream of the tagging site at the Hanford town site boat ramp (river kilometer [rkm] 582; as measured from the mouth of the Columbia River) to reduce the likelihood of re-capturing previously tagged fish (Figure 2.1).

Captured wild fall Chinook salmon juveniles were temporarily placed into 19-L plastic buckets before being transferred to the oxygen-aerated holding tank of the boat. Once a full load of approximately 10,000 fish had been captured, or, more commonly, until about three hours had passed, the fish were transported to the tagging site located at the Hanford town site boat ramp. Fish were then transported from the boat in the 19-L plastic buckets to a 0.9 m × 0.9 m × 4.9 m fiberglass tank equipped with a pump to provide a continuous flow of river water. Fish that measured ≥80 mm fork length (FL) were held separately from smaller fish in four partially-perforated 76-L buckets within the fiberglass tanks. Captive fish were not directly fed; however, they did have access to organisms present in the river water. On June 5, 2014, surgical candidates were netted from the perforated holding buckets in batches of 20 to 50 and transferred in a 38-L bucket to the mobile tagging trailer.

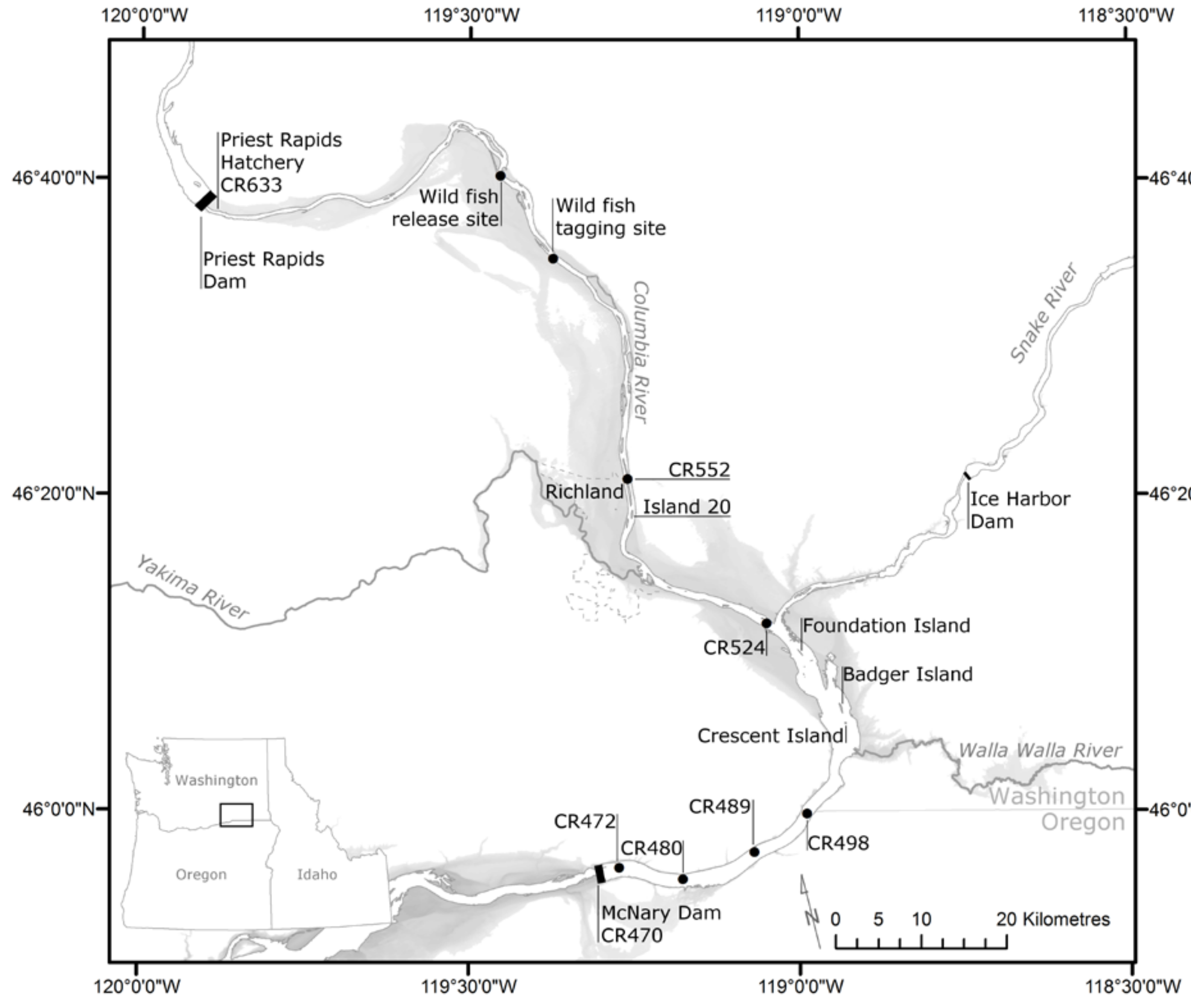


**Figure 2.1**. Map of the Columbia River from Priest Rapids Dam to McNary Dam. Locations of cabled and autonomous acoustic telemetry receiver arrays deployed in 2014 are shown as a concatenation of "CR" and the river kilometer (as measured from the mouth of the Columbia River) at which they were deployed. Other locations of interest are also shown: these include the tagging and release location for acoustic-tagged wild Hanford Reach fall Chinook salmon juveniles; and the islands that host avian predator nesting colonies.

*Priest Rapids Hatchery fall Chinook salmon*

Hatchery URB fall Chinook salmon juveniles were reared at the Priest Rapids Hatchery (PRH) from the time of spawning until release to the river in June 2014. The hatchery is located along the bank of the Columbia River immediately downstream of Priest Rapids Dam and is operated by Washington State Department of Fish and Wildlife (WDFW) and owned by the Public Utility District No. 2 of Grant County, Washington. Prior to tagging, juvenile hatchery fall Chinook salmon were held at PRH in a concrete raceway supplied with a continuous flow of river water. Food was withheld for 24 h prior to tagging. On May 28, 2014, surgical candidates were netted from the raceway and transferred to the mobile tagging trailer in a 38-L plastic bucket in batches of 20 to 50 fish.

### 2.1.2 Transmitter Specifications

All Chinook salmon were implanted with an acoustic transmitter and a passive integrated transponder (PIT). The mean dimensions of the downsized Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic transmitter (developed by the U.S. Army Corps of Engineers and Pacific Northwest National Laboratory [PNNL]; Chen et al. 2014) were 15.0 mm long by 3.3 mm in diameter (Figure 2.2). Transmitters had a mean weight in air of 0.22 g, a mean weight in water of 0.11 g, and a mean volume of 0.11 mL. The transmitters had a nominal pulse rate interval (PRI) of one complete transmission every 3 seconds with a source level of 155–156 dB. The nominal transmitter life was expected to be about 60 days. The PIT tag (Model HPT12, Biomark, Inc., Boise, Idaho) was 12.5 mm long, 2 mm wide, and weighed 0.10 g in air (0.06 g in water; 0.04 mL volume; 134.2 kHz). The combined weight of the tags gave each implanted fish an added burden of 0.32 g in air.

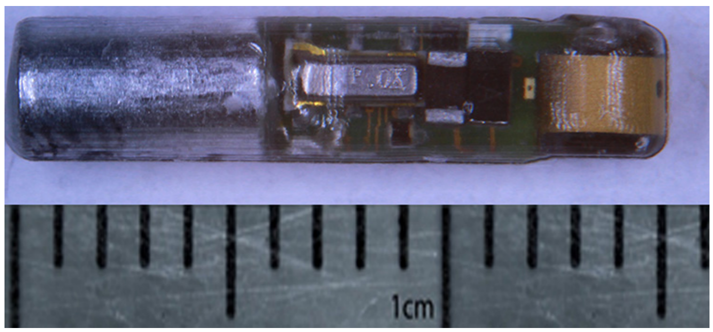


**Figure 2.2**. Photo of the Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic transmitter implanted in juvenile fall Chinook salmon in the Hanford Reach and at Priest Rapids Hatchery in 2014. The transmitter is shown next to a metric ruler to display the size of the transmitter.

### 2.1.3 Tagging Procedure

After surgical candidates were delivered to the mobile tagging trailer, they were anesthetized in batches of 2-3 fish. A dose of 80 mg/L of tricaine methanesulfonate (MS-222; buffered with 80 mg/L of sodium bicarbonate) was used to sedate juvenile Chinook salmon to stage 4 anesthesia (as described by Summerfelt and Smith 1990). The FL and weight of sedated fish were obtained as the acoustic transmitter and PIT tag codes were assigned. Only fish that measured ≥80 mm FL were selected for this study based on results from a 60-day laboratory study conducted at PNNL that found a very high rate of fish survival (99.2%) and tag retention (100%) of fish implanted with both a PIT tag and downsized JSATS transmitter ($n$ = 126 fish) using the same surgical technique described below.

An anesthetized fish and tags were delivered to one of two surgeons. The fish was placed on its left side in a small pool of water on a foam pad lubricated with PolyAqua, a water conditioner. The surgeon then made a shallow incision 3 mm in length with a sterile #11 surgical blade approximately 3-5 mm away from the linea alba and beneath the distal end of the pectoral fin. The PIT tag was then inserted through the incision into the peritoneal cavity. With the subsequent insertion of the acoustic transmitter, there was an attempt by the surgeon to get the two tags side-by-side (not end-to-end), by slightly changing the angle of insertion, with the intent to reduce the likelihood of tag expulsion through the open wound. In addition, the wound was gently massaged posteriorly, to ensure the tags were completely inside the peritoneal cavity and to move them away from the incision opening. Immediately, the tagged fish was placed in a recovery bucket filled with aerated river water. The entire surgical process took approximately 20 to 30 s per fish. The same two surgeons tagged all fish in the wild Hanford Reach and Priest Rapids Hatchery groups; each surgeon tagged half of each group.

### 2.1.4 Recovery, Holding, and Release

*Wild Hanford Reach fall Chinook salmon*

Following implantation, the 200 acoustic-tagged wild Hanford Reach fall Chinook salmon juveniles were held at densities of less than 5 g/L in four partially-perforated 76-L buckets that were placed into a 0.9 m × 0.9 m × 4.9 m fiberglass holding tank equipped with a pump to provide a continuous flow of river water. The buckets remained in the holding tank for about 24 hours until the day of release (June 6) when they were loaded into a trailered boat and transported with continuous aeration to the White Bluffs boat launch (rkm 595; Figure 2.1). The dissolved oxygen and water temperature in the buckets were measured with an YSI meter before and during transport to ensure these metrics stayed within acceptable limits. Once at the ramp, the boat was launched and maneuvered downstream 0.5 km to the release location. Equal numbers of fish were released at four locations along a line transect across the river. Before release, buckets were checked for dead fish and dropped tags then each bucket was submerged in the water so that fish could swim out on their own volition.

*Priest Rapids Hatchery fall Chinook salmon*

After each group of PRH fall Chinook salmon juveniles were implanted with transmitters and had recovered from surgery, they were placed in one of four partially-perforated 76-L buckets that were suspended in the concrete raceway. The 200 tagged fish recovered at densities less than 5 g/L for approximately 24 hours, at which time holding buckets were removed from the raceway and inspected for dead fish and dropped tags. The buckets were taken to the adjacent channel pond and submerged in the water so that fish could swim out on their own volition. Tagged hatchery Chinook salmon resided in the channel pond for a full two weeks before releases of all fish in the channel ponds began with the removal of the pond gates on June 12, 2014. However, acoustic-tagged juveniles were detected on PIT and acoustic receiver arrays migrating from the outflow channel between June 12 and 21, 2014.

## 2.2 Site Description and Array Locations

The area of the Columbia River between Priest Rapids and McNary dams defines the primary study area. However, data collected opportunistically from reaches of the Columbia River located between McNary and The Dalles dams are also presented. The array locations used in this study were chosen to differentiate survival among important reaches of the river and were selected because the associated river characteristics allow for good detection of acoustic tags. This section provides details about where detection arrays were deployed.

### 2.2.1 Site Description

The Hanford Reach, an 80-km stretch of river located between Priest Rapids Dam (river kilometer [rkm] 639) and the head of McNary Reservoir (rkm 557) near the town of Richland, Washington, is the last segment of the Columbia River that has not been inundated, dredged, or channelized (Whidden 1996) and is available to anadromous salmonids (Figure 2.1). As such, the Hanford Reach contains the only remaining substantial mainstem spawning area for fall Chinook salmon in the Columbia River (Bauersfeld 1978; Chapman et al. 1986; Dauble and Watson 1997).

Three major tributaries, the Yakima, Snake, and Walla Walla rivers flow into the Columbia River in McNary Reservoir. The Yakima River flows into McNary Reservoir at rkm 538, near the town of Richland, Washington. The Yakima River has been identified as a major spawning area for smallmouth bass of the Columbia River (Fritts and Pearsons 2004). The Snake River flows into McNary Reservoir at rkm 522 and the Walla Walla River enters McNary Reservoir at rkm 505. Between the mouths of these two rivers are three islands used as nesting and roosting sites by multiple piscivorous water bird species. These include a nesting colony of cormorants on Foundation Island at rkm 518, a nesting colony of pelicans on Badger Island at rkm 510, and nesting colonies of terns, gulls, and herons on Crescent Island, a manmade island constructed of dredge spoils, at rkm 508 (Antolos et al. 2004, 2005; Evans et al. 2012).

### 2.2.2 Acoustic Receiver Locations

Acoustic transmissions from tagged fish were decoded by stationary JSATS autonomous receivers (Model N201, Sonic Concepts, Inc., Bothell, Washington; and SR5000 Trident, Advanced Telemetry Systems, Inc., Isanti, Minnesota), which were deployed via the methods described by Titzler et al. (2010). In total, autonomous acoustic telemetry receivers were deployed at 48 locations between the head of McNary Reservoir (near the town of Richland, Washington) and McNary Dam and at 94 locations between McNary and Bonneville dams during the outmigration of fall Chinook salmon juveniles (June 6 to August 1). The majority of these receivers ($n$=133) were deployed for studies funded by the U.S. Army Corps of Engineers, but data were made available for analyses for this predation loss assessment. Receivers were deployed in lines, referred to as arrays, which ran approximately perpendicular to the shore. Based on their effective detection range, receivers were spaced about 100 to 200 m apart.

A total of six autonomous receiver arrays were deployed upstream of McNary Dam and an additional 12 arrays were deployed downstream of McNary Dam (Figures 2.1 and 2.3; Table 2.1). JSATS acoustic transmissions were detected and decoded by these receiver arrays and used to estimate survival and travel times of acoustic-tagged natural-origin Hanford Reach and PRH fall Chinook salmon juveniles in the reaches located between the arrays.

In addition to the autonomous receivers deployed to detect acoustic-tagged fish in the Columbia River, cabled JSATS receiver systems (Weiland et al. 2011) were deployed in the PRH outflow channel and on the face of McNary and John Day dams for dam passage survival studies conducted by PNNL for the U.S. Army Corps of Engineers. The deployment of hydrophones along the dam faces generally followed the design and methodology described by Deng et al. (2011). Prior to field deployment, all autonomous and cabled receivers were calibrated in an acoustic tank located at the PNNL Bio-Acoustics and Flow Laboratory, which is accredited by the American Association for Laboratory Accreditation (Deng et al. 2010). Detections of acoustic-tagged fall Chinook salmon juveniles on autonomous and dam face systems were used for estimation of reach survival and travel times.

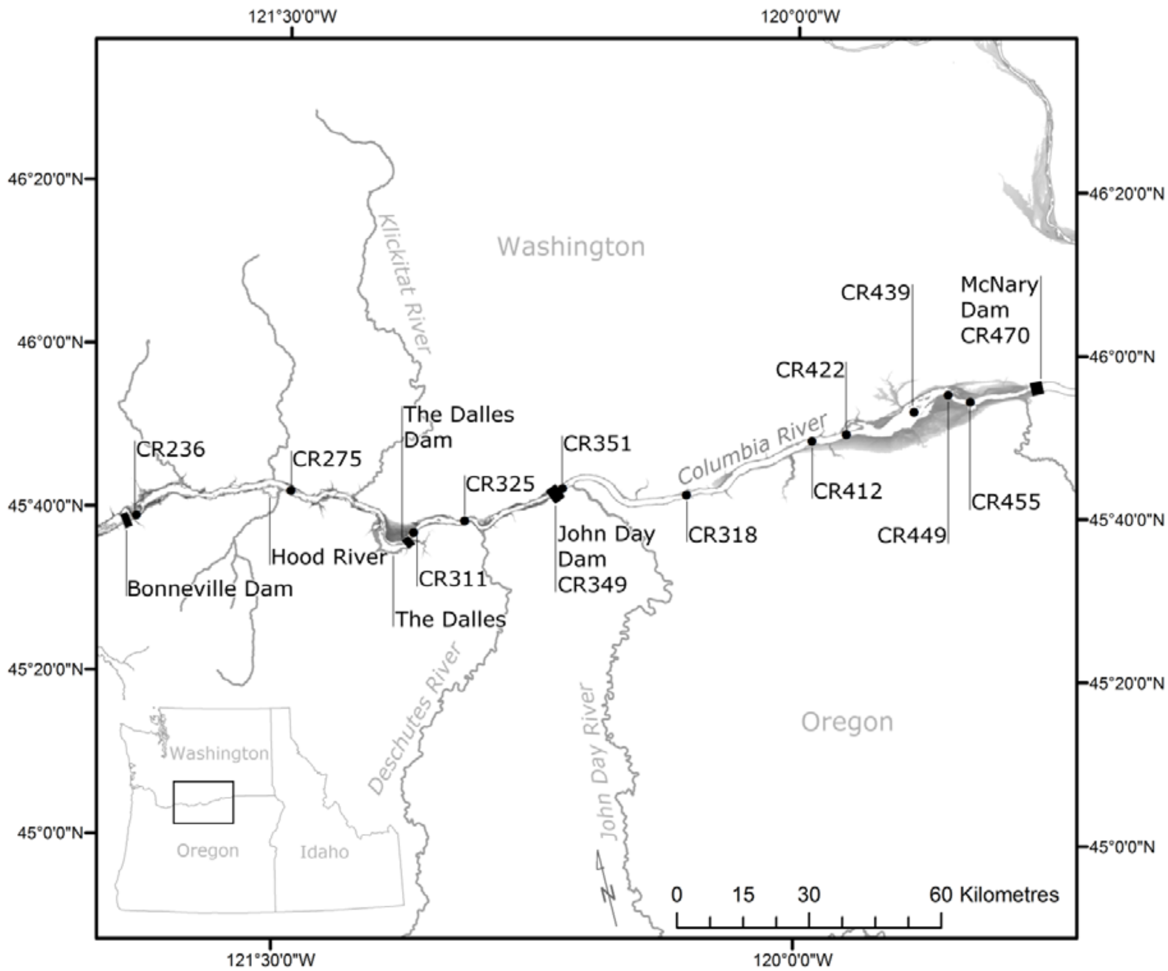


**Figure 2.3**. Map of the Columbia River from McNary Dam to Bonneville Dam. Locations of cabled and autonomous acoustic telemetry receiver arrays deployed in 2014 are shown as a concatenation of "CR" and the river kilometer (as measured from the mouth of the Columbia River) at which they were deployed.

