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

John R. Skalski and Richard L. Townsend
Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington, 1325 4th Ave, Suite 1820, Seattle, WA 98101, USA

Final Report

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For copies of this document, please contact:

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

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Abstract

Public Utility District No. 2 of Grant County, Washington, owns and operates two hydropower projects on the mid-Columbia River, Wanapum and Priest Rapids dams. Both developments (dam and reservoir) strive to meet a performance standard of 93% survival for downstream migrant juvenile steelhead. Juvenile steelhead survival estimation has been completed on an annual basis at both developments since 2006 but performance standards have only been met at the Wanapum Development in 2008 and 2009. Survival standards for steelhead have not been achieved at the Priest Rapids Development. While survival through Priest Rapids Dam has been high, we believe the majority of steelhead losses have occurred in the Priest Rapids Reservoir due to piscivorous fish and bird activity. This study was designed to measure the single-release survival of downstream migrant juvenile steelhead and to determine where losses from predators occurred throughout the Priest Rapids Reservoir. A total of 53 JSATS receivers were deployed in cross-river arrays at one-mile increments between Wanapum and Priest Rapids dams. Receivers were also deployed in the forebay of each dam and downstream of Priest Rapids Dam. Nearly two hundred predatory fish (northern pikeminnow, walleye, and smallmouth bass) were captured, tagged with Lotek acoustic tags, and released into the Reservoir in April 2011. Acoustic tags were surgically implanted into 1,032 juvenile steelhead smolts randomly selected from run-of-the-river fish; smolts were gatewell dipped, tagged, and released upstream of Wanapum Dam in 18 unique release groups, one release per day, starting on May 8, 2011. The origin of test fish was estimated to be 78% hatchery-reared and 22% wild. Array detection efficiencies were highly variable (range 13-97%), depending on the number of receivers and the hydraulic conditions at each array which varied seasonally. The 2011 steelhead survival through the Priest Rapids Development was estimated at 97%, which is 7% higher than the highest survival rate in the last five years, though survival in previous years was measured using alternative techniques and across various hydrological conditions. High river flows likely contributed to high reach by reach survival rates as river flows were twice the 10-year average (300 kcfs in 2011, 150 kcfs 10-year average). High river flows contributed to faster steelhead travel time through the Reservoir (40% faster in 2011 than the 2006-2010 average) and reduced the exposure time of smolts to piscivorous predators. There is some evidence that increased flows, with

Correspondence: Mark Timko +1.509.858.3141 (mtimko@blueleafenviro.com)

consequently increased total dissolved gas, may have contributed to a decrease in Reservoir survival of fish released in late May. Additionally, steelhead losses that did occur (3%) were in loosely defined hot-spots, or areas of recorded predation events and/or high concentrations of acoustic-tagged predators, that overlapped with the movement of tagged predators, particularly northern pikeminnow. These hot-spots included the tailrace of Wanapum Dam, the entrance to Crab Creek, and the Reservoir immediately upstream of the Priest Rapids Dam forebay. Additional losses from avian predation were confirmed by the recovery of paired PIT tags at nesting colonies on the Columbia River Plateau (Potholes Reservoir) and mid-Columbia basin (Crescent Island, near McNary Dam). Though this study was designed to identify zones of migratory steelhead loss between Wanapum and Priest Rapids dams, the measured losses were fewer than expected. However, we were able to directly measure predation events by northern pikeminnow on migrating smolts and identify in-river hot-spots of predation.

Introduction

It is widely recognized that cross-river dams act as impediments to downstream migrating juvenile salmonids and upstream migrating adult salmonids, which has had varying impacts on salmonid survival (Raymond 1979; Budy et al. 2002; McClure et al. 2003; Williams 2008). In response to survival concerns, federal regulators have established performance standards that hydropower facilities throughout the Columbia and Snake River basins strive to meet. Performance standards for the Priest Rapids Project (joint Wanapum and Priest Rapids dams and reservoirs, hereafter referred to as the Project) were established for Public Utility District No. 2 of Grant County, Washington (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 Endangered Species Act and are required under the 2006 Priest Rapids Project Salmon and Steelhead Settlement Agreement (SSSA) (Grant PUD 2006). The requirements of both documents, the BiOp and SSSA, were incorporated into the Federal Energy Regulatory Commission's (FERC) license that was issued to Grant PUD for the operation of the Project on April 17, 2008 (FERC 2008).

Survival standards are defined for Wanapum and Priest Rapids dams as 95% at each dam, 93% through each development (dam and reservoir), and 86.5% through the Project. To achieve these standards, Grant PUD has aggressively worked to improve the downstream passage of juvenile salmonids over that past decade with new turbines, bypass structures, and altered dam operations during the spring and summer out-migrations. Grant PUD has also researched, monitored, and sought to facilitate changes in environmental conditions that would likely increase smolt survival throughout the Project. In addition to water quality monitoring, these projects have included a northern pikeminnow (*Ptychocheilus oregonensis*) removal program, avian predator hazing, installation of avian deterrents (bird wires) below each dam, avian predation monitoring at known colonies of piscivorous birds on the Columbia River Plateau, and predation studies on piscivorous fish species including northern pikeminnow, walleye (*Sander vitreus*), and smallmouth bass (*Micropterus dolomieu).*

To measure the survival of downstream migrant juvenile steelhead (*Oncorhynchus mykiss*) throughout the Project, Grant PUD has conducted annual survival studies between 2006 and 2010 in which classic mark-recapture acoustic telemetry techniques were used. In each year, paired smolt releases (treatment and control groups) were introduced into the tailraces of successive dams and investigated, with the exception of 2007 studies. In 2007, three single-release groups of steelhead, distinguished by their collection source, tagging location, and tagging surgeon were studied (Robichaud et al. 2005; Sullivan et al. 2008; Timko et al. 2007a, 2007b, 2010, 2011). Survival estimates were calculated based on the detection of fish at downstream arrays, detection probabilities, tag-life expectancy, and other factors. In five years of juvenile steelhead survival studies, Grant PUD has not reached overall Project survival requirements, or Priest Rapids Development survival, though due to study execution issues, 2006 and 2007 survival numbers likely underestimate true survival. In two of the five years studied, Grant PUD met Wanapum Development survival standards (2008 and 2009). However, Grant PUD has regularly met concrete survival standards at each dam: Wanapum Dam in 2008-2010; and Priest Rapids Dam in 2007, and 2009-2010 (Timko et al. 2011). In short, Grant PUD is meeting survival requirements at each dam, but struggling to achieve performance standards within each reservoir (Figure 1).

In this report, we present the findings of an acoustic telemetry study that was designed to define and better understand the in-river steelhead mortalities that have been observed in preceding survival studies. The 2011 study differed from past steelhead performance studies which were designed to measure survival over the entire Project. The 2011 study focused on defining zones of fish mortality between Wanapum and Priest Rapids dams using Juvenile Salmon Acoustic Telemetry Systems (JSATS) technology. In addition to juvenile steelhead being tagged and released upstream of the Wanapum forebay, three species of piscivorous fishes (northern pikeminnow, walleye, and smallmouth bass) were tagged and released into the Priest Rapids Reservoir (hereafter referred to as the Reservoir). Single release survival estimates were calculated at each zone for steelhead, as well as predator residence time and movement with correlated smolt-predator interactions.

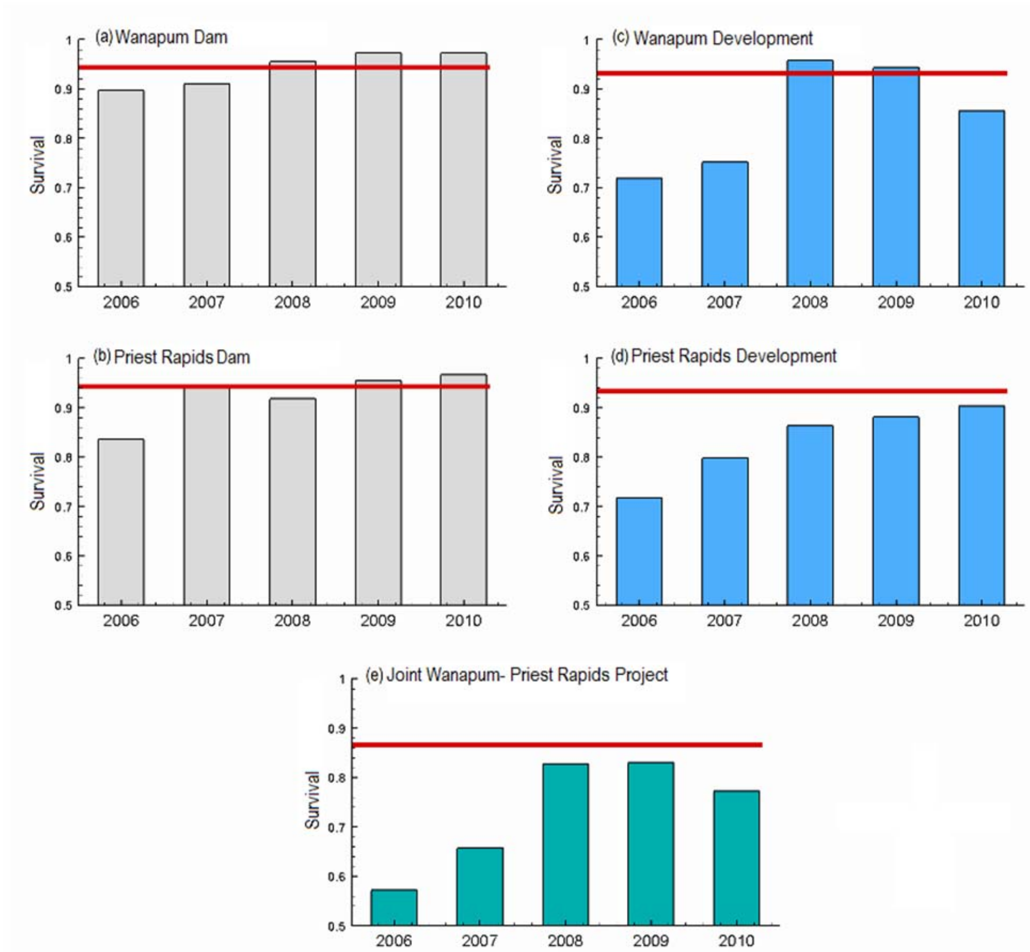


Figure 1. Steelhead concrete (dam) survival is presented in (a) and (b) for Wanapum and Priest Rapids dams with a corresponding survival target line of 95%. Steelhead survival per development (dam and reservoir) is presented in (c) and (d) with a corresponding target survival (93%) presented as a red line. Joint Wanapum-Priest Project steelhead survival is also presented with a survival target of 86.5% in (e). *Note that 2006 and 2007 survival estimates displayed were not used for performance standards testing due to study design issues, and likely underestimate true survival.*

Methods

Acoustic Tags

Juvenile steelhead were surgically implanted with a Lotek *Model L-AMT-2.1* JSATS acoustic micro-transmitters (5.1 x 11.8 mm, 0.43 g in air) and a Destron Fearing FishID *Model SST-1* PIT tags (2.04 x 12.34 mm, 0.10 g in air). PIT tags were implanted along with the micro acoustic tags to identify avian predation events through PIT tag detection at piscivorous bird colonies and to record downstream PIT tag detections after acoustic tag battery expiration. Tag lots were received from the manufacturer prior to the start of, and throughout the study. Additional replacement tags were received weekly to compensate for failed tags.

To avoid potential effects of variability in the quality of manufactured tag lots, tag-life test tags were randomly sampled from each shipment and pre-assigned to tag life release groups prior to tag activation. The remaining tags were randomized and selected for surgical implantation into study fish. As replacement tags were received during the study, they were randomized into the remaining pool of tags.

Study Design and Fish Releases

To identify areas of juvenile steelhead loss to predation, the Reservoir (Reservoir defined from the tailrace of Wanapum Dam to the forebay of Priest Rapids Dam), was monitored with 53 acoustic receivers (50 Teknologic Autonomous Data-logging Receivers, and three Lotek WHS4000 Wireless Receivers, hereafter 'receivers') to detect and record movement of JSATS-tagged steelhead smolts and resident piscivorous fish (Figure 2).

Receivers at in-river arrays were distributed perpendicular to the thalweg, at approximately one mile intervals along the total length of the Reservoir, which was nearly 19 miles.

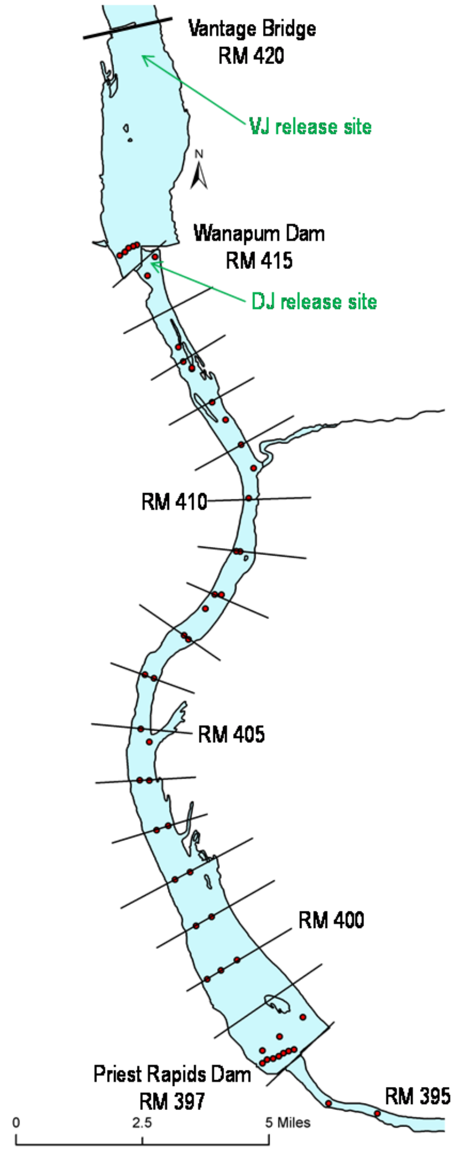


Figure 2. The Columbia River study area between Wanapum and Priest Rapids dams, illustrates in-river JSATS arrays (bars) and individual receivers (dots) at each river mile. Release location for VJ and DJ release groups are indicated (VJ = live acoustic-tagged steelhead by helicopter, DJ = dead acoustic-tagged steelhead by truck and transport at the Wanapum Fish Bypass).

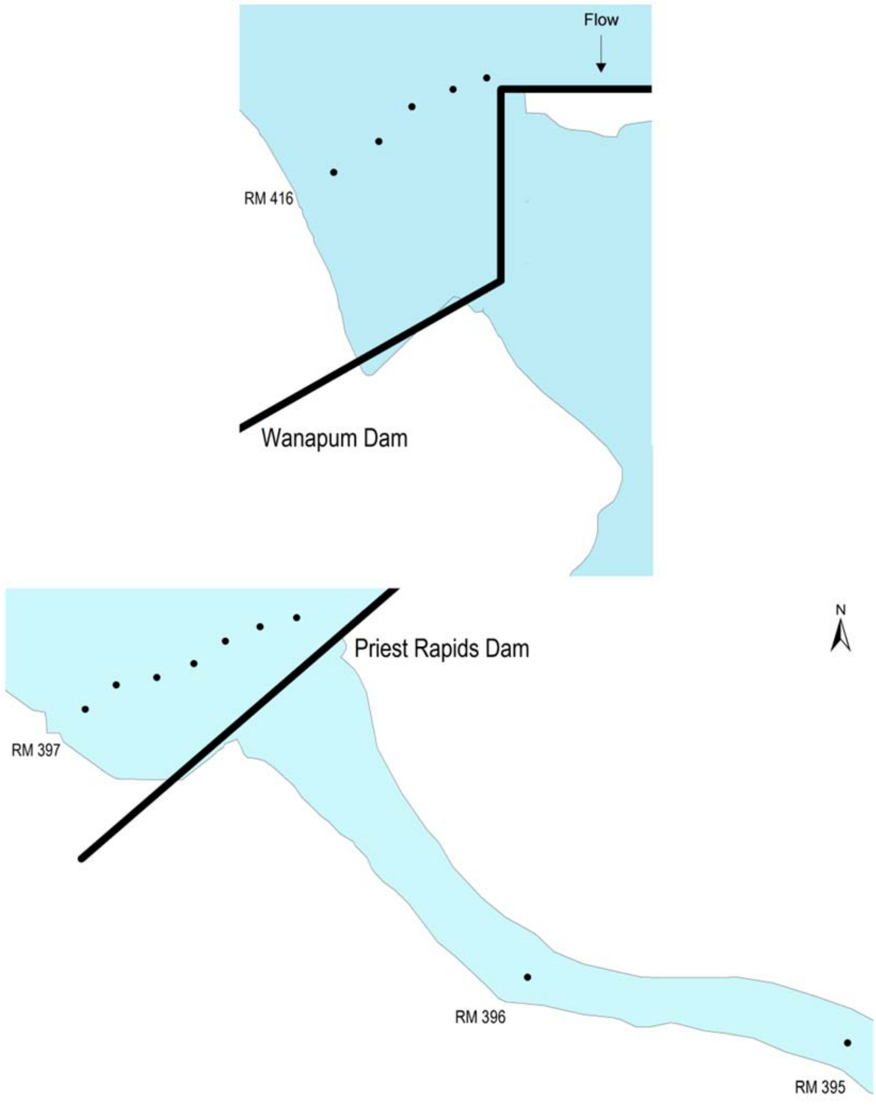


Figure 3. Deployment positions of acoustic receivers at the Wanapum Dam forebay Boat Restricted Zone (BRZ; RM 416, upper figure), the Priest Rapids Dam forebay BRZ (RM 397, lower figure), and the Priest Rapids Dam tailrace (RM 396, RM 395).

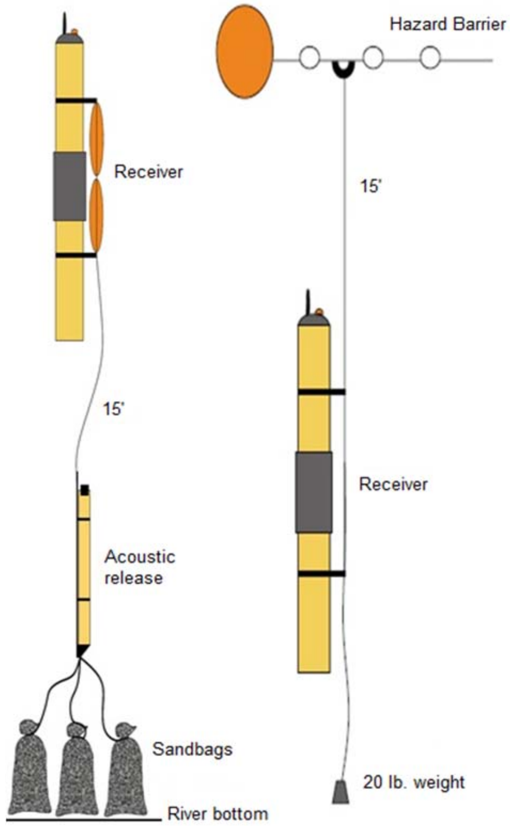


Figure 4. Deployment schematic of in-river JSATS receivers fixed to the river bottom (left) with three sandbags (40 lb. each, 120 lb. total). Receivers were tethered to the release-anchor assembly with 15' of 3/8" aircraft cable. Receivers attached to the hazard barrier of the BRZ at Wanapum and Priest Rapids dams (right) 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 were also deployed spanning the forebay of both Wanapum and Priest Rapids dams along the boat restricted zone (BRZ) barrier (Figure 3). Additional receivers were placed at areas of particular interest and suspected high predator activity such as the mouth of Crab Creek at RM 410. Finally, two receivers were placed in the tailrace of Priest Rapids Dam as a "system exit" array at RM 396 and RM 395.

Acoustic receivers at in-river arrays were deployed from a research boat by davit arm and were anchored to the river bottom with sand-filled biodegradable burlap sacks and burlap line. 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) (Figure 4). Acoustic releases were controlled by a surface command unit that allowed range measurement from the deployed release unit and remote sonic-mechanical release of the anchor system. Acoustic receivers in the forebays of each dam were suspended at overlapping detection range intervals from the hazard barrier, or BRZ, positioned between shock-absorbing tethers and large weights (Figure 4).

Run-of-the-river steelhead smolts were collected from the wheel gate slots (vertical still-water wells that run from the ceiling of each turbine intake to the intake deck of the dam) at Wanapum and Priest Rapids dams by means of lowering a specialized net into the slot; fish were entrained upon removal of the net. Smolts were deposited into a tank equipped with oxygen, then transported by truck to the west bank of Wanapum Dam to the fish processing facility for sorting and pre-surgery holding. After a 24 hour holding period, fish were anesthetized in MS-222, surgically implanted with transmitters (Appendix A), and held for an additional 24 hours to ensure post-surgery survival. The cumulative holding time for all smolts was 48 hours.

Live acoustic-tagged juvenile steelhead were released by helicopter in the Wanapum Reservoir approximately 0.5 km downstream of the I-90 Vantage Bridge (Vantage, Washington) at RM 419.7 (hereafter referred to as RM 420). Similar to the methods of Timko et al. (2010, 2011), fish were moved into specialized fly tanks supplied with ambient river water one hour prior to release and tags were confirmed operational. Water flow to the fly tanks was stopped 10 minutes 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. 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.

Live fish releases occurred each day at approximately 10:00 AM between May 8-25, 2011 (18 replicates; n=1,032). Release quantities varied to represent a bell curve of the natural migration of run-of-the-river smolts; therefore, more fish were released during the middle of the study compared to the beginning and end. Additionally, a subset of tagged steelhead were euthanized each day; fish were anesthetized, gills were removed, then transported by truck and released at approximately 10:30 AM (18 replicates; n=50) into the outfall of the Wanapum Fish Bypass (WFB). Dead acoustic-tagged juvenile steelhead were released to determine if mortality events that occurred during passage at Wanapum Dam would be detected on acoustic arrays downstream.

Survival Analysis

Survival estimates for out-migrating steelhead smolts between Wanapum and Priest Rapids dams were analyzed on a reach by reach scale by Columbia Basin Research (CBR), School of Aquatic and Fishery Sciences at the University of Washington (Seattle, Washington). Estimates were generated based on acoustic tag detection histories (presence/absence) (Appendix B). Acoustic-tagged smolts were released at a single point, which was replicated by 18 unique releases with an average of 57 fish per release.

The single release-recapture model (Skalski et al. 1998), corrected for the probability of tag failure (Townsend et al. 2006), was used to estimate reach survival per river mile (RM), as well as to compare reach survival and detection probabilities from the forebay of Wanapum Dam through the tailrace of Priest Rapids Dam. Adjustments for dead fish detections were evaluated to determine whether false-positive detections occurred at downstream detection arrays as a result of fish that died during dam passage still having active tags and floating downriver.

The assumptions of the single release-recapture model (Skalski et al. 1998) include the following:

A1. Individuals marked for the study are a representative sample from the population of interest;
A2. Survival and capture probabilities are not affected by tagging or sampling; tagged animals have the same probabilities as untagged animals;
A3. All sampling events are "instantaneous;" sampling occurs over a negligible distance relative to the length of the intervals between sampling events;
A4. The fate of each tagged individual is independent of the fate of all others;
A5. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event;
A6. All tagged individuals alive at a sampling location have the same probability of being detected on that event; and
A7. All tags are correctly identified and the status of smolts (i.e., alive or dead), are correctly assessed.

For the single release-recapture model to be valid, certain data patterns should be evident from the capture histories. For each release group, a series of tests of assumptions were performed to determine the validity of the model (i.e., tested goodness-of-fit of the acoustic-tag data to the release-recapture model, pooling the release-recapture data across the replicates within a season) (Burnham et al. 1987). Similar analytical methods were used by Skalski et al. (2007), in which the effects on survival of three different surgeons were also analyzed.

Survival estimates of steelhead were analyzed for fish passing through: (1) the lower Wanapum Development (the proportion of fish that were detected entering the Wanapum Dam forebay and were detected downstream of the dam); (2) the Priest Rapids Development (the proportion of fish that were detected entering the Priest Rapids Dam forebay and were detected downstream of the dam); (3) the Project (the proportion of fish that entered the Wanapum Dam forebay and were detected downstream of Priest Rapids Dam); (4) small-scale reach survival of 19 unique stretches of river, approximately one-mile increments, between release (RM 420, upstream of the Wanapum Dam forebay), throughout the Reservoir, and downstream of Priest Rapids Dam (RM 396); and (5) refined larger-scale relative reach survival at nine unique stretches of river, approximately three-mile increments, between release (RM 420) and downstream of Priest Rapids Dam (RM 396). It should be noted that relative survival estimates for the Wanapum Development in 2011 did not include the entire Wanapum Reservoir, as fish were released at RM 420.

Downstream cumulative survivorship curves were derived from the reach survival estimates, and tests were performed on a reach-by-reach basis and examined for consistency of patterns. Seasonal trends in survival were explored by pooling release groups by three consecutive release dates. Survival by fish source (hatchery versus wild), was also estimated for reach and cumulative survival.