**Table 2.1.** Locations of cabled and autonomous acoustic telemetry receiver arrays deployed in the Columbia River to detected JSATS acoustic transmitters during the spring and summer of 2014.

| Array | Location | Latitude | Longitude | Autonomous or Cabled | # of Hydrophones |
|---|---|---|---|---|---|
| CR633 | Priest Rapids Hatchery | 46.637033 | -119.878798 | Cabled | 4 |
| CR552 | Richland, WA | 46.352325 | -119.2610833 | Autonomous | 6 |
| CR524 | Snake River | 46.19887143 | -119.051 | Autonomous | 7 |
| CR498 | Port Kelly, WA | 45.99767042 | -118.9906672 | Autonomous | 8 |
| CR489 | Van Skinner Island | 45.95559753 | -119.0678685 | Autonomous | 9 |
| CR480 | Hat Rock | 45.92761134 | -119.1772737 | Autonomous | 10 |
| CR472 | McNary Dam forebay | 45.9393581 | -119.2732181 | Autonomous | 8 |
| CR470 | McNary Dam | 45.93569206 | -119.2974027 | Cabled | 89 |
| CR455 | Irrigon, OR | 45.90591741 | -119.4938649 | Autonomous | 6 |
| CR449 | Paterson, WA | 45.92042962 | -119.5584028 | Autonomous | 6 |
| CR439 | Boardman, OR | 45.88502679 | -119.6585717 | Autonomous | 10 |
| CR422 | Crow Butte | 45.83856001 | -119.8555434 | Autonomous | 7 |
| CR412 | Willow Lake | 45.82475567 | -119.9559078 | Autonomous | 8 |
| CR381 | Sundale, WA | 45.71256584 | -120.3204116 | Autonomous | 6 |
| CR351 | John Day Dam forebay | 45.72255187 | -120.6810192 | Autonomous | 8 |
| CR349 | John Day Dam | 45.71583597 | -120.6929465 | Cabled | 85 |
| CR325 | Wishram, WA | 45.65323093 | -120.9653195 | Autonomous | 18 |
| CR311 | The Dalles Dam forebay | 45.62699729 | -121.1126313 | Autonomous | 15 |
| CR275 | Bingen, WA | 45.70758426 | -121.472588 | Autonomous | 6 |
| CR236 | Bonneville forebay | 45.64968612 | -121.9202764 | Autonomous | 4 |

The cabled system deployed in the PRH outflow channel consisted of four hydrophones located in the deepest pool of the channel, which was located about 1.5 km downstream from the holding ponds and 1.1 km upstream from the mouth of the channel (Figure 2.4). A PIT array consisting of multiple antennas was also present in the outflow channel about 200 m upstream from the mouth of the channel. Detections of the double-tagged (acoustic + PIT) fall Chinook salmon juveniles on the cabled JSATS and PIT arrays were used to evaluate post-tagging/pre-release mortality and tag loss/failure and to estimate the number of tagged fish that actually left the hatchery with an active acoustic transmitter. Detections of double-tagged fall Chinook salmon in the juvenile bypass systems (JBS) of McNary and John Day dams were also used to evaluate acoustic tag loss/failure.


**Figure 2.4**. Google Earth image of Priest Rapids Dam that displays the channel pond in which acoustic-tagged fish were held following surgery and the cabled JSATS array (CR633) and PIT array that were located in the outflow channel to detect acoustic- and PIT-tagged fish as they migrated from the channel pond to the Columbia River.

## 2.3 Autonomous Receiver Data Processing and Validation

Signals received by JSATS receivers were processed and filtered to validate the presence of a tagged fish within the vicinity of a receiver at a specific time. Receivers recorded receptions of possible tag signals along with a timestamp for each reception. Raw files from autonomous receivers were time-corrected and files from both autonomous and cabled receivers were filtered to remove spurious receptions. The time series of validated locations for individual fish were then used to estimate survival rates and travel times. A laboratory study of tag-life was conducted to allow estimates to be corrected for early tag failures if necessary.

### 2.3.1 Time Correction

Some of the autonomous receivers used in this study were subject to clock errors that resulted in timestamps being incorrect at unpredictable times throughout the file. Raw files were processed through a time correction application to repair incorrect timestamps based upon correct timestamps that preceded it. In many cases, the algorithm precisely identified a correction that was accurate to the second, whereas in others, the correction resulted in a difference of a few seconds for the block of data being corrected. After time correction, the files are referred to as time-corrected files, whether or not a correction was needed and applied.

### 2.3.2 Filtering

Because JSATS autonomous receivers are configured to detect tag signals just above the acoustic noise floor, raw files often include spurious receptions that arise from noise in addition to valid tag signals (Ingraham et al. 2014). To filter out detections that did not meet criteria (false detections), a post-processing program was used (McMichael et al. 2010). This program comprised a sequence of steps that included comparing each detection to a list of tags that were released (only detections of tags that were released were kept), then comparing the detection date to the release data (only tags detected after they were released were kept). Then, a minimum of four detections in 60 seconds was required, and the time spacing between these detections had to match the PRI of the tag or be a multiple of the PRI for the detections to be kept in the valid detection file. This final filter takes advantage of the fact that spurious receptions do not exhibit the temporal consistency among pulses that is characteristic of an actively transmitting JSATS tag.

## 2.4 Tag-Life

For the tag-life study, 32 tags (3-s PRI) were randomly chosen over time from the manufacturing line of tags used in this study. All tag-life tags were enclosed in water-filled plastic bags and suspended from a rotating foam ring within a 2-m (diameter) fiberglass tank. Two $90^{o} \times 180^{o}$ hydrophones were positioned $90^{o}$ apart in the bottom of the tank and angled upward at approximately $60^{o}$ to maximize coverage for detecting acoustic signals. Hydrophones were cabled to a quad-channel receiver that amplified all acoustic signals, which were then saved, decoded, and post-processed. Post-processing software calculated the number of hourly decodes for each acoustic tag, allowing tag failure times to be determined within $\pm$ 1 hour.

## 2.5 Survival Estimation

Survival estimates were derived from conventional statistical models for mark-recapture data (Cormack 1964; Jolly 1964; Seber 1965; Skalski et al. 1998). This model is known by various names, including Cormack-Jolly-Seber (CJS), Single-Release, or Single-Release-Recapture Model. For survival ($S_i$) and detection ($p_i$) probability estimation of mark-recapture data, detection data are summarized as the "detection history" for each marked fish. With only two opportunities for detection, the possible detection histories for tagged fish are:

00 = never detected;
10 = detected by the upstream (primary) array but not the downstream (secondary) array(s);

01 = detected by the downstream (secondary) array(s) but not by the upstream (primary) array; and

11 = detected by the upstream (primary) array and the downstream (secondary) array(s).

To estimate survival to the primary array for a release group of tagged fish, the number of fish in the group with each detection history is determined, denoted $n_{00}$, $n_{10}$, $n_{01}$, and $n_{11}$, along with the total number of fish released ($R$). The proportion of fish detected on the primary array $[(n_{10} + n_{11})/R]$ is an estimate of the joint probability that a fish survived from release to the primary array and that the fish was detected given that it survived. The joint probability of both events occurring is the simple product of the two probabilities.

To separate the two probabilities in the product requires a method to estimate either of the probabilities individually. The remaining probability can then be estimated by dividing the joint estimate by the estimate of the first. Detection probability of the primary array can be estimated independently by assuming that fish that survived to the secondary array and were detected there ($n_{11} + n_{01}$) represent a random sample of all fish from the group that were alive as they passed the primary array. Detection probability of the primary array is then estimated as the proportion of the sample detected by the primary array (i.e., $n_{11}/[n_{11} + n_{01}]$).

The program ATLAS (Acoustic Tag Life Adjusted Survival; version 1.5.3; http://www.cbr.washington.edu/analysis/apps/atlas) and the methods described by Townsend et al. (2006) were used to adjust CJS survival estimates for the probability of premature tag failure. Preliminary tag-life data were fit with the two- and three-parameter Weibull models and the vitality model of Li and Anderson (2009). The model that provided the best fit to the tag-life data was used to adjust survival estimates by the conditional probability of a tag being active at each detection array.

Cumulative survival of acoustic-tagged PRH and wild Hanford Reach fall Chinook salmon was estimated from release to the each downstream detection array. For PRH fish, only those fish that were detected by the cabled JSATS receiver array located in the outflow channel were included in the estimate[1]. Survival was also estimated for each river reach located between receiver arrays by forming a "virtual release" of fish detected by the upstream (primary) array.

Because the distance between receiver arrays was not equal, it was desirable to have a measure of reach survival that was independent of the distance over which it was estimated. Therefore, survival per river kilometer was estimated from each reach survival estimate by:

$$S_{\text{km}} = S_{\text{reach}}^{1/L}$$

where

$S_{\text{km}}$ is the estimate of survival per river kilometer,

$S_{\text{reach}}$ is the reach survival estimate, and

$L$ is the reach length in river kilometers.

We assessed the effect of fish length on the probability of survival to McNary Dam for acoustic-tagged fall Chinook salmon in 2014 using program SURPH (SURvival under Proportional Hazards; version 3.5.2), whereby survival probabilities were modeled as a function of FL as an individual-based covariate using the hazard link (Skalski et al. 1993; Smith et al. 1994). A nonparametric survival curve

[1] Survival from tagging to acoustic tag detection in the outflow channel was estimated separately.

that did not depend on the parameters of any particular model was also plotted. The nonparametric curve can be thought of as a "moving average" survival as the selected individual covariate (i.e., fish length) increases across the range of observed values. The size of the "window" for which the moving average survival probability was calculated ranged from a minimum of eight individuals up to 20% of the entire number at risk in the selected interval (Smith et al. 1994). The effect of fish length on survival probability was evaluated using the likelihood ratio test to compare the fish length covariate model to a model of no covariate effect.

## 2.6 Travel Time and Travel Rate

Travel time was calculated for acoustic-tagged wild Hanford Reach and PRH fall Chinook salmon in each river reach studied in 2014. Travel time was calculated for each fish detected at both the upstream and downstream arrays by subtracting the date and time of first detection (or release) at the upstream array from the date and time of the first detection at the downstream array. Travel rate was calculated from each travel time by dividing the travel time by the distance between arrays. Because calculation of travel time requires detection at both the upstream and downstream arrays, estimates of travel time and travel rate within each reach only consider fish that successfully migrated through the entire reach and were detected at both arrays.

# 3.0 Results

The results section includes a brief summary of the environmental conditions in the mid-Columbia River during the study period to provide context for the detailed results of the estimated survival and travel time of acoustic-tagged fish in this study. The tag-life and detection probability information for the JSATS used in this study are presented to provide the necessary background information on system performance.

## 3.1 Environmental Conditions

A sharp decline in total daily discharge, as measured at Priest Rapids (Figure 3.1) and McNary (Figure 3.2) dams, coincided with the release and early migration period of acoustic-tagged wild Hanford Reach fall Chinook salmon, which were released on June 6. Discharge from Priest Rapids Dam declined from about 6,000 $m^3/s$ on June 6 to about 3,500 $m^3/s$ on June 15. This reduction in discharge was part of normal spring river management to allow for the refilling of reservoirs by June 30. The volitional release of acoustic-tagged fall Chinook salmon from PRH began on June 12; thus, discharge was increasing throughout much of their early migration period before stabilizing around the 10-year average.

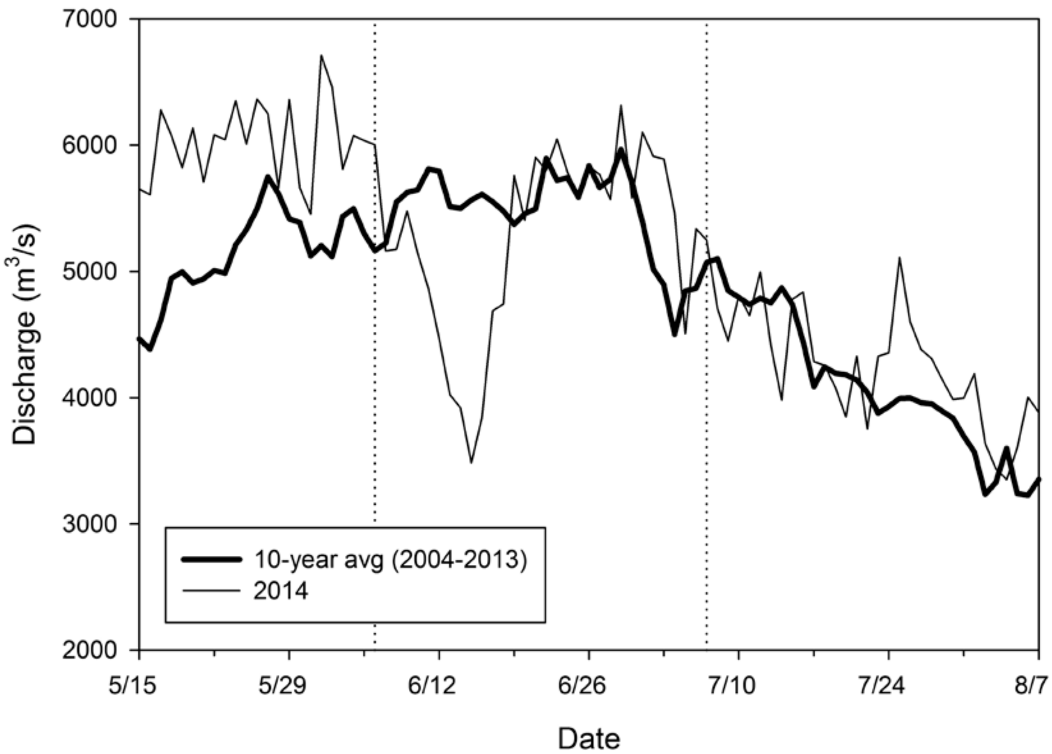


**Figure 3.1**. Priest Rapids Dam (PRD) discharge from May 15 through August 7, 2014 versus the 10-year (2004–2013) average. Dotted lines indicate the approximate time period in which acoustic-tagged fish were affected by PRD discharge. This period included the time between the release of wild Hanford Reach fall Chinook salmon (June 6) and the last detection at McNary Dam (CR470; July 7).

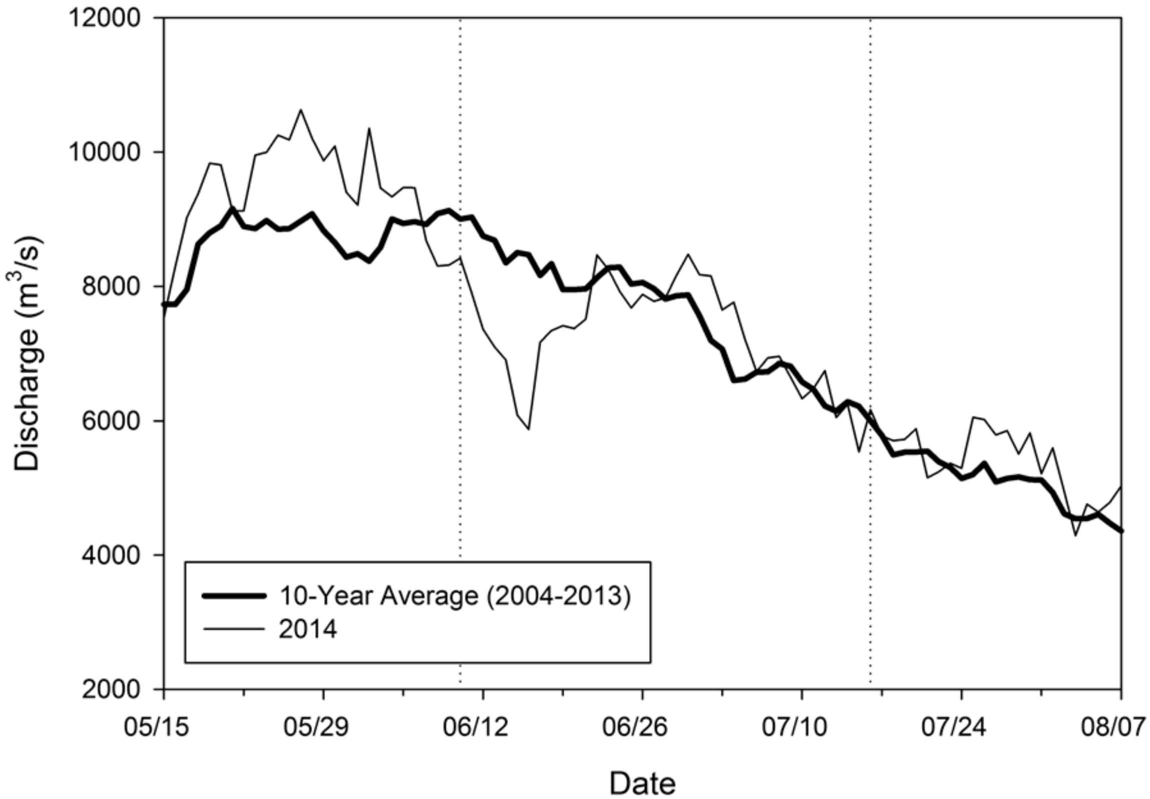


**Figure 3.2**. McNary Dam (MCN) discharge from May 15 through August 7, 2014 versus the 10-year (2004–2013) average. Dotted lines indicate the approximate time period in which acoustic-tagged fish were affected by MCN discharge. This period included the time between the first detection of acoustic-tagged fish at MCN (CR470; June 10) and the last detection at CR275 (July 15).

The temperature of the mid-Columbia River, as measured at Priest Rapids Dam, was slightly above-average during most of the study period (Figure 3.3). Colder than average water temperatures in the Snake River resulted in near-average temperatures at McNary Dam during the period of interest (Figure 3.4).