Fish were omitted from the survival analysis if one of two events occurred: (1) tags were inactive at the time of release, or (2) fish were entrained in gatewells at either dam, recollected by gatewell dipping activities, and either held at the fish sorting facility or released directly downstream. Fish were also censored from the survival analysis data set at subsequent downstream reaches if valid predation events were detected. The definition of valid detections is further described below in the Results Section, *Incomplete Smolt Migrations.*

Predator Collection

Northern pikeminnow, walleye, and smallmouth bass (n=193) were captured throughout the Reservoir using angling, set lines, and electrofishing (Figure 5). Standard electrofishing methods were conducted by Washington Department of Fish and Wildlife (WDFW) personnel using a Smith Root GPP series electrofishing boat. Detailed electrofishing methods can be found in *Statement of Work* between USGS and Grant PUD (2010). A concurrent study was conducted by USGS and WDFW to index predator species in the Priest Rapids Reservoir and to determine via gastric analysis how steelhead survival may be impacted by foraging behavior of these predators. This report is available from USGS (Counihan et al. 2012 *in press*).

All predatory fish captured for the study were transported in water to a surgery station on shore where they were transferred into a solution of MS-222 until equilibrium was lost. Fish were transferred to a surgical table for length and weight measurement, then irrigated with MS-222 solution for the duration of the surgical procedure. Because all three species are encountered by sport anglers, WDFW issued an emergency regulation to stop the retention of fish species associated with the study from April 1, 2011 to May 31, 2011. This served to both deter anglers from potentially removing tagged fish from the river, and to fulfill the requirement that fish treated with MS-222 not be consumed for 21 days. A circular hole punch in the dorsal fin of each fish was used as an additional measure to help anglers identify study fish.

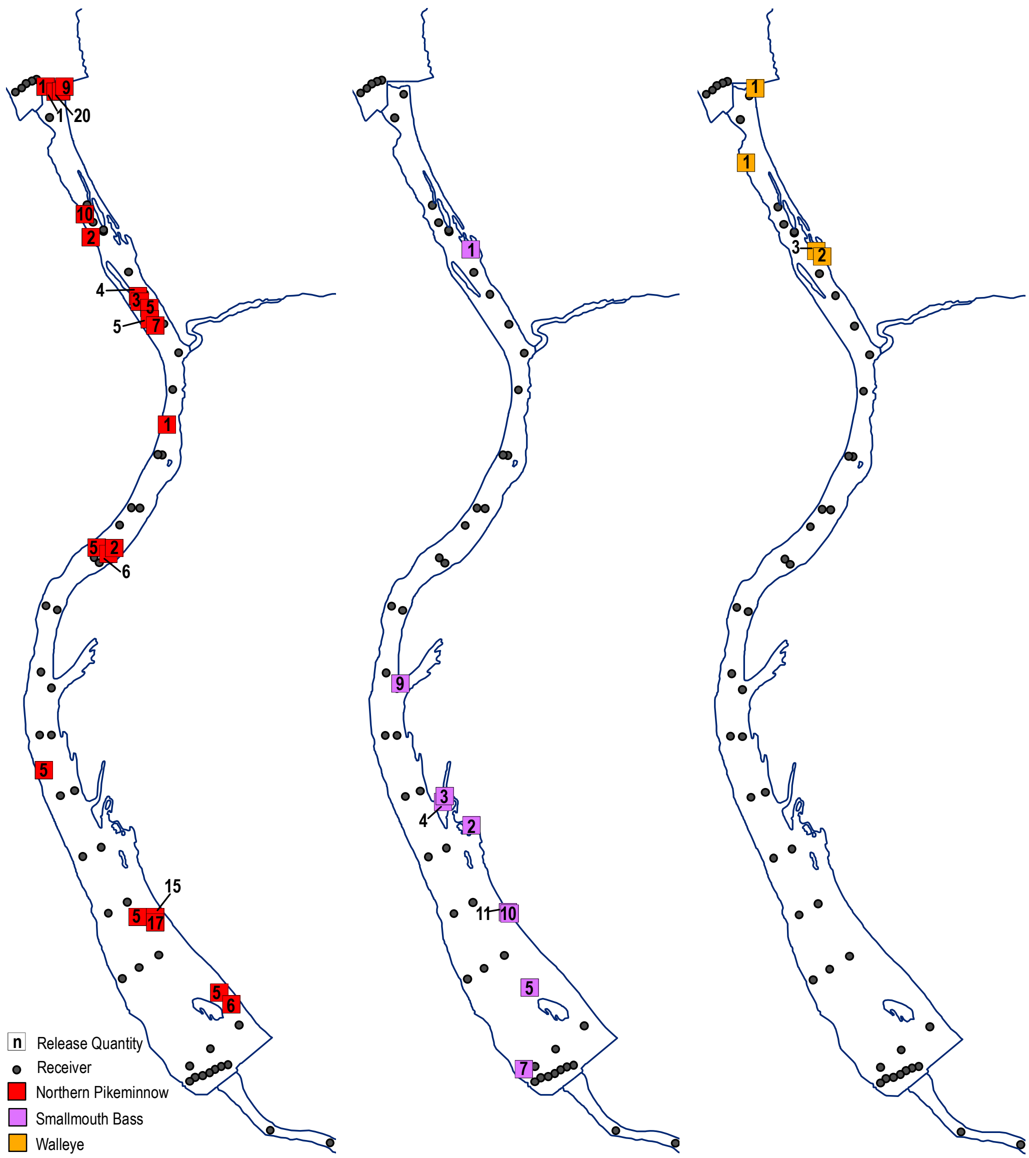


Figure 5. Release locations and quantities of northern pikeminnow (n=134, red), smallmouth bass (n=52, purple), and walleye (n=7, yellow) in the Priest Rapids Reservoir, spring 2011.

Two acoustic transmitters, one HTI *Model 795LM/PIT* and one JSATS Lotek *Model L-AMT 5.1*, were implanted into each predator through incisions made along the mid-ventral line. Incisions were closed using 3/0 sutures. Cutting heads were used on the suture needles for smallmouth bass due to the toughness of their skin. All other sutures used a tapered needle. Fish were held in a recovery bath of fresh river water until equilibrium was regained, then transported back to their original capture location for release. Fish surgeries were conducted by LGL Limited; detailed surgical methods are described in Appendix A.

Predator Behavior

Movement patterns of predators were analyzed using acoustic tag detection histories and GIS spatial analysis tools to investigate interactions of tagged predators with tagged smolts. The range and cumulative distance traveled between arrays was calculated for each tagged predator based on detection histories throughout the JSATS in-river arrays. Range was defined as the maximum distance between two receivers that both detected a fish. Cumulative distance was computed by summing distances between receivers with consecutive detections of a moving fish. Residence time at each array was calculated. Finally, overall movement trends during the study period were summarized for each species.

PIT Tag Recollection at Avian Colonies

An annual investigation of avian predation through PIT tag recovery and/or detection at piscivorous bird colonies on the Columbia River Plateau and mid-Columbia River was conducted as a collaborative effort by NOAA Fisheries, USGS-Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University, and Real Time Research. To further investigate the loss the juvenile steelhead in the Project area, the nesting colonies and species of specific interest to Grant PUD in 2011 were Caspian tern nesting sites on Goose Island (Potholes Reservoir) and Crescent Island (upstream of McNary Dam)(Timko et al. 2010, 2011). Detailed methods of PIT tag recovery and detections are outlined in Evans et al. (2011).

Areas used for nesting by piscivorous birds during the 2011 breeding season were systematically scanned with a PIT tag antenna after birds had left the colony. This process was repeated until the quantity of undetected tags was ≤ 5% of the total number of PIT tags previously detected. Tag detection efficiency was based on the detection of a known number of control PIT tags that were randomly dispersed and sown into nesting areas occupied by birds throughout the breeding season (Roby et al. 2011). The recovered PIT tags were cross-reference with the paired PIT tags released by Grant PUD for further analysis.

JSATS Data Filtering

A JSATS tag transmits a unique code at 416.6 kHz, which is comprised of three parts:

1. 7 bit Barker code (always 1110010);
2. 16 bit hexadecimal tag code; and
3. 8 bit CRC (cyclic redundancy check).

A Teknologic JSATS receiver examines incoming acoustic noise (binary, 1/0) at the JSATS frequency, and attempts to align and invert the incoming 1s and 0s to match the correct JSATS Barker code. When a full 7-bit Barker code is found, the receiver records the following 16 bits of tag code then records the 8 bit CRC. The CRC is used to validate the received transmission and is appended in the form of a 'valid'/'invalid' flag to all recorded tag code detections.

In general, JSATS technology produces large volumes of invalid data due to the presence of acoustic background noise. There is a moderate probability that background noise can 'sound' like a JSATS tag code. To separate

JSATS Filtering Criteria:

1. The tag code must be in the list of 2011 season released tags.
2. The detection date/time must be after the tag release date/time.
3. The tag detection must be before the receiver removal date/time.
4. The detection must have a valid CRC, for Teknologic nodes only.
5. The time between contiguous detections of the same tag code (gap) is a function of the tag frequency. The minimum and maximum allowable gaps were as follows:
   a) Predator (5 sec repetition rate), minimum=5 sec and maximum=60 sec; and
   b) Smolt (3 sec repetition rate), minimum=3 sec and Maximum=36 sec
6. A detection was rejected if the gap between two contiguous detections of the same tag code was less than the minimum time, or greater than the maximum time (for example, a valid detection was '3 detects in 36 sec' for smolt tags).

noise from meaningful detections, a rigorous filtering protocol was adopted and is based on the US Army Corps of Engineers filtering protocols, which has been recently accepted and used by researchers in the Columbia River basin (Skalski et al. 2010a, 2010b).

The raw data were downloaded from each receiver's memory card to a data server primarily using Teknologic software *Autonode*. Data from Lotek receivers were downloaded using Lotek software *WH400 Host*. The Lotek data did not include CRCs and therefore, did not designate detections as valid or invalid. The following criteria were used to filter detections to be used for further analyses. These criteria were designed to minimize the inclusion of false positive data. A sensitivity analysis of survival estimates, specifically criteria number six listed below, was completed by CBR where the minimum of three and four detections were required in the minimum time of 36 sec. It was determined that the criteria used were valid.

Results

Smolt Characteristics

In 2011, a total of 1,082 steelhead smolts were tagged with both a JSATS and a PIT tag. Hatchery reared juvenile steelhead comprised 800 (77.5%) of the total 1,082 steelhead released between May 8 and May 24, 2011, with the remaining 231 (22.4%) being wild (fish without a clipped adipose fin were assumed of wild origin); one fish of unknown origin. All live steelhead (VJ release groups, n=1,032) were released at the Vantage Bridge (Table 1). An additional two to four dead fish (DJ, n=50) were released at the WFB per live release group.

Based on the Rock Island Smolt Index (Columbia DART website), all steelhead tagged in 2011 were released between the 5^{th} and 56^{th} percentile of run-timing. Run timing of juvenile steelhead was difficult to predict in 2011.

Consequently, the subsample of steelhead was captured on the front-end of run-of-the-river steelhead smolt migration compared to previous years. In 2009 and 2010, steelhead were released over a longer period of the downstream migration run-timing; in 2009 between the 4th and 78th percentile; and in 2010, between the 8th and 88th percentile of run-timing (Timko et al. 2010, 2011).

Table 1. The quantities of steelhead that were collected, tagged, and released by release groups during the spring of 2011. VJ are live fish releases 0.5 km downstream of the Vantage Bridge; DJ are dead fish releases into the WFB, Wanapum Fish Bypass.

Steelhead				**Date**		
VJ	**n_{VJ}**	**DJ**	**n_{DJ}**	**Collection**	**Surgery**	**Release**
VJ01	50	DJ01	2	6-May	7-May	8-May
VJ02	54	DJ02	2	7-May	8-May	9-May
VJ03	56	DJ03	2	8-May	9-May	10-May
VJ04	56	DJ04	2	9-May	10-May	11-May
VJ05	57	DJ05	3	10-May	11-May	12-May
VJ06	59	DJ06	3	11-May	12-May	13-May
VJ07	59	DJ07	3	12-May	13-May	14-May
VJ08	61	DJ08	4	13-May	14-May	15-May
VJ09	65	DJ09	4	14-May	15-May	16-May
VJ10	66	DJ10	4	15-May	16-May	17-May
VJ11	60	DJ11	4	16-May	17-May	18-May
VJ12	60	DJ12	3	17-May	18-May	19-May
VJ13	59	DJ13	3	18-May	19-May	20-May
VJ14	58	DJ14	3	19-May	20-May	21-May
VJ15	57	DJ15	2	20-May	21-May	22-May
VJ16	55	DJ16	2	21-May	22-May	23-May
VJ17	51	DJ17	2	22-May	23-May	24-May
VJ18	49	DJ18	2	23-May	24-May	25-May
∑ VJ	**1032**	**∑ DJ**	**50**	**Total fish released:**		**1082**

Length and weight of steelhead smolts released in 2011 were normally distributed over time. Steelhead fork length ranged from 125-225 mm (mean length 190 mm) and weight ranged from 21.0-89.0 g (mean weight 64.5 g) (Figure 6). There was no significant difference in length or weight between release groups (one-way ANOVA; n=1,032, p<0.001). Tag burden, defined as the ratio of tag weight to total fish mass, was calculated for all released steelhead. The average tag burden for steelhead smolts in 2011 was 0.9% (range 0.5-2.4%). The tag burden for steelhead smolts in 2011 was slightly lower than in the past five years of survival studies. For comparison, in 2009 and 2010, the tag burden of steelhead was 2.6% and 1.2% respectively (Timko et al. 2011).

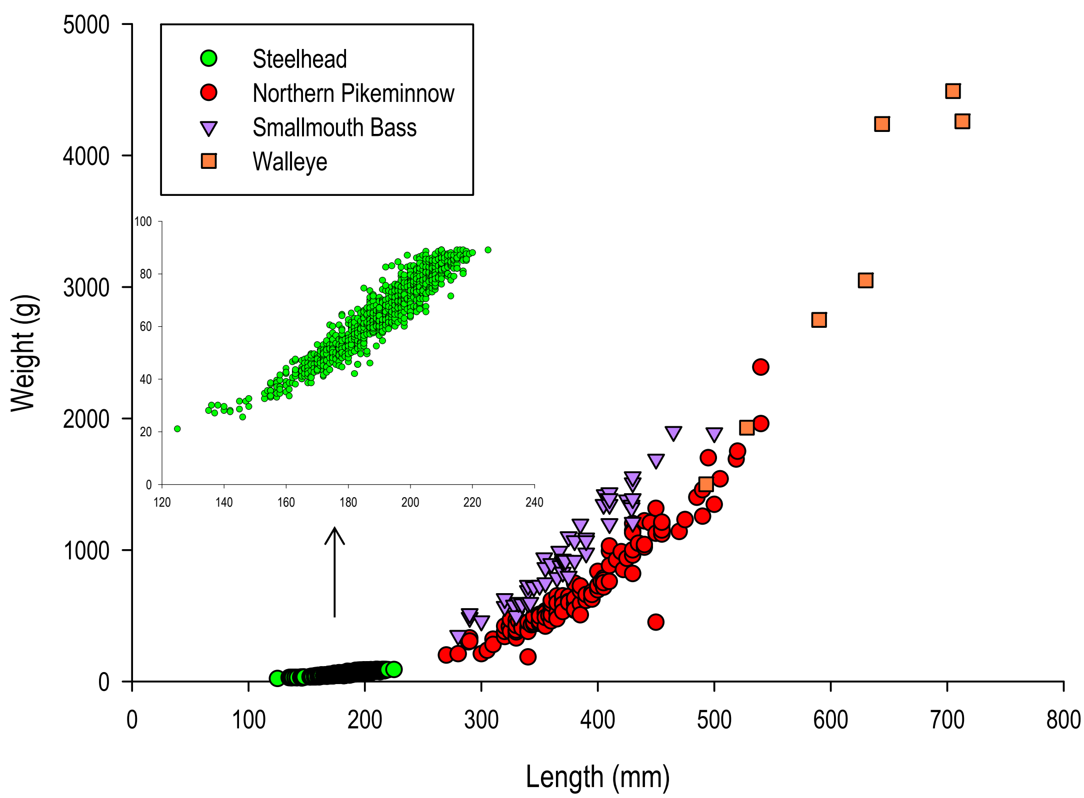


Figure 6. Size distribution of tagged steelhead (n=1,032, green circles and inset), northern pikeminnow (n=134, red circles), smallmouth bass (n=52, purple triangles), and walleye (n=7, orange squares) that were released for 2011 survival/predation analysis. Steelhead were measured at fork length, and predators were measured at total length.

Survival Analysis

Detailed results are described in Appendix B.

Reach Designation. The detection arrays were originally deployed one river mile apart to identify smolt and predator behavior; however, in some areas additional receivers were deployed at half-mile increments. The single release-recapture model assumed that all mortality occurred between, and not at, detection sites. In typical survival studies, this assumption has been satisfied by establishing larger reaches (i.e., 8-10 miles) (Timko et al. 2010, 2011). The detection range of receivers was underestimated and detection widths at each in-river array were less than one-mile, because many receivers were detecting fish within 0.3 river miles upstream and downstream of their position. The combination of these high detection probabilities which overlapped detection widths in some arrays, and mortality events occurring at, not within detection sites (i.e., Crab Creek, RM 410), resulted in unreliable survival estimates using the release-recapture model in one-mile increments. CBR found that mortality events could not be assigned correctly within reaches, violating the assumption of independent events between arrays (Appendix B).

In order to identify the smallest spacing between receivers where assumptions would not be violated, the JSATS data was re-analyzed by CBR using alternative array spacing: (a) the original array spacing (one-mile); (b) every other array (two-mile); and (c) every third array (three-mile), etc. was analyzed to estimate reach survivals. Two criteria were used in selecting the optimal array spacing: (1) individual reach survival should have survival estimates of equal to or less than 1.0, and the cumulative survivorship curve should be monotonically decreasing, and (2), the product of the individual survivals should closely approximate the overall survival estimate obtained using the last two detection arrays in the survival analysis (Appendix B). For the purposes of the estimating reach survivals using the release-recapture model (Skalski et al. 1998), the proper spacing chosen by CBR for further analysis was in three-mile increments (Figure 7).

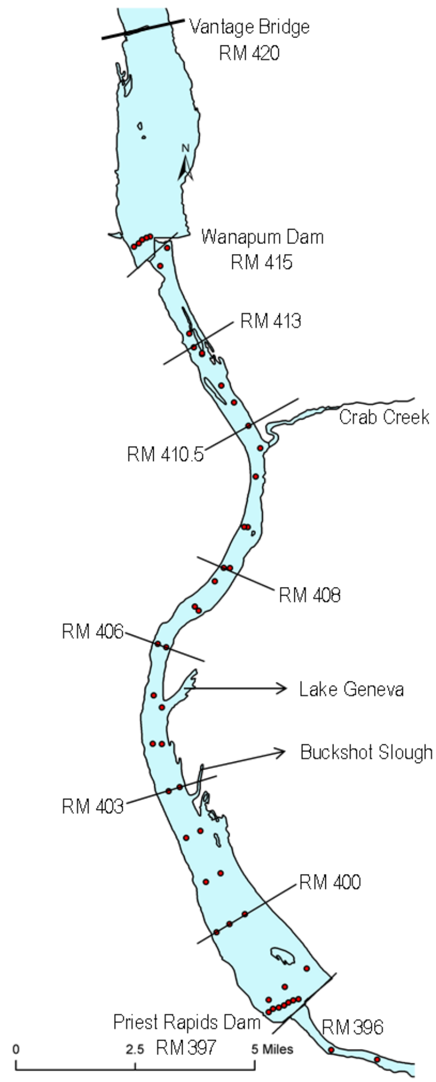


Figure 7. Detection arrays selected for survival release-recapture model by Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington.

Dead Fish Released. The analysis of dead fish released at the WFB with acoustic tags resulted in 20 out of 50 tags being detected at the first array downstream of Wanapum Dam, located within the immediate tailrace (RM 415). Dead fish were not detected at any additional acoustic array. Furthermore, dead fish were not detected at any downstream PIT tag array; the PTAGIS website was queried. Because of the altered array spacing for survival analysis, and strategic array reselection for the final analysis, no adjustments to the survival data set were required.

Tag-Life Test. The average tag life expectancy was 23.4 d. All study fish had passed through the last array at RM 395 before the first tag failure in the tag-life study had occurred. Therefore, no tag-life corrections were required in the analysis of 2011 JSATS acoustic tag data. Further tag-life test details are shown in Appendix B.

Tagger and Tag-Lot Effects. Three different surgeons were employed to tag all fish in the JSATS study. Tagger effects were examined and no apparent effects were found that could have negatively impacted the study (Appendix B). A total of eight different tag lots were used during the course of the study. Examination of the reach survivals by tag lot found none to be significantly different within a reach. All tag lots were used in the survival analysis (Appendix B).

Survival Trends. Pooling the recapture histories for the 18 replicate releases resulted in an overall survival probability of 0.9661 (SE=0.0057) from release to the Wanapum Dam forebay (Table 2). Survival through Wanapum Dam was estimated at 0.9816 (SE=0.0046). Survival through Priest Rapids Dam was estimated to be 0.9987 (SE=0.0190). Survival between each three-mile reach from RM 413 to the Priest Rapids forebay at RM 397 ranged from 0.9901-0.9993 (SE ranged from 0.0011-0.0043) with an overall survival estimate of 0.9675 (SE=0.0078) through the majority of the Reservoir (Wanapum Dam tailrace excluded). The overall survival from release to downstream of Priest Rapids Dam (RM 396) was estimated to be 0.9163 (SE=0.0194). This estimate includes survival through both dams and the Reservoir. The cumulative survivorship curve illustrates the drop in survival from initial release to the forebay of Wanapum Dam (RM 416), another drop in survival through Wanapum Dam at RM 413, and then a shallow rate of decline in survival within the Reservoir between RM 413 and Priest Rapids Dam (Figure 8).

Pairwise comparisons of reach survival and of reach survival rates (survival by river mile) indicated the same pattern. Reach survival through the initial reach (i.e., release to the forebay of Wanapum Dam at RM 416) was significantly lower than all other reaches. As might be expected, the next lowest survival occurred during smolt passage through Wanapum Dam (RM 416-413). Beyond these two differences, reach survival pairwise comparisons of the reach between RM 408-406 were significantly different from three distinct reaches that included: RM 406-403 (reach included Lake Geneva), RM 410.5-408 (reach included Crab Creek); and RM 403-400 (reach included Buckshot Slough) (Appendix B). When survival rates were analyzed by river mile, the survival in the reach between RM 406-403 was not significantly different. These tag losses are explored in the behavior analysis below.

Seasonal Trends and Fish Source. Three consecutive days of releases were pooled in order to compare survival trends across the season. The resulting six release groups were separately analyzed to estimate reach survivals and cumulative survivorship curves (Figure 9). Although significant differences in survival were difficult to establish, cumulative survivals became significant starting at RM 410.5 and remained so until almost the end of the study area (RM 397). Examination of the data indicates that survivals were homogeneous for the first five groups (i.e., releases that occurred between May 8-22, 2011), but dropped significantly in the last three days of the study (i.e., releases that occurred between May 23-25, 2011). Additional details for the estimates of reach and cumulative survival after pooling the data for seasonal analysis, including p-values associated with the *F*-test of homogeneous survivals across the season, are presented in Appendix B.

Finally, run-of-the-river steelhead smolts tagged in the study included both hatchery and wild fish, which were pooled across the study for reach survival estimates and cumulative survivals. Survivals from release to the first detection site (RM 416) where fish were detected entering the Wanapum Dam forebay was significantly different between hatchery and wild stocks ($p \leq 0.0917$). Wild steelhead had lower survival in the initial reach than hatchery fish; no other individual reaches were significantly different between stocks. Cumulative survivals for wild steelhead lagged behind that of hatchery steelhead through the entire study area; however, cumulative survivals were only significant from release to RM 410.5 ($p \leq 0.07$) (Appendix B).

Table 2. Reach survival estimates, standard errors, and detection probabilities based on the original 23-array design and the 10-array reconfigured design are listed. Results were provided by Columbia Basin Research (CBR) (Appendix B).

Original Arrays				**Reduced Arrays**			
Array	$\hat{S}$	SE $(\hat{S})$	$\hat{p}$	Array	$\hat{S}$	SE $(\hat{S})$	$\hat{p}$
Release – 416	0.9661	0.0057	0.9918	Release –416	0.9661	0.0057	0.9918
416 –415	1.0258	0.0169	0.1361				
415–413.5	0.9556	0.0177	0.3618	416–413	0.9816	0.0046	0.6825
413.5–413	1.001	0.0007	0.6829				
413–412	0.9969	0.0022	0.371				
412–411.5	1	0	0.5539	413–410.5	0.9974	0.0028	0.7234
411.5– 411	1	0	0.0677				
411–410.5	1.0004	0.0004	0.7238				
410.5–410	1.0021	0.0023	0.542				
410–409	0.9922	0.0039	0.8225	410.5–408	0.9928	0.0033	0.9531
409–408	1	0	0.9522	*includes Crab Creek RM 410			
408–407.5	1	0	0.1796				
407.5–407	1.0002	0.0002	0.9084	408–406	0.9993	0.0011	0.9346
407–406	0.998	0.0017	0.9348				
406–405	0.9955	0.0023	0.9443				
405–404	0.9989	0.0011	0.9775	406–403	0.994	0.0028	0.9403
404–403	0.9991	0.0011	0.9409	*includes Lk Geneva RM 405, Buckshot RM 403			
403–402	0.9978	0.0021	0.7829				
402–401	0.9966	0.0029	0.7199	403–400	0.9901	0.0042	0.6328
401–400	0.9944	0.0035	0.634				
400–398.5	0.9965	0.0031	0.6689	400-397	0.9935	0.0043	0.9712
398.5–397	0.9989	0.0029	0.9712				
397–396	0.9987	0.019	0.6121	397-396	0.9987	0.019	0.6121

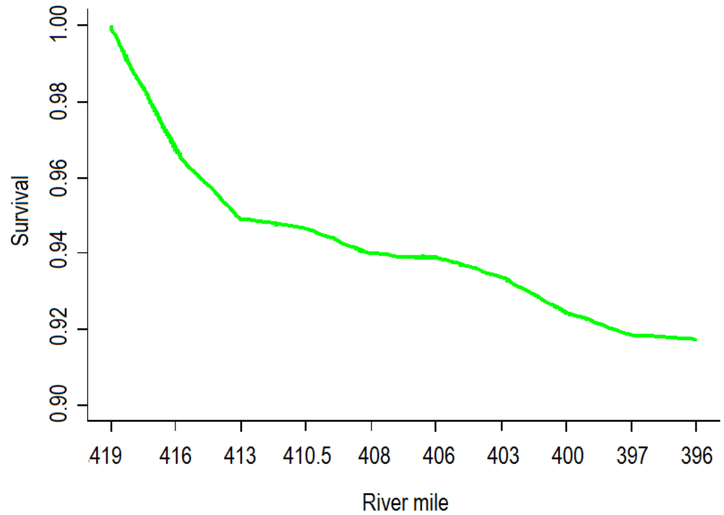


Figure 8. Cumulative survivorship curve for steelhead smolts between release (RM 419.7) and RM 396 between May 8-25, 2011 (Appendix B).