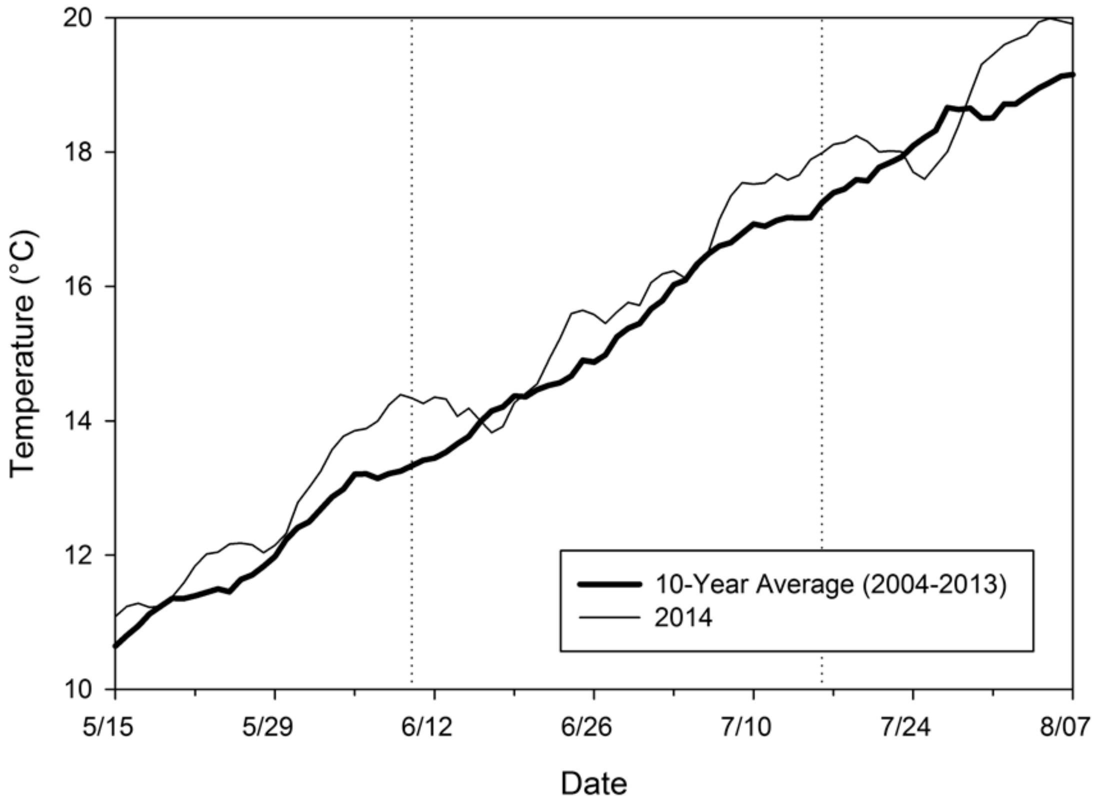


**Figure 3.3**. Water temperature, as measured at Priest Rapids Dam, from May 15 through August 7, 2014 versus the 10-year (2004–2013) average. Dotted lines indicate the approximate time period in which acoustic-tagged fish were affected by the temperature in this area of the Columbia River. This period included the time between the release of wild Hanford Reach fall Chinook salmon (June 6) and the last detection at McNary Dam (CR470; July 7).

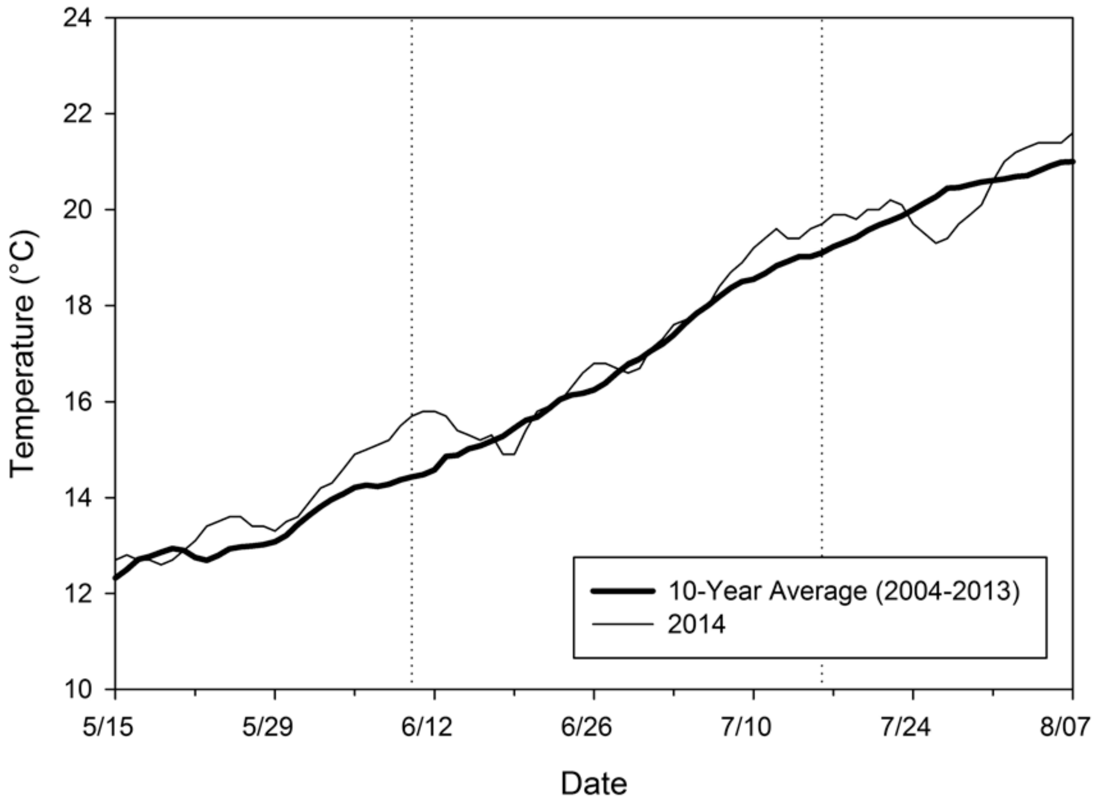


**Figure 3.4**. Water temperature, as measured at McNary Dam (MCN), from May 15 through August 7, 2014 versus the 10-year (2004–2013) average. Dotted lines indicate the approximate time period in which acoustic-tagged fish were affected by water temperatures near MCN. This period included the time between the first detection of acoustic-tagged fish at MCN (CR470; June 10) and the last detection at CR275 (July 15).

## 3.2 Size of Tagged Fish

The length distributions of acoustic-tagged PRH and wild Hanford Reach fall Chinook salmon were similar at the time of tagging (Figure 3.5; Table 3.1). However, fish tagged at PRH were held in the channel ponds and fed for an additional two weeks after tagging, whereas wild Hanford Reach fall Chinook were released the day after tagging. Based on the water temperature of the Columbia River during this time (~12 $^{o}$C) and the temperature-growth relationship of PRH fall Chinook salmon from a laboratory study, we would expect these fish to grow an additional 9 mm between tagging and release. Thus, we suspect the acoustic-tagged PRH fish were significantly larger, on average, than the acoustic-tagged wild Hanford Reach fish at the time they entered the river in the Hanford Reach. Both tagged groups were substantially larger than the random subsample of wild Hanford Reach fall Chinook salmon that were captured in seines and measured for length by the CRITFC (Figure 3.5). We attempted to minimize tag burden (tag weight expressed as a percentage of fish weight) and any potential tag or tagging effects by only implanting tags into fish that measured 80 mm FL or greater. Therefore, the size distribution of wild Hanford Reach fall Chinook salmon implanted with transmitters differed significantly from the size distribution of the general population.

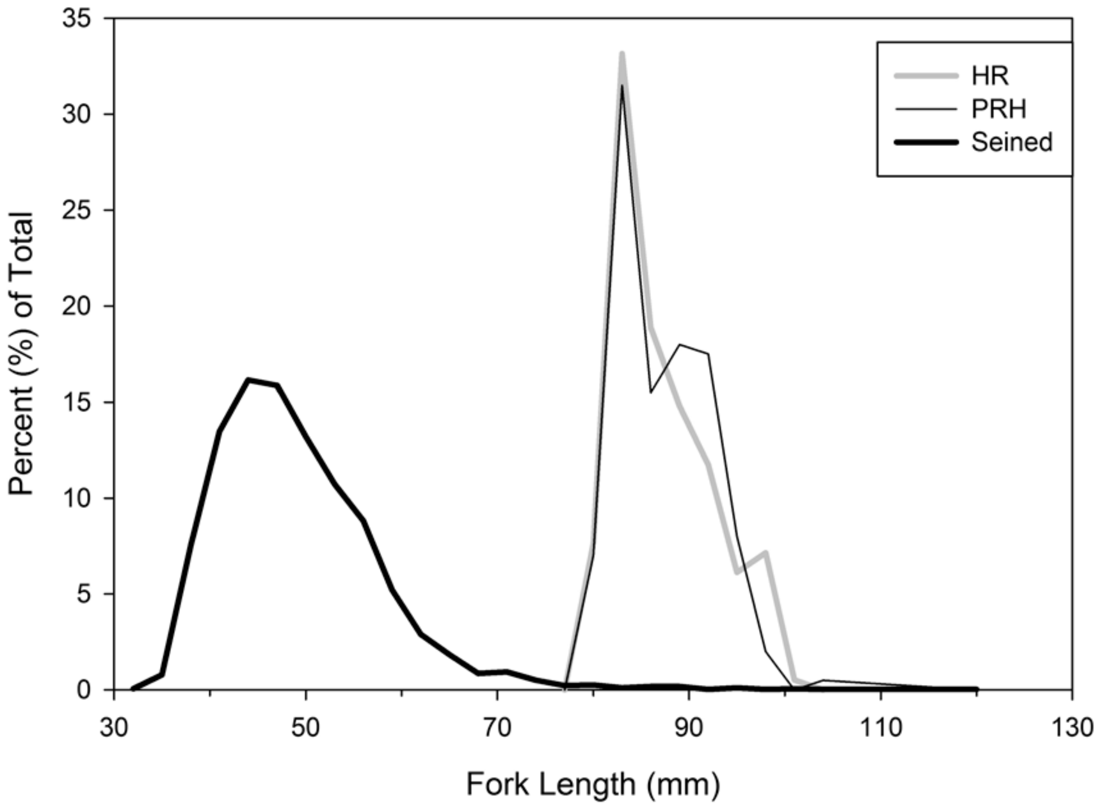


**Figure 3.5**. Length frequency distributions for acoustic-tagged Priest Rapids Hatchery fall Chinook salmon smolts (PRH), wild Hanford Reach fall Chinook salmon juveniles captured via seining that were implanted with acoustic transmitters (HR), and wild Hanford Reach fall Chinook salmon juveniles captured via seining that were randomly selected for length measurement in 2014 (Seined).

**Table 3.1**. Number, fork length, tag burden, (acoustic + PIT tag weight expressed as a percentage of fish body weight), and release dates for acoustic-tagged Priest Rapids Hatchery upriver bright fall Chinook salmon juveniles (H-URB) and wild Hanford Reach upriver bright fall Chinook salmon juveniles (W-URB) released into the Columbia River at Priest Rapids Hatchery or in the Hanford Reach in 2014 (rkm = river kilometer; min = minimum; max = maximum)

| Release location | Release rkm | Rearing type | Release date | *n* | Fork length (mm) | | | Tag burden (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Mean | Min | Max | Mean |
| Priest Rapids Hatchery | 633 | H-URB | June 12 | 200 | 80 | 103 | 87 | 2.6 | 6.8 | 4.6 |
| Hanford Reach | 595 | W-URB | June 6 | 198 | 80 | 100 | 87 | 3.1 | 6.8 | 4.9 |

## 3.3 JSATS Performance

### 3.3.1 Tag-Life

Although tag-life expectancy was 60 days for acoustic tags in this study, 30 of the 32 (93.8%) tag-life transmitters lasted longer than 60 days. In fact, the average transmitter life was 101.5 days at the time of this report (September 10, 2014). However, 25 of the tags were still transmitting at the time of this report, having been activated 97 to 131 days ago. Therefore, the actual average life of tag-life transmitters is greater than 101.5 days. The first tag-life transmitter expired after 47.6 days. Because greater than 99% of the fish we tagged migrated through the study area before the time at which any tag failure was observed during the tag-life study (Figures 3.6 and 3.7), only a relatively small adjustment for tag failure was required. The three-parameter Weibull model (Figure 3.8) fit the preliminary tag-life data better than either the two-parameter Weibull model or the four-parameter vitality model of Li and Anderson (2009). Therefore, this tag-life survivorship model was subsequently used to estimate the probabilities of tag failure and provide tag-life adjusted estimates of juvenile fall Chinook salmon survival.

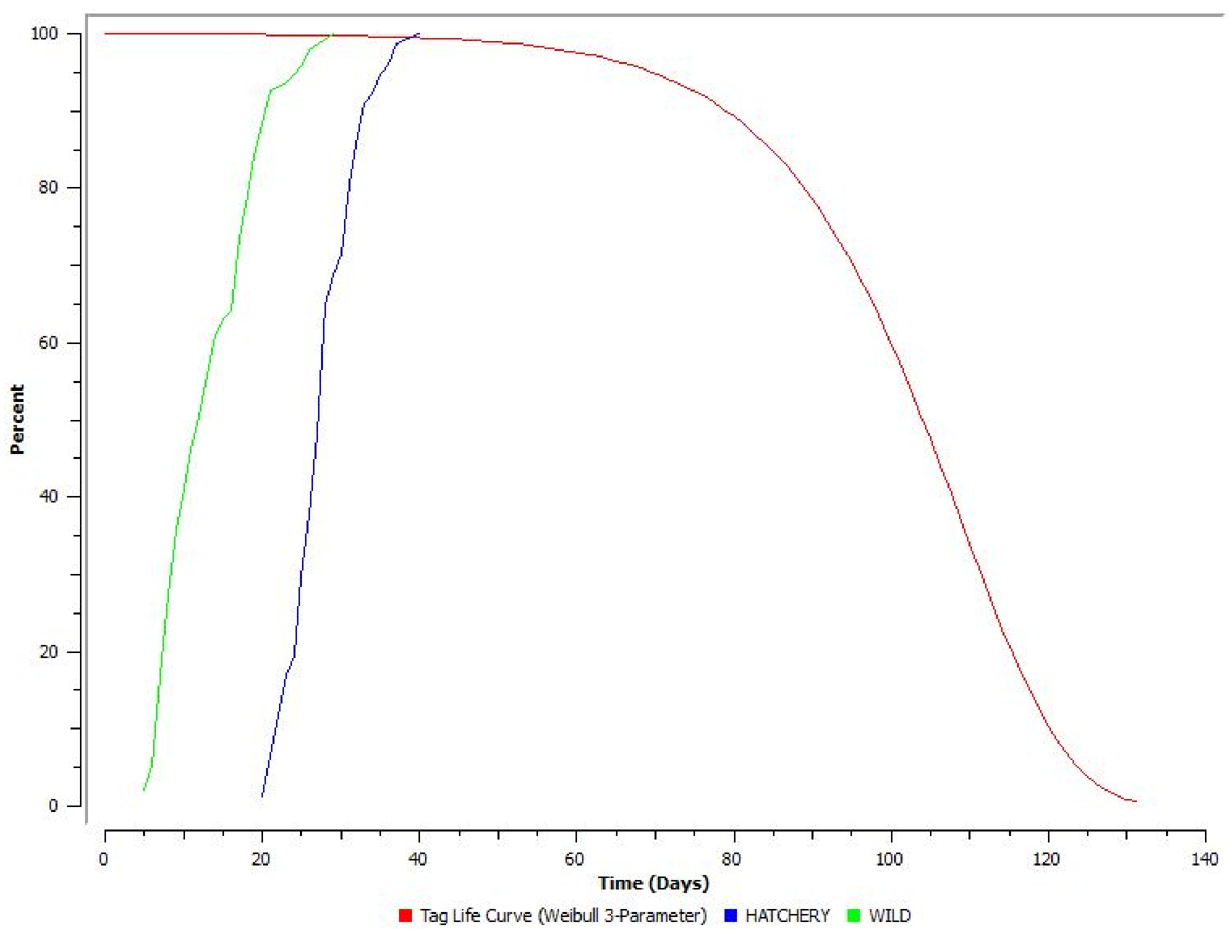


**Figure 3.6**. Fitted three-parameter Weibull model tag-life survivorship curve (red line) and the arrival-time distributions of acoustic-tagged wild Hanford Reach (green line) and Priest Rapids Hatchery (blue line) fall Chinook salmon juveniles at the McNary Dam cabled array (CR470).