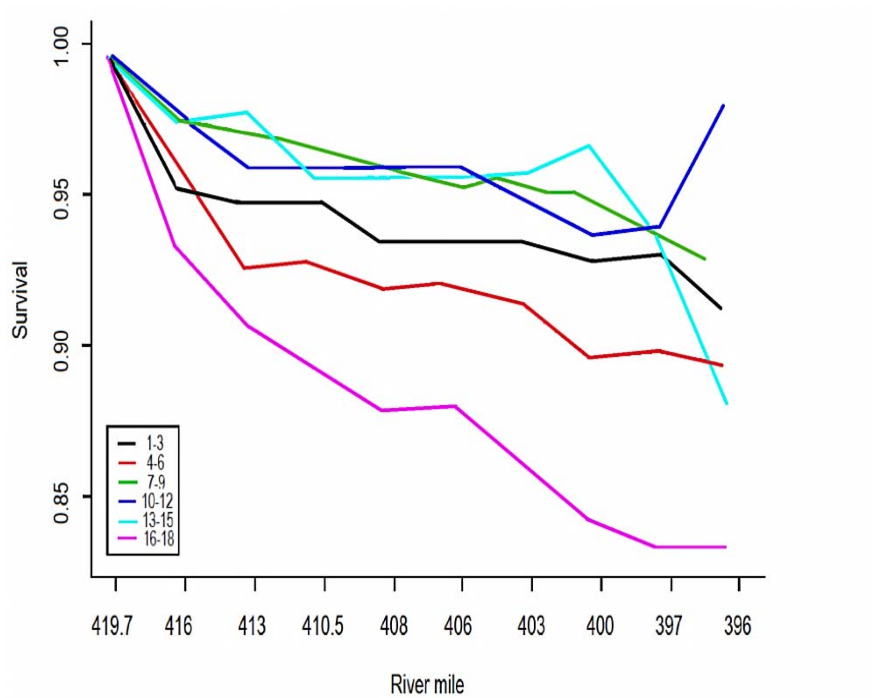


Figure 9. Cumulative survivorship curves for tri-daily pooled releases across the duration of the study area (Appendix B).

Environmental Conditions

Flow. The spring of 2011 was an atypical water year on the mid-Columbia River during the steelhead smolt migration, with abnormally high water levels and discharge conditions at both dams. Environmental conditions including river flow, total dissolved gas (TDG), and temperature were monitored downstream of Wanapum and Priest Rapids dams from April 1-June 15, 2011. Detailed conditions allowing comparison with previous years, and 10-year average conditions were provided by the Columbia River DART website and are shown in Figure 10.

Flow at both dams was comparable to previous years (2008-2010) at the beginning of the 2011 season. However, in mid- May, flow conditions surpassed previous years and abnormally high tailrace elevations for Wanapum (500 ft above mean sea level) and Priest Rapids (420 ft above mean sea level) dams were recorded in addition to above average flow velocities.

While flow levels throughout the season were greater than previous years, conditions in the river were not considered extreme until May 20 when the total outflow below Wanapum Dam doubled the ten-year average high water level.

Temperature. Water temperatures in 2011 were slightly cooler than previous years (Appendix C), and were consistently below the 10-year average. Temperatures in the Wanapum tailrace ranged from 8.7-10.9°C over the course of the study with a daily median of 9.7°C (Figure 9).

Total Dissolved Gas. The total dissolved gas in the tailrace of Wanapum Dam was at, or below the 10 year average when median daily TDG was 110.4% saturation (May 1-9, 2011). The period from May 10-19 was marked by an increase in median daily TDG to 115.7 % saturation, which was slightly (but not significantly) above the en-year average. Beginning May 20, 2011, TDG daily medians jumped to 128.1% saturation and remained high through the end of the period of steelhead smolt releases (May 25, 2011) above Wanapum Dam. These increases in TDG are concurrent with extreme flows at both Wanapum and Priest Rapids dams, though the TDG levels at Priest Rapids were slightly lower than Wanapum (median daily TDG was 111.6% May 1-8; 118.6% May 10-19; and 124.3% May 20-25, 2011)(Figure 10).

Thus, in addition to experiencing extreme flow conditions, steelhead smolts released between May 20-25, 2011 also experienced considerably higher TDG below Wanapum and Priest Rapids dams than those released earlier in the season. This difference is correlated with the depression of survival performance in steelhead smolts released during this period of extreme environmental conditions. However, a stepwise multiple regression found negligible significance for the effect of TDG and total flow in explaining variance in steelhead survival performance over the season (R squared=0.56, p value for model inclusion was 0.21 for TDG; .30 for total outflow). This indicates that other variables, such as exposure to predation risk, may have been more important factors in 2011 steelhead survival performance.

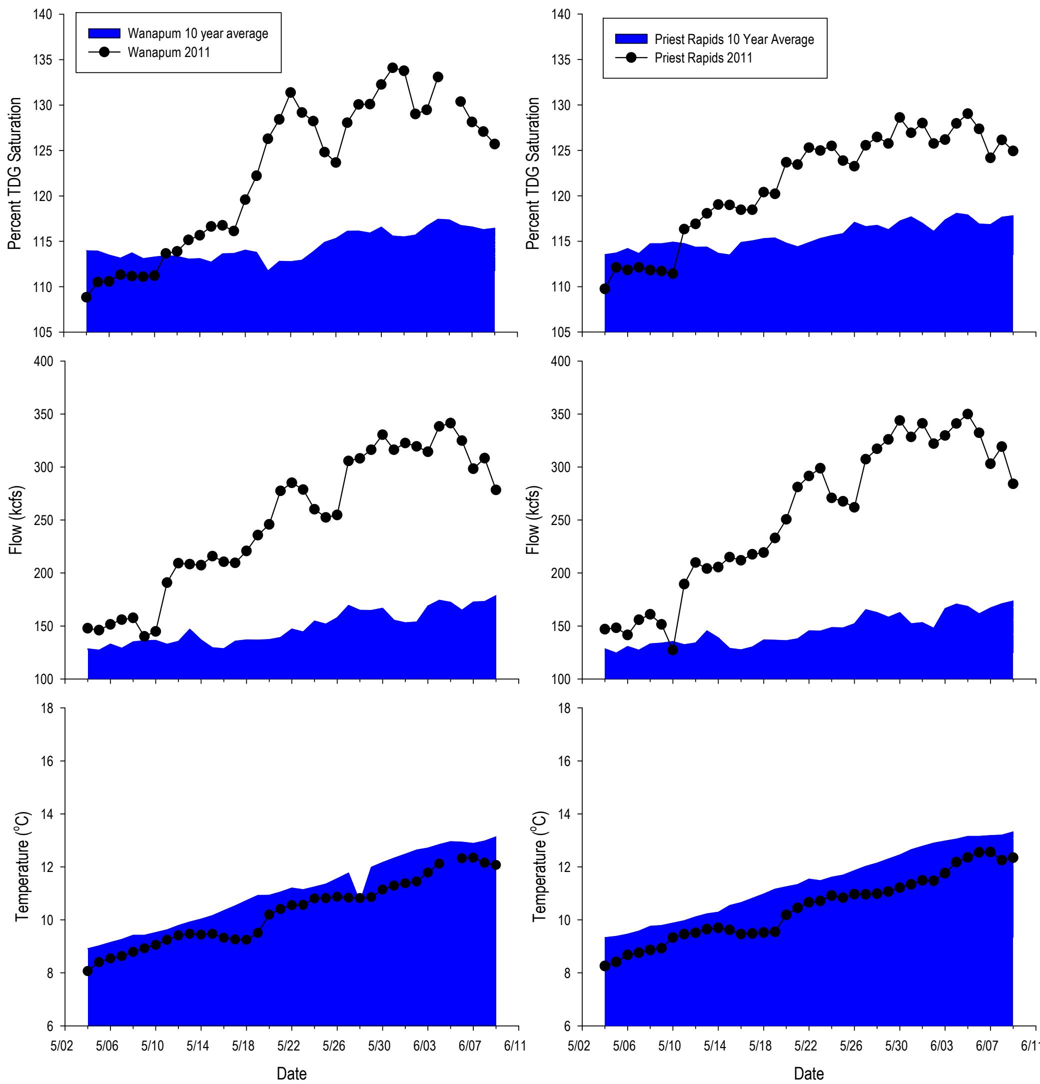


Figure 10. Daily median water quality values downstream of Wanapum and Priest Rapids dams are shown from May 4-June 9 2011, along with the 10 year average which is depicted in blue. Unconnected points note where data were not available (data source: <www.cbr.washington.edu/dart/dart.html>).

JSATS Detection Array

Deployment. A total of 53 JSATS receivers were deployed from April 1-5, 2011. A total of 51 receivers were recovered from the Project area June 1-10, 2011. Of the two receivers deployed in high velocity current at RM 414, one was never recovered and the other was recovered approximately six miles downstream near Mattawa, Washington, thus, the RM 414 array was removed from all analyses. Additionally, one receiver that was initially deployed at RM 409 broke free and drifted over the Priest Rapids spillway and was destroyed, leaving a detection coverage gap at RM 409.

The remaining 50 receivers were queried for system performance, data storage, and battery life following acoustic release retrieval. Over the 45 days of the 2011 deployment, all receivers maintained sufficient battery voltage and there were no power failures. No receivers exhibited internal system performance issues. Data storage ranged from 20-99% of the total 2 GB capacity of each receiver (Appendix D).

The in-river detection arrays collected a total of 694,628,533 raw data points. Filtering to remove invalid data and to isolate valid '3 detections in 36 seconds' detections, yielded a valid data set of 1,455,952 data points. Generally, receivers deployed in fast water had lower detection frequencies than those deployed in slow water (Appendix D). This was due in part to variable detection threshold, which is a top-side controlled parameter on Teknologic receivers that allows assessment of ambient noise and manipulation of the threshold of tag amplitude required for recognition of detection.

Tagged steelhead smolts were detected on an average of 14 out of the 18 cross-thalweg detection arrays. The mean quantity of arrays where each release group was detected decreased over time from 16.5 (release VJ01 on May 8, 2011) to 11.9 (release VJ18 on May 25, 2011) as water level and flow velocity increased. Additionally, the mean number of individual receivers where smolt tags detected decreased from 21.0 (release VJ01 on May 8,

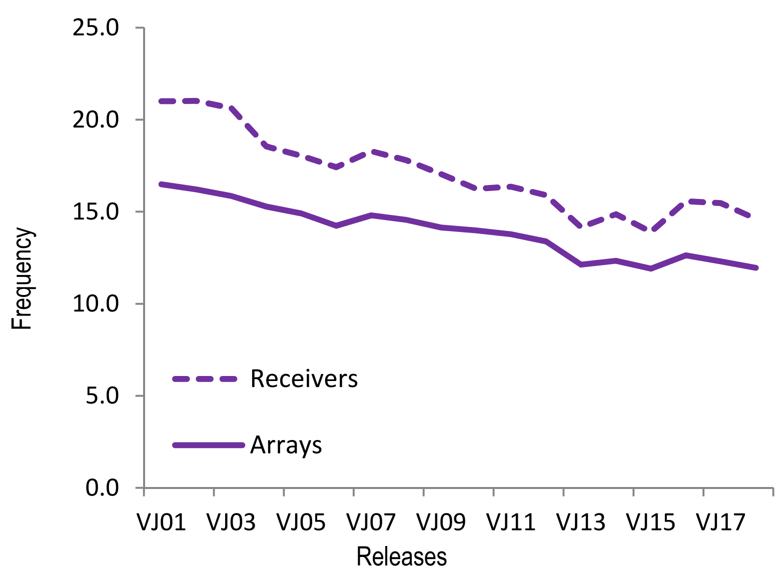


Figure 11. Mean number of JSATS arrays (solid line) and individual receivers (dotted) where steelhead release groups were detected. Release VJ01 occurred on May 8, 2011 and VJ18 on May 25, 2011.

2011) to 14.6 receivers (release VJ18 on May 25, 2011) (Figure 11).

Steelhead Travel Time

Release to Wanapum Forebay. Travel time for migrating steelhead smolts was calculated from release (I-90 Vantage Bridge) to arrival at the beginning of the in-river detection array at the Wanapum Dam hazard barrier. Arrival of each smolt (n=997) was determined as the first valid detection of a smolt tag at the Wanapum BRZ. Median steelhead travel time was 0.47 d (n=997, SD=0.32 d) with a range of 0.09-3.13 d. A one sample t-test yielded significant evidence for the presence of variable mean migration speeds to the Wanapum BRZ, 'fast arrival' and 'slow arrival' which cannot be explained by differences in flow rate but may be related to delayed downstream smolt movement (n=997, 2 tailed p value=0.001).

Median migration time in the 'fast arrival' group from release to the Wanapum BRZ was 0.33 d (n=667, SD=0.14) with a range of 0.09 - 0.62 d. Median migration time to the Wanapum BRZ for the 'slow arrival' group was 0.83 d (n=322, SD =0.27) with a range of 0.63-3.13 d.

Wanapum Forebay to Priest Rapids Forebay. Travel time statistics through the Reservoir were calculated for tagged smolts that successfully reached the forebay of Priest Rapids Dam. Smolts that failed to reach the Priest Rapids BRZ were excluded. Travel time was calculated as time elapsed between last detection at t the Wanapum BRZ and first detection at the Priest Rapids BRZ a distance of approximately 18.2 river miles.

Median travel time for tagged steelhead smolts from the last detection at the Wanapum BRZ to the first detection at the Priest Rapids BRZ was 0.56 d (n=914, SD=1.0 d) with a range of 0.26-8.78 d. Due in part to high variability of river discharge over the migration season, travel times were re-calculated for a 'high flow' period from May 8-May 19, 2011, and an 'extreme flow' period from May 20 through June 9, 2011.

Steelhead travel time was regressed against total outflow below Wanapum Dam as well as date. Statistically, travel time was loosely inversely related to flow (r-squared=0.2 from linear regression was likely due to the presence of some travel time outliers), but flow rate was generally a good predictor of travel time (Figure 12).

Median travel time for tagged steelhead smolts during high flow conditions was 0.61 d (n=598, SD=1.13) with a range of 0.33-8.79 d. Smolts migrating during extreme flow conditions had a median travel time of 0.45 d (n=298, SD=0.89) with a range of 0.31-6.61 d. High flow and extreme flow smolt migration times were significantly different with median extreme flow migration rates approximately 35% faster than high flow rates for complete steelhead smolt migrations (two tailed p=0.001 from a one-way ANOVA).

Median travel times for steelhead smolts migrating from the Wanapum BRZ to the Priest Rapids BRZ in 2011 was compared to travel times from the period from 2006-2010 (Figure 13). Median 2011 travel times were similar to those observed for the period from 2006-2008, and approximately 40% faster than observed travel times in 2009 and 2010. The median travel time of smolts experiencing extreme flow conditions in 2011 (45.3% of steelhead smolts) was 30% faster than the pooled median for 2006-2008 and 2011 (Appendix E).

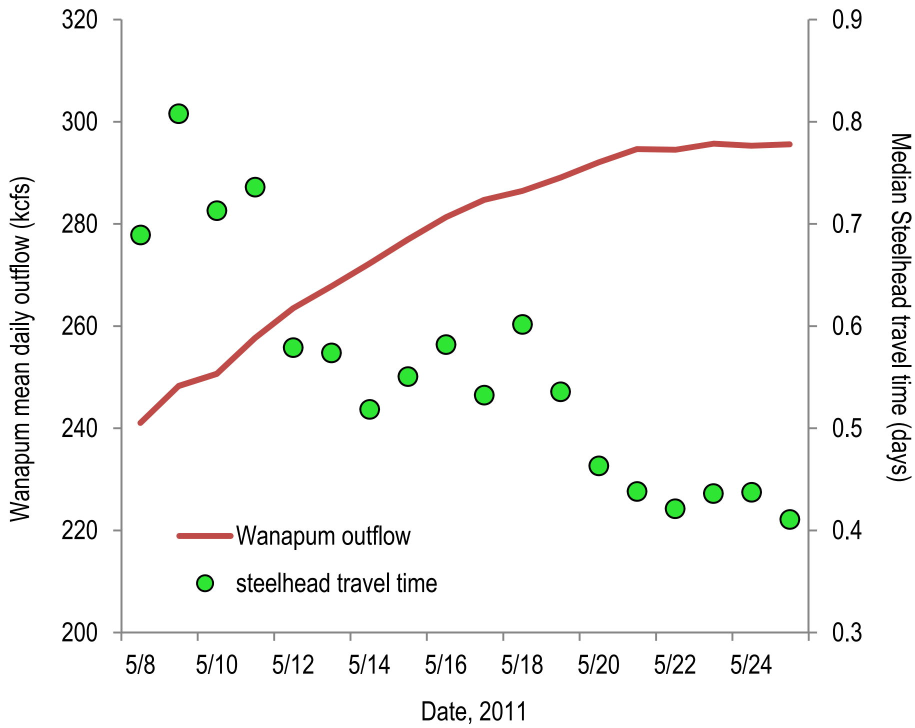


Figure 12. Median outflow at Wanapum Dam (kcfs, red line) during fish releases, and mean travel time (days) for steelhead smolts (circles) corrected for Wanapum Dam arrival that survived to the Priest Rapids Dam forebay between May 8-25, 2011. Steelhead data are corrected to exclude extreme outliers (n=12)

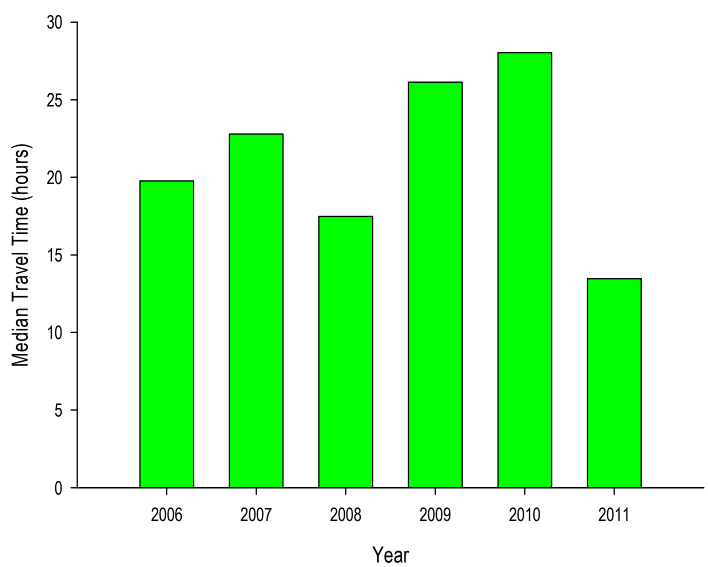


Figure 13. Median travel times for steelhead smolts between Wanapum Dam (RM 416) and Priest Rapids Dam (RM 397) from 2006-2011.

Incomplete Smolt Migrations

The 2011 survival data set included the 997 smolts that were detected at the Wanapum BRZ; 3.4% (n=35) of the total released smolts (n=1,032) were never detected by acoustic receivers. There were also 38 incomplete smolt migrations in 2011 (3.8% of study fish), in which smolts tags were not detected at (or downstream of) the Priest Rapids BRZ. These fish were considered 'not survived'. Fish with incomplete migrations were evenly distributed across release groups (2.5 tags were lost per release) with slightly, but insignificantly, more fish per release lost during extreme flows compared to high flows.

The last valid detection location of tags with incomplete migrations is shown in Figure 14. All tags (including 'survived' tags) with abnormal detection histories were flagged during initial data filtering and analyzed individually to determine smolt fate.

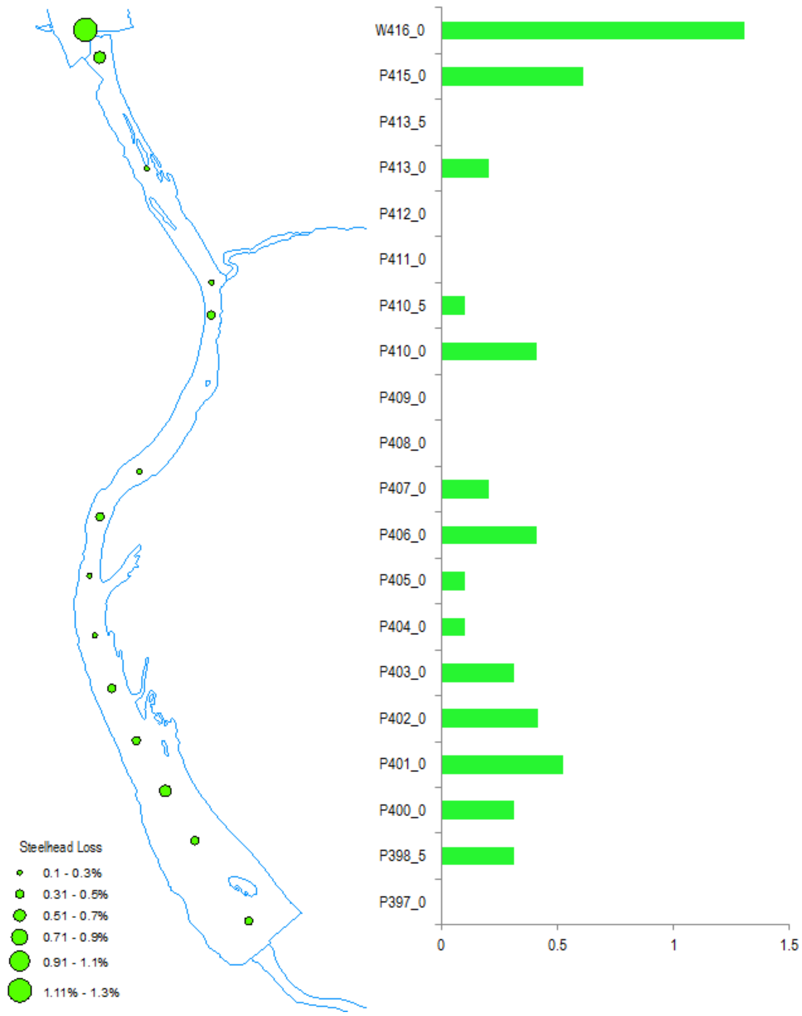


Figure 14. Steelhead tag loss in the Priest Rapids Reservoir, 2011. Tag losses were calculated as a percent of the total remaining tags at subsequent in-river arrays (river miles on y-axis). Percentages are displayed visually in the left panel and in bar form on the right. Tag losses were most significant in the lower reaches of the Reservoir and the Wanapum Dam tailrace.

Behavior abnormalities included:

- *'Residence time violation'* at an array, defined as a smolt tag that remained within the detection range of an array for a time period greater than twice the 90th percentile (i.e. longest 10% of residence times) mean residence time for survived smolts at that receiver;
- '*Travel time violation*', defined as a smolt tag with a between-receiver travel time greater than twice the 90th percentile (i.e. slowest 10% of travel times) mean travel time for survived smolts at that location; and,
- '*Incomplete migration*', defined as a smolt tag with a last detection at RM 398.5 or further upstream.

Abnormal smolt behavior was flagged in the data set, and smolt tag fate for flagged smolts was manually assigned by analysis of detection amplitude plots. Concurrent with a valid detection of a JSATS acoustic tag, the receiver also records the amplitude of the detection. A tagged smolt swimming downstream past a receiver will be recorded as a series of increasing detection amplitudes as the fish approaches the receiver followed by decreasing detection amplitudes as the fish swims downstream and out of range, creating a roughly normal distribution of detection amplitudes in uniform current (Figure 15). In other words, the closer a smolt is to a receiver, the louder its acoustic signal. Detection amplitude plotted over time for flagged smolts allows basic analysis of upstream/downstream movement within the detection array of a particular receiver when operating under the following assumptions: (1) detection amplitudes of a dead fish or an expelled tag resting on the river bed would be a stationary value; and (2) detection amplitudes showing multiple peaks indicate that the tag is moving in a 'looping/patrolling' behavior, which is more typical of a larger piscivorous fish than a downstream migrating smolt.