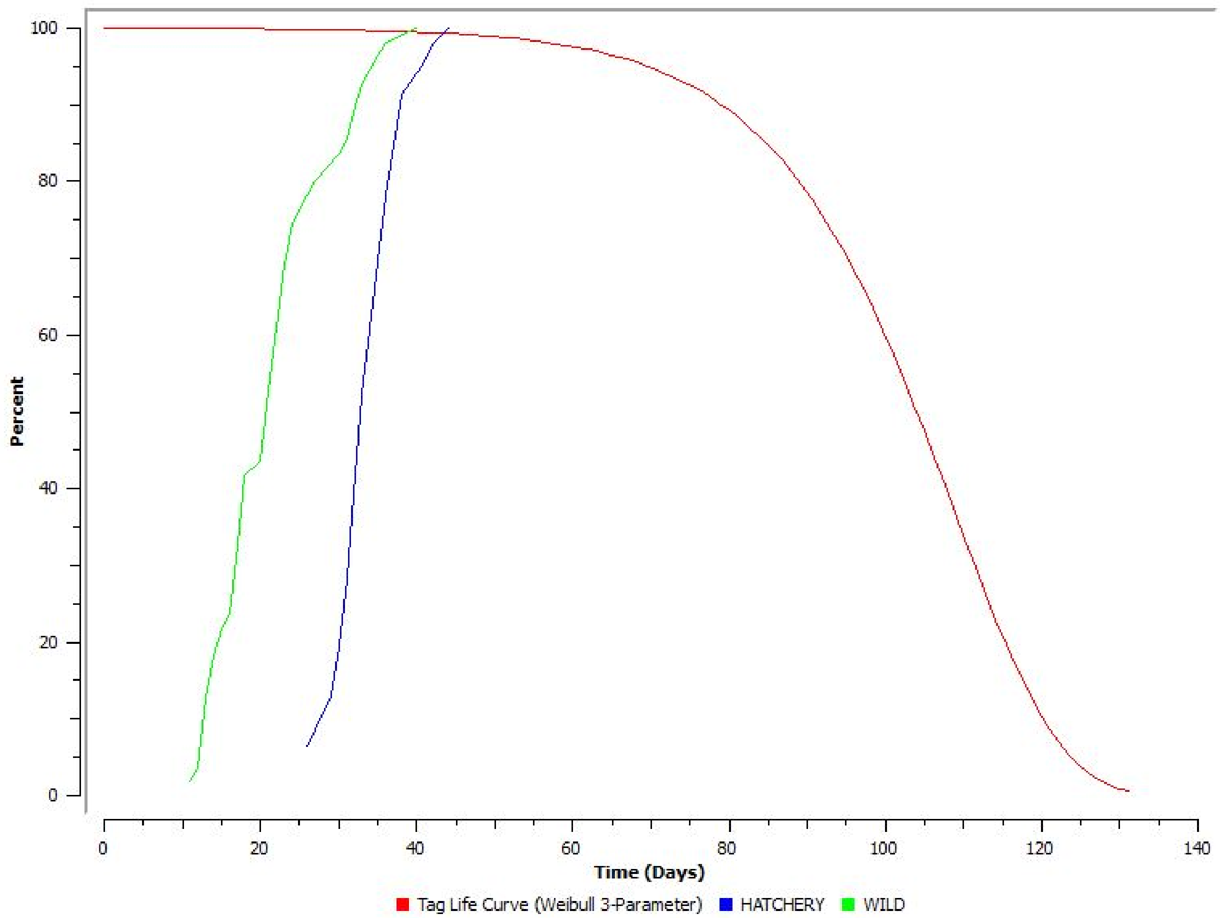


**Figure 3.7**. Fitted three-parameter Weibull model tag-life survivorship curve (red line) and the arrival-time distributions of acoustic-tagged wild Hanford Reach (green line) and Priest Rapids Hatchery (blue line) fall Chinook salmon juveniles at the autonomous array located near Bingen, Washington (CR275).

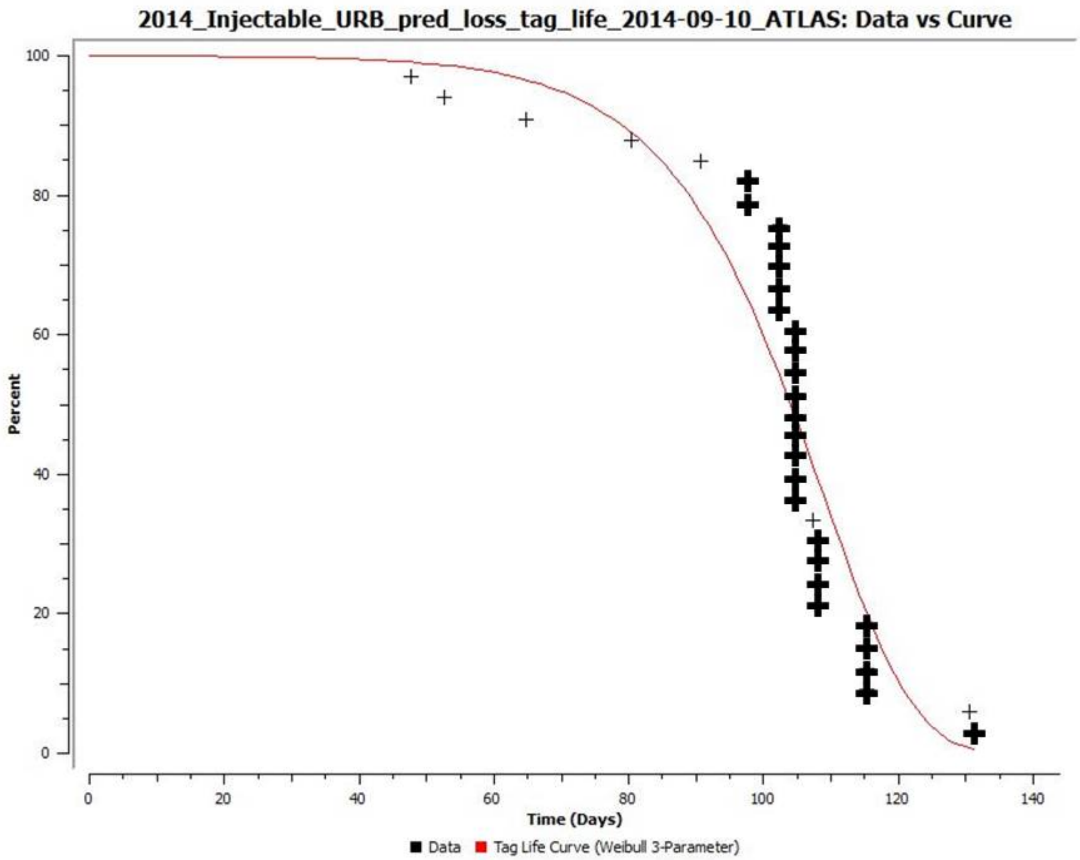


**Figure 3.8**. Observed failure times of tag-life acoustic transmitters (+) and the fitted three-parameter Weibull model survivorship curve used to adjust survival estimates for tag-life. The average tag-life at the time of this report was 101.5 days. Bold crosses (**+**) indicate transmitters that were still transmitting at the time of this report (September 10, 2014); thus, the model does not fit the data particularly well and tag-life is likely underestimated.

### 3.3.2 Array Detection Probability

Detection probability was quite high at all arrays for both PRH and wild Hanford Reach fall Chinook salmon (Table 3.2). The probability of detecting acoustic-tagged fish was ≥0.945 for PRH fish and ≥0.959 for wild fish at all arrays and equaled 1.000 at most arrays.

**Table 3.2**. Probability of detecting acoustic-tagged Priest Rapids Hatchery and wild Hanford Reach fall Chinook salmon at autonomous and cabled JSATS acoustic telemetry receiver arrays deployed in the mid and lower Columbia River in 2014.

| Array | Wild Hanford Reach | Priest Rapids Hatchery |
|---|---|---|
| CR633 | N/A | 1.000 (0.000) |
| CR552 | 1.000 (0.000) | 1.000 (0.000) |
| CR524 | 1.000 (0.000) | 1.000 (0.000) |
| CR498 | 1.000 (0.000) | 1.000 (0.000) |
| CR489 | 0.990 (0.010) | 1.000 (0.000) |
| CR480 | 1.000 (0.000) | 1.000 (0.000) |
| CR472 | 1.000 (0.000) | 1.000 (0.000) |
| CR470 | 0.967 (0.019) | 0.945 (0.027) |
| CR455 | 1.000 (0.000) | 1.000 (0.000) |
| CR449 | 1.000 (0.000) | 1.000 (0.000) |
| CR439 | 0.959 (0.023) | 0.984 (0.016) |
| CR422 | 1.000 (0.000) | 1.000 (0.000) |
| CR412 | 1.000 (0.000) | 0.983 (0.017) |
| CR381 | 1.000 (0.000) | 1.000 (0.000) |
| CR351 | 1.000 (0.000) | 1.000 (0.000) |
| CR349 | 1.000 (0.000) | 1.000 (0.000) |
| CR325 | 1.000 (0.000) | 1.000 (0.000) |
| CR311 | 1.000 (0.000) | 1.000 (0.000) |
| CR275 | 1.000 (0.000) | 1.000 (0.000) |

## 3.4 Survival Probability

Survival is an important metric for identifying when or where unfavorable conditions may exist for juvenile fall Chinook salmon. Evaluating survival on a per-kilometer basis can put the reach survival estimates into a relative context for comparisons between reaches. This section provides reach survival probabilities and $S_{km}$ estimates for each river reach examined in this study. Cumulative survival probabilities, as estimated from release to each downstream detection array, are also presented.

### 3.4.1 Wild Hanford Reach Fall Chinook Salmon

The probability of acoustic-tagged wild fall Chinook salmon surviving migration through the lower half of the Hanford Reach (from release at rkm 595 to CR552) was estimated to be 0.824 (SE = 0.027) and the probability of surviving from release to McNary Dam was 0.497 (0.036) in 2014 (Figure 3.9). Survival probability from release to the most downstream array, located in the reservoir of Bonneville Dam at rkm 275 (CR275), was 0.278 (0.032).

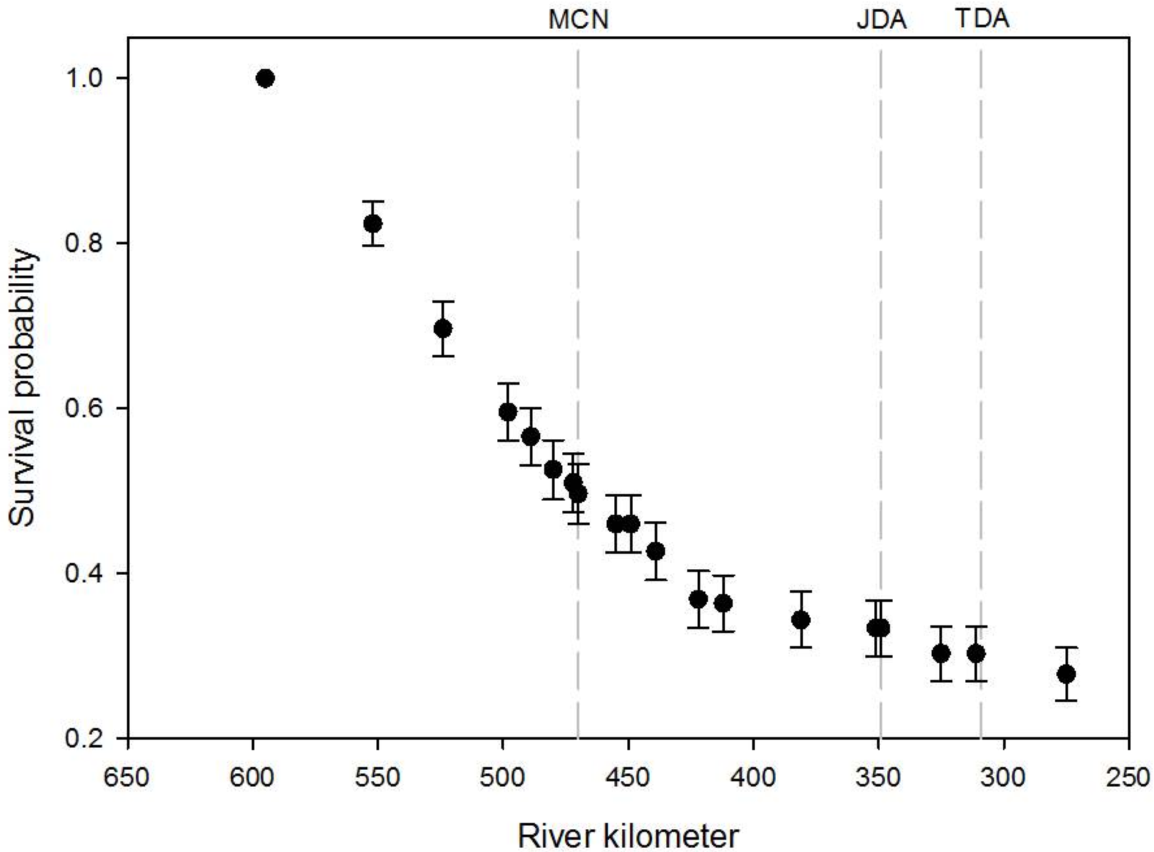


**Figure 3.9**. Overall cumulative survival probability estimates for acoustic-tagged wild Hanford Reach fall Chinook salmon from release in the Hanford Reach (rkm 595) to downstream acoustic telemetry receiver arrays. Error bars denote standard errors.

Survival of acoustic-tagged wild Hanford Reach fall Chinook salmon varied among reaches, from 0.824 (SE=0.027) between release and CR552 to 1.00 (multiple reaches; Table 3.3). Because reaches differed in length, survival is better compared among reaches using $S_{km}$ estimates.

**Table 3.3**. Reach-specific survival probability estimates ($S$, and associated SE) for acoustic-tagged wild Hanford Reach fall Chinook salmon juveniles through each river reach studied in 2014 from release at rkm 595 to CR275. Survival-per-kilometer ($S_{km}$) estimates are also shown.

| Reach | $S$ (SE) | $S_{km}$ |
|---|---|---|
| Release to CR552 | 0.824 (0.027) | 0.9937 |
| CR552 to CR524 | 0.847 (0.028) | 0.9942 |
| CR524 to CR498 | 0.855 (0.030) | 0.9943 |
| CR498 to CR489 | 0.950 (0.020) | 0.9936 |
| CR489 to CR480 | 0.928 (0.025) | 0.9919 |
| CR480 to CR472 | 0.971 (0.017) | 0.9962 |
| CR472 to CR470 | 0.973 (0.017) | 0.9865 |
| CR470 to CR455 | 0.926 (0.027) | 0.9952 |
| CR455 to CR449 | 1.000 (0.003) | 1.0000 |
| CR449 to CR439 | 0.928 (0.028) | 0.9924 |
| CR439 to CR422 | 0.864 (0.038) | 0.9917 |
| CR422 to CR412 | 0.986 (0.014) | 0.9983 |
| CR412 to CR381 | 0.945 (0.027) | 0.9983 |
| CR381 to CR351 | 0.971 (0.021) | 0.9991 |
| CR351 to CR349 | 1.000 (0.004) | 1.0000 |
| CR349 to CR325 | 0.909 (0.036) | 0.9961 |
| CR325 to CR311 | 1.000 (0.004) | 1.0000 |
| CR311 to CR275 | 0.917 (0.036) | 0.9976 |

Upstream of McNary Dam, $S_{km}$ was considerably lower in the immediate forebay of McNary Dam ($S_{km}$ = 0.9865; CR472 to CR470) compared to all other reaches (Figure 3.10). The other reach upstream of McNary with a $S_{km}$ estimate that was notably low was also near McNary Dam between CR489 and CR480 ($S_{km}$ = 0.9919). Anomalously, the reach located between these two reaches (CR480 to CR472) had the highest $S_{km}$ of all reaches upstream of McNary Dam for acoustic-tagged wild Hanford Reach fall Chinook salmon. Survival-per-kilometer estimates were generally similar among all reaches located between release and CR489, ranging from 0.9936 to 0.9943.

Downstream of McNary Reservoir, two reaches had $S_{km}$ estimates that were considerably lower than all others for acoustic-tagged wild Hanford Reach fall Chinook salmon. These included the reach located between Boardman, OR (CR439) and Crow Butte (CR422; $S_{km}$ = 0.9917) and the next upstream reach, located between Paterson, WA (CR449) and Boardman, OR (CR439; $S_{km}$ = 0.9924).

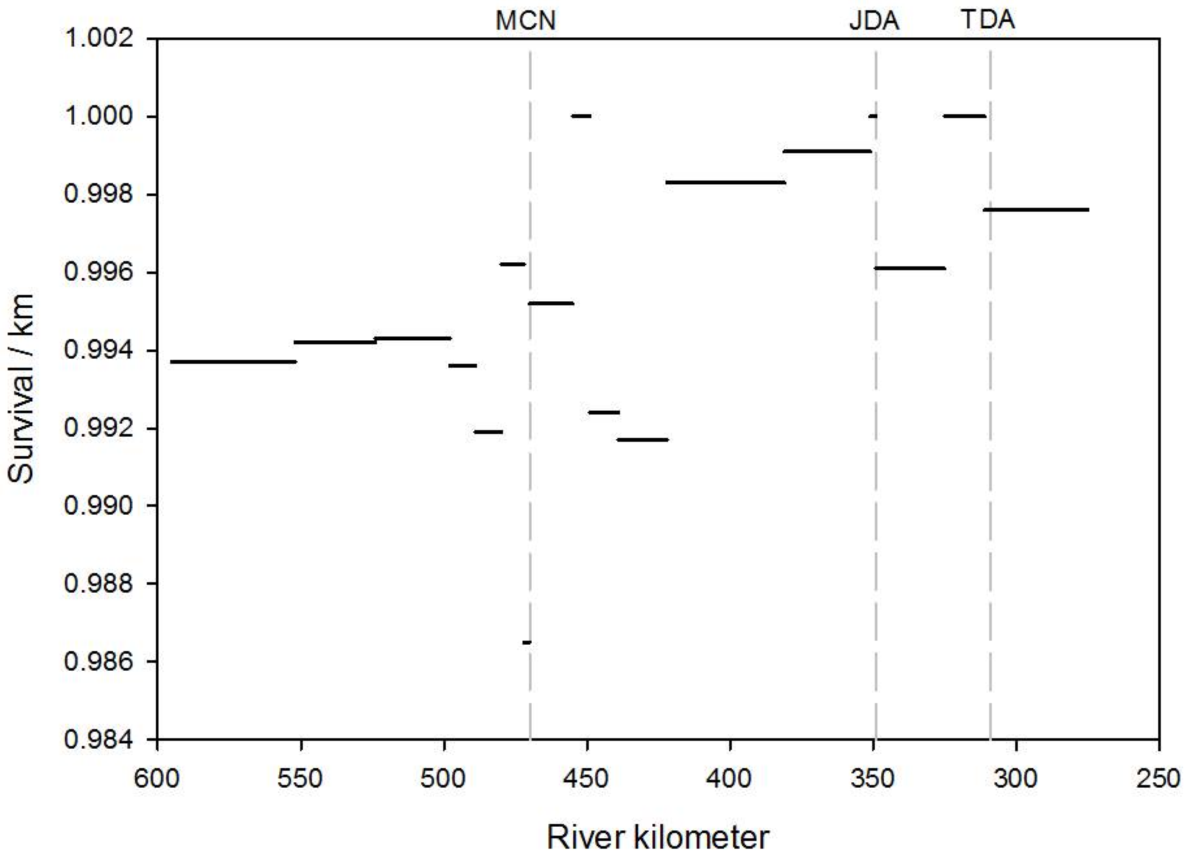


**Figure 3.10.** Survival probability-per-kilometer estimates for acoustic-tagged wild Hanford Reach fall Chinook salmon through reaches of the Columbia River, 2014. Dashed vertical lines indicate the locations of McNary (MCN), John Day (JDA), and The Dalles (TDA) dams.

We observed a significant, positive relationship between the probability of survival to McNary Dam and fish length for wild Hanford Reach fall Chinook salmon ($\chi$ = 7.486; $p$ = 0.006; Figure 3.11). The difference in survival was rather large across the length range of tagged fish. Those at the upper end of the length distribution (100 mm FL) were about twice as likely to survive to McNary Dam as fish at the lower end of the distribution (80 mm FL).

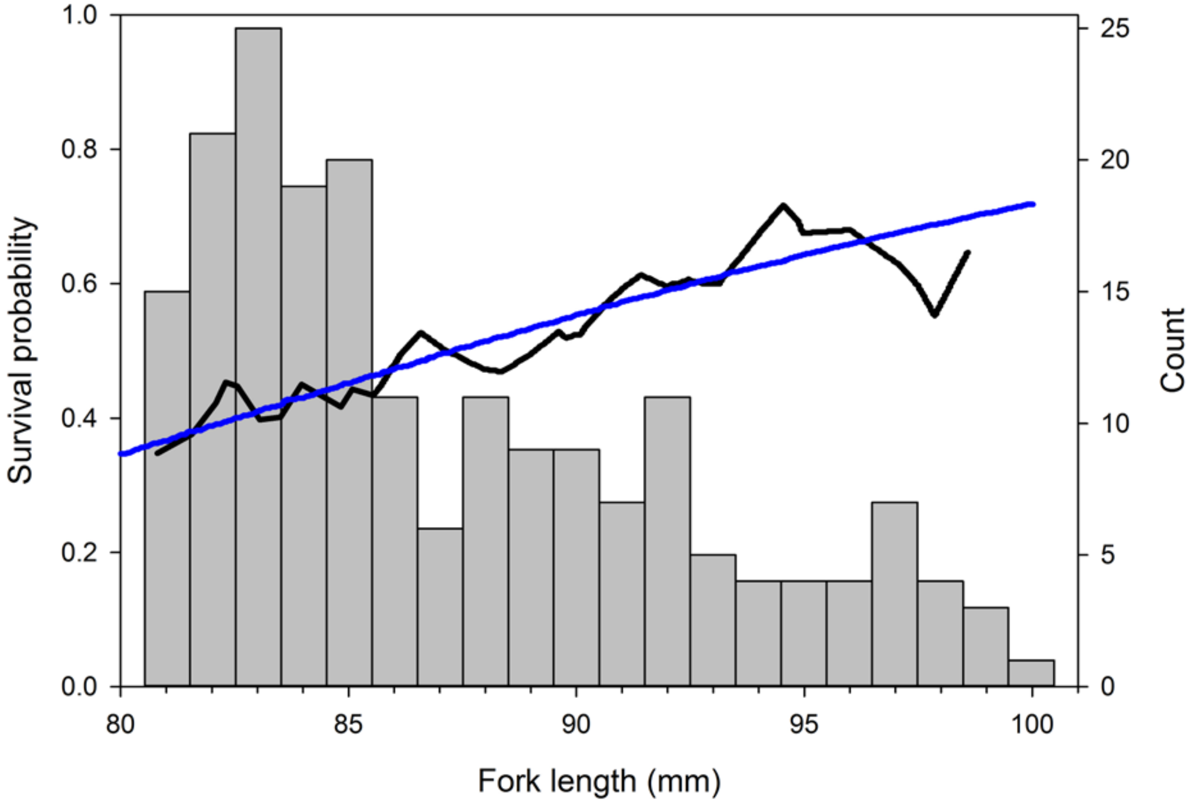


**Figure 3.11.** Covariate analysis results displaying nonparametric (black line) and modeled (blue line) survival probabilities of acoustic-tagged wild Hanford Reach fall Chinook salmon from release in the Hanford Reach (rkm 595) to McNary Dam (rkm 470) in relation to fork length. The frequency histogram displays the number of tagged fish in each 1-mm fork length bin.

### 3.4.2 Priest Rapids Hatchery Fall Chinook Salmon

The probability of acoustic-tagged PRH fall Chinook salmon surviving migration through the Hanford Reach (from CR633 to CR552) was estimated to be 0.659 (SE = 0.037) and the probability of surviving to McNary Dam was 0.498 (0.039) in 2014 (Figure 3.12). Survival probability from CR633 to the most downstream array, located in the reservoir of Bonneville Dam at rkm 275 (CR275), was 0.281 (0.035).

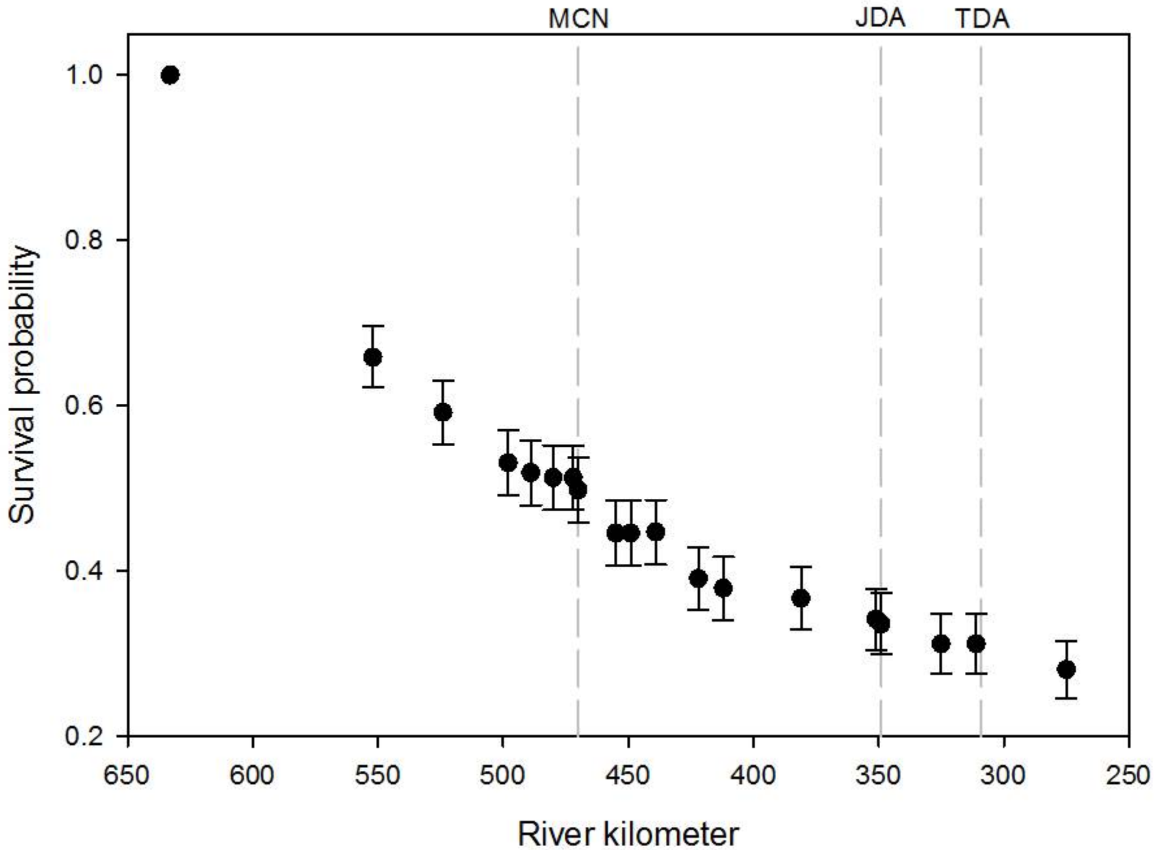


**Figure 3.12.** Overall cumulative survival probability estimates for acoustic-tagged Priest Rapids Hatchery fall Chinook salmon from acoustic detection in the PRH outflow channel (CR633) to downstream acoustic telemetry receiver arrays. Error bars denote standard errors.

Survival of acoustic-tagged PRH fall Chinook salmon varied widely among reaches, from 0.659 (SE=0.037) between CR633 and CR552 to 1.00 (multiple reaches; Table 3.4). Because reaches differed in length, survival is better compared among reaches using $S_{km}$ estimates.

**Table 3.4**. Reach-specific survival probability estimates ($S$, and associated SE) for acoustic-tagged Priest Rapids Hatchery fall Chinook salmon juveniles through each river reach studied in 2014 from virtual release (detection in the hatchery outflow channel) at rkm 633 to CR275. Survival from tagging to virtual release (Release to CR633) and survival-per-kilometer ($S_{km}$) estimates are also shown.

| Reach | $S$ (SE) | $S_{km}$ |
|---|---|---|
| Release to CR633 | 0.821 (0.027) | N/A |
| CR633 to CR552 | 0.659 (0.037) | 0.9951 |
| CR552 to CR524 | 0.898 (0.029) | 0.9962 |
| CR524 to CR498 | 0.897 (0.031) | 0.9960 |
| CR498 to CR489 | 0.977 (0.016) | 0.9971 |
| CR489 to CR480 | 0.988 (0.012) | 0.9987 |
| CR480 to CR472 | 1.000 (0.003) | 1.0000 |
| CR472 to CR470 | 0.970 (0.021) | 0.9850 |
| CR470 to CR455 | 0.896 (0.035) | 0.9932 |
| CR455 to CR449 | 1.000 (0.003) | 1.0000 |
| CR449 to CR439 | 1.002 (0.004) | 1.0002 |
| CR439 to CR422 | 0.875 (0.039) | 0.9924 |
| CR422 to CR412 | 0.969 (0.022) | 0.9961 |
| CR412 to CR381 | 0.967 (0.023) | 0.9990 |
| CR381 to CR351 | 0.934 (0.032) | 0.9978 |
| CR351 to CR349 | 0.982 (0.018) | 0.9857 |
| CR349 to CR325 | 0.928 (0.035) | 0.9970 |
| CR325 to CR311 | 1.000 (0.005) | 1.0000 |
| CR311 to CR275 | 0.902 (0.042) | 0.9971 |

Similar to the results observed for wild tagged fish, $S_{km}$ of PRH fall Chinook salmon was considerably lower in the immediate forebay of McNary Dam ($S_{km}$ = 0.9850; CR472 to CR470) compared to all other reaches upstream of McNary Dam (Figure 3.13). With the exception of this reach, $S_{km}$ generally increased from upstream to downstream between CR633 and CR472 for acoustic-tagged PRH fall Chinook salmon.

Downstream of McNary Reservoir, the $S_{km}$ of PRH fall Chinook salmon was considerably lower in the immediate forebay of John Day Dam ($S_{km}$ = 0.9857; CR351 to CR349) than all other reaches. The reach that included McNary Dam (CR470 to CR455) and the reach located between Boardman, OR and Crow Butte (CR439 to CR422) also had relatively low $S_{km}$ estimates for PRH fall Chinook salmon (0.9932 and 0.9924, respectively).

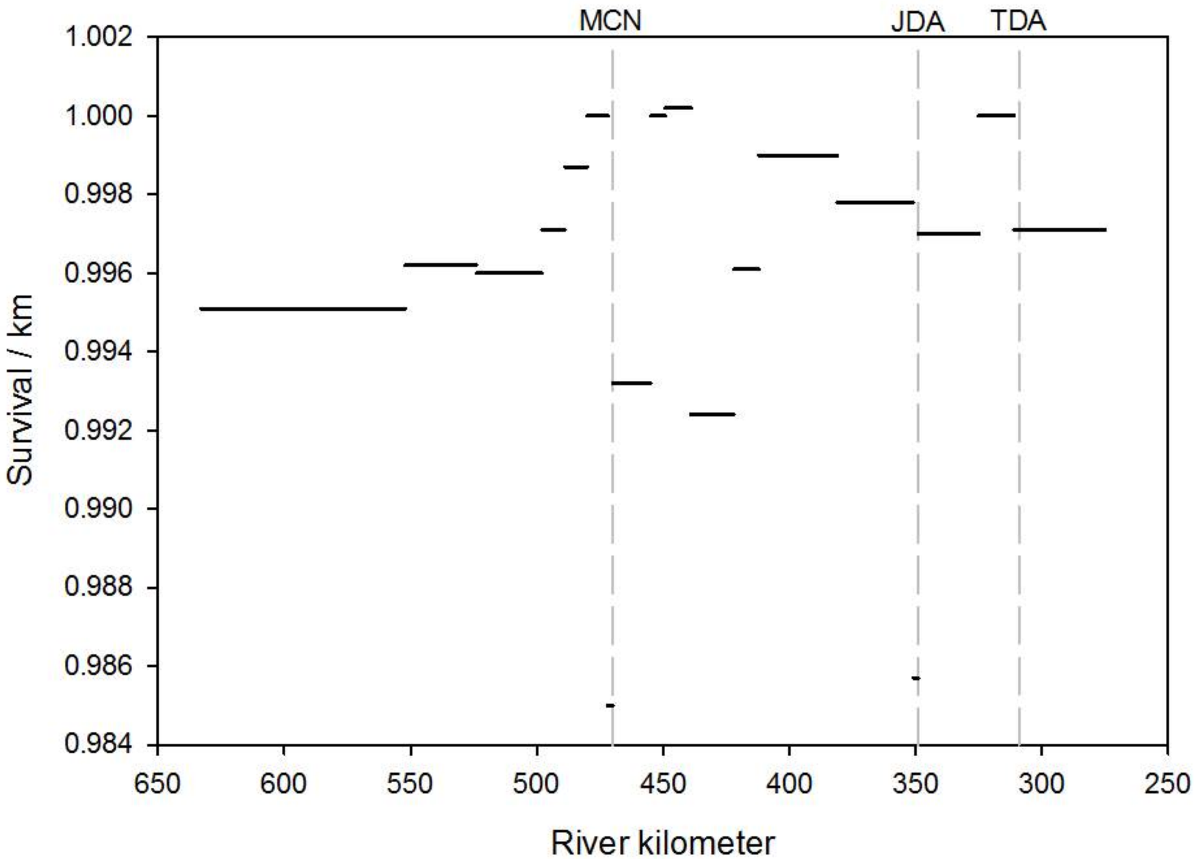


**Figure 3.13.** Survival probability-per-kilometer estimates for acoustic-tagged Priest Rapids Hatchery fall Chinook salmon through reaches of the Columbia River, 2014. Dashed vertical lines indicate the locations of McNary (MCN), John Day (JDA), and The Dalles (TDA) dams.

Similar to the relationship found for wild Hanford Reach fall Chinook salmon, we observed an even stronger, positive relationship between survival probability to McNary Dam and fish length for PRH fall Chinook salmon ($\chi$ = 14.164; $p < 0.001$; Figure 3.14). Again, there was a large difference in survival across the length range of tagged fish. Those at the upper end of the length distribution (~100 mm FL) were more than twice as likely to survive to McNary Dam as fish at the lower end of the distribution (80 mm FL).

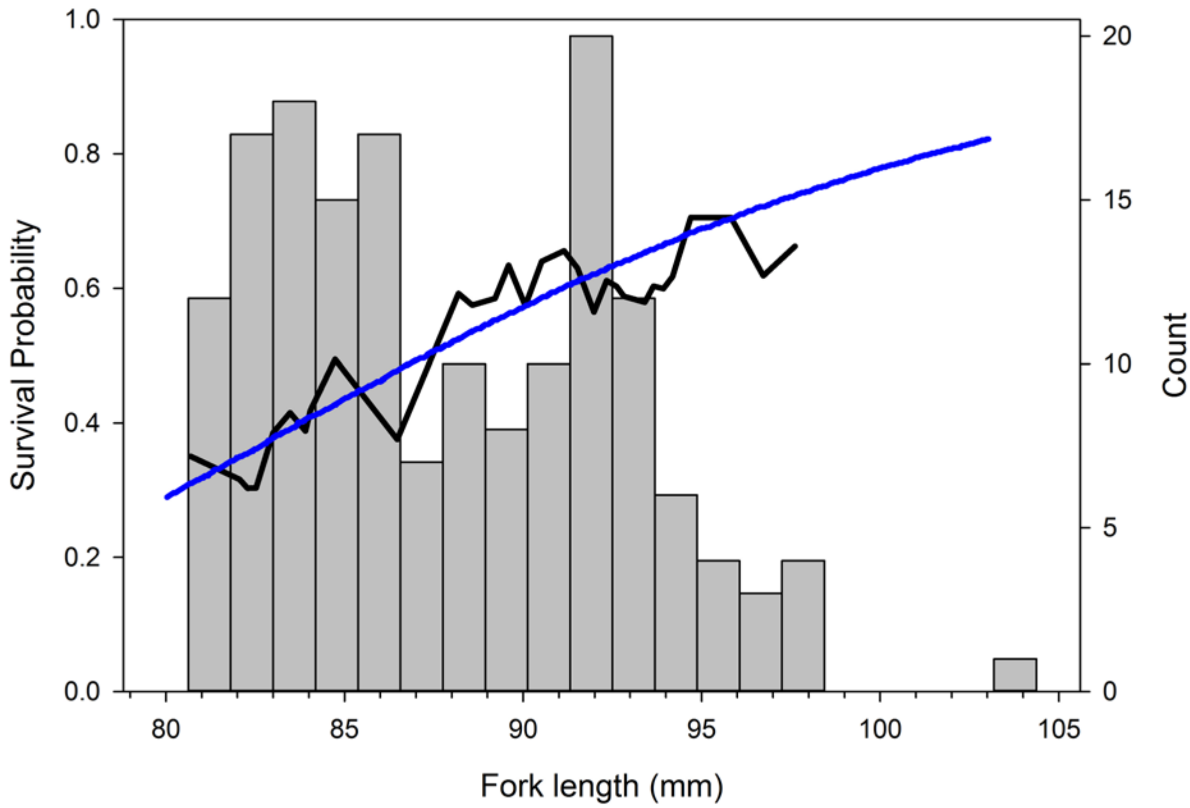


**Figure 3.14**. Covariate analysis results displaying nonparametric (black line) and modeled (blue line) survival probabilities of acoustic-tagged Priest Rapids Hatchery fall Chinook salmon from Priest Rapids Hatchery (CR633) to McNary Dam (CR470) in relation to fork length. The frequency histogram displays the number of tagged fish in each 1-mm fork length bin.

## 3.5 Travel Time and Travel Rate

The amount of time fish spend in a particular river reach and the speed at which they travel is often linked to survival probability. This section describes the travel times and rates of acoustic-tagged wild Hanford Reach and PRH fall Chinook salmon through reaches of the mid and lower Columbia River in 2014.

### 3.5.1 Wild Hanford Reach Fall Chinook Salmon

The median travel time was less than 2 days for acoustic-tagged wild Hanford Reach fall Chinook salmon in each river reach examined in 2014 (Figure 3.15). We observed relatively little variability in travel times within each reach except in the first reach (release to CR552) where the median travel time was 1.4 days but over 25% of the fish took >6 d and 25% took <13 h to traverse the reach. The median travel time of wild Hanford Reach fall Chinook salmon detected at McNary Dam was 10.7 d ($25^{th}$ percentile = 6.7 d; $75^{th}$ percentile = 16.2 d).