Analysis of detection amplitude and residence time allowed designation of tag fate in some areas of the river. The forebays of both dams and the large pool in the tailrace of Wanapum Dam below the powerhouse (RM 415) were not-suitable for this behavioral analysis due to lack of uniform current and the expected milling behavior of smolts preparing to pass the dams. Tag losses in these areas are designated as 'unknown', but likelihood of predation may be partially inferred from the subsequent predator behavior analysis.

Filtering for abnormal travel and residence times was done for all smolt tags. There were a total of 35 residence time violations and 25 travel time violations for survived fish (all at arrays below RM 403 where the current begins to decrease). In 92% of these 60 total violations, behavior returned to 'normal' at the next receiver/river mile, thus no predation was suspected. The remaining 8%, however, had both residence time and travel time violations but were still detected at Priest Rapids tailrace exit gates (RM 396 or RM 395). The combination of violations suggests that these smolts may have been predated but since they were detected at RM 397, there are considered 'survived' even though they may have been transported in-stomach through subsequent arrays.

A total of nine travel time and six residence time violations were filtered for the 38 smolts with incomplete migrations (3.8% of smolts that entered the Reservoir). In contrast to violations observed for survived fish, non-survived (incomplete) fish tended to have repeated normalcy violations at a series of sequential arrays with no return to normal behavior, which suggested predation. In most cases, abnormal residence and between-site travel times were not significantly different from those of tagged predators such as northern pikeminnow, but variance in this group was too high to draw significant statistical inferences. Fish with incomplete migrations that did not

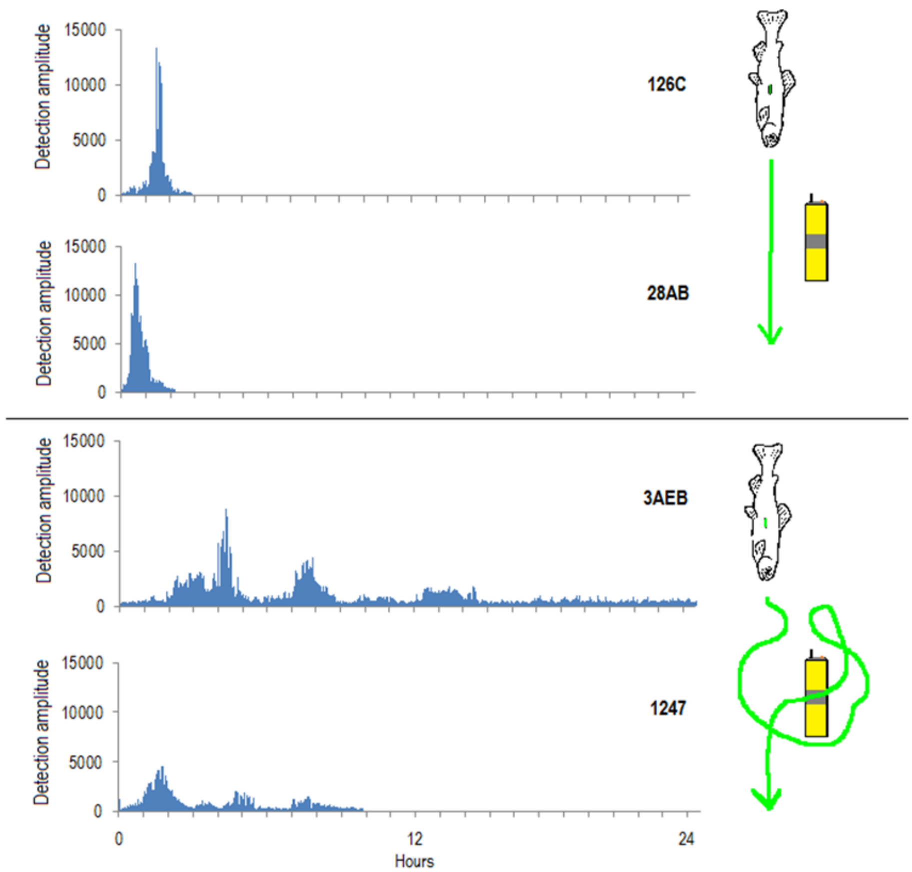


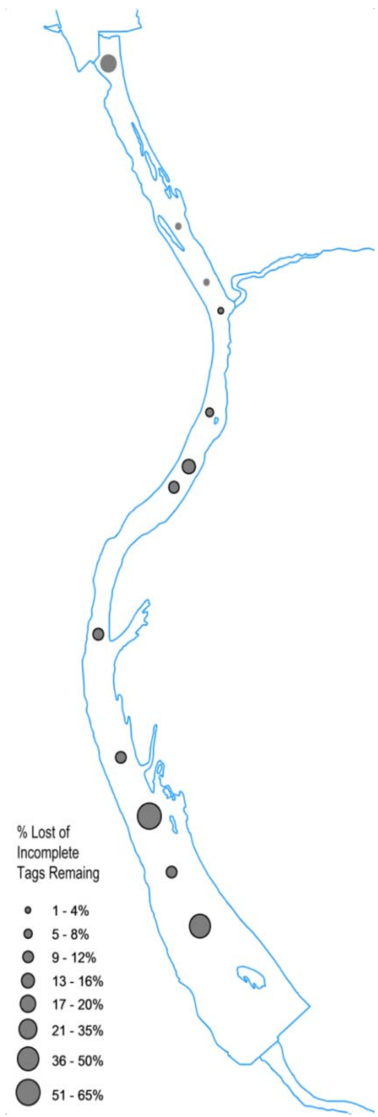
Figure 15. Detection amplitude frequency plots showing normal detection plots associated with normal behavior of a smolt passing a receiver (tag codes 126C, 28AB, top schematic) and abnormal behavior and the resulting abnormal detection plots with multiple amplitude peaks associated with multiple approaches to the receiver (tag codes 3AEB, 1247, bottom schematic).

have any abnormality of behavior were designated as 'unknown tag loss'.

<u>Detection Amplitude Analysis</u>. Detection amplitude at 'last detection' receivers was plotted for all smolt tags flagged for abnormal detection history with the abovementioned filtering criteria. Amplitude plots for 42 smolts were analyzed (38 incomplete migrations and four complete migrations with residence and travel time violations). The six tags that were lost at RM 415 (Wanapum Dam tailrace) were not analyzed, nor were any tags lost after detection at Priest Rapids Dam, RM 397 (i.e. not detected at RM 396 or RM 395) due to the difficulty of categorizing behavior in a pool-like habitat.

Amplitude plots were surveyed for normalcy of amplitude distribution, truncation, and extreme skewedness on either tail. Circling/patrolling behavior, which included upstream swimming (multiple amplitude peaks), was evidence of predator-like behavior. A total of 28 out of 42 tags (66.6%) had abnormal detection amplitude curves and were designated "predation suspected." An additional six smolts (14.3%) did not have sufficient detection data to analyze. The remaining eight tags had normal detection amplitude curves.

The location of predation events was determined by identifying the last array where detection history was normal (Figure 16). In most cases, the location of the predation event was between zero and two river miles from the last detection of the smolt tag.



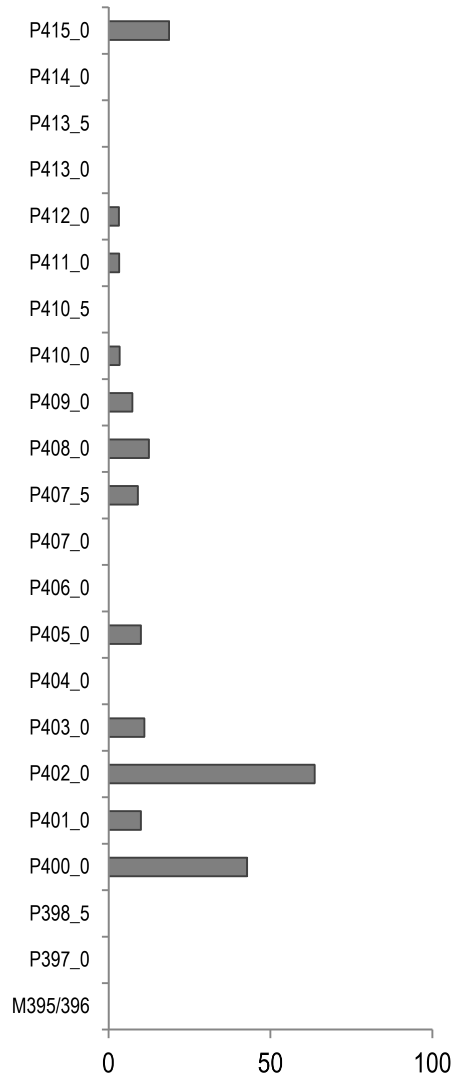
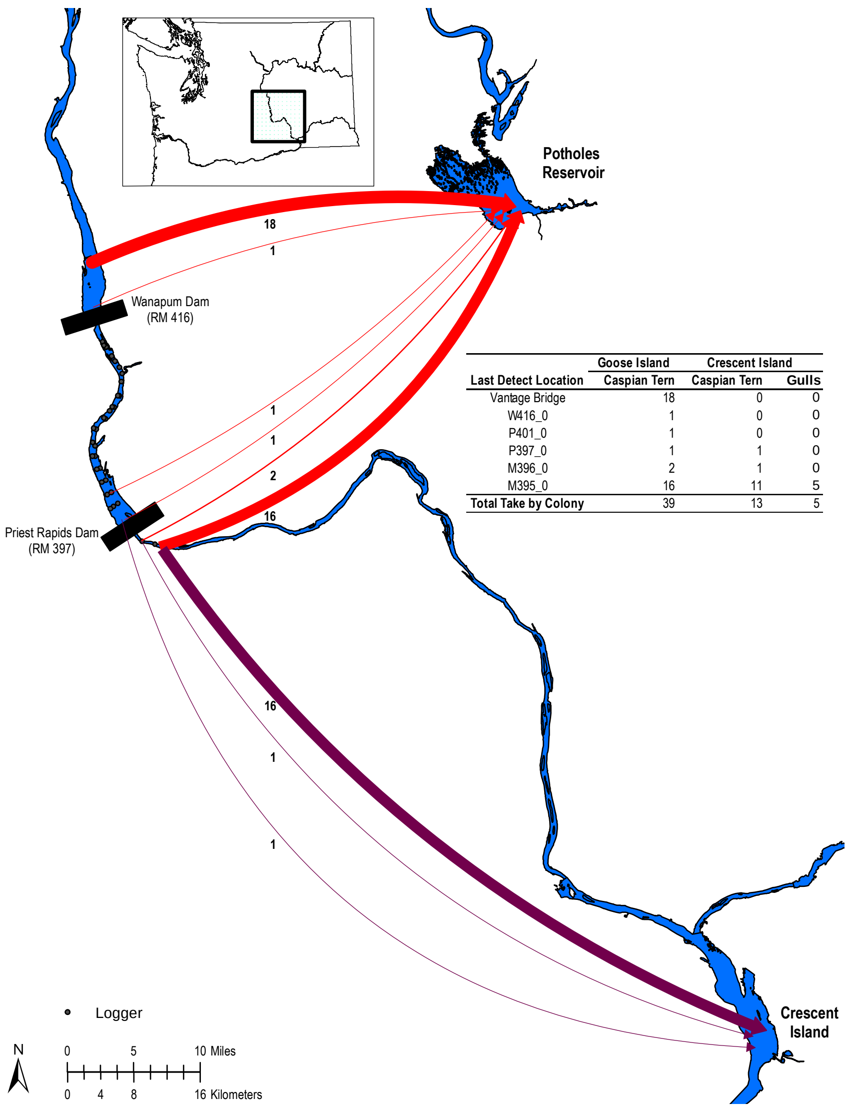


Figure 16. Suspected predation events by river mile expressed as a percentage of the total number of predated tags remaining that were lost at each in-river array (river miles on y-axis). For example, at RM 4150 six tags of the 38 total predated tags equals 18% lost. At RM 403, three tags of the 18 lost tags remaining equals 11%.

Avian Predation. A total of 57 PIT tags associated with fish released in the 2011 JSATS study were recovered from bird colonies at Goose Island in the Potholes Reservoir and Crescent Island. Based on last acoustic detections, 98% of these tags were removed either from the vicinity of the release site (fish were never detected at the Wanapum BRZ), or from a point downstream of the last JSATS receiver in the Priest Rapids tailrace (fish which successfully 'survived' the study reach) (Figure 17). Only one tag was removed from the Reservoir near the detection array at RM 401.



	Goose Island	Crescent Island	
Last Detect Location	Caspian Tern	Caspian Tern	Gulls
Vantage Bridge	18	0	0
W416_0	1	0	0
P401_0	1	0	0
P397_0	1	1	0
M396_0	2	1	0
M395_0	16	11	5
Total Take by Colony	39	13	5

Figure 17. Steelhead smolt losses to avian predation by location of last JSATS tag detection, and locations where PIT tags were found at nesting bird colonies. Arrows represent tag transfer, not flight path.

Predatory Fish

<u>Fish Characteristics</u>. A total of 193 piscivorous fish, including 134 northern pikeminnow, seven walleye, and 52 smallmouth bass were captured and tagged for the study. Northern pikeminnow were captured with set lines and angling throughout the Reservoir from April 8, 2011 to May 4, 2011. Walleye were captured from RM 412.5-414 by angling from April 9-27, 2011. Smallmouth bass were captured by angling and electrofishing between April 9 and May 4, 2011 with most captured between RM 397.5 and RM 405.5 (Appendix F). The average northern pikeminnow length was 38.4 cm (range 27.0-54.0 cm) and weight was 0.7 kg (range 0.2-2.4 kg). Average walleye length was 61.5 cm (range 49.3-71.3 cm) and weight was 3.2 kg (range 1.5-4.5 kg). The average smallmouth bass length was 37.6 cm (range 28.0-50.0 cm) and weight was 1.0 kg (range 0.4-1.9 kg)(Figure 6).

<u>Fish Movement</u>. All but two of the 134 tagged northern pikeminnow were detected on JSATS receivers. All seven tagged walleye, but only 26 of the 52 smallmouth bass tagged and released were detected. The range of movement of each tagged predator was determined by calculating the farthest distance between JSATS receivers that detected the fish. Most predators tagged in 2011 ranged less than five river miles from their release location (Figure 18). Smallmouth bass in particular displayed less movement than the other species with only one fish exceeding a range of five river miles. Several northern pikeminnow ranged more than 15 miles, as did one walleye.

One smallmouth bass was detected downstream of Priest Rapids Dam as well as in the left bank fishway at the dam. One tagged walleye and one tagged northern pikeminnow were captured after the study period by anglers downstream of Priest Rapids Dam.

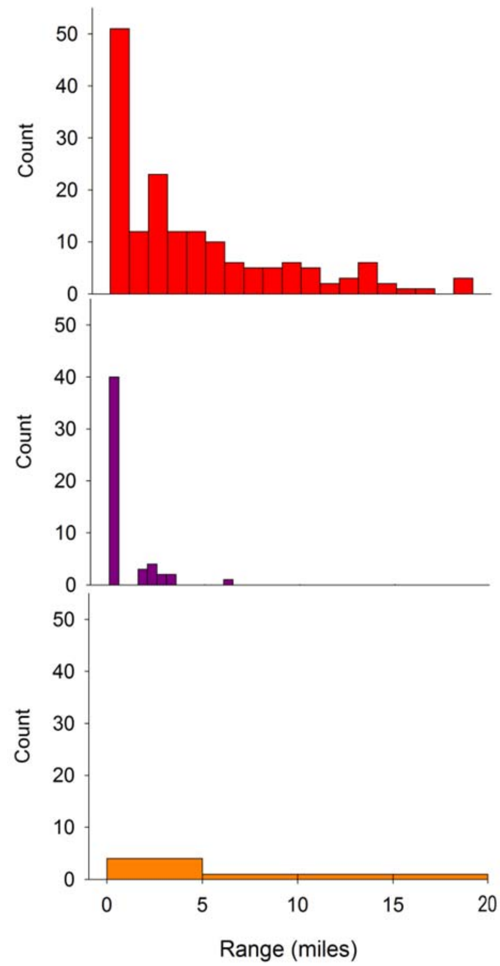


Figure 18. Range of movement for tagged northern pikeminnow, smallmouth bass, and walleye (top to bottom) detected in the Priest Rapids Reservoir, spring 2011.

<u>Cumulative Movement</u>. Cumulative movement for tagged predators was determined by summing the distances moved between consecutive detections at JSATS arrays over the study period. The median cumulative movement of tagged northern pikeminnow was 6.8 miles (SD 11.9). The median cumulative movement for walleye was 6.0 miles (SD 93.8) and for smallmouth bass was 1.0 mile (SD 4.1). Release location of tagged northern pikeminnow appeared to have an effect on cumulative movement. There was a general trend of fish released near the middle of the Reservoir (RM 404-411) showing more cumulative movement than those released either below RM 402 or above RM 412 (Figure 19).

The extreme flows after May 20, 2011 did appear to affect behavior of tagged predators. Most detections of smallmouth bass prior to May 20, 2011 were at receivers between Buckshot Slough (RM 403) and Auvil Orchard (RM 408). After May 20, 2011, most detections were from Buckshot Slough downstream to Priest Rapids Dam along the right bank boat basin (RM 398) (Figure 20).

The number of smallmouth bass tags detected after May 20, 2011 was half that of the early study period which suggests that many tagged smallmouth bass resided in locations outside the detection range of the JSATS receivers. Most of the walleye detections before May 20, 2011 occurred on receivers from the mouth of Crab Creek (RM 410.5) upstream to the Wanapum Dam tailrace (RM 415). From May 20-27, 2011, most walleye detections were in the islands around RM 413. From May 29, 2011 through June 9, 2011 only two walleye were detected; one moved downstream to the Priest Rapids Dam right bank boat basin area (RM 398) and the other was detected at RM 403 and RM 404. The extreme flows later in the study period may have allowed the remaining tagged walleye to use parts of the river outside the detection range of the JSATS receivers.

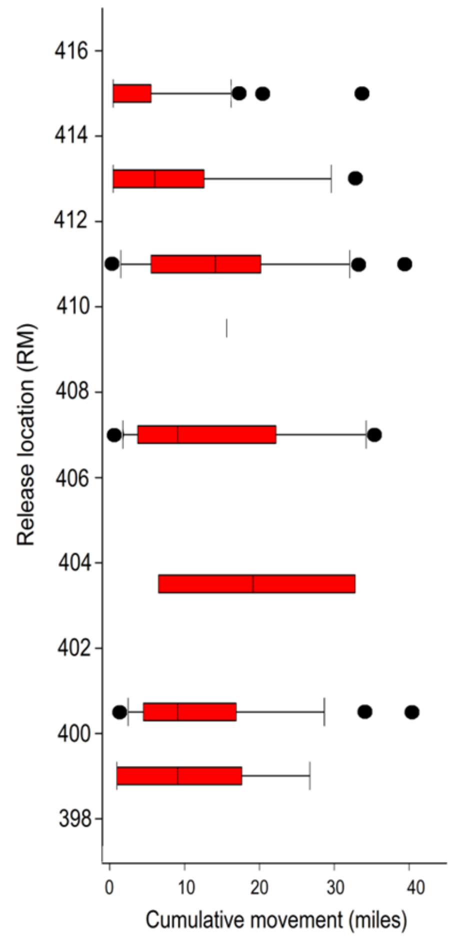


Figure 19. Cumulative movement by release location for tagged northern pikeminnow detected in the Priest Rapids Reservoir, spring of 2011. Due to small sample size, walleye and smallmouth bass are not presented.

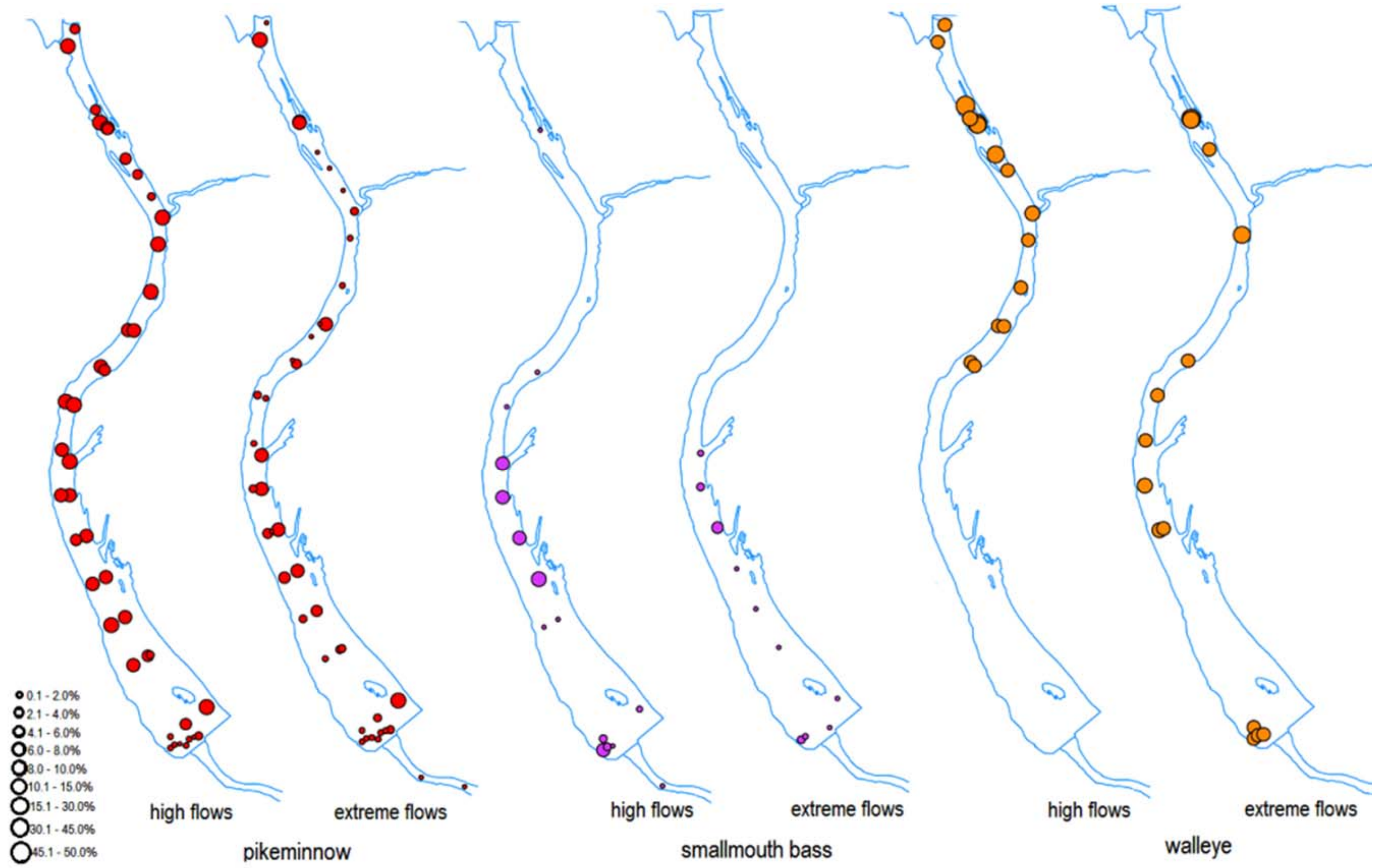


Figure 20. Detections of northern pikeminnow (red circles), smallmouth bass (purple circles), and walleye (orange circles) by percentage of unique tags in the Priest Rapids Reservoir during high flows (May 1-19, 2011) and extreme flows (May 20-June 9, 2011). Dot size indicates percentage of unique tags detected at individual receivers.

Piscivorous Fish Residence Time. The larger sample size and greater frequency of detections for tagged northern pikeminnow allowed for a reservoir-wide analysis of cumulative residence time at each detection array (Figure 20). The mean residence time for the 55 northern pikeminnow that were detected immediately downstream of Wanapum Dam (RM 415) was 115 hr during the study period. No other array recorded mean residence times of more than 3.5 hr. While the number of northern pikeminnow detected was relatively constant among the arrays in the Reservoir, it appeared that the Wanapum Dam tailrace was a uniquely attractive location.

Since the end of the study period, a total of eight tagged northern pikeminnow (5.9% of 134) have been recaptured by USDA anglers on the Wanapum Dam transformer deck. Salmonid smolts were found in the stomachs of all northern pikeminnow recaptured by USDA anglers (Keith. Garner, pers. comm., July 27, 2011 and August 24, 2011).

The small sample size of tagged walleye and inconsistent detections of smallmouth bass made residence time analysis inappropriate for those species in 2011.

Northern Pikeminnow Removal. Over the past five years, Grant PUD has operated a removal program of northern pikeminnow in the Reservoir using capture methods that have included set lines, beach seines, and angling (Garner 2010). Since 2006, the set line fishery has captured the majority of northern pikeminnow in a size range (>9") that are likely to be a threat to migrating steelhead smolts (Garner and Keeler, 2008).

The removal of large, adult northern pikeminnow from both reservoirs in the Priest Rapids Project is expected to remove some of the piscivorous fish predation pressure on migrating juvenile steelhead, thus increasing the survival potential of steelhead smolts in subsequent years (Garner and Keeler 2008). While there are many factors that contribute to the survival of steelhead smolts passing

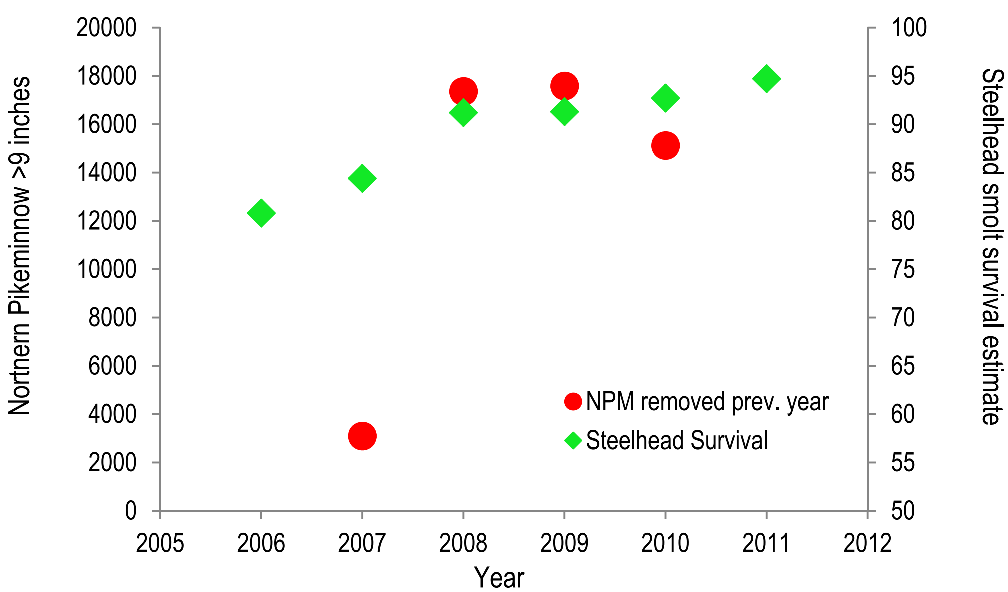


Figure 21. Steelhead survival estimates relative to the number of northern pikeminnow (>9 inches) removed by set-lining in the previous year.

through the Project, there is loose correlation between northern pikeminnow removal numbers and subsequent year steelhead survival (Figure 21). The number of northern pikeminnow removed increased from 3,099 in 2006 to 16,357 in 2007, which corresponded with an increase in steelhead survival from 84.4% in 2007 to 91.2% in 2008.

Predation Hot-Spots. Exclusive of the forebay at Wanapum and Priest Rapids dams and the immediate tailrace of Wanapum Dam, suspected predation events were most concentrated in two areas of the Reservoir in 2011: 1) Auvil Orchard (RM 408) to Crab Creek (RM 410.5), and 2) Desert Aire (RM 403) to Goose Island (RM 398.5). These two hot-spots accounted for over 90% of smolt tags lost to predation in the arrays between RM 413.5 and RM 395 (Figure 22).

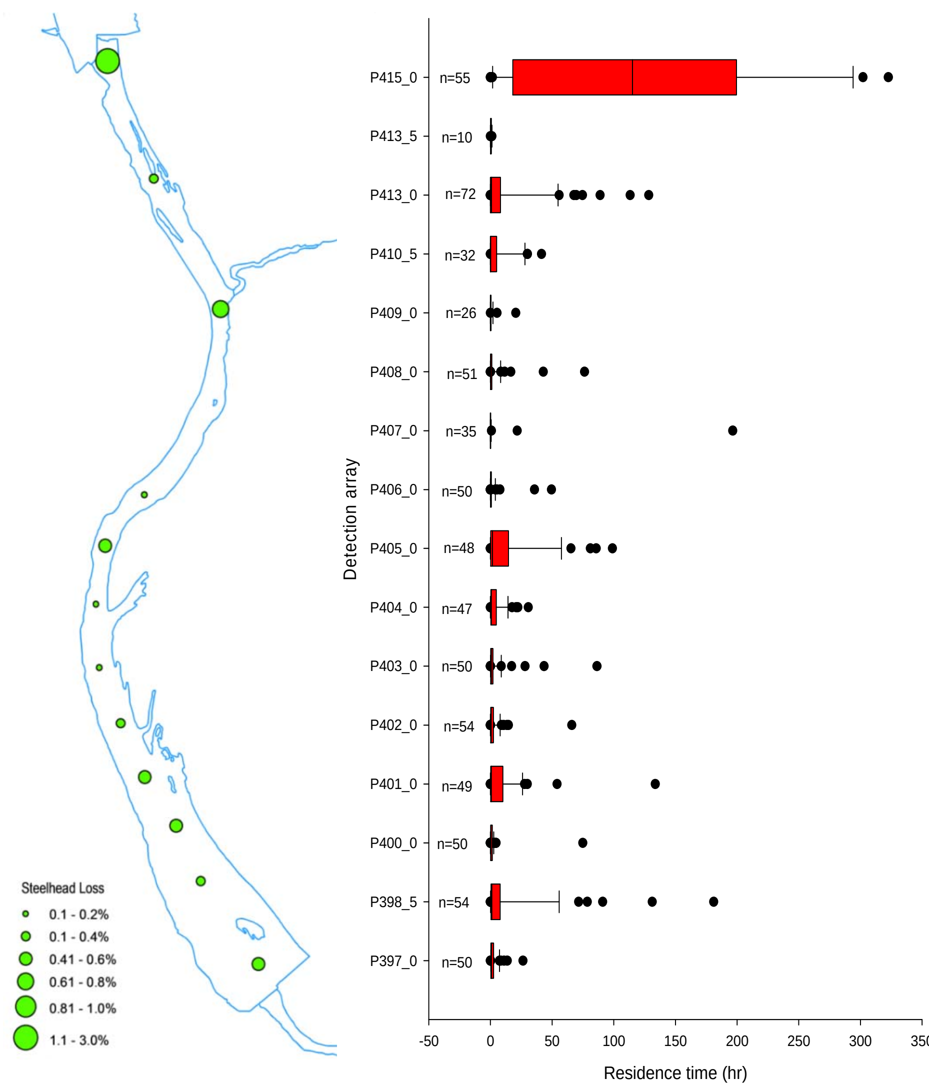


Figure 22. Percent loss of steelhead smolts by detection array (river miles on y-axis) in the Priest Rapids Reservoir (green circles) compared to cumulative residence time of northern pikeminnow during the study period in spring, 2011 (red bars).

Discussion

The goal of this study was to examine the in-river steelhead mortalities between Wanapum and Priest Rapids dams that have been documented in previous studies. A new technology, JSATS, was used to monitor mile by mile survival of steelhead smolts released above Wanapum Dam through the Priest Rapids Reservoir, to the forebay of Priest Rapids Dam and was effective in allowing a more fine-scale analysis of steelhead behavior between projects than previous studies. In addition to highlighting areas where steelhead mortalities occurred, behavior patterns of steelhead and three piscivorous fish species were analyzed throughout the Reservoir.

Survival

While the 2011 study did not estimate survival performance standards for juvenile steelhead through the entire Project, the Priest Rapids Reservoir was studied reach by reach and single-release survival estimates were higher than those measured in previous years by paired-release studies; survival estimates were 0.97 for 2011, a 9% increase from previous years.

Over the past five years, steelhead survival has increased each year due to a variety of reasons. In 2006, the survival estimates were believed to be compromised by less than ideal collection and handling methods, but since then, study techniques were developed and refined. In 2006, steelhead Project survival was estimated at 0.71, and increased incrementally to 0.80, 0.86, 0.88, and 0.90 from 2007-2010 respectively. In 2011, the sub-section of the Project studied had a survival of 0.97 (Figure 23). Additionally, Grant PUD has made substantive modifications in the Project that have included the installation of the WFB, tailrace bird wires at both dams, increased piscivorous fish control, to name a few. With these modifications, steelhead survival estimates have increased annually, though providing a quantitative measure of the degree to which these improvements aid steelhead survival is difficult.

Conversely, down river, NOAA Fisheries have observed the opposite trend in steelhead survival through the Snake and Columbia rivers. This year, juvenile steelhead experienced an estimated drop in survival of 6% from Lower Granite Dam to McNary Dam (survival was 0.94 in 2010, 0.88 in 2011) and a 2% decrease in survival from McNary Dam to Bonneville Dam (survival was 0.92 in 2010, 0.90 in 2011) (NOAA Fisheries 2011)

There are several variables which may have contributed to the high survival estimates for the sub-section of the Priest Rapids Project studied in 2011 relative to some of the reaches lower in the Columbia Basin. One of those variables was the above normal flow conditions. The outflow (kcfs) at Wanapum and Priest Rapids dams increased dramatically across the period of steelhead smolt releases in 2011. This upward trend in velocity and total water volume impacted several aspects of the 2011 data set including: steelhead travel time, cumulative reach survival, detection efficiency and functionality of in-river JSATS arrays, and predator behavior and movement.

Other factors that may have influenced this year's survival estimate and should be noted include: decreased tag burden on juvenile steelhead; and the subsample of steelhead tagged in this years' study was primarily composed of the first half of the migration run. Also, the entire Project was not monitored and the Wanapum Reservoir survival may have been overestimated because the 2011 release location was just four miles from the dam, whereas in previous years, fish were released in the tailrace of Rock Island Dam, 37 miles upstream.

Steelhead Travel Time

Steelhead travel time in 2011 decreased significantly during the period of extreme flows after May 20, 2011 with median travel times approximately 30% faster than the high flow period from May 8 -19, 2011. While downstream migration times were faster, there was no statistically significant difference in the survivorship of steelhead smolts released in high versus extreme flow conditions. As a whole and compared to previous years, median travel times in 2011 were nearly 40% faster than the pooled average from 2006 to 2010 (14.0 hr in 2011 and 19.6 hr in 2006-2010)(Timko et al. 2011). However, this decrease in travel time of 5.6 hr was correlated with higher overall survivorship of steelhead smolts passing through the Reservoir than that observed in previous years. This suggests that the 2011 increase in survivorship may be partially attributed to the intense 2011 flow regime in the mid-Columbia River, and undoubtedly reduced the exposure of migrating smolts to piscivorous fishes. Increased flows may have also had a negative impact on piscivorous fish, which appear to have been pushed out of favored feeding zones by strong currents. It is unclear what additional impact the high flows had on piscivorous fish, i.e., did increase flows require an increase in energy expenditure to manage high flows that resulted in a decrease in feeding.

Predator Fish Behavior

Of the three species of piscivorous fish tagged in 2011, it is likely that two species were influenced by spawning behavior during the study period. The spawning period for smallmouth bass was under way by May 20 when water temperatures in the main river reached 10°C and temperatures in the sloughs likely reached 12-13°C (Wydoski and Whitney 2003). Spawning behavior of smallmouth bass may explain the decreasing trend in detection over the study period. Walleye spawning likely occurred between March 19 and April 20, 2011

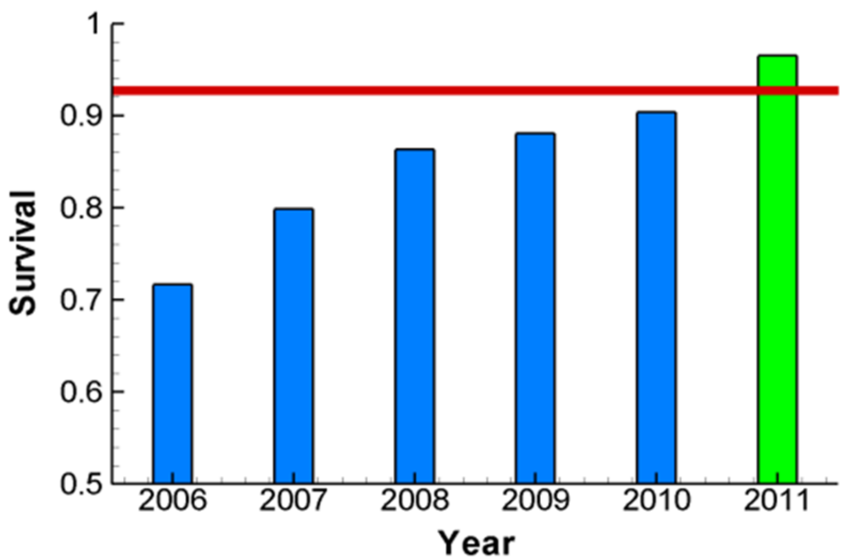


Figure 23. Survival of juvenile steelhead through the Priest Rapids Development, 2006-2010. The target performance standard for steelhead is 93% (red line). Steelhead survival in 2011 was high for the sub section of the Project in which it was estimated although (like 2006 and 2007) this was not a true survival study.

(3.3-6.6°C) which was when anglers were attempting to capture them for the study, and may partially explain the low capture numbers. Northern pikeminnow spawning probably did not begin until July 1, 2011 (13.9°C) and thus they were the only piscivorous fish species not affected by spawning during the study period.

Northern pikeminnow produced the most complete data set of the predators tagged in this study. This was due to their widespread availability and susceptibility to capture throughout the Reservoir, and tendency, once tagged, to move within the primary river channel where the JSATS receivers were deployed. In contrast, walleye were difficult to catch during the study period resulting in small sample size. Finally, smallmouth bass seemed to reside primarily outside the detection range of the JSATS receivers resulting in relatively little information on their behavior patterns.

All piscivorous fish species showed a response to changes in flow regime. Northern pikeminnow shifted out of extreme current areas and into areas of relative refuge once flows spiked after May 20, 2011. These areas were primarily downstream of RM 408. The exceptions were that those northern pikeminnow would remain in the Wanapum Dam tailrace at RM 415. Walleye largely disappeared from detection range after May 27, which suggests that they may have also sought refuge from the extreme flows in areas outside the detection range of the JSATS receivers, such as the islands in the vicinity of RM 413. The two walleye detected between May 27 and June 9, 2011 moved downstream to Lake Geneva and along the Priest Rapids Dam right bank boat basin (RM 398). Smallmouth bass were believed to have moved to their preferred spawning locations in the off-channel habitat around Lake Geneva (RM 405), Buckshot Slough (RM 403), and along the right bank of the main river between RM 397 and RM 400.

Predation Hot-Spots

Identification of predation events on steelhead smolts by piscivorous fish in 2011 was approached in two steps. First, smolts with abnormal behavior patterns were flagged and analyzed individually to determine whether their mortality could be attributed to a predation event. In approximately two thirds of these cases, smolt losses could be attributed to measureable changes in behavior patterns, i.e. assumed predation. For smolts that were confidently characterized as predated, the second analytical step was to assign a location to the predation event. Three hot-spots of smolt loss due to fish predation, and two hot-spots of smolt loss due to avian predation were identified in 2011 and are discussed individually.

<u>Release to Wanapum Dam</u>. In the stretch of river between where fish were released (0.5 km downstream of the I-90 Vantage Bridge) and the forebay of Wanapum Dam, 3.4% of the total released smolts were lost; 35 out of 1,032 tagged juveniles steelhead were never detected at Wanapum Dam. These losses may be attributable to several factors that could include delayed mortality associated with handling (collection, tagging and release), predation, failure to correctly orient downstream, and/or residual behavior in the Wanapum Reservoir. In 2011, there were no piscivorous fishes tagged in this area. It is most probable that a significant portion of the lost fish were removed by avian predators.

A total of 19 (54%) tagged steelhead that were lost between release and Wanapum Dam had their tags recovered at a Caspian tern nesting colony, Goose Island, in the Potholes Reservoir. The average detection efficiency of PIT tags at this nesting site in 2011 was 60% (SE=16.9), however, there was only 20% detection efficiency of the tags distributed at the nesting site in mid-April (Sebring et al. 2012). Assuming these detection efficiencies adequately represent those of PIT tags surgically implanted and released by Grant PUD in May 2011 (range in detection efficiency of 20-60%), we believe that the majority of the steelhead losses in the Wanapum Reservoir and forebay can be accounted for by avian predators (an estimated 27-34 out of 35 steelhead were taken by Caspian terns in this area).

Wanapum Dam Tailrace. The immediate tailrace of Wanapum Dam, the area directly below the powerhouse, was the most significant hot-spot of juvenile steelhead loss in the Reservoir. The currents in this area are eddy-like and thus, behavioral analysis of smolt movement patterns could not be completed as for in-river arrays. Steelhead losses at this area could be attributed to either mortality during dam passage due to factors associated with pressure, trauma, impact (i.e., blade strike), etc., or predation. Due to the behavior of northern pikeminnow at this location, significant loss of smolts to predation is assumed. Northern pikeminnow were especially active and abundant in this location; USDA anglers report capturing northern pikeminnow with stomachs full of steelhead smolts.

Crab Creek to Auvil Orchard. Although fewer total smolt losses occurred in this area, there was a concentration of lost steelhead tags between RM 410.5 (Crab Creek) and RM 408 (Auvil Orchard) with losses attributable to predation. This is one area where high flows, particularly at the end of the season, compromised the detection efficiency of the JSATS array, and where one receiver was lost. More thorough coverage of this area in subsequent year(s) might provide better resolution on smolt losses occurring in the vicinity of the left bank tributary (Crab Creek) and plentiful marginal habitat suitable for predator residence (left bank, Mattawa). Predator behavior in this area was not well documented due to widening of the river with increasing flow and decreased detection coverage by the JSATS array.

Lake Geneva to Priest Rapids Dam. The third hot-spot of steelhead loss due to fish predation covers the entire section from Lake Geneva (RM 405) to the Priest Rapids BRZ (RM 397). This area is characterized by slower flows due to increased width and depth of the river approaching the dam. In this area, 0.2% of all remaining steelhead were lost (20 total tags). Many (but not all) of these losses were attributable to predation following behavior and detection amplitude analysis. In the forebay of Priest Rapids Dam, behavior analysis was not attempted because the reservoir does not have sufficient flow. Predators favored this reach during the extreme flows. Additionally, smallmouth bass spent most of their time in these lower reaches during the beginning of the season before dispersing to spawn.

Priest Rapids Dam Tailrace. The likelihood of smolt predation by fish below Priest Rapids Dam was not estimated, but evidence from JSATS tag recovery at Goose Island (Potholes Reservoir) and Crescent Island (near McNary Dam) suggests that smolts may encounter more predation pressure from birds below Priest Rapids Dam (and above Wanapum Dam) than they do in the Reservoir. The subset of avian predation/tag recovery data indicated that at least 36 fish (63% or 36 out of 57 recovered tags at bird colonies) successfully survived through the Reservoir. This data is consistent with avian predation trends in 2009 and 2010, where the heaviest bird predation rates occurred below Priest Rapids Dam (Timko et al. 2011).

Summary

Grant PUD has commissioned steelhead survival studies in the Project for the past six years. These studies have yielded findings that show steelhead performance standards of 95% survival have been, and can be consistently met at both dams. Although survival estimates in 2011 were high, previous studies have shown that Priest Rapids Development survival of 93% and overall Project survival of 86.5% cannot be consistently met under the present conditions.

The 2011 study demonstrated that current techniques and technologies provided a successful, basin-wide analysis of steelhead loss and predator behavior. Yet, this spring was a unique year with extreme river flow conditions that we believe resulted in high steelhead survival performance through the Priest Rapids Development, which is likely an outlier compared to normal flow years. While this study identifies in-river zones of predation on steelhead smolts (primarily by northern pikeminnow) and associated survival estimates by river mile, it is uncertain how these findings would compare to a more typical flow year.

We recommend completing a similar study in 2012 utilizing JSATS technology, as proven in 2011 to be an appropriate tool to identify and quantify steelhead losses in the Reservoir. We'd also recommend an additional year of research in monitoring the associated predator behavior in a typical flow year (one in which we suspect juvenile steelhead survival standards would not be met). If the study is repeated in 2012, we would likely make minor modifications to receiver deployment locations that would increase the detection efficiency throughout the Reservoir and in hot-spots of predator activity. Lastly, if predator behavior is to be monitored in 2012, we recommend fishing for walleye earlier in the year (i.e. early March) at a time when local anglers have suggested that our catch per unit effort would be more successful in targeting walleye.

Acknowledgements

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List of Appendices

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Appendix A

Guidelines for Surgical Tagging Implantation Procedures, Anesthetic Guidelines for Piscivorous Fish and Guidelines for Culling Fish

The guidelines presented were provided by LGL Limited (Sydney, British Columbia). For further information, please contact Anita Blakley or Megan Mathews at (250) 656-0127.

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LGL LIMITED
environmental research associates

9768 Second Street
Sidney, BC
V8L 3Y8
250-656-0127
www.lgl.com

Field Standard Operating Procedures

Surgical Tagging Implantation Procedures Used in Telemetry and Acoustic Survival Studies

Purpose: To provide guidelines and standard protocols for surgical tagging of juvenile salmonids and piscivorous fish specifically for the Grant County Public Utility District (GCPUD) survival, behavior and predator studies.

Area of applicability: For all LGL staff involved in surgical tagging of juvenile salmonids and piscivorous fish (i.e., pike minnow, smallmouth bass, walleye, and catfish) for the GCPUD survival, behavior and predator studies. However, the Standard Operating Procedures (SOP) can be applied to most other projects in a lab environment, and is an excellent resource for anyone wanting to learn about fish tagging.

Surgical Equipment and Materials Needed:

- Dissolved oxygen (DO) meters which include temperature readings
- Total dissolved gas (TDG) meter
- Autoclave (M11 Ultraclave, Midmark) (available at Wanapum Dam)
- Tags (radio or acoustic), receivers or other equipment
- Tricaine methanesulfonate (MS 222; 55.5 g/L stock solution)
- Baking soda – sodium bicarbonate (buffering solution)
- Stress coat – (original concentration and 25% solution 250 ml/L)
- 20 L buckets marked at 10 L and clearly labeled “HEAVY” (referring to anesthetic buckets)
- 20 L numbered recovery buckets with lids
- Pair of 20 L buckets (gravity feed) marked at 10 L connected by rubber tubing with in-line shut-off valves – one labeled “MS222” and one labeled “H2O”
- Syringes for measuring anesthetic (60 cc)
- Oxygen delivery system (i.e., gas/aerators)
- Pump for water circulation for predator studies
- Small and large dip nets – all modified as sanctuary nets
- Nitrile gloves
- Waterproof scale measuring to the nearest 0.5 g
- Large plastic weigh boats
- Surgery table – plexi-glass box with a built in v-shaped trough (trough is covered with plastic cupboard lining to avoid mucus and scale loss). Plastic hoses are also connected to the surgery table for outtake and intake of water. The water from outtake hose is emptied into a 20 L bucket. A large custom-made tagging trough is used for the predator studies.
- Large coolers (anesthetic and freshwater coolers for predator studies)
- Car batteries and battery chargers to power pump for predator studies
- Trays for holding solutions used to clean surgical tools
- Needle drivers
- Forceps
- disposable scalpels: size #15 for smolts, or #10 for predator studies
- Germiphene (bactericidal, fungicidal and virucidal; diluted 16 ml of Germiphene to 1 L of water)

- Chlorhexidine solution (Nolvasan; 30 ml/L) prepared with distilled or de-ionized water
- Sutures: for smolts use size: 5-0, 4-0 or 3-0 (vicryl coated with tapered RB-1 needle – antibacterial type); for the predator studies, use size 3-0 (monofilament with tapered or cutting needle)
- Distilled or de-ionized water as a rinse solution for disinfectant (chlorhexidine)
- Catheters (shielded needle – 14 G or 16G) – only for radio tagging
- 2 L bottles to make up stock solutions for stress coat, Germiphene and MS222
- Timepiece
- Spray bottles for stress coat and disinfectant
- Shop towels
- Sharps container and Ziploc Bags
- Data sheets, writing tools, computer

Procedures:

Collection and Pre-Tag Holding

Verify that proper collection and transport permits have been obtained and are in possession at the time of collection and tagging. All staff involved in the tagging procedures must be aware of permit restrictions. Copies of the permits are to be visible at the collection facility.

Before putting fish in pre-tagging holding tanks, the tanks are scrubbed, flushed, and re-filled. The DO and temperature of the water are checked to ensure adequate water quality. All pre-holding tanks should have no light access (i.e., windows) as darkness is thought to reduce Frustrated Smolt Syndrome (FSS).

Pre-tagging holding density is approximately 30 steelhead or 100 sockeye per tank, which is about half the density recommended as maximum by aquaculturists (50 g of fish per L of water). Holding tanks must have flowing, untreated river water supplied at all times when in use. Fish should be separated by species.

The pre-tag holding period begins once fish are placed in holding tanks. Pre-tag holding times for study fish should be between 15 to 24 hours and not exceed 36 hours. For example, if LGL is delivered fish at noon, and tagging the following day runs from 8 AM until 4 PM, then our pre-tagging holding times will range from 20-28 hours, and any fish tagged after 12 PM would be over the recommended holding time. All fish (including gatewell dipped fish) would have to be delivered by 5 PM in order for our pre-holding times to range from 15-23 hours. In 2011, the majority of the fish were delivered to the tagging site prior to 3 PM.

Each species collected is held in a separate holding tank to reduce stress. Record the species and collection date on each pre-tag holding container using erasable wax pencils.

Pre-tag holding containers are monitored for DO and temperature twice daily until tagging begins.

Anglers will be capturing the piscivorous fish using barbless hooks within the 18 mile Priest Rapids pool and transporting the fish in a live tank to a shore-based field tagging set-up. Fish are to be tagged as soon as possible.

Fish Size Criteria

Minimum size of fish tagged is dependent on the type of tag being used. Determine the maximum tag weight to body weight ratio that will be used for your project. Some licensing bodies require a 2% ratio; others will allow a 5% (read proposal for specific requirements). Use this ratio to calculate minimum fish size. For example, at Wanapum in 2011 the minimum salmonid size was 15.2 g. Any salmonid under this mass was culled because it did not meet the 5% tag weight to body weight ratio. You may also have a maximum size cut-off.

LGL/GCPUD FIELD STANDARD OPERATING PROCEDURES

Pre-Tag Preparations

Environmental conditions – All staff must be trained on all water quality measuring equipment.