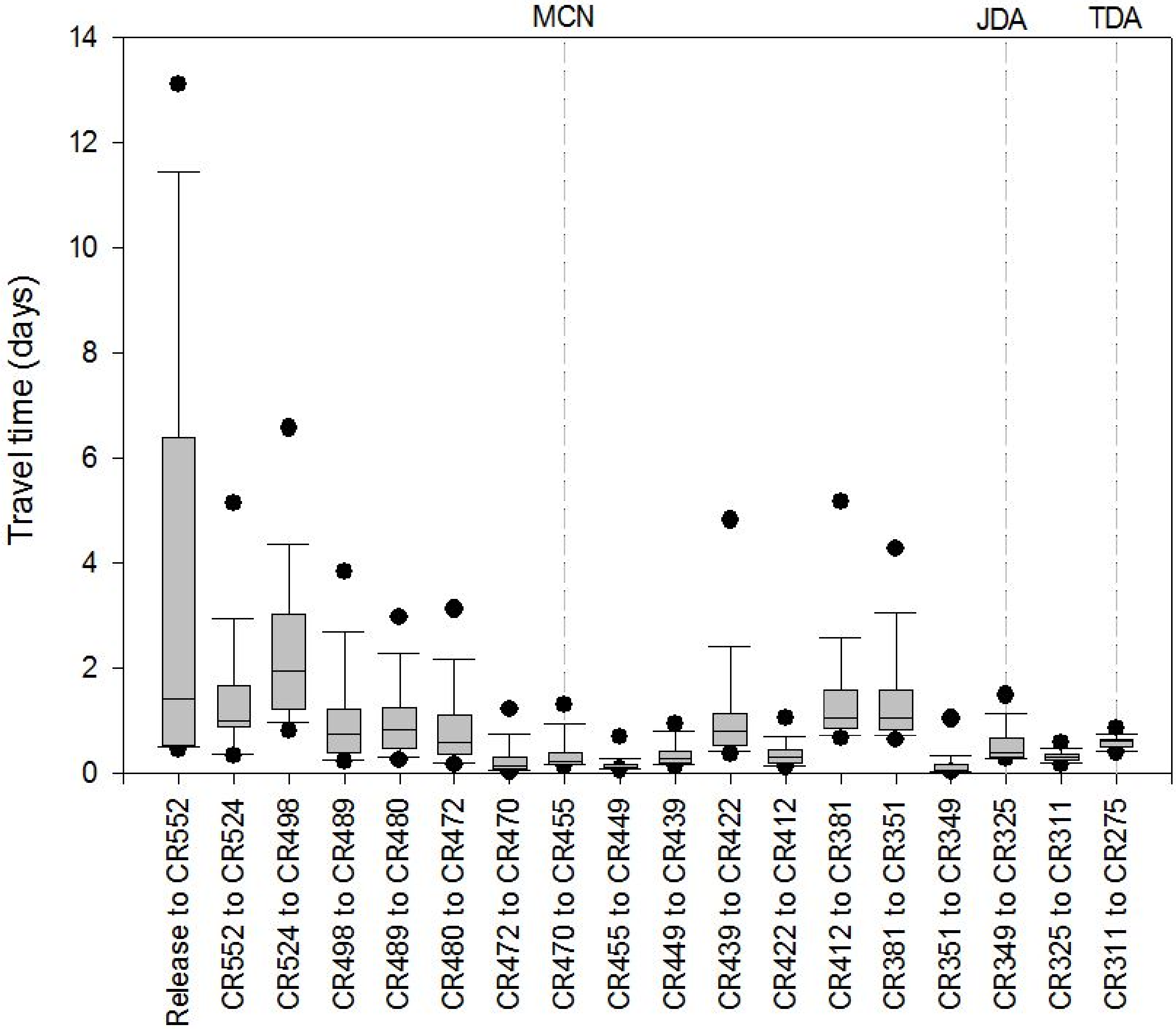


**Figure 3.15**. Travel time (days) of acoustic-tagged wild Hanford Reach fall Chinook salmon juveniles in each reach of the Columbia River studied in 2014. Solid lines within the boxes are median, the box boundary represents the 25th and 75th percentiles, whiskers indicate the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. Dashed vertical lines indicate the locations of McNary (MCN), John Day (JDA), and The Dalles (TDA) dams.

Acoustic-tagged wild Hanford Reach fall Chinook salmon generally migrated most quickly through the free-flowing Hanford Reach (release to CR552), and through the tailraces of Federal Columbia River Power System (FCRPS) dams (CR470 to CR455; CR349 to CR325; CR311 to CR275; Figure 3.16). We also observed the greatest variability in travel rate within these reaches. For example, wild Hanford Reach fall Chinook salmon had a median travel rate of 30 km/d from release to CR552; however, 25% of the fish had travel rates <10 km/d and 25% had rates >80 km/d. Conversely, travel rates were slowest, with the least amount of variability in reservoir reaches (all reaches between CR552 and CR470, between CR449 and CR349, and from CR325 to CR311). For example, median travel rates were generally around 10 km/d for acoustic-tagged wild Hanford Reach fall Chinook salmon in reaches of McNary Reservoir (part of CR552 to CR524, and all reaches between CR524 and CR470).

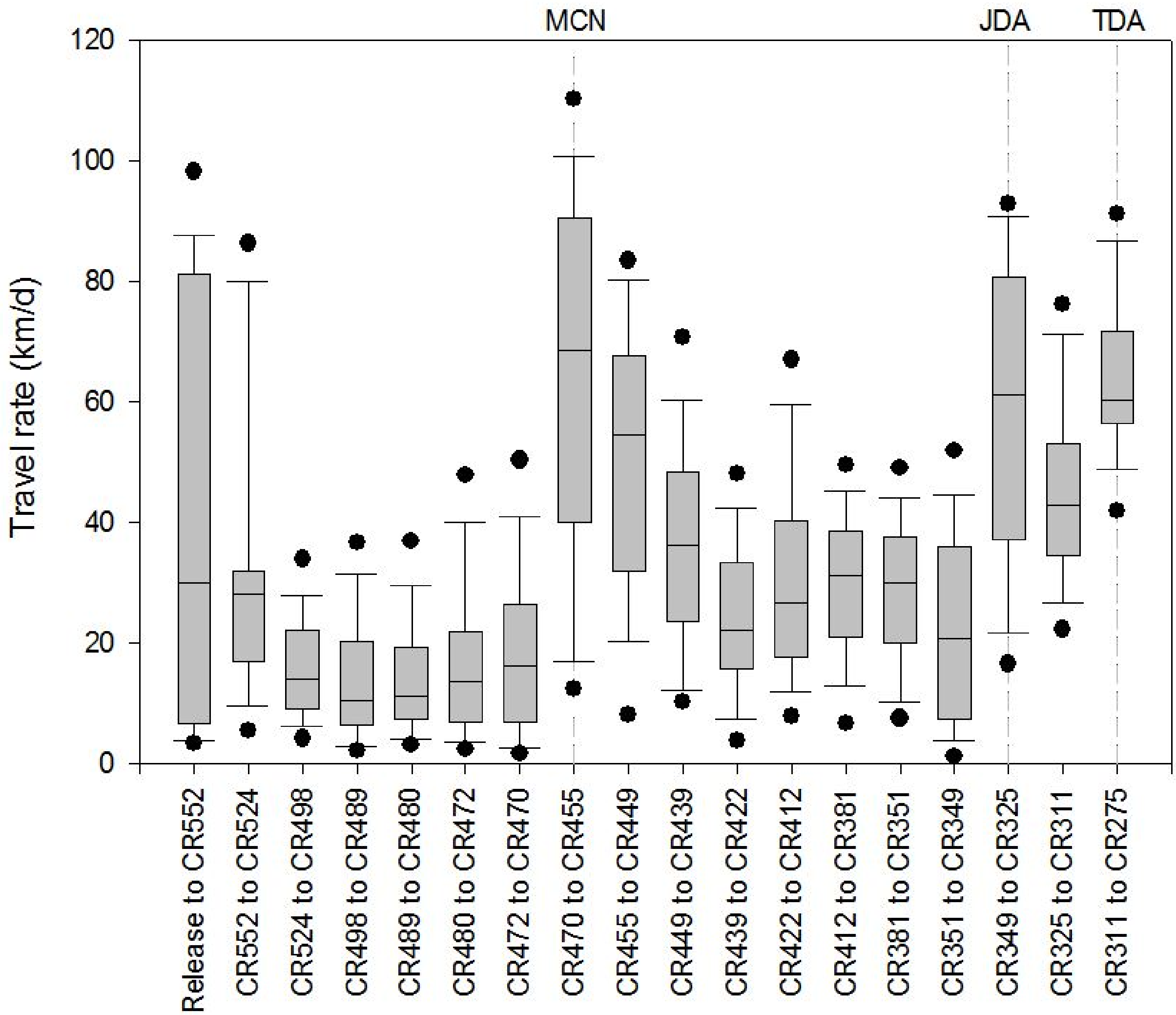


**Figure 3.16.** Travel rate (km/d) of acoustic-tagged wild Hanford Reach fall Chinook salmon juveniles in each reach of the Columbia River studied in 2014. Solid lines within the boxes are median, the box boundary represents the 25th and 75th percentiles, whiskers indicate the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. Dashed vertical lines indicate the locations of McNary (MCN), John Day (JDA), and The Dalles (TDA) dams.

### 3.5.2 Priest Rapids Hatchery Fall Chinook Salmon

Similar to the trends observed for wild Hanford Reach fall Chinook salmon, acoustic-tagged fall Chinook salmon from PRH migrated through most river reaches in less than 2 d (Figure 3.17). The one exception was the Hanford Reach (release at PRH to CR552) where the median travel time was 3.7 d. PRH fall Chinook salmon had a longer travel time through the Hanford Reach than wild fish because they had a longer distance to travel to CR552 (81 km versus 43 km). Also similar to the trend observed for wild fish, we found the variability in travel times was greatest for acoustic-tagged PRH fall Chinook salmon in the Hanford Reach where 25% of the fish had travel times <1.5 d and 25% of the fish took >7.0 d to migrate through the reach. The median travel time of PRH fall Chinook salmon detected at McNary Dam was 11.6 d (25th percentile = 9.1 d; 75th percentile = 14.1 d).

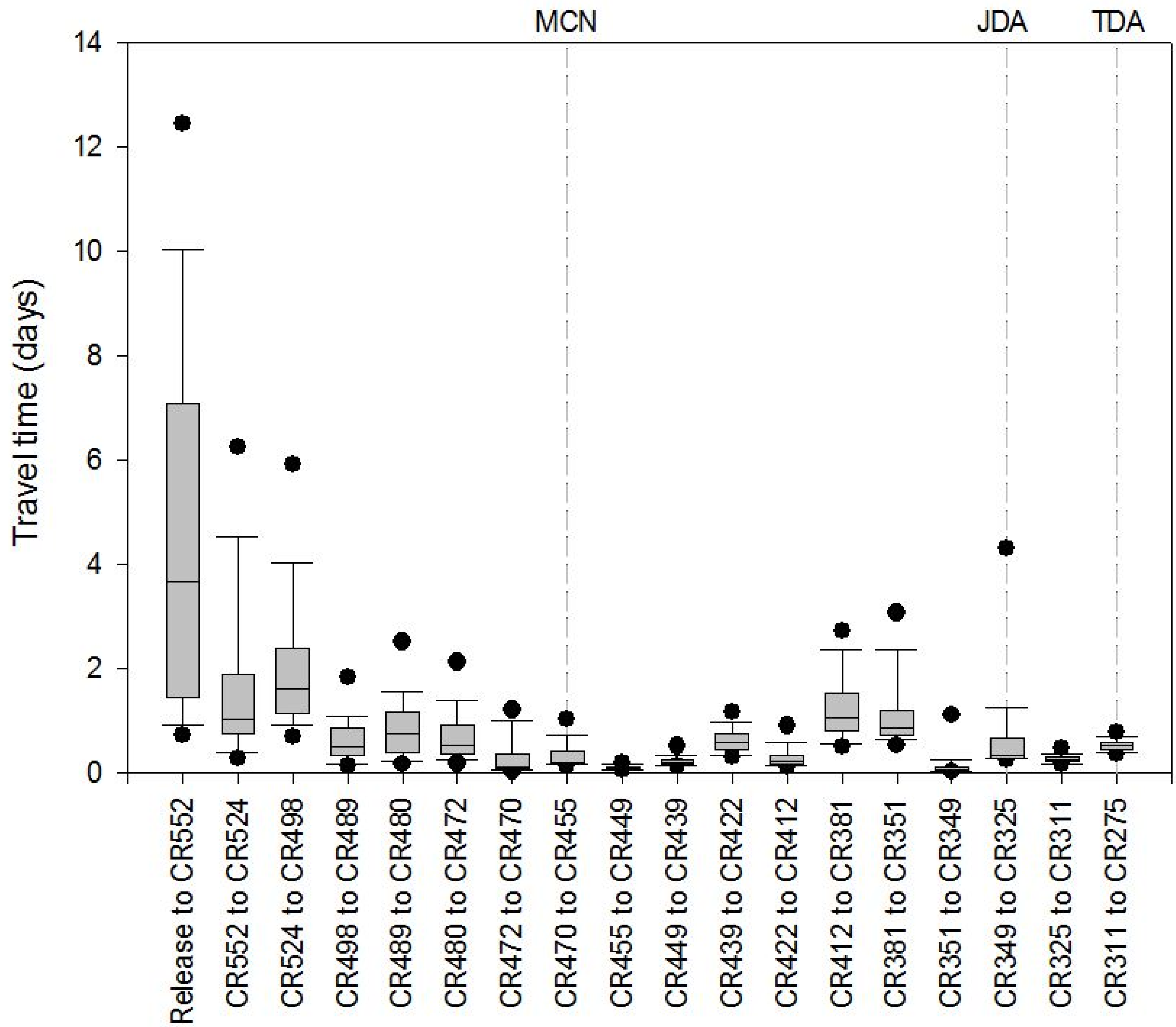


**Figure 3.17**. Travel time (days) of acoustic-tagged Priest Rapids Hatchery fall Chinook salmon juveniles in each reach of the Columbia River studied in 2014. Solid lines within the boxes are median, the box boundary represents the 25th and 75th percentiles, whiskers indicate the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. Dashed vertical lines indicate the locations of McNary (MCN), John Day (JDA), and The Dalles (TDA) dams.

Similar to the trends observed for wild Hanford Reach fall Chinook salmon, acoustic-tagged PRH fall Chinook salmon migrated most quickly, with the greatest variability, through flowing reaches, particularly those downstream from FCRPS dams (Figure 3.18). Again, the slowest travel rates were observed in McNary Reservoir where median travel rates were around 15 km/d. PRH fall Chinook salmon had higher median travel rates than wild fall Chinook salmon through all reaches examined in 2014, except in the two most upstream reaches (release to CR552 and CR552 to CR524).

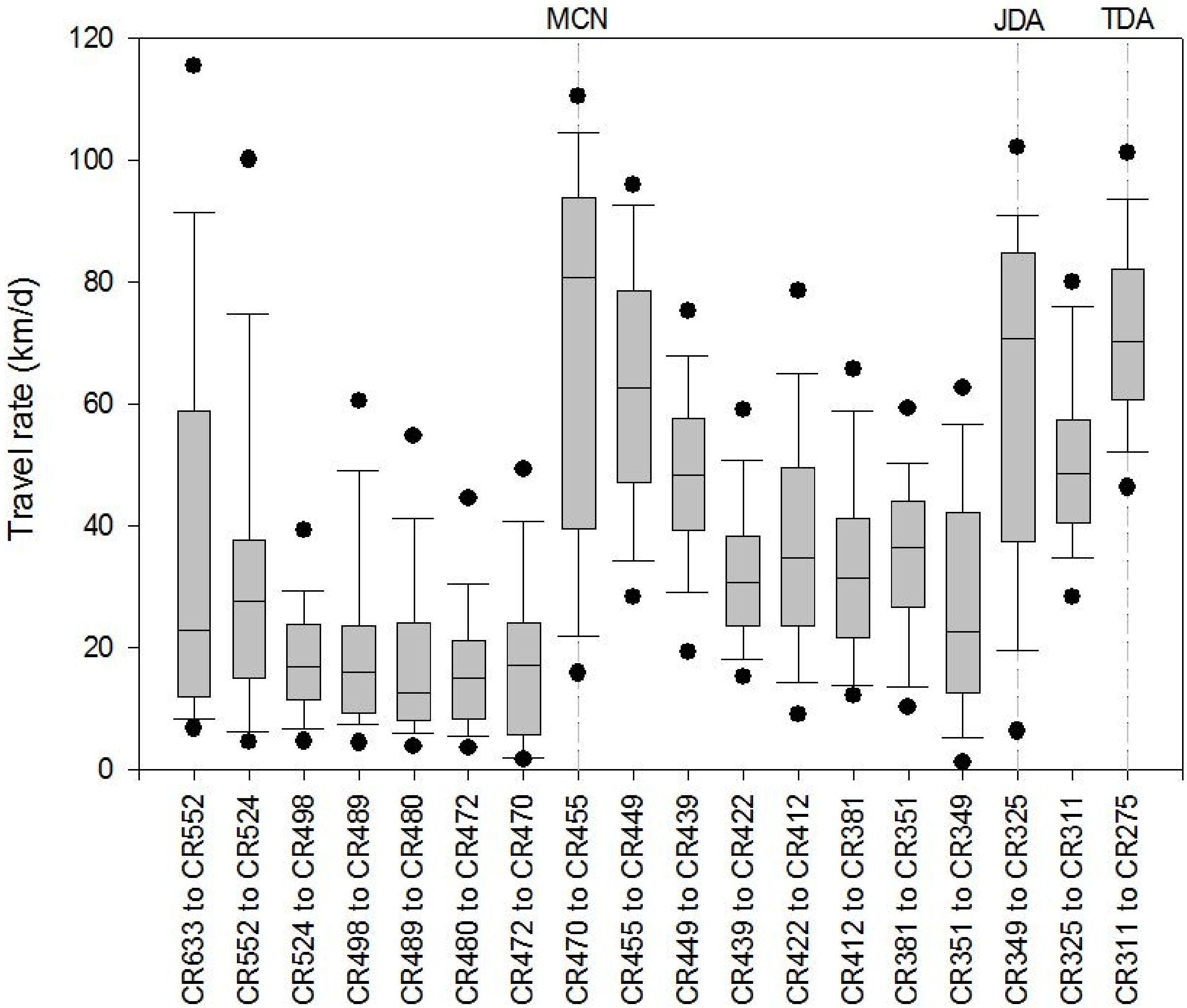


**Figure 3.18.** Travel rate (km/d) of acoustic-tagged Priest Rapids Hatchery fall Chinook salmon juveniles in each reach of the Columbia River studied in 2014. Solid lines within the boxes are median, the box boundary represents the 25th and 75th percentiles, whiskers indicate the 10th and 90th percentiles, and dots indicate the 5th and 95th percentiles. Dashed vertical lines indicate the locations of McNary (MCN), John Day (JDA), and The Dalles (TDA) dams.

# 4.0 Discussion

This study was the first to attempt to partition mortality of wild Hanford Reach and PRH fall Chinook salmon into specific river reaches to identify potential sources of mortality. We identified river reaches in which survival was low, relative to the length of the reach. These data, combined with existing knowledge from previous studies, provided us with the information necessary to make inferences about the causes of the observed mortality.

We found groups of acoustic-tagged wild Hanford Reach and PRH fall Chinook salmon had a 0.50 probability of surviving to McNary Dam. Whereas this estimate is considerably higher than has been previously found for wild Hanford Reach fall Chinook salmon juveniles, it is substantially lower than what is typical for PRH smolts.

Survival of wild Hanford Reach fall Chinook salmon juveniles to McNary Dam has been estimated since 1995 from annual releases of ~3,000 to ~23,000 PIT-tagged fish (Fish Passage Center 2013). Survival of these groups to McNary Dam has ranged from 0.27 to 0.62 with an average survival probability of 0.37 (SE = 0.02). Similarly, the 9,940 wild Hanford Reach fall Chinook salmon juveniles that were implanted with PIT tags (PIT only) and released in 2014 had a survival probability of 0.34 (SE = 0.02) to McNary Dam. The large discrepancy between survival estimates derived from acoustic-tagged versus PIT-only groups is likely a result of the difference in fish size between groups. For comparison, PIT-only fish that measured <80 mm FL had a 0.31 (SE = 0.02) survival probability from release to McNary Dam in 2014 compared to 0.72 (SE = 0.12) for PIT-only fish that measured ≥80 mm FL. As previously mentioned, we attempted to minimize the effect of the transmitter on the performance of implanted fish by only tagging fish that measured ≥80 mm FL; whereas, fish as small as 60 mm FL were implanted with PIT tags. As we demonstrated, survival of these fish is strongly, positively correlated with fish length. Therefore, we expect that the survival of the overall population of juvenile wild Hanford Reach fall Chinook salmon through the study area was substantially lower than it was for the fish we tagged. However, we believe that the relative losses of tagged fish by reach were representative of the overall population.

Survival of PRH fall Chinook salmon juveniles to McNary Dam has been estimated since 1997 from annual releases of PIT-tagged fish (Richards et al. 2013). Survival of these groups to McNary Dam has ranged from 0.50 to 0.84 with an average of 0.68 (SE = 0.02). In 2014, the 31,980 PRH fall Chinook salmon juveniles that were implanted with PIT tags (PIT-only) had a 0.66 (SE = 0.02) probability of surviving to McNary Dam. The difference in survival between groups of acoustic-tagged and PIT-only PRH fall Chinook salmon juveniles observed in 2014 may have been the result of a reduction in performance of acoustic-tagged fish caused by the tagging procedure or presence of the tag, and/or a result of acoustic transmitter failure or loss.

A laboratory study was conducted at PNNL in 2013 to determine the minimum size fish that could be implanted with the downsized acoustic transmitter without affecting fish performance or survival. Results from this study found only 1 of 126 (0.8%) fall Chinook salmon (80–104 mm FL) surgically implanted (no suture; same method as used in this study) with a PIT tag and downsized acoustic transmitter died over a 60-day examination period and no fish dropped either tag during the study. Based on the results of this study, we felt confident in using this method during a field trial. However, we observed relatively high post-tagging, pre-release mortality for the group of PRH fall Chinook salmon we implanted with acoustic transmitters for the in-river survival evaluation described in this report.

Acoustic-tagged PRH fall Chinook salmon juveniles had an estimated probability of surviving from tagging to acoustic detection in the outfall channel of 0.82 (SE = 0.03). Although several great blue herons *Ardea herodias* were frequently observed foraging in the outfall channel, it is unlikely heron predation accounted for all the mortality we observed in the channel pond and outflow channel since we did not observe the same level of mortality for the PIT-only group. The group of 31,980 PIT-only PRH fall Chinook salmon, which were implanted on May 29 (the day after acoustic tagging), had an estimated survival probability of 0.97 (SE < 0.01) from tagging to PIT detection in the outfall channel. Thus, it appears the acoustic-tagged group may have suffered some tag- or tagging-related mortality.

It is also apparent that some level of acoustic tag loss or failure occurred between tagging and volitional release to the river for the PRH group. Of the 167 PRH juveniles implanted with acoustic transmitters and PIT tags that were detected by the PIT array in the outflow channel, only 159 (95.2%) were also detected by the cabled acoustic array located in the outflow channel. Because the acoustic array in the outflow channel had a detection probability of 1.0, these results suggest an acoustic tag loss or failure rate of 4.8% occurred between tagging and detection in the outflow channel. The first tag in the tag-life study that died did so after 47.6 days, with over 75% of the tags lasting >100 days. Therefore, it is likely tag loss and not tag failure accounted for the 5% non-detection rate observed during the first couple of weeks between tagging and detection in the outflow channel.

Because we estimated survival of acoustic-tagged PRH juveniles by forming a virtual release of only those fish detected by the cabled acoustic array located in the outflow channel (CR633), fish that died or dropped their tag prior to volitional release into the river were not included in the estimate. However, it is possible that some tag- or tagging-related mortality continued to occur once fish left the PRH outflow channel and entered the Columbia River. We also have evidence that tag loss continued after fish entered the river. Twenty-one acoustic-tagged hatchery fall Chinook salmon that had an active transmitter when they left PRH (i.e., they were detected at CR633) were detected by the PIT array in the JBS of McNary Dam. Of those, two (9.5%) were not detected by any adjacent acoustic receiver arrays, suggesting the fish were still alive but no longer had acoustic transmitters. Two of 27 (7.4%) acoustic-tagged wild Hanford Reach fall Chinook salmon that were detected by the McNary Dam JBS PIT array appeared to have dropped their acoustic tags (i.e., they were not detected by adjacent acoustic arrays). Three of 23 (13.0%) acoustic-tagged fish detected by the PIT array in the JBS of John Day Dam were not detected by adjacent acoustic receiver arrays.

Existing evidence suggests that fish routed through the JBS at hydroelectric dams of the FCRPS may be smaller or weaker, on average, than fish that pass the dams using other routes (Zabel et al. 2005). Fish that expelled their transmitter may be expected to have complications that could potentially inhibit their performance, making them more likely to pass through the JBS at FCRPS dams. Thus, the tag loss percentages presented above may be biased high and represent an absolute worst-case scenario. However, even at these rates, the effect of tag loss on survival estimation is relatively small. For example, 101 of the 198 (51.0%) acoustic-tagged wild Hanford Reach fall Chinook salmon were detected at CR472. Because this array had a detection probability of 1.0, the probability of survival from release to CR472 is 0.51 (SE = 0.04). If we assume 7.4% of the fish that were not detected at CR472 were living fish that had expelled their transmitter, the survival estimate becomes 0.55, which is within the 95% confidence interval of the original estimate.

The greatest bias associated with the survival estimates for the group of wild Hanford Reach fall Chinook salmon may be the presence of a tag or tagging effect, which we would expect to manifest itself soon after implantation, as we observed for the PRH fish. Because wild Hanford Reach fall Chinook salmon were released just 24-h after tagging, they were not afforded the time to exhibit the tag or tagging effect prior to release. Thus, survival of the wild Hanford Reach group was likely underestimated in reaches located near the release site if they exhibited a tag or tagging effect similar to that experienced by the PRH group.

Reach survival of wild Hanford Reach fall Chinook salmon, estimated on a per-kilometer basis, was lower in all reaches located between release (rkm 595) and CR422 compared to those located downstream of CR422. We observed relatively low and similar estimates of $S_{km}$ among the three most upstream reaches we studied. As mentioned previously, the presence of a tag or tagging effect may have contributed to relatively low survival of acoustic-tagged wild fall Chinook salmon in the Hanford Reach between release and CR552. However, the potential for predation from piscivorous birds and fishes exists within the Hanford Reach.

Each spring (May and June), the Oregon Department of Fish and Wildlife (ODFW) conducts electrofishing surveys for predators in the Columbia River. The focus of the electrofishing effort is to capture and tag as many pikeminnow as possible for estimation of sport-reward fishery exploitation rates. Therefore, capture priorities have focused on northern pikeminnow with other predators (particularly smallmouth bass, walleye, and channel catfish) sampled less consistently. However, these data provide empirical information of the distribution of piscivorous fish predators in the Columbia River. Electrofishing catches indicate northern pikeminnow and walleye are more abundant in the Hanford Reach than in McNary Reservoir (Peter McHugh, [ODFW], unpublished data; Figure 4.1). Using recoveries of marked fish at the sport reward stations and the Cormack-Jolly-Seber model for open populations (Seber 1982; Hayes et al. 2007), we estimated the annual (2001–2009) population abundance for northern pikeminnow ≥228 mm FL that inhabit the Columbia River between the mouth of the Yakima River and Priest Rapids Dam. Excluding two years that were obvious outliers due to low numbers of recaptures, population abundance averaged 37,392 (SE = 6,843) northern pikeminnow.

Northern pikeminnow have been identified as a major predator of juvenile salmonids in the Columbia River (Poe et al. 1991; Rieman et al. 1991; Vigg et al. 1991; Zimmerman 1999). Poe et al. (1991) and Zimmerman (1999) estimated juvenile salmonids accounted for 67% and >84%, respectively, of northern pikeminnow diets in reservoirs of the Columbia River. Although to a lesser extent, these same studies also identified walleye as a predator of juvenile salmonids. For example, Poe et al. (1991) found juvenile salmonids made up 14% of the diet of walleye. The presence of these predators has the potential to reduce survival of upriver bright fall Chinook salmon juveniles migrating through the lower Hanford Reach.

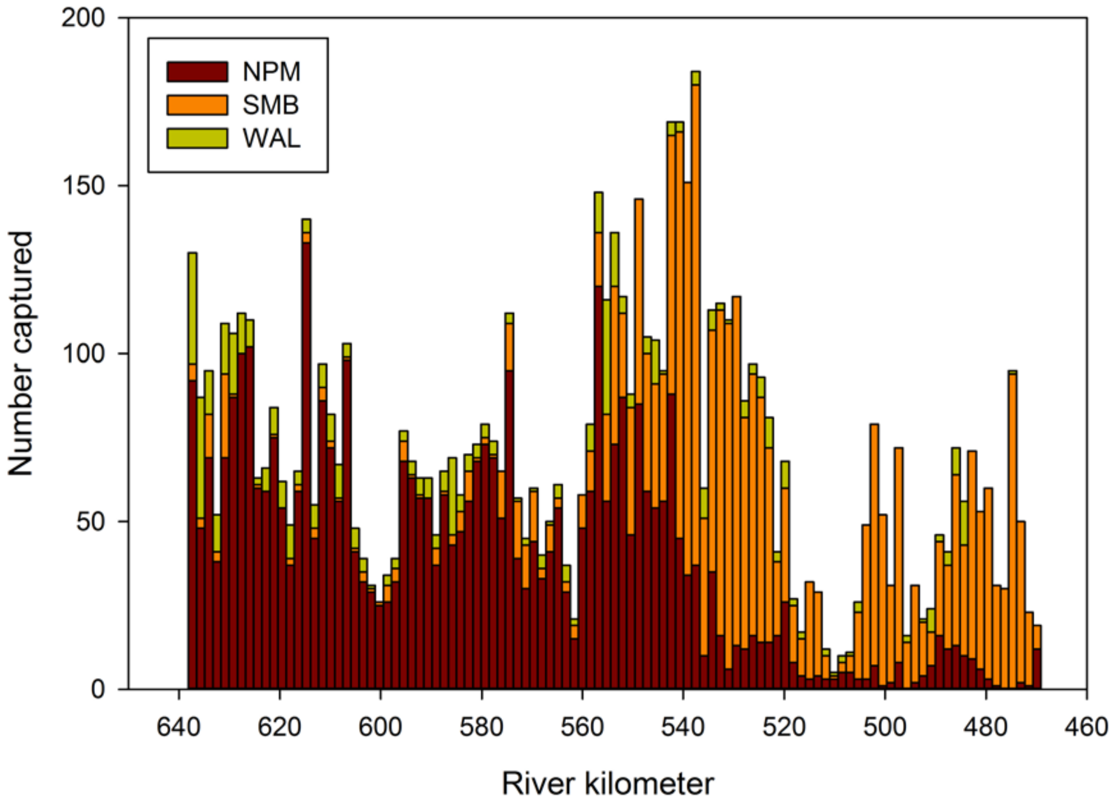


**Figure 4.1**. Total numbers of northern pikeminnow (NPM), smallmouth bass (SMB), and walleye (WAL) captured during Oregon Department of Fish and Wildlife electrofishing surveys conducted annually from 1993–2010 between McNary and Priest Rapids dams.

Upriver bright fall Chinook salmon are also susceptible to predation from Caspian terns *Hydroprogne caspia* that nest on Goose Island on Potholes Reservoir, which is located about 33 km north-northeast of the Hanford Reach. GPS-tagged terns from this colony have been recorded making foraging trips to the Hanford Reach. Avian predation rates, estimated as the proportion of PIT tags recovered (i.e., detected by mobile PIT antennas) on Goose Island that were previously detected by the PIT array at Rock Island Dam, averaged 0.2% for this colony on upper Columbia River summer/fall Chinook salmon between 2009–2012 (Roby et al. 2013). In 2014, the nesting colony consisted of 340 breeding pairs (Bird Research Northwest 2014).

Acoustic-tagged wild Hanford Reach fall Chinook salmon also experienced relatively low survival in the reach located between CR552 and CR524. Results from ODFW electrofishing surveys reveal an abundance of both northern pikeminnow and smallmouth bass within this reach (Figure 4.1). This reach contains the mouth of the Yakima River, which has been identified as a major spawning tributary for Columbia River smallmouth bass. From 1998 to 2001, Fritts and Pearsons (2004) observed an increase in the abundance of smallmouth bass >150 mm in the Yakima River from an annual average of about 3,000 bass in mid-March to almost 20,000 bass in mid-June. The authors attributed the increase primarily to immigration of fish from the Columbia River and estimated that an average of just over 200,000 salmonids, most of which were fall Chinook salmon, were consumed annually by smallmouth bass in the Yakima River during the spring. It is likely that high rates of smallmouth bass predation on fall Chinook salmon occur in the Columbia River during this time as well. A study conducted by Tabor et al. (1993) in a 6-km stretch of the Columbia River near Richland, WA found juvenile salmonids, primarily subyearling fall Chinook salmon, made up 59% of smallmouth bass diet by weight. The authors attributed the high predation rates to the abundance of subyearling fall Chinook salmon juveniles of suitable forage size emigrating from the Hanford Reach and the overlap of habitats of the two species. Others have identified the vulnerability of wild subyearling fall Chinook salmon juveniles to predation by smallmouth bass due to habitat overlap in low velocity nearshore areas (Curet 1993) and the small size of wild fall Chinook salmon juveniles at the time of emigration (Zimmerman 1999).

Although difficult to quantify, the Yakima River also seems to contain a rather sizeable population of channel catfish, which appear capable of consuming large numbers of juvenile salmonids (Pearsons et al. 2001). A naturally reproducing population of channel catfish also inhabits the Columbia River where they have been found to consume large numbers of juvenile salmonids (Poe et al. 1991). The presence of large populations of predatory fish, combined with the reduction in water particle travel rate as the river transitions from free-flowing to reservoir-influenced, makes juvenile fall Chinook salmon vulnerable to predation within this reach (CR552 to CR524).

The risk of avian predation in this reach (CR552 to CR524) remains relatively unknown. Large nesting colonies of California gulls *Larus californicus* and ring-billed gulls *Larus delawarensis* inhabit Island 20 near the town of Richland, Washington at rkm 545 (Figure 2.1). In 2014, 12,500 nesting gulls were observed on the island (Bird Research Northwest 2014), which has only ever been partially scanned for PIT tags (Roby et al. 2013). Thus, reliable predation rate estimates do not exist for these colonies. However, diet analyses of gulls from colonies located upstream of McNary Dam indicated these birds consume very small amounts of salmonids (Roby et al. 2013).

The next downstream reach, CR524 to CR498, contains the mouth of the Snake River, a large backwater slough, several islands that host colonies of piscivorous birds, and the mouth of the Walla Walla River. The ODFW electrofishing survey data indicate the abundance of northern pikeminnow and walleye are relatively low in this reach. However, walleye are frequently the target of recreational fishers in this section of the Columbia River, suggesting they are present. Electrofishing catches indicate a rather sizeable smallmouth bass population is present in this reach as well (Figure 3.18). In addition, the Snake and Walla Walla rivers are two of the few rivers in Washington that contain naturally reproducing populations of channel catfish (Lower Columbia Fish Recovery Board 2004). Thus, there is no shortage of piscivorous fishes in this reach of the Columbia River that may contribute to the below-average survival estimate we observed for acoustic-tagged wild Hanford Reach fall Chinook salmon.

As mentioned, the reach located between CR524 and CR498 is also home to several nesting colonies of piscivorous waterbirds. These include populations of double-crested cormorants *Phalacrocorax auritus* on Foundation Island, American white pelicans *Pelecanus erythrorhynchos* on Badger Island, and California gulls, ring-billed gulls, and Caspian terns on Crescent Island (Evans et al. 2012). Bird Research Northwest conducted waterbird surveys of the islands during the spring and summer of 2014 and counted 390 nesting pairs of double-crested cormorants on Foundation Island, 273 American white pelicans on Badger Island, and 395 nesting pairs of Caspian terns and 6,200 California gulls on Crescent

Island (Bird Research Northwest 2013). Several other bird species, including great blue herons, great egrets *Ardea alba*, black-crowned night-herons *Nycticorax nycticorax*, and ring-billed gulls, were frequently observed on the islands in relatively small numbers.