Dissolved oxygen (DO): will be measured in mg/L in pre- and post-tag holding tanks/buckets during each tag session.

- Measurements will be taken using a DO meter.
- DO concentrations in pre- and post-tag holding tanks/buckets should be between 7 mg/L and 13 mg/L. If readings are outside of this range, inform your field manager and check for limited water flow to the tank which may cause low oxygen levels. Add supplemental oxygen or increase flow if necessary.

Water temperature: will be measured in °C in a pre- and post-tag holding tank during each tag session. Temperature may be taken with a DO meter. Temperature of the pre- and post-tag holding tanks/buckets should be within 2° C of the ambient water temperature. If readings are outside this range inform your field manager and change the water.

Air temperature: within the surgical area should be controlled to ensure that the fish on the surgical table are not too hot or too cold. Typically, the tagging trailer and post-op recovery trailer are equipped with swamp coolers.

Total dissolved gas (TDG): will be measured as percent saturation twice a day in the head-box and in a recovery bucket. Measure once at the start of the day and again at the end of tagging for the day.

- Measurements will be taken using a TDG meter (various models)
- Gas super saturation (TDG > 110%) may lead to gas bubble disease and must be avoided. Contact your field manager if TDG approaches 110%. Check that water inflows are being off-gassed before use.

Setup of equipment

Tags should be activated, tested, and prepared for implantation (procedure depends on tag type, either radio or acoustic).

Specific directions for Wanapum Dam: Disinfect all tags in diluted chlorhexidine solution (i.e., Nolvasan). The tags remain in disinfectant for at least one hour and then transferred to a distilled water rinse bath to soak overnight. The tags are taken out of the rinse bath and actively rinsed under running distilled water. The tag will be placed, using forceps, in a vessel of distilled water just prior to implantation. Note that some chemicals in certain disinfectants may adversely affect the coating on the transmitters.

Nolvasan is not sold in Canada, Super Germiphene is used instead. The tags must be soaked in the Germiphene solution for a minimum of 10 minutes, and then rinsed in distilled water.

Prepare surgical table (or trough) and equipment for use.

Setup measuring board and scale. All staff must be trained on the use of all weight and length measuring equipment. In some cases the girth of the fish is also measured. This will require a measuring tape.

- Ensure the scale is functioning properly. Scales should be calibrated at the start of the season and whenever they are moved, and should be recalibrated as necessary.
- Put approximately 1-2 ml of diluted stress coat on the surgical table.

Recovery: Recovery buckets/coolers must be filled with untreated river water and supplied with oxygen if necessary. Dissolved oxygen levels should be consistent with that of the river as the recovery buckets are filled with water just prior to the fish being placed in the bucket. If there is a delay (due to rejecting fish) it is the surgeon's decision whether or not to add oxygen to the recovery bucket.

Administration of anesthetic: The effectiveness of MS-222, as an anesthetic, varies with factors such as temperature, size of fish, species, exposure, and fish density.

Adjustment of the anesthesia concentration should be based on the amount of time it takes for a fish to lose equilibrium. However, the anesthesiologist should target between 60-80 mg/L MS 222 concentration level for salmonids. MS222 administration for piscivorous fish will vary - refer to guideline table in the Appendix A. Communication among the tagging crew is very important to ensure that MS-222 is only administered to the anesthetic buckets and gravity feed buckets once. Never administer MS-222 into a bucket until you confirm that no one else has.

Fill the "HEAVY" anesthetic bucket with 10 L of untreated river water. Start with adding approximately 10 ml of MS-222 stock solution to yield a concentration of 56 mg/L. For piscivorous fish studies, a large cooler is used instead of a bucket for the "HEAVY" anesthetic. More than 50 L of untreated river water may be placed in the anesthetic cooler. Therefore, for predator and salmonid studies, adjust the amount of anesthesia concentration accordingly based on the amount of time it takes for a fish to lose equilibrium and the amount of water in the bucket/cooler.

Fill both gravity feed buckets with 10 L of untreated river water. Add 3 ml of MS-222 stock solution to the bucket marked "MS222" for a light dose. Do NOT add MS-222 to the bucket marked "H_20". In piscivorous fish studies, instead of gravity feed buckets, re-circulated water is pumped from the "HEAVY" cooler and flushed over the fish in the tagging trough during surgery or a pitcher can be used to pour the MS222 solution directly over the gills of the fish.

Stress-coat helps maintain the slime coat on the fish, which helps prevent infection and reduce stress. Add the stress coat solution (stress coat solution is 25% stress coat, 75% river water) to all buckets (anesthetic, anesthetic gravity feed, and recovery buckets). Undiluted Stress-Coat is lightly sprayed to the weigh boat and surgery table.

Since MS222 solution changes the pH level of the river water, add a sodium bicarbonate solution (buffer) to any bucket that has anesthetic. Add 1 ml of buffer solution (buffer solution is made from 100 g baking soda and 1L river water) for every ml of anesthetic added.

Water in all buckets (anesthetic and gravity feed) should be changed and monitored periodically to minimize dilution of anesthetic water and temperature changes (such as a temperature change of more than 2° C above or below ambient water temperature) and to ensure that there is sufficient water in your gravity feed buckets to last the complete duration of a surgical tag insertion. Typically, water in the anesthetic and gravity feed buckets is discarded and refilled after about 10 fish were tagged. During warm days water may need to be changed more frequently due to rapid increases in water temperature.

All gravity-feed "MS222" and "H20" buckets will be monitored for dissolved oxygen. Oxygen levels should be maintained near saturation. It is the surgeon's or anesthesiologist's call to add oxygen to the necessary buckets.

Anesthetic and freshwater buckets should be filled and prepared just prior to tagging.

It is recommended that sanctuary nets be used for the transfer of fish between pre-tagging holding tanks and "HEAVY" anesthetic buckets.

Implantation of tags

Anesthetizing fish

A fish is dip-netted (using sanctuary net) from the large holding container and placed in the "HEAVY" anesthetic bucket. Secure the lid of the anesthetic bucket as soon as the fish is in the bucket. After one minute the fish will have slowed down enough to quickly check for abnormalities. If the fish is rejected after one minute then it is transferred to a freshwater recovery tank and released into the river.

If the fish is not rejected after one minute it remains in the “HEAVY” anesthetic bucket. The fish should take an additional 1-3 minutes to loose equilibrium and then it is ready for tagging. If after sedating a few fish, you notice that the time required for fish to lose equilibrium is more or less than normal, then adjust the concentration of the anesthetic up or down. If loss of equilibrium takes less than one minute or greater than 5 minutes, reject the fish. The data recorder will document the time the fish entered “HEAVY” to monitor the duration that each fish is in “HEAVY” anesthetic.

Once the fish loses equilibrium, the surgeon will visually screen the fish for tags, fin clips, fungus, disease, descaling, bloated belly, or any obvious abnormalities. Relay any necessary information to the data recorder. See LGL’s culling SOP for the type of fish that are acceptable for tagging (APPENDIX B).

Rejects – If the fish is unacceptable for tagging, transfer the fish to a freshwater tank and release it into the river once it has regained equilibrium.

Recording fish length and weight

Transfer (using sanctuary net) the anesthetized fish to the scale and weigh the fish to the nearest 0.5 g. The data recorder will stop the “HEAVY” sedation timing once the fish is removed from the “HEAVY” bucket. The data recorder will also document the start time of surgery at this point.

Transfer the fish to the measuring board (on the surgery table) and measure the fork length to the nearest millimeter. Data must be vocally relayed to the data recorder to avoid data errors. The data recorder should then record this information and repeat numbers back to avoid any miscommunication.

Any fish dropped on the floor or ground before tagging must be rejected. A fish that flops from the tagging trough into the surgical table during tagging can still be tagged; exception, if MS222 water enters the incision, reject the fish. If a fish is dropped on the floor after it is tagged, remove the tag and reject the fish.

Surgery

Place the fish on the surgery table ventral side up. Anesthetic should be administered through the gravity feed tubing as soon as the fish is on the surgery table. The tubing must be placed just inside the mouth or as close as possible so the water flows across the gills. The flow of water should be just enough to cover the gills. If the flow is too low, the fish will flare its gills and become agitated. Adjust to a flow that keeps the respiration of the fish normal throughout the surgery. Use the in-line valve to control the flow of anesthetic, fresh water, or a mixture of both. Start with a constant flow of anesthetic and monitor the condition of the fish. In piscivorous fish studies, instead of using gravity feed tubing, anesthetic and river water will be flushed over the gills using either a battery-operated pump or pitcher.

Using a scalpel, make an incision, approximately 8 mm in length (dependent on tag size), about 3 mm away from and parallel to the mid-ventral line. Start your incision a few millimeters anterior to the pelvic girdle (Figure 1). The incision should be just deep enough to penetrate the peritoneum (the thin membrane separating the gut cavity from the musculature), avoiding the internal organs. The spleen is close to the incision position, so pay close attention to the depth of the incision.

- There is no exact specification for what size scalpel blade to use for each fish. For most smolts, we use a veterinary purchased #15 disposable scalpel. Since fish come in all sizes, there will be fish for which a #10 scalpel is more appropriate (e.g., for piscivorous fish).

You may prefer to use a micro-scalpel on small fish. You can decide which scalpel you prefer in the pre-season training session.

- One scalpel blade can be used on about 7-10 fish before it becomes dull. If the blade is pulling roughly or making jagged incisions, it needs to be changed immediately. If you believe you cut an internal organ, do not implant the tag, stitch the incision, and reject that fish. Excessive bleeding should be noted on the datasheet.

Figure 1. Ventral view of a juvenile salmonid showing the location and proper placement of incision.

<u>Antenna insertion</u>

- If the tag does not have an antenna, skip to Section 4.C.iv.
- There is no exact specification for what size catheter to use for each fish. For juvenile salmonids we typically use 16 gauge catheter size for smolts, and 14 gauge for adults.
- If the tag has an antenna, make an antenna exit site in the body wall using a shielded needle. Holding the shielded needle between thumb and forefinger, guide it through the body cavity, keeping the needle tip covered by the catheter to protect the organs. Using your thumb and forefinger, push the end of the needle through the catheter to puncture the body wall. The exit hole should be located posterior to the incision, between the pelvic girdle and viscera, to a point 5-10 mm off-center from the mid-ventral line and posterior to the origin of the pelvic fins (Figure 2). Figure 3 is a photograph of the lateral view of an adult bull trout showing proper placement of the antenna exit hole in relation to the incision. Note the incision for the bull trout is closer to the pelvic girdle due to the length limitation of the catheter.
- One end of the catheter should remain in the body wall while the needle is removed from the catheter sheath. While removing the needle, take care to control the free end of the catheter sheath as it slides off the needle.

- Route the antenna through the free end of the catheter sheath until it slides out of the other end. Gently pull the sheath out of the body wall, leaving the antenna threaded through the side of the fish.

Gently push the tag into the body cavity. It should lie directly under the incision and will aid in keeping the organs from protruding through the incision. If the tag has an antenna, you can gently pull on the antenna to help position the tag within the body cavity. If the tag is dropped prior to implanting into the fish it will be necessary to soak the tag in a chlorhexidine solution for a minimum of 10 minutes, then rinsed thoroughly with distilled or de-ionized water before being put into another fish.

Figure 2. Lateral view of a juvenile salmonid showing proper placement of the antenna exit hole.

Figure 3. Lateral view of an adult bull trout showing proper placement of the antenna exit hole in relation to the incision. Note the incision for the bull trout is closer to the pelvic girdle due to the limited length of the catheter.

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Begin suturing the incision. Two or three interrupted stitches are usually used to close the incision, depending on the size of the tag and incision. For larger piscivorous fish (e.g., bull trout, walleye, etc) you may need a maximum of 5 stitches to close the incision.

- To make a stitch, lock the needle (at the end of the suture) in the needle drivers so the needle point faces you. Enter the outside edge of the incision on the side farthest from you and exit through the other edge of the incision, pulling the suture perpendicular through the two edges. The needle should enter and exit the skin as close to the edge of the incision as possible without tearing the skin (~ 2 mm from edge of incision). Pull the needle and suture through the skin to leave a tag end of about 2-3 cm of suture material protruding from the needle entrance location, then release the needle from the needle drivers. With your non-dominant hand, grasp the long end of the suture material (usually with thumb and forefinger) at or below the needle, and make two forward wraps (i.e., away from your body) around the tip of the needle driver, which should be held in your dominant hand. With the two wraps still around the needle driver, grasp the short end of suture material with the needle driver and tighten the stitch by pulling the wraps off the needle driver and pulling both ends of suture material perpendicular to the incision. On the first knot, the dominant hand holding the needle driver should pull toward your body and the non-dominant hand should pull away from your body. Tighten the suture lightly, just so the edges of the incision meet, but do not overlap, pucker, or bulge the edges of the incision. The second knot is in reverse order from the first knot and there is only one wrap with the suture material around the needle holder. The second knot is looser than the first, again taking care not to overlap, pucker, or bulge the edges of the incision. This allows room for tissue swelling. On the third knot, grasp the long end of suture material with your non-dominant hand, make one reverse wrap (i.e., towards your body) around the end of the needle driver, grasp the short end of suture with the needle driver, and tighten the stitch. This time, the knot should be tightened by pulling your dominant hand (holding the needle drivers) away from you and your non-dominant hand toward you. This completes one stitch. Cut the suture with the needle drivers, leaving ends approximately 5 mm in length.

  An alternative stitch consists of three knots, each with two wraps around the needle driver. The first knot consists of two forward wraps around the needle driver, and then is tightened by pulling the needle forward toward your body. The second is the same as the first, but in reverse order as described above.

  In addition, another alternative stitch consists of four knots; with the first throw consisting of two wraps and the three remaining throws only have one wrap around the needle driver. This stitch can be modified and used for any suture material (e.g., monofilament, vicryl, etc.). For vicryl suture material, three knots may give sufficient knot security (see above). See “additional reference” list for further discussion of suture materials and knot types.
- When making wraps around the needle driver, it is easiest to make the wraps closer to your hand holding the suture, rather than closer to the fish. After making wraps around the needle driver, be sure to

grab (with the needle drivers) the short end of the suture close to the end of the suture material. If you grab the suture material closer to the fish than to the end of the suture, then the tag end will fold onto itself, get tightened into the knot, and leave two strands of suture material in the knot. This is a common mistake.

- When pulling a knot tight, be sure the knot lays flat and does not twist onto itself into a "balled-up" knot. If the knot begins to "ball-up" when pulling tight, it can sometimes be coaxed to lay flat by twisting the suture material between your thumb and forefinger. With experience, each surgeon develops their own "tricks" for making sure the knot lays flat. Although not every knot is perfect, you should strive for perfection on every stitch, rather than settling for an imperfect stitch. An imperfect stitch will be more likely to come untied, possibly resulting in slower wound healing or tag loss, which could ultimately affect the survival of the fish or bias the study results.
- There is no exact specification for what size suture to use. Generally, 4-0 suture is used for hatchery steelhead, which typically weigh greater than 50 g. For fish weighing less than 50 g, such as yearling and subyearling Chinook or sockeye salmon, 5-0 suture is used. The 3-0 suture is used for bull trout and other adult / piscivorous fish. A tapered needle is used on all juvenile salmonids and some adult salmon/ non-salmonids; however, if the skin/scales are thick and tough (i.e. Smallmouth Bass) a cutting needle is suggested. Since fish come in all sizes, there will be some overlap in these approximate parameters.
- Generally, a good time to switch the in-line valve on the gravity feed buckets or hose to untreated river water is just prior to the last stitch. This initiates recovery from anesthesia as early as possible. However, if the fish appears to be inadequately gilling, you should provide a mixture or all fresh water as soon as possible. If the fish is reviving too quickly and the surgery is not yet complete, do not switch to fresh water.
- If the incision is too long, it is acceptable to add a third stitch. Relay this information to the data recorder so that note can be made on the datasheet.
- If a radio tag has been used, attach the antenna to the side of the fish with a single suture in the caudal peduncle about 5-6 mm posterior to the antenna exit site.
- Because sutures are long, each individual suture (one packet) can be used on 4-6 fish.

When multiple successive fish are to be tagged, and to keep the tagging process flowing, the anesthesiologist should start sedating the next fish before the first fish's surgical procedure is complete. The surgeon should indicate to the anesthesiologist when the next fish should be sedated. Typically, a good time to start sedation on the next fish is immediately after the previous fish has been taken out of the HEAVY bucket.

Post-surgery

Transfer the fish from the surgery table directly to a labeled recovery bucket using your gloved hands. The data recorder will document the end time of surgery at this point. The data recorder should also record the label of the bucket as the location for that fish. There should be no more than 2 fish per recovery bucket. Recovery buckets are hooked up to flow-through river-water in the post-tagging recovery facility.

For predator studies, the post-surgical process will be similar to the salmonid studies, but will vary depending on the number of fish caught.

Between surgeries, the surgeon should prepare their tools for the next surgery. Disinfect the tools in chlorhexidine solution and ensure that the scalpel blade and suture are acceptable to use on the next fish. If necessary, replace the scalpel blade, suture or catheter. All surgical equipment must be disinfected (by soaking them in chlorhexidine solution for several minutes - see directions on bottle, typically at least 10 minutes) between each fish to avoid transmitting disease among individuals. Once disinfected in, rinse the tools thoroughly with distilled or de-ionized water. It may be necessary to have 3-4 sets of surgical instruments which are rotated in order to increase soak time between uses. Organic debris in the disinfectant bath reduces its effectiveness, so be sure to change the disinfectant baths regularly.

Tagged fish are checked at various times throughout the day. Typically tagged fish are checked approximately 2 hours after surgery. If a tagged fish does not exhibit signs of proper swimming behaviour or has not gained equilibrium it is up to the surgeon to decide if the fish should be rejected. If the fish is rejected then the tag is pulled, soaked in a chlorhexidine solution for a minimum of 10 minutes, then rinsed thoroughly with distilled or de-ionized water before being put into another fish. The rejected fish is re-sutured and released into the river.

Optimal post-op recovery time should be 15-24 hours, and should not exceed 36 hours. Post-op holding time should start when the last fish is tagged. Therefore, the first fish of the day could be held about 8 hours longer than the last fish of the day. Currently, GCPUD study fish are held up to 24 hours after surgery. This will not pertain to piscivorous fish studies.

In piscivorous fish studies, once the fish has gained equilibrium and exhibits signs of normal swimming behaviour the fish will be released back into the reservoir in the same area that they were caught.

Cleanup at the end of the tagging day

Wipe down all counter tops, scales and measuring boards with the Germiphene solution to disinfect. Germiphene solution should not be made of river water, but rather distilled water.

Soak scalpels, catheters, forceps, and scissors in chlorhexidine solution and thoroughly dry to prevent rusting.

Scrub needle drivers with a small brush or scour sponge.

Wanapum has an autoclave for the sterilization of instruments. All autoclavable surgical equipment should be autoclaved prior to the next days tagging session. Most other tagging projects do not have autoclaves available, so sterilization is not possible.

Buckets and nets should be washed with Germiphene solution and then rinsed thoroughly with untreated river water and placed upside down to dry. Buckets that contained fish that died need to be scrubbed with disinfectant and rinsed before being placed upside down to dry for 24 hours.

Store electronics in proper cases.

Extra fish in the pre-tagging holding tanks are released back into the river. Empty holding tanks are scrubbed, flushed, and either re-filled (for use the next day), or left empty.

Datasheets

The appropriate tagging and water quality data sheets for your project will be filled out before and during tagging. At the end of the tagging day, the field manager should review these datasheets to ensure proper collection procedures were followed.

LGL/GCPUD FIELD STANDARD OPERATING PROCEDURES

REFERENCES: *(The above surgical methods are documented in the following reports.)*

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2002

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ANESTHETIC GUIDELINES FOR PISCIVOROUS FISH

Table 1. Concentrations Required For Rapid Anesthesia (induction Time Less Than 2-5 Minutes; Used In Spawning, Marking, Measuring, And Some Surgical Operations):

Drugs.com. 2011. Finquel MS-222 (Tricaine Methanesulfonate) <http://www.drugs.com/vet/finquel-ms-222-tricaine-methanesulfonate.html > Website referenced April 2011

Fish	Temperature	Concentration (mg/liter)	Max. Tolerated Exposure Time* (min.)	Recovery Time In Fresh Water (min.)
Salmonidae [4] (Pacific and Atlantic salmon; trout; chars; etc.)	7-17°C (45-63°F).	80-135	4-12	3-19
Esocidae [5] (Northern Pike; muskellunge)	8-12°C (46-54°F).	150 28 ml for heavy dose in 10 L of water	8-28	8-31
Cyprinidae [3] (Carp; goldfish)	16°C (61°F).	150-200		
Ictaluridae [2] (Channel catfish)	7-27°C (45-81°F).	140-270 start with 26 ml for heavy dose up to 48 ml for 10 L water	4-11	3-24
Centrarchidae [6] (Bluegill; largemouth bass)	10-27°C (50-81°F).	260-330	3-5	7-11
Percidae [5] (Walleye)	10-16°C (50-61°F).	100-120 18 ml – 22 ml for heavy dose in 10 L water	7-18	5-40
Pet and Tropical [7]				
Live-bearers	24-27°C (75-81°F).	85	12 hrs.	
Egg layers	24-27°C (75-81°F).	75	12 hrs.	

** Maximum tolerated exposure time (in minutes) of fish to FINQUEL solution*

Culling Guidelines for Juvenile Salmonids

A Criteria for culling fish prior to a tagging session (fish sorters and taggers)

1) Anesthetize all fish with MS-222 prior to handling.

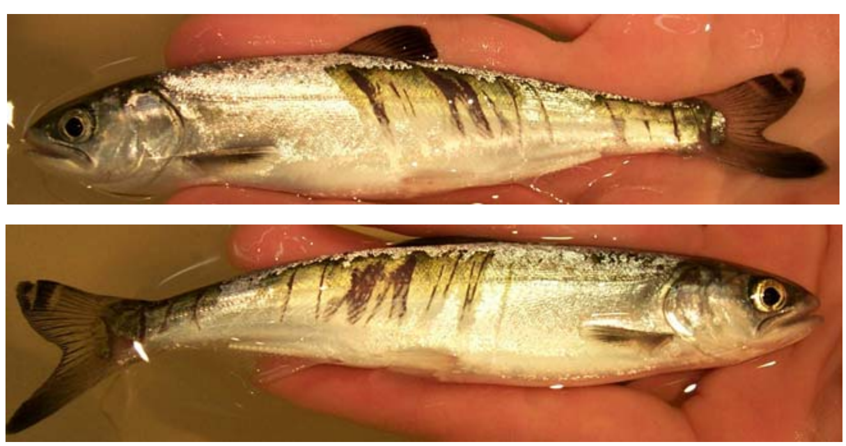
2) Keep fish underwater throughout the examination process, handling fish as quickly and gently as possible.

3) Examine fish individually for external marks before tagging, including:

- **Scale loss: *Normal* (< 4%); *Partial* (4-19%); *De-scaled* (>19%);**

Scale loss is calculated per side. For example, 10% scale loss on each side would not be a reject, whereas 20% on one side would. Divide fish into ~ 25% portions as a reference when estimating scale loss. Example of normal (< 4%) scale loss (top) and partial scale loss (4-19%).

- **Bird wounds, head and body injuries, net marks, bleeding, etc.;**



- **Fungus, parasites, leeches and overall fish health. Note in 2011, GCPUD gave us permission to tag sockeye with gill parasites covering less than 33% of each gill. Sockeye exhibiting more than 33% parasite coverage per gill were culled).**

- **Missing or extremely damaged fins (tattered fins are acceptable);**
- **Severe abnormalities (stunted, duplicated fins, etc.);**

- **Signs of BKD include hemorrhaging near the eyes and bloating;**

- **Elastomer or VI (visual implants) marks, or other brands (note in 2011 , GCPUD gave us permission to tag all elastomer tagged fish);**

- **PIT tag entry scars (between pectoral and ventral fins);**
- **Cull all fish that have been previously anesthetized, handled, and tagged (except elastomer tagged fish).**

4) Size criteria (exclude):

- Fish weight under 15.2 g.
- Sockeye over 210 mm
- Steelhead over or 89 g.
- Do not tag any fish that have been dropped or mishandled in any way.

B Criteria for culling fish during a tagging session (criteria for taggers only)

1) Do not tag any fish you feel does not exhibit the same behavior as the group of fish being tagged during each tagging session. For example, if you have a fish that loses equilibrium in substantially less time (compared to the other fish you have been anesthetizing), there is probably a reason. The fish might have been handled recently or is unhealthy.

2) Do not tag a fish that exhibits excess bleeding during tagging.

3) Do not tag a fish that has excess body fluid once incised (sign of BKD).

C Criteria for culling fish post-tagging (criteria for taggers only)

1) If a tagged fish does not exhibit signs of proper swimming behavior or has not gained equilibrium within 2 hours of being tagged, it should be rejected. If the fish is rejected then the tag is pulled and put into another fish. The rejected fish should be re-sutured and released into the river.

D Overall

1) Keep an accurate tally of all rejected fish and the reasoning you used to reject it. Keep an accurate tally of all surplus fish.

GCPUD Culling Guidelines for Piscivorous Fish:

DO NOT TAG IF:

- Fish exhibits signs of decompression;
- Fish does not gain equilibrium and exhibit proper swimming behavior after being tagged; and
- Fish is in MS-222 for a period longer than 5 min.