The outmigration timing of upriver bright fall Chinook salmon coincides with the chick rearing period (May and June) for the majority of birds on these colonies. Thus, juvenile fall Chinook salmon from the Hanford Reach are migrating through this reach during the period of highest energy demand for these predatory birds. Roby et al. (2012) found salmonids accounted for almost 70% of tern prey items at the Crescent Island colony over a 12-year period between 2000 and 2011, representing an average of about 500,000 salmonids consumed annually. However, this estimate includes steelhead, coho, sockeye, spring Chinook, and Snake River fall Chinook in addition to URB fall Chinook salmon. During the period of URB fall Chinook salmon outmigration, salmonids, which would be primarily fall Chinook salmon at this time, still make up about 60–70% of the Crescent Island tern diet (Roby et al. 2013). We observed a negative relationship between survival to McNary Dam as estimated for PIT-tagged wild Hanford Reach fall Chinook salmon and the number of Caspian tern breeding pairs counted on colonies of the Columbia Plateau (primarily Crescent and Goose islands; Figure 4.2). However, the relationship was not significant ($p = 0.210$; $R^2 = 0.248$) but should continue to be evaluated into the future to determine whether a significant trend develops. It is unlikely cormorants of the Foundation Island colony substantially affect survival rates of URB fall Chinook salmon in McNary Reservoir. Roby et al. (2013) found salmonids accounted for only 10% of the prey biomass in the diet of Foundation Island cormorants during the outmigration period of URB fall Chinook salmon juveniles.

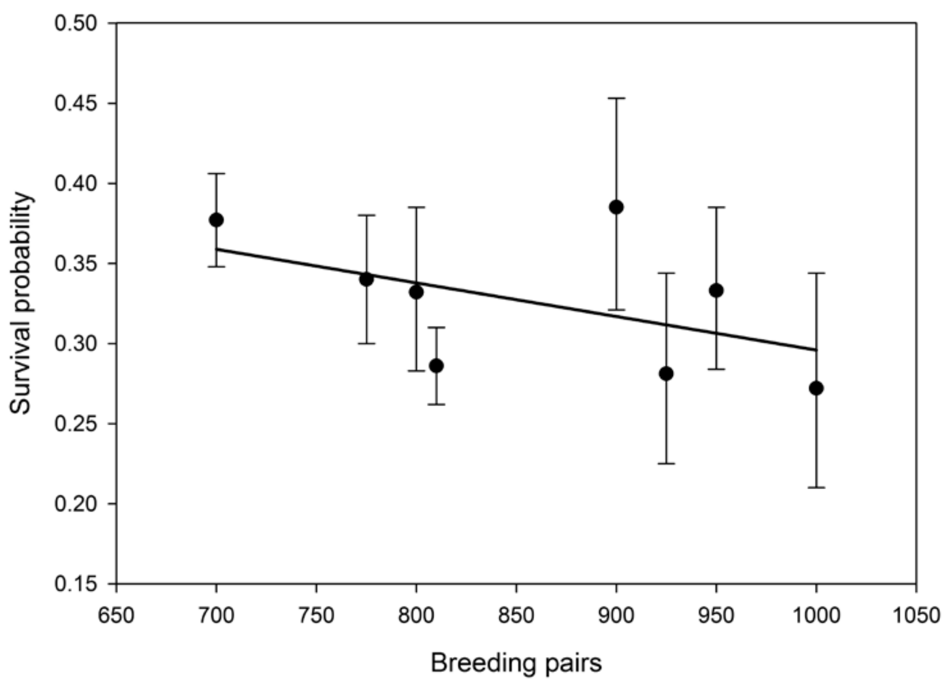


**Figure 4.2**. Relationship between annual survival probability of PIT-tagged wild Hanford Reach fall Chinook salmon and the number of Caspian tern breeding pairs counted on colonies of the Columbia Plateau (2005, 2007–2013). Error bars denote standard errors.

Although the estimated number of smolts consumed by the Crescent Island tern colony is relatively large, it may not represent a significant percentage of the population of salmonid smolts that migrate past the island. Avian predation rates, estimated as the proportion of tags recovered (i.e., detected by mobile PIT antennas) on the islands that were previously detected by PIT arrays at upstream dams, have been consistently low for subyearling fall Chinook salmon juveniles at these colonies. In a study to estimate avian predation rates on Endangered Species Act-listed salmonid evolutionary significant units of the Columbia River basin between 2007 and 2010, Evans et al. (2012) found that all colonies in this reach combined to consume an annual average of 1.6% of the Snake River fall Chinook salmon that were last detected at Lower Monumental Dam. Although this should be viewed as a minimum estimate due to the large distance between the colonies and Lower Monumental Dam (76 km) and uncertainty regarding the off-colony deposition of tags (Roby et al. 2013), it indicates the actual predation rate on juvenile Snake River fall Chinook salmon may be quite low. We would expect the predation rate of URB fall Chinook salmon to be similarly low.

The reaches with the lowest $S_{km}$ estimates were those located near McNary Dam, with the lowest being observed in the immediate forebay. An evaluation of predation by resident piscivorous fish on juvenile salmonids between McNary and John Day dams revealed predation was most intense in areas near the dams (Poe et al. 1988). The authors attributed this finding to the delay and disorientation of salmonids associated with dam passage and the increased densities of piscivorous fish species in slack water areas near dams. Indeed, we observed the slowest travel rates of acoustic-tagged fish in reaches of McNary Reservoir, indicating their migration was slowed by presence of the dam, thereby subjecting them to predation for a longer period of time. Electrofishing catches indicate the forebay of McNary Dam may contain a rather sizeable smallmouth bass population (Figure 4.1).

In addition to attracting predaceous fishes, feeding aggregations of piscivorous waterbirds are also frequently observed near dams of the Columbia River. In addition to terns and cormorants, even gulls find success preying on salmonid smolts near dams of the Snake and Columbia rivers. Low survival of acoustic-tagged juvenile salmonids in the tailrace of McNary Dam in 2012 was attributed to high rates of avian predation by ring-billed gulls (Hughes et al. 2013). Juvenile salmonids, disoriented after dam passage, are particularly susceptible to avian predation in the immediate tailrace of FCRPS dams (Williams 2006). For example, gull predation rates of 6% and 11% were observed in the tailrace of The Dalles Dam for radio-tagged subyearling and yearling Chinook salmon, respectively (Collis et al. 2002). High rates of avian predation at FCRPS dams has led to bird hazing and installation of wires stretched across the river to discourage birds from entering the tailrace.

The tailrace of McNary Dam has also been identified as an area of high salmonid predation by piscivorous fish. Poe et al. (1991) found that about 80% of northern pikeminnow and 60% of channel catfish diets (by weight) were composed of juvenile salmonids in the immediate tailrace of McNary Dam. Salmonids made up a smaller percentage of the diets of walleye (~15%) and smallmouth bass (<5%) in McNary tailrace. Rieman et al. (1991) estimated an average of 2.7 million juvenile salmonids were lost annually (for the period 1983–1986) to predation by piscivorous fish (northern pikeminnow, walleye, smallmouth bass) between McNary and John Day dams, which represented about 9% to 19% of all salmonids that entered the reach. Much of the loss (21%) was estimated to have occurred in the immediate tailrace of McNary Dam where northern pikeminnow and channel catfish were abundant (Poe et al. 1991; Rieman et al. 1991). Thus, the reported estimates would likely have been higher had predation by channel catfish been included. Of the species that were included, northern pikeminnow accounted for 78% of the total salmonid loss, walleyes accounted for 13%, and smallmouth bass for 9%. However, the contribution of walleyes and smallmouth bass to the total mortality increased in July and August when mortality rates were highest and the majority of salmonids consumed were subyearling fall Chinook salmon.

Although Rieman et al. (1991) observed very high predation rates in the immediate tailrace of McNary Dam, predation in the main body of John Day Reservoir represented the majority (79%) of the total salmonid loss to piscivorous fish. The authors observed relatively low consumption rates by northern pikeminnow in the main body of the reservoir but emphasized the effect a low consumption rate can have when the abundance of predators is high, as appears to be the case in John Day Reservoir. Rieman et al. (1991) estimated there to be 85,000 northern pikeminnow and 10,000 walleyes >250 mm and 35,000 smallmouth bass >200 mm in the reservoir.

We observed low survival of acoustic-tagged wild Hanford Reach fall Chinook salmon between CR449 and CR422. This reach contains Paterson Slough on the Washington shore, McCormack Slough on the Oregon shore, a backwater area near Crow Butte, and many miles of heavily rip-rapped shorelines. The three embayments (Paterson, McCormack, and Crow Butte), which cover about 1,700 acres (U.S. Army Corps of Engineers 1995), have been identified as flow refugia and potential spawning areas for nonnative piscivorous fish species (Nigro et al. 1985). Smallmouth bass and walleye are frequently targeted by anglers in the area around Paterson Slough, McCormack Slough, and the Blalock Islands, suggesting increased densities of these predators in those areas.

In addition to providing habitat to nonnative predaceous fishes, several islands in this reach, including the Blalock Islands, are home to nesting colonies of multiple avian predators, including California and ring-billed gulls and Caspian and Forster’s terns. Surveys conducted by Bird Research Northwest during the spring and summer of 2014, revealed colonies of 199 terns (both Caspian and Forster’s terns) and 4,630 gulls (both California and ring-billed) on the island complex (Bird Research Northwest 2014). Other birds, such as great egrets, black-crowned night-herons, great blue herons, and American white pelicans were also observed on the island in smaller numbers. Minimum predation rates of Blalock Island-nesting terns on Snake River fall Chinook salmon have been historically quite low, averaging <0.1% from 2007–2010 (Evans et al. 2012). Again, we would expect the predation rate on URB fall Chinook salmon to be similarly low. Predation rates from the Blalock Island complex gull colonies have not been estimated to our knowledge.

Relative survival ($S_{\mathrm{km}}$) was high for acoustic-tagged wild Hanford Reach fall Chinook salmon from CR422 down to John Day Dam (CR349) before dipping slightly in the reaches that included passage through John Day and The Dalles dams and their tailraces (CR349 to CR325 and CR311 to CR275). The reach between CR349 and CR325 is home to a nesting colony of California gulls on Miller Rocks Island that numbered 3,100 individuals in 2014 (Bird Research Northwest 2014). Evans et al. (2012) estimated the average annual minimum predation rate of the Miller Rocks Island gulls to be 0.4% of the Snake River fall Chinook salmon that passed McNary Dam. The rate is likely similarly low for URB fall Chinook salmon juveniles.

Much of the mortality in the tailraces may be attributed to predation by resident fish, which is known to be a substantial source of mortality in dam tailraces and outfall locations (Lower Columbia River Fish Recovery Board 2004). The tailrace of John Day Dam has been identified as an area with relatively high densities of walleye (Porter 2009). The Dalles Dam tailrace has a complex basin with a series of downriver islands where predators reside, is relatively shallow with armored bedrock substrate, has an adjacent slough-like habitat on the south side of the river, and riprap-lined banks. Petersen et al. (2001) found relatively high numbers of smallmouth bass compared to northern pikeminnow in The Dalles Dam tailrace. The authors estimated 1,000 to 2,000 smallmouth bass were present in the immediate tailrace of The Dalles Dam, although this estimate was based on relatively few marked and recaptured fish.

Acoustic-tagged fall Chinook salmon from PRH survived at a higher rate than the wild group in most reaches, particularly those located upstream of McNary Dam. The lower survival of wild Hanford Reach fall Chinook salmon upstream of McNary Dam may have been a result of a tagging effect. As mentioned previously, the group of acoustic-tagged PRH fish suffered high mortality, likely as a result of a tagging effect during the two-week period between tagging and release. The wild group was released 24 hours after tagging and therefore suffered any potential tagging effect in-river. Trends in $S_{km}$ were generally similar between groups of acoustic-tagged wild Hanford Reach and PRH fall Chinook salmon. The primary differences included higher $S_{km}$ rates for PRH fish in the forebay of McNary Dam between CR498 and CR472 and lower $S_{km}$ for PRH fish in the immediate forebay of John Day Dam.

Data from this study and others indicate much of the mortality incurred by URB fall Chinook salmon juveniles between Priest Rapids and Bonneville dams can likely be attributed to predation from resident piscivorous fish. We observed no significant relationship between the survival of PIT-tagged wild Hanford Reach fall Chinook salmon to McNary Dam and the size of the primary avian predator nesting colonies located in McNary Reservoir. We also did not observe mortality “hot spots” in the reaches of the Columbia River that contain the largest colonies of predaceous waterbirds. Instead, we observed relatively consistent mortality rates between release and CR422, which is more indicative of predation from piscivorous fish, which are more widely distributed than avian predators. Additionally, it is likely we “missed” much of the predation by piscivorous fish (thereby overestimating reach survivals) due to the relatively large size of fish we were able to implant with acoustic transmitters. Avian predators, on the other hand, appear to target larger individuals, as evidenced by their high predation rates on steelhead smolts (Collis et al. 2001; Antolos et al. 2005); thus, it is unlikely we would have “missed” any mortality “hot spots” due to avian predation. In addition, results of studies conducted to assess avian predation rates have consistently estimated very low predation rates on subyearling fall Chinook salmon upstream of Bonneville Dam (<2%; Evans et al. 2012; Roby et al. 2013). Alternatively, predation rates estimated for piscivorous fish suggest they may be consuming 17% of the juvenile salmon that enter John Day Reservoir during June, July, and August, when most salmon smolts entering the reservoir are subyearling fall Chinook salmon (Rieman et al. 1991). Harnish et al. (2013) estimated about 43 million URB fall Chinook salmon presmolts were produced annually in the Hanford Reach between BY 1984–2004. Assuming a survival probability of 0.37 to McNary Dam (as estimated from annual releases of PIT-only wild URB fall Chinook salmon in the Hanford Reach), about 16 million Hanford Reach URB juveniles enter John Day Reservoir annually. Thus, if piscivorous fish consume 17% of the population, an estimated 2.7 million URB fall Chinook salmon juveniles would be consumed annually in John Day

Reservoir. If predation rates are of similar magnitude in other reservoirs, predation by resident piscivorous fish is clearly an important source of mortality.

The high rate of salmonid smolt predation observed by Rieman et al. (1991) for resident piscivorous fish in John Day Reservoir led to development of the Northern Pikeminnow Management Program (NPMP) in 1990–1991. The NPMP consists of a “sport-reward” fishery, which offers public anglers a monetary incentive to catch northern pikeminnow, and “dam-angling”, whereby agency personnel are hired to angle for northern pikeminnow at FCRPS dams. The program was founded on modeling simulations that indicated a 10–20% exploitation rate on predator-sized northern pikeminnow would reduce predation on juvenile salmonids by 50% (Rieman and Beamesderfer 1990). The program has appeared effective at reducing the abundance of northern pikeminnow. The catch-per-unit-effort and abundance index data have shown a continued and persistent decrease in the number of northern pikeminnow ≥250 mm in the Snake and Columbia rivers since the NPMP was implemented (Gardner et al. 2013; Barr et al. 2014).

Removal of northern pikeminnow will only improve survival of migrating juvenile salmonids if a compensatory response by other predatory fishes does not offset the net benefit of removal. Although an increase in the proportion of smallmouth bass diets containing juvenile salmonids has not been observed from smallmouth bass captured annually during electrofishing and dam-angling efforts of the NPMP, smallmouth bass abundance and predation index values have increased in recent years in some areas of Snake and Columbia river reservoirs (Gardner et al. 2013; Barr et al. 2014). As noted by Carey et al. (2011), smallmouth bass have become a large component of the fish community of the Snake and Columbia rivers, largely due to the habitat created by human modifications (e.g., dams) of the landscape. Juvenile salmonids continue to be a common item in the diets of Columbia River walleyes, which have also shown an increase in abundance index in areas of John Day and The Dalles reservoirs (Gardner et al. 2013). Increases in the abundance index of these predators may be an early indication of a compensatory response to the removal of northern pikeminnow from the system (Gardner et al. 2013; Barr et al. 2014).

If indeed a compensatory response develops, the NPMP may need to be expanded to include other predatory species, such as smallmouth bass and walleye to achieve the same benefit to salmonid survival. Whereas smallmouth bass and walleye represent a potential significant threat to the survival of salmonid smolts in the Snake and Columbia rivers, options to manage these species are complicated because fisheries agencies are simultaneously charged with enhancing fishing opportunities and controlling predators of threatened and endangered salmon (Carey et al. 2011). However, if salmon survival and conservation is to be prioritized, there is a clear need to identify and test potential management options aimed at reducing predation from resident piscivorous fishes.

Altering dam operations is another potential management option that has been used successfully in the past to improve survival of smolts through the FCRPS. For example, increases in the amount and percentage of water that is routed through the spillways at dams has been attributed to increased survival of salmonid smolts in the Snake and Columbia rivers (e.g., Adams et al. 2012). It may be possible to manage reservoir levels in such a way as to disrupt the spawning activities or recruitment success of predaceous fish species. Several studies have demonstrated that fluctuations in discharge can negatively affect the reproductive success of smallmouth bass by flooding nests with cooler water, depositing silt, driving away adult bass guarding nests, exposing eggs to desiccation, or stranding emerged fry (Henderson and Foster 1957; Becker et al. 1981; Lukas and Orth 1995). A study of factors that influence smallmouth bass production in the Hanford Reach indicated fluctuations in discharge from Priest Rapids Dam reduced productivity (Montgomery et al. 1980). In order to be successful, disruptions to spawning activities would need to occur throughout the major spawning areas for sufficient duration over multiple years to cause year-class failures. Major spawning areas would need to be identified and a feasibility study would be required to assess whether the operational flexibility exists at dams of the Columbia River to implement the operations necessary to create the desired disruptions.

Our study confirmed that the loss rates of juvenile URB fall Chinook salmon from the Hanford Reach were high in areas where habitat has been influenced by hydropower development and native and non-native predatory fish species. Whereas our study had some limitations due to 1) the size of fish we were able to tag, 2) the potential for a tag or tagging effect on fish performance, and 3) possible tag loss, we believe that the relative loss rates are representative for the wild Hanford Reach and Priest Rapids Hatchery portions of the URB stock. Most of the loss appears to be concentrated in the river/reservoir transition area where large predator-rich tributaries enter as well as in the immediate dam forebays where travel rates of outmigrating smolts are slowed. Additional work to document how the predation rates we observed in the larger size classes of juvenile URB fall Chinook salmon relate to the overall population, as well as efforts to determine the potential effectiveness of management actions intended to reduce the populations and/or productivity of piscivorous fish species will provide the information necessary to enable managers to design and implement strategies to improve the freshwater survival of this important stock.

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