Signs of Decompression issues where a fish should not be tagged include:

- Protruding stomach or other organs from the mouth;
- Any eye issues: protruding, embolisms, discolored or cloudy;
- Protruding cloacae;
- External hemorrhaging;
- External skin embolisms; and/or
- Stomach bloating appears to be moderate to high.

OK TO TAG IF:

- Stomach bloating: None to Slight;
- Yellow discoloration;
- Red dots on fins or skin;
- Minor bleeding (i.e. hook in mouth caused minor bleeding);
- Leeches and parasites present Open wounds;
- Bleeding (either due to injury, tagging or because of angling hook);
- Fungus infection;
- Missing or extremely damaged fins (tattered fins acceptable);
- Severe abnormalities (stunted, duplicated fins);
- Scale loss >19% on one side of the fish;
- Fish dropped on ground; and
- Excessive body fluid once incised.

Document updated 26 August 2011.

Appendix B

Survival Analysis of the Juvenile Steelhead in the Wanapum-Priest Rapids Project, 2011

The reach and cumulative survival presented has been provided by Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington. For further information, please contact John Skalski at (206) 616-4851.

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Analysis of the JSATS Steelhead Study at Wanapum – Priest Rapids Project in 2011

Prepared for:
Curt Dotson
Public Utility District No. 2 of Grant County, Washington
P.O. Box 878
30 C Street SW
Ephrata, Washington 98823

Prepared by:
John R. Skalski
Richard L. Townsend
Columbia Basin Research
School of Aquatic and Fishery Sciences
University of Washington
1325 Fourth Avenue, Suite 1820
Seattle, Washington 98101-2509
and
Mark A. Timko
Leah S. Sullivan
Blue Leaf Environmental
2301 W Dolarway Road, Suite 3
Ellensburg, Washington 98926

14 October 2011

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Methods

Survival Estimation

The run-of-river steelhead smolt JSATS data were analyzed using the single release-recapture model of Skalski et al. (1998), corrected for the probability of tag failure using the methods in Townsend et al. (2006). Reach survivals (survival from one detection array to the next) were estimated, along with associated standard errors. The reach survival estimates were also re-expressed in terms of survival on a per-river-mile (RM) basis using the transformation

$$\hat{S}_{\text{Per RM}} = \sqrt[k_i]{\hat{S}_i} \tag{1}$$

where

$\hat{S}_i$ = survival in the *i*th reach,

k_i = length of the river reach in RM.

For example, the area between arrays at RM 416 and RM 413 defines a three-mile reach. Reach survival was 0.9816 overall, with a 0.9938 per RM survival rate (0.9938*0.9938*0.9938 ≈ 0.9816). The variance of the per-RM survival probabilities was derived using the delta method (Seber 1982:7-9), where

$$\text{Var}\left(\hat{S}_{\text{Per rm}}\right) = \text{Var}\left(\hat{S}_i\right)\left(\frac{1}{k_i}\hat{S}_i^{\frac{1}{k_i}-1}\right)^2. \tag{2}$$

Downstream cumulative survivorship curves were derived from the reach survival estimates based on the relationship

$$\hat{S}_{(j)} = \prod_{i=1}^{j}\hat{S}_i \tag{3}$$

where $\hat{S}_{(j)}$ = cumulative survival to the *j*th reach. The variance of $\hat{S}_{(j)}$ was derived using the delta method, taking into account the variance-covariance matrix for the individual reach survival estimates.

Statistical comparison of individual reach survivals was based on the asymptotic *Z*-test

$$Z = \frac{\hat{S}_i - \hat{S}_j}{\sqrt{\text{Var}\left(S_i\right) + \text{Var}\left(\hat{S}_j\right) - 2\text{Cov}\left(\hat{S}_i, \hat{S}_j\right)}}. \tag{4}$$

Comparison of survivorship curves was based on likelihood ratio tests. All tests were performed at α = 0.10. An α level of 0.10 was selected over, say, α = 0.05, for higher statistical power to detect difference in reach survival if they occurred.

Tag-Life Adjustments

The standard single release-recapture model estimates the joint probability of the fish being alive and the tag being active at a detection site. Tag-life adjusted survival estimates were calculated based on smolt travel times and an independently estimated tag-life curve. A total of 50 tags were systematically sampled during the fish tagging process to perform a tag-life study. Those tags were continuously monitored in ambient river water until failure.

The failure-time data were fit to a four-parameter vitality model of Li and Anderson (2009). The survivorship function was then integrated over the travel times of the smolts to a detection site to calculate the overall probability of a tag being active at a downstream detection location.

Tests of Assumptions

Examination of Tagger Effects

Three taggers were responsible for tagging all the fish in the survival study. The distribution of tagger effect over time was examined using an R × C contingency table (i.e., 3 taggers × 8 release groups) test of homogeneity.

Pooling all the fish tagged by a tagger, reach survivals were estimated for each reach. A test of homogeneous survival was tested using the asymptotic *F*-test

$$F_{2,\infty} = \frac{s^2_{\hat{S}_i}}{\left(\frac{\sum_{i=1}^{3} \widehat{\text{Var}}\left(\hat{S}_i \middle| S_i\right)}{3} \right)}$$

where

$$s^2_{\hat{S}_i} = \frac{\sum_{i=1}^{3} \left(\hat{S}_i - \hat{\bar{S}}\right)^2}{(3-1)},$$

$\widehat{\text{Var}}\left(\hat{S}_i \middle| S_i\right)$ = estimated sampling variance for the survival estimate for fish tagged by the *i*th tagger $(i = 1,\ldots,3)$.

Tests were performed on a reach-by-reach basis and examined for consistency of patterns.

Appropriate Reach Size

The single release-recapture model assumes all mortality events occur between detection sites and not *at* the detection sites. This assumption is largely satisfied by making the reaches relatively large compared to the detection zones of the individual hydrophone arrays. In the 2011 study, however, detection arrays varied between 0.5 and 1.0 RM apart with each array having about a 0.3-RM detection width. Arrays too close together can make assignment of mortalities within a reach difficult and potentially violate the assumption of independent detection events between arrays.

In order to identify the smallest, yet proper, spacing between hydrophone arrays, the JSATS data were analyzed using alternative array spacing. The original array spacing, every other array, every third array, etc., was analyzed to estimate reach survivals. Two criteria were used in selecting the optimal array spacing for this report.

1. Individual reach survival should have survival estimates ≤ 1 and the cumulative survivorship curve should be monotonically decreasing.
2. The product of the individual survivals, i.e.,

$$\hat{S}(k-1) = \prod_{i=1}^{k-1} \hat{S}_i$$

   should closely approximate the overall survival estimate obtained using just the last two detection arrays (i.e., arrays $k - 1$ and k) in a survival analysis.

All analyses in the report are based on the proper spacing identified by the initial analysis, given in Section 2.1, in three-mile reaches. **One final note**: though the release site is designated as RM 420 throughout the report, the actual release location was estimated to be RM 419.7. This matters when estimating survival/RM in the first reach.

Adjustment of Dead Fish Detections

A total of 50 dead tagged fish were released below Wanapum Dam (RM 416) to determine whether false-positive detections might occur at downstream detection arrays as a result of the fish that died during dam passage still having active tags and floating downriver. Empirical results found 20 of the 50 dead tagged fish detected at the first downstream detection array below Wanapum Dam (deployed at RM 415) but no detections elsewhere. Because of the strategic array reselection of arrays used in the final analyses (see Section 2.1 and Table 2.1), the array at RM 415 was omitted, eliminating the need for any adjustments in survival results.

Results

Optimal Reach Designations

The detection arrays were originally placed between 0.5–1.0 RM apart in an attempt to find locations of any mortality "hot spots" in the Priest Rapids Reservoir. Initial analysis found, in general, that individual reach survivals were very high (often >>0.99) with point estimates often >1.0 (Table 2.1). To allow more distance for mortality to operate and to be expressed, and to better assign mortality events to the correct reaches, longer reaches were selected for the final analysis.

Detection arrays were selected such that the resulting reaches within the Priest Rapids Reservoir were approximately of equal length and 3 RM apart. This reduced the original 23 detection arrays to 10 detection arrays, and the reaches from 23 to 10. The resulting spacing of the detection arrays tended to produce individual reach survivals that were always ≤ 1 and produced standard errors that were smaller than produced by the original array design (Table 2.1). The resulting cumulative survival curve was monotonically decreasing as the fish traveled downriver. This reduced array design was the basis of all subsequent analyses.

Tag-Life Analysis

The failure times of the 50 tags in the tag-life study were fit to the four-parameter vitality model of Li and Anderson (2009) (Figure 2.1). The average life expectancy of the tags was 23.375 days. All study fish passed through the last hydrophone detection array RM 395 before the first tag failed in the tag-life study (Figure 2.2). The vitality model estimated the probability of a tag being active at all detection sites to be 1.0. Therefore, no tag-life corrections were required or used in the analyses of the 2011 acoustic-tag study.

Tagger and Tag-Lot Effects

Three different taggers (i.e., A, B, and C) tagged all the fish in the 2011 JSATS study (Table 2.2). The distribution of tagger effort was not evenly distributed across the season $\left(P\left(\chi^2_{34} \geq 575.4\right) \approx 0\right)$. Tagger B worked throughout the study, while tagger A worked the last three quarters of the study and tagger C worked only during the first quarter of the study.

Table 2.1. Reach survival estimates, standard errors $\left(\widehat{\mathrm{SE}}(\hat{S})\right)$, and detection probabilities based on the original 23-array design and the 10-array reconfigured design.

Original arrays				Reduced arrays			
Array	$\hat{S}$	$\widehat{\mathrm{SE}}(\hat{S})$	$\hat{p}$	Array	$\hat{S}$	$\widehat{\mathrm{SE}}(\hat{S})$	$\hat{p}$
Release – 416	0.9661	0.0057	0.9918	Release –416	0.9661	0.0057	0.9918
416 –415	1.0258	0.0169	0.1361	416–413	0.9816	0.0046	0.6825
415–413.5	0.9556	0.0177	0.3618				
413.5–413	1.0010	0.0007	0.6829				
413–412	0.9969	0.0022	0.3710	413–410.5	0.9974	0.0028	0.7234
412–411.5	1.0000	0.0000	0.5539				
411.5– 411	1.0000	0.0000	0.0677				
411–410.5	1.0004	0.0004	0.7238				
410.5–410	1.0021	0.0023	0.5420	410.5–408	0.9928	0.0033	0.9531
410–409	0.9922	0.0039	0.8225				
409–408	1.0000	0.0000	0.9522				
408–407.5	1.0000	0.0000	0.1796	408–406	0.9993	0.0011	0.9346
407.5–407	1.0002	0.0002	0.9084				
407–406	0.9980	0.0017	0.9348				
406–405	0.9955	0.0023	0.9443	406–403	0.9940	0.0028	0.9403
405–404	0.9989	0.0011	0.9775				
404–403	0.9991	0.0011	0.9409				
403–402	0.9978	0.0021	0.7829	403–400	0.9901	0.0042	0.6328
402–401	0.9966	0.0029	0.7199				
401–400	0.9944	0.0035	0.6340				
400–398.5	0.9965	0.0031	0.6689	400-397	0.9935	0.0043	0.9712
398.5–397	0.9989	0.0029	0.9712				
397–396	0.9987	0.0190	0.6121	397-396	0.9987	0.0190	0.6121

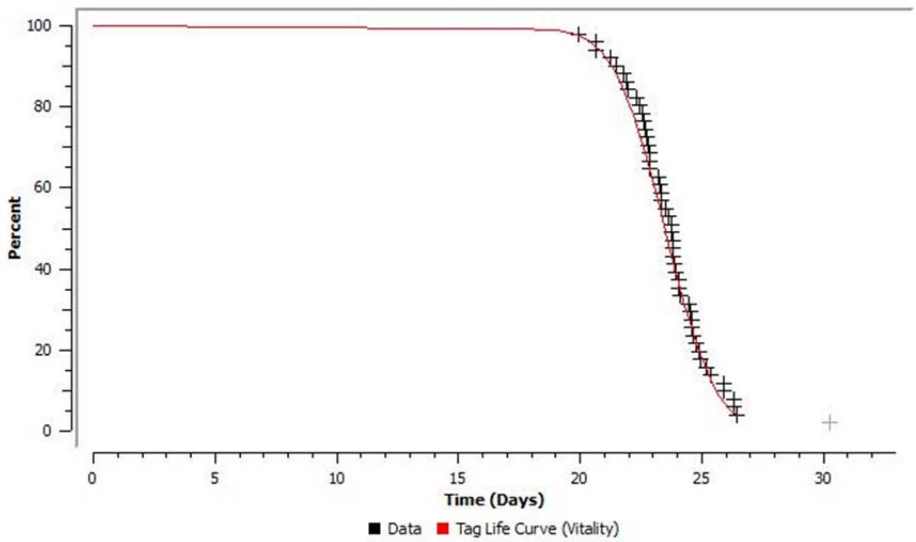

Figure 2.1. Fitted vitality curve (Li and Anderson 2009) to the 2011 JSATS tag-life data.

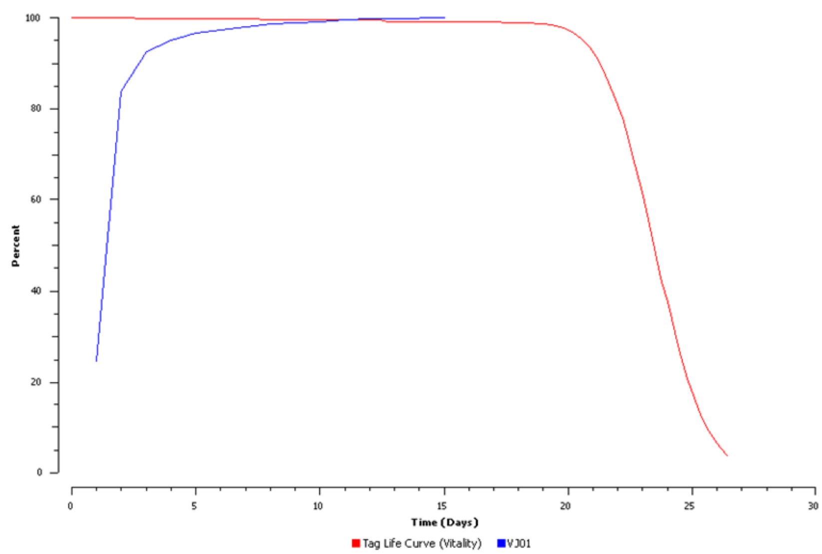

Figure 2.2. Cumulative arrival distribution of steelhead at the last detection array (RM 395) and the fitted tag-life curve for the 2011 JSATS study at Grant County PUD. Graph illustrates all fish passing through the study area before tag failures begin.

Table 2.2. Numbers of fish tagged by each staff member during the 18 replicate releases of steelhead smolts over the course of the 2011 study. Chi-square test of homogeneity was significant $\left(P\left(\chi^2_{34} \geq 575.4\right) \approx 0\right)$.

Release	Tagger A	Tagger B	Tagger C
1	0	23	27
2	0	54	0
3	0	32	24
4	0	41	15
5	0	57	0
6	33	26	0
7	29	30	0
8	30	31	0
9	34	31	0
10	31	35	0
11	30	30	0
12	26	34	0
13	31	28	0
14	31	27	0
15	29	28	0
16	30	25	0
17	24	27	0
18	26	23	0

Tagger effects were examined during sub-blocks of the study. Fish tagged by taggers B and C had no significant differences in survival for replicates 1–4 ($P \geq 0.1738$) (Table 2.3). Taggers A and B has no significant differences in the survival of the fish they tagged during replicates 6–18 ($P \geq 0.6209$) (Table 2.3). We therefore concluded no apparent tagger effects were present that could have negatively impacted the study.

A total of 8 different tag lots were used during the course of the study. The tag lots were received as the study progressed. Consequently, tag lots were not homogeneously distributed over the course of the study, i.e., over the replicate releases $\left(P\left(\chi^2_{119} \geq 1590.8\right) \approx 0\right)$ (Table 2.4). Examination of the reach survivals by tag lot found none of the reach survivals to be significantly different within a reach ($P \geq 0.1162$) (Table 2.5). Consequently, all tag lots were used in the survival analysis.

Survival Estimates

Overall Survival Trends

Pooling the capture histories for the 18 replicate releases resulted in an overall survival probability of $\hat{S}$ = 0.9661 ($\widehat{SE}$ = 0.0057) from release (RM 420) to RM 416 (Figure 2.2), just above Wanapum Dam (Table 2.6). Survival through Wanapum Dam to RM 413 (i.e., RM 416 to RM 413) was estimated at $\hat{S}$ = 0.9816 ($\widehat{SE}$ = 0.0046). Survival between RM 413 to RM 397 (just above Priest Rapids Dam) was estimated to be $\hat{S}$ = 0.9675 ($\widehat{SE}$ = 0.0078). Survival through Priest Rapids Dam (RM 397) to RM 396 was estimated to be $\hat{S}$ = 0.9987 ($\widehat{SE}$ = 0.0190). It should be noted this last estimate is likely positively biased by false positive detections due to fish that died during passage through Priest Rapids Dam and still have active tags as they floated past the array at RM 396. Overall survival from release (RM 420) to RM 396 was estimated to be $\hat{S}$ = 0.9163 ($\widehat{SE}$ = 0.0194) (Table 2.6). Again, this estimate is likely positively biased by false-positive detections due to fish that died during passage through Priest Rapids Dam with still active tags one mile beyond the detection array at RM 396. This survival estimate includes downstream passage through two dams, Wanapum and Priest Rapids dams, as well as the Priest Rapids Reservoir. The cumulative survivorship curve illustrates the drop in survival from initial release to RM 416, another drop in survival through Wanapum Dam at RM 413, and then a very shallow rate of decline in survival within the Priest Rapids pool (i.e., RM 413–397) (Figure 2.3).

Pairwise comparisons of reach survivals (Table 2.7) and of reach survival rates (survival/RM) (Table 2.8) indicate a similar pattern of results. Steelhead within reach RM 408-406 had significantly higher survival than all other Priest Rapids Reservoir reaches (i.e. RM 413-397), except for reach RM 400-397. None of the other within-Priest Rapids pool reaches were significantly different from one another ($P > 0.10$). The only consistent differences in survival were associated with the release at RM 420 to RM 416, and through Wanapum Dam (RM 416-413). Those two reaches had significantly lower survival than almost all of the within-Priest-Rapids-pool reaches (Table 2.7)

Per-mile survival rates varied among the six within-Priest Rapids Reservoir reaches from 0.9967 to 0.9996 per mile (Table 2.8). On a per-mile basis, the survival rate through reach RM 408-406 was significantly higher than RM 410.5-408 and RM 403-400 (Table 2.8). None of the survival rates at the other reaches within Priest Rapids Reservoir (i.e., RM 413-397) were significantly different from one another. The most notable differences were the lower survival rates from RM 420 to RM 416, immediately after release, and through Wanapum Dam (i.e., RM 416-413). These survival rates were generally significantly lower than the reaches within Priest

Rapids Reservoir. There is no evidence of a mortality "hot spot" within the Priest Rapids Reservoir. If one exists, the data suggests reach RM 403-400, with the lowest point estimate, would be the best candidate for further investigation.

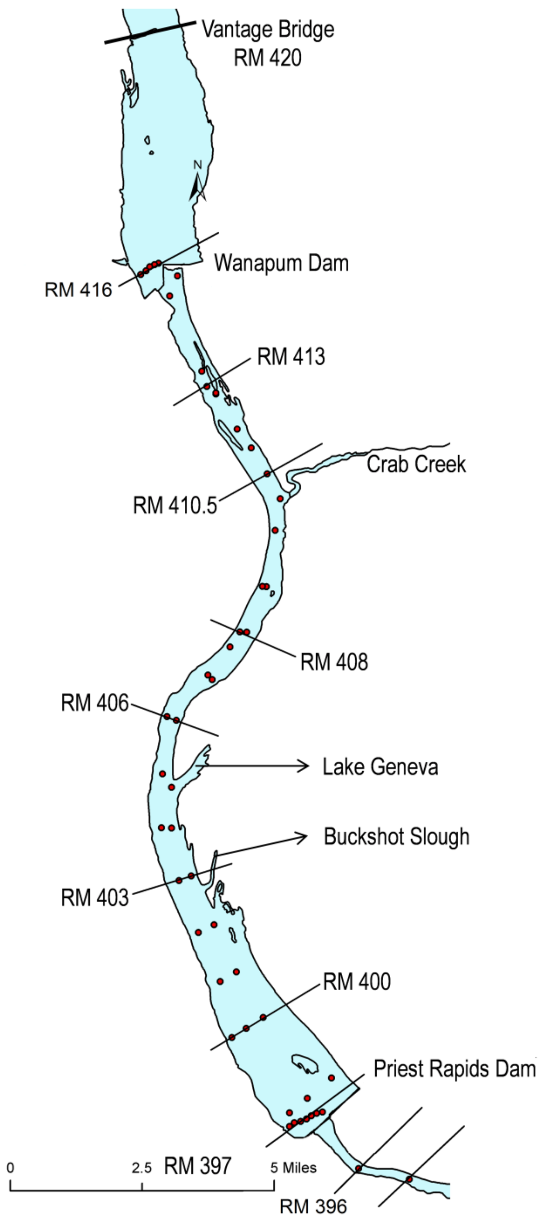

Figure 2.2. Map showing the final arrays used to estimate survival in the Priest Rapids Reservoir.

Table 2.3. Reach survival estimates by tagger, comparing taggers B and C for replicate releases 1–4 and taggers A and B for replicate releases 6–18. *P*-values for *F*-tests of homogeneous survival presented. No significant tagger effects found for any of the reach survival comparisons ($P \geq 0.1738$).

Release group	Tagger	Release to 416		416 to 413		413 to 410.5		410.5 to 408		408 to 406		406 to 403		403 to 400		400 to 397		397 to 396	
		$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
1–4	B	0.9533	0.0172	1.0000	NA	1.0009	0.0009	0.9919	0.0080	1.0006	0.0006	0.9926	0.0078	0.9850	0.0106	1.0022	0.0013	0.9600	0.0219
	C	0.9846	0.0153	0.9839	0.0160	1.0018	0.0020	0.9818	0.0180	1.0000	N/A	1.0000	N/A	1.0000	N/A	1.0013	0.0015	1.0131	0.0576
***P*-value**		*0.1738*		*N/A*		*0.6780*		*0.6086*		*N/A*		*N//A*		*N/A*		*0.6470*		*0.3890*	
6–18	A	0.9717	0.0085	0.9790	0.0089	0.9914	0.0072	0.9957	0.0043	1.0004	0.0003	0.9922	0.0052	0.9899	0.0077	0.9909	0.0085	1.0587	0.0465
	B	0.9654	0.0095	0.9790	0.0082	0.9981	0.0052	0.9914	0.0061	0.9975	0.0030	0.9944	0.0045	0.9937	0.0072	0.9881	0.0088	1.0113	0.0377
***P*-value**		*0.6209*		*1.0000*		*0.4503*		*0.5639*		*0.3434*		*0.7499*		*0.7196*		*0.8191*		*0.4287*	

Table 2.4. Numbers of fish tagged per tag lot and replicate release group during the 2011 JSATS study at Grant County PUD. Tag lots were not homogeneously distributed across replicate release groups $\left(P\left(\chi^2_{119} \geq 1590.8\right) \approx 0\right)$ because of their sequential use over the course of the study.

Release group	Lot number							
	SS32008	SS32044	SS32091	SS32101	SS32145	SS32158	SS32207	SS32258
1	34	16	0	0	0	0	0	0
2	17	7	16	14	0	0	0	0
3	22	4	16	14	0	0	0	0
4	17	8	15	16	0	0	0	0
5	14	7	24	12	0	0	0	0
6	13	2	14	14	16	0	0	0
7	14	5	18	5	17	0	0	0
8	8	5	19	8	21	0	0	0
9	12	5	15	8	16	9	0	0
10	13	2	7	2	23	19	0	0
11	11	4	12	2	16	15	0	0
12	13	5	11	3	10	18	0	0
13	11	2	13	7	13	13	0	0
14	10	9	5	6	8	12	8	0
15	9	4	5	2	15	9	13	0
16	3	8	7	6	8	6	17	0
17	7	8	8	6	12	3	7	0
18	1	1	0	1	0	0	0	46

Table 2.5. Reach survival estimates by tag lot. *P*-values associated with the *F*-test of homogeneous survivals.

	Release to 416		416 to 413		413 to 410.5		410.5 to 408		408 to 406		406 to 403		403 to 400		400 to 397		397 to 396	
Tag Lot	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
SS32008	0.9527	0.0145	0.9862	0.0108	1.0013	0.0085	0.9940	0.0103	1.0006	0.0086	0.9959	0.0103	0.9872	0.0131	0.9959	0.0126	0.9894	0.0334
SS32044	0.9909	0.0103	0.9902	0.0125	1.0000	0.0083	1.0001	0.0085	1.0000	0.0090	1.0008	0.0095	0.9956	0.0159	0.9865	0.0196	0.9853	0.0433
SS32091	0.9664	0.0131	0.9911	0.0103	0.9961	0.0107	0.9869	0.0124	0.9941	0.0099	1.0002	0.0081	0.9973	0.0108	0.9941	0.0127	0.9808	0.0324
SS32101	0.9442	0.0209	0.9915	0.0115	1.0025	0.0096	0.9886	0.0147	1.0004	0.0094	0.9909	0.0134	0.9907	0.0136	1.0056	0.0112	0.9629	0.0592
SS32145	0.9848	0.0103	0.9726	0.0153	0.9907	0.0117	1.0000	0.0071	1.0012	0.0074	0.9877	0.0120	0.9908	0.0131	0.9992	0.0143	1.0099	0.0691
SS32158	0.9719	0.0167	0.9695	0.0186	1.0000	0.0074	1.0000	0.0076	1.0000	0.0078	1.0013	0.0082	1.0018	0.0176	0.9671	0.0256	1.1910	0.1156
SS32207	0.9340	0.0373	1.0155	0.0802	0.9091	0.0870	1.0000	0.0079	1.0027	0.0087	0.9697	0.0310	1.0000	0.0091	1.0001	0.0098	1.1764	0.2514
SS32258	1.0018	0.0034	0.9524	0.0334	1.0271	0.0289	0.9500	0.0493	1.0022	0.0087	0.9751	0.0282	0.9211	0.0446	1.0000	0.0097	0.9629	0.0873
***P*-value**	*0.1162*		*0.9416*		*0.3739*		*0.6404*		*0.9988*		*0.8458*		*0.0999*		*0.7415*		*0.6351*	

Table 2.6. Reach survivals, cumulative survivals, and survival/RM estimated after pooling the data over the course of the study.

	Release to 416		416 to 413		413 to 410.5		410.5 to 408		408 to 406		406 to 403		403 to 400		400 to 397		397 to 396	
Parameter	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Reach survival	0.9661	0.0057	0.9816	0.0046	0.9974	0.0028	0.9928	0.0033	0.9993	0.0011	0.9940	0.0028	0.9901	0.0042	0.9935	0.0043	0.9987	0.0190
Survival / mile	0.9907	0.0016	0.9938	0.0015	0.9990	0.0011	0.9971	0.0013	0.9996	0.0006	0.9980	0.0009	0.9967	0.0014	0.9978	0.0014	0.9987	0.0190
	Release[1] to 416		to 413		to 410.5		to 408		to 406		to 403		to 400		to 397		to 396	
Cumulative survival	0.9661	0.0057	0.9484	0.0071	0.9459	0.0073	0.9391	0.0075	0.9384	0.0076	0.9328	0.0079	0.9235	0.0087	0.9175	0.0089	0.9163	0.0194

[1] Release location was estimated to be RM 419.7

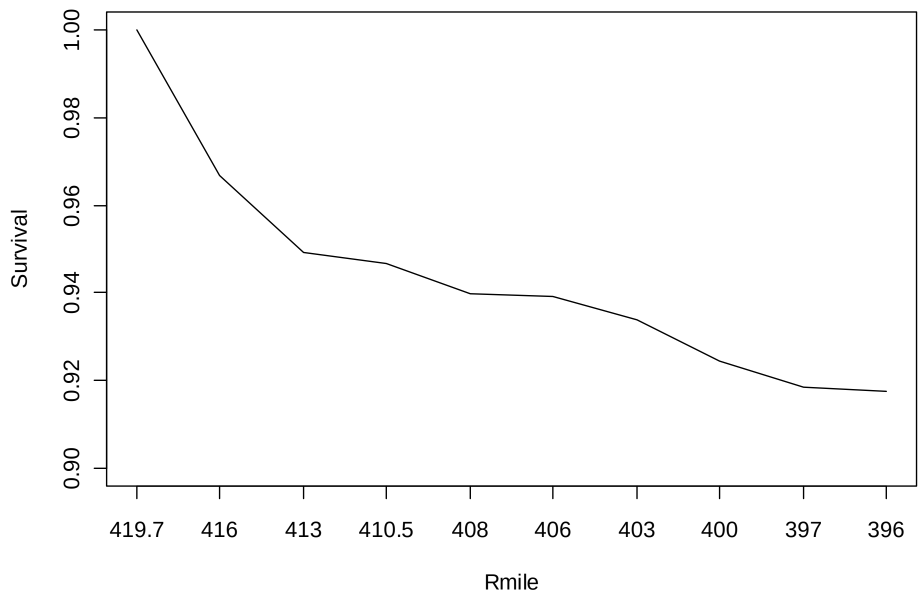

Figure 2.3. Cumulative survivorship curve for steelhead smolts between release and river mile 396 over the 2011 spring study.

Table 2.7. Summary of reach survival pairwise comparisons (α = 0.10). Reaches are listed in decreasing order of survival by row and column. Reaches that were significantly different are indicated by an "X".

		Reach tested							
Estimate	Reach	408 to 406	397 to 396	413 to 410.5	406 to 403	400 to 397	410.5 to 408	403 to 400	416 to 413
0.9993	408 to 406								
0.9987	397 to 396								
0.9974	413 to 410.5								
0.9940	406 to 403	X							
0.9935	400 to 397								
0.9928	410.5 to 408	X							
0.9901	403 to 400	X							
0.9816	416 to 413	X		X	X	X	X		
0.9661	419.7 to 416	X		X	X	X	X	X	X

Table 2.8. Summary of reach survival rates (i.e., S / river mile) pairwise comparisons (α = 0.10). Reaches are listed in decreasing order of survival by row and column. Reaches that were significantly different are indicated by an "X".

		Reach tested							
Estimate	Reach	408 to 406	413 to 410.5	397 to 396	406 to 403	400 to 397	410.5 to 408	403 to 400	416 to 413
0.9996	408 to 406								
0.9990	413 to 410.5								
0.9987	397 to 396								
0.9980	406 to 403								
0.9978	400 to 397								
0.9971	410.5 to 408	X							
0.9967	403 to 400	X							
0.9938	416 to 413	X	X		X	X			
0.9907	419.7 to 416	X	X		X	X	X	X	

Seasonal Trends in Survival

Three consecutive days of releases were pooled in order to compare survival trends across the season (Table 2.9). The resulting 6 release groups were separately analyzed to estimate reach survivals and cumulative survivorship curves (Figure 2.4). Although individual reach survivals were never significant ($P \geq 0.2322$), cumulative survivals became significant starting at RM 410.5 and remained so until almost the end of the study area (RM 397). Examination of the data indicates that survivals were homogeneous for the first 5 groups (i.e., releases 8– 22 May 2011) but dropped off in the last three days of the study (i.e., 23–25 May 2011).

Hatchery vs. Wild Stocks

The run-of-river steelhead smolts tagged in the study included both hatchery and wild fish (Table 2.10). Pooling across the study, reach survival estimates and cumulative survivals were calculated for hatchery and wild fish (Table 2.11). Survivals from the release to the first detection site (i.e., RM 416) were significantly different between hatchery and wild stocks (P = 0.0917). The wild steelhead had lower survival in that initial reach than hatchery fish. No other individual reaches were significantly different between stocks ($P \geq 0.4780$).

Cumulative survivals for wild steelhead lagged behind that of hatchery steelhead all the way through the study area (Figure 2.5, Table 2.11). However, cumulative survivals were only significant from release to RM 410.5 ($P \leq 0.07$).

Table 2.9. Estimate of (a) reach survival and (b) cumulative survival after pooling the data for three consecutive days of releases. *P*-values associated with the *F*-test of homogeneous survivals across the season.

a. Reach survivals

Replicate releases	N	Release to 416		416 to 413		413 to 410.5		410.5 to 408		408 to 406		406 to 403		403 to 400		400 to 397		397 to 396	
		$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
1–3	160	0.9570	0.0165	0.9935	0.0097	1.0014	0.0080	0.9852	0.0131	1.0000	0.0083	1.0001	0.0087	0.9932	0.0115	1.0021	0.0103	0.9827	0.0240
4–6	171	0.9656	0.0144	0.9628	0.0166	1.0014	0.0089	0.9923	0.0120	1.0007	0.0095	0.9937	0.0119	0.9794	0.0153	1.0026	0.0110	0.9954	0.0281
7– 9	184	0.9791	0.0113	0.9954	0.0097	0.9947	0.0112	0.9931	0.0117	0.9942	0.0112	1.0007	0.0098	0.9943	0.0141	0.9894	0.0172	0.9853	0.0591
10–12	185	0.9793	0.0113	0.9832	0.0124	1.0000	0.0084	1.0000	0.0085	1.0011	0.0090	0.9890	0.0127	0.9871	0.0130	1.0012	0.0104	1.0459	0.0617
13–15	174	0.9779	0.0117	1.0029	0.0190	0.9787	0.0223	1.0000	0.0070	1.0000	0.0070	1.0005	0.0074	1.0098	0.0143	0.9691	0.0215	0.9415	0.0512
16–18	155	0.9364	0.0199	0.9726	0.0248	0.9842	0.0261	0.9844	0.0171	1.0014	0.0075	0.9770	0.0158	0.9808	0.0173	0.9882	0.0161	0.9999	0.0650
***P*-value**		*0.2322*		*0.5030*		*0.8665*		*0.9006*		*0.9935*		*0.6438*		*0.6972*		*0.5869*		*0.8225*	

b. Cumulative survivals

Replicate releases	N	Release to 416		Release to 413		Release to 410.5		Release to 408		Release to 406		Release to 403		Release to 400		Release to 397		Release to 396	
		$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
1 - 3	160	0.9570	0.0165	0.9508	0.0177	0.9521	0.0178	0.9380	0.0196	0.9381	0.0197	0.9382	0.0197	0.9318	0.0207	0.9338	0.0209	0.9176	0.0282
4 - 6	171	0.9656	0.0144	0.9296	0.0203	0.9309	0.0203	0.9237	0.0211	0.9243	0.0211	0.9186	0.0218	0.8996	0.0238	0.9019	0.0240	0.8977	0.0329
7 - 9	184	0.9791	0.0113	0.9746	0.0128	0.9694	0.0140	0.9626	0.0150	0.9570	0.0159	0.9577	0.0160	0.9523	0.0183	0.9422	0.0197	0.9283	0.0572
10 - 12	185	0.9793	0.0113	0.9628	0.0147	0.9628	0.0147	0.9629	0.0147	0.9639	0.0148	0.9533	0.0166	0.9411	0.0181	0.9422	0.0183	0.9855	0.0602
13 - 15	174	0.9779	0.0117	0.9807	0.0211	0.9598	0.0156	0.9598	0.0155	0.9599	0.0156	0.9603	0.0156	0.9697	0.0194	0.9398	0.0196	0.8848	0.0504
16 - 18	155	0.9364	0.0199	0.9108	0.0297	0.8964	0.0270	0.8824	0.0264	0.8836	0.0265	0.8633	0.0284	0.8467	0.0306	0.8367	0.0306	0.8366	0.0618
***P*-value**		*0.2322*		*0.1083*		*0.0595*		*0.0187*		*0.0295*		*0.0049*		*0.0013*		*0.0042*		*0.4333*	

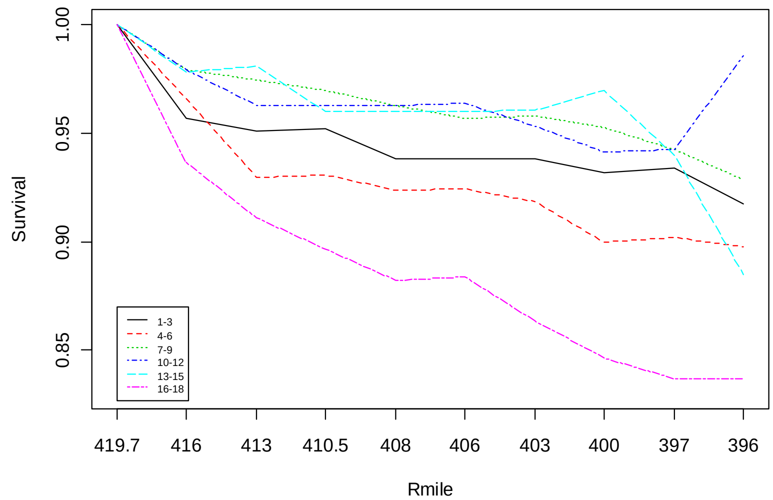

Figure 2.4. Cumulative survivorship curves for tri-daily pooled releases across the duration of the study area.

Table 2.10. Numbers of hatchery, wild, and unknown steelhead smolts tagged in each replicate release over the course of the 2011 study.

Replicate releases	Fish stock		
	Hatchery	Wild	Unknown
1	34	15	1
2	42	12	0
3	44	12	0
4	46	10	0
5	35	22	0
6	40	19	0
7	41	18	0
8	53	8	0
9	42	23	0
10	45	21	0
11	49	11	0
12	47	13	0
13	51	8	0
14	50	8	0
15	45	12	0
16	46	9	0
17	46	5	0
18	44	5	0

Table 2.11. Estimates of (a) reach and (b) cumulative survivals for hatchery and wild steelhead smolts through the Wanapum – Priest Rapids project in 2011. Capture data pooled over the season.

a. Reach survivals

		Release to 416		416 to 413		413 to 410.5		410.5 to 408		408 to 406		406 to 403		403 to 400		400 to 397		397 to 396	
Stock	*N*	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Hatchery	798	0.9732	0.0068	0.9828	0.0095	0.9986	0.0097	0.9906	0.0102	1.0005	0.0096	0.9936	0.0104	0.9893	0.0115	0.9928	0.0123	0.9964	0.0244
Wild	230	0.9445	0.0156	0.9778	0.0133	0.9935	0.0111	1.0003	0.0092	0.9952	0.0106	0.9954	0.0108	0.9928	0.0126	0.9964	0.0135	1.0038	0.0434
***P*-value**		*0.0917*		*0.7597*		*0.7288*		*0.4780*		*0.7106*		*0.9043*		*0.8371*		*0.8435*		*0.8818*	

b. Cumulative survivals

		Release to 416		Release to 413		Release to 410.5		Release to 408		Release to 406		Release to 403		Release to 400		Release to 397		Release to 396	
Stock	*N*	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Hatchery	798	0.9732	0.0068	0.9566	0.0087	0.9552	0.0089	0.9463	0.0093	0.9468	0.0093	0.9407	0.0098	0.9307	0.0108	0.9240	0.0112	0.9207	0.0225
Wild	230	0.9445	0.0156	0.9235	0.0184	0.9175	0.0188	0.9178	0.0188	0.9134	0.0193	0.9092	0.0197	0.9026	0.0208	0.8994	0.0212	0.9028	0.0428
***P*-value**		*0.0917*		*0.1043*		*0.0700*		*0.1742*		*0.1188*		*0.1525*		*0.2305*		*0.3055*		*0.7111*	

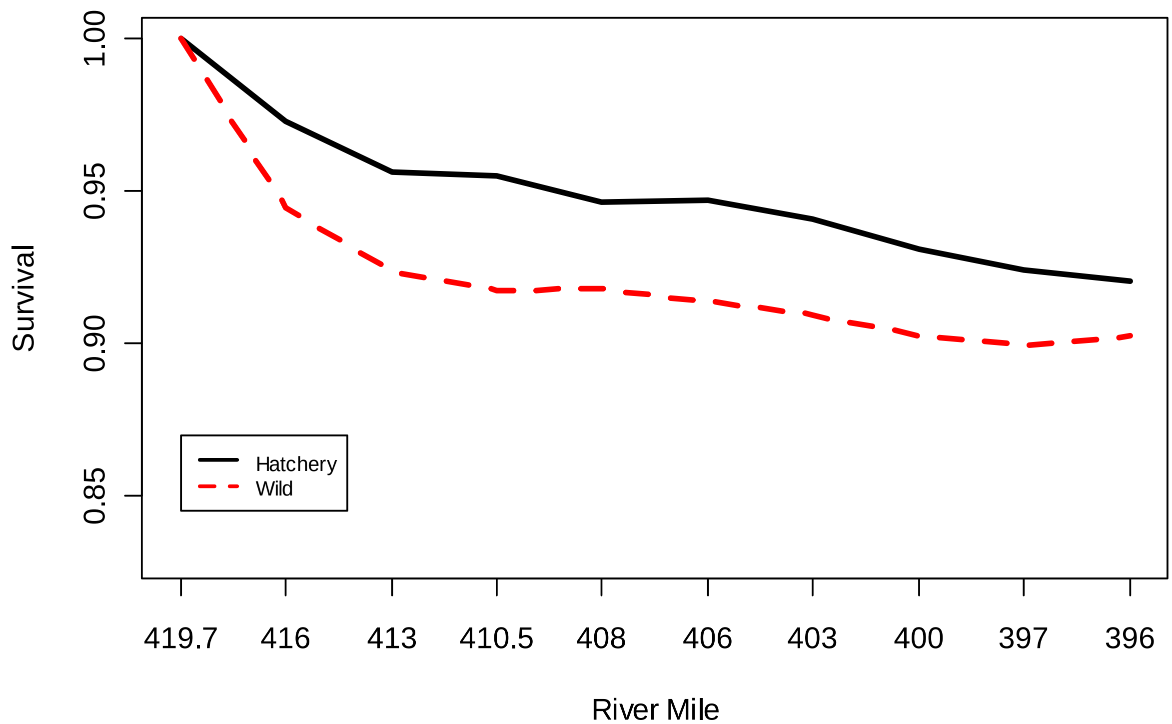

Figure 2.5. Cumulative survivorship curves for hatchery and wild steelhead smolts through the Wanapum – Priest Rapids project in 2011.

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Appendix C

Wanapum-Priest Rapids Project 2011
Environmental Conditions

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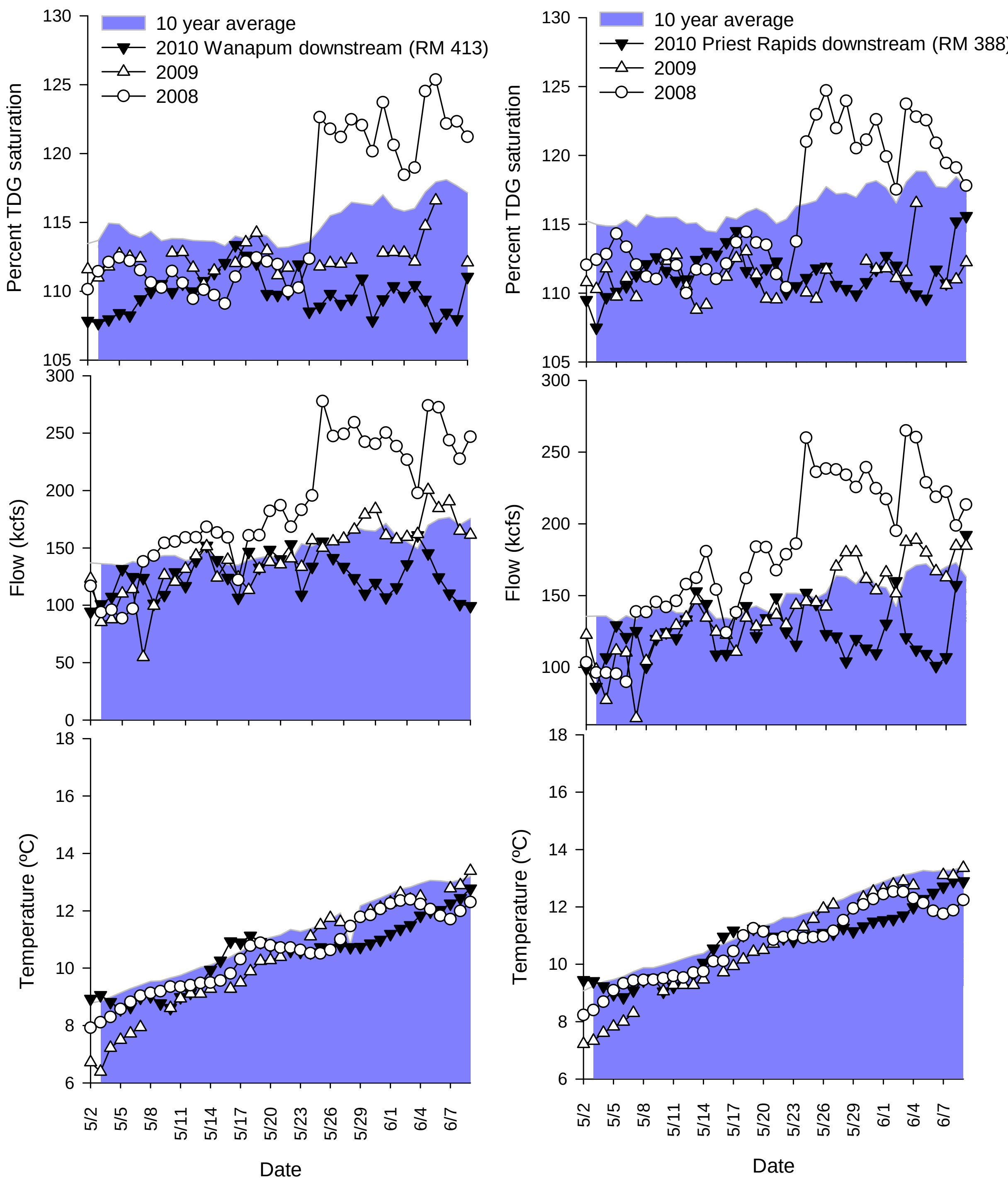

Figure C.1. Daily median water quality values downstream of Wanapum and Priest Rapids dams are shown from May 2 – June 9, 2008-2010 along with the 10 year average, which is depicted in blue. Unconnected points represent gaps where data were not available (data source: www.cbr.washington.edu/dart/dart.html).

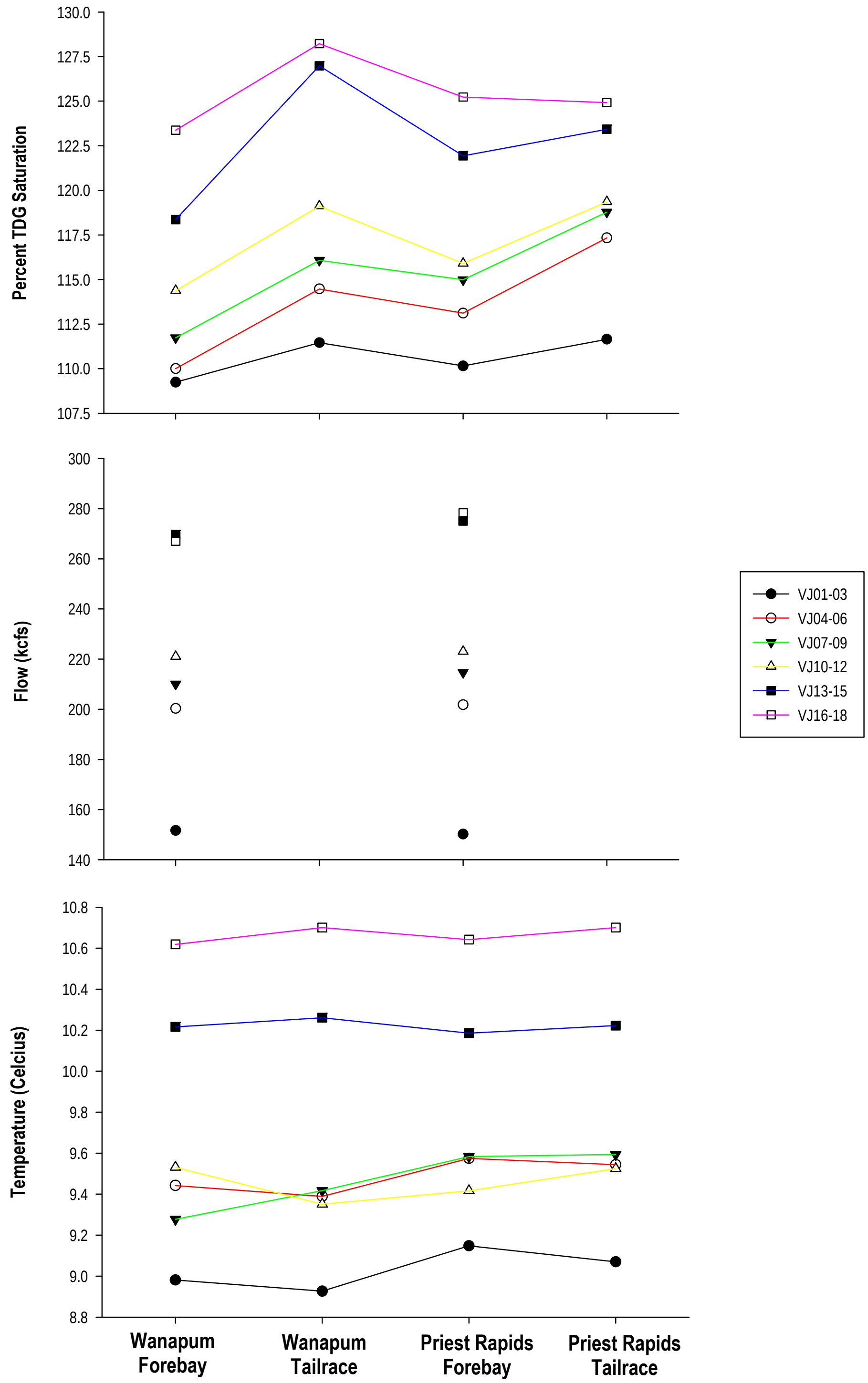

Figure C.2. Average environmental conditions plotted seasonally (per every three release groups) at Wanapum Dam forebay and tailrace (left) and Priest Rapids Dam forebay and tailrace: (a) TDG (percent saturation), (b) flow (kcfs), and (c) temperature (Celcius). Flow is a function of discharge and can only be shown at each forebay.

Appendix D

Juvenile Salmon Acoustic Telemetry System (JSATS) Performance

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Table D.1. Percent memory usage by Teknologic JSATS acoustic receivers that were deployed in the Priest Rapids Reservoir in 2011. Variability in memory usage is partially a function of ambient noise, and detection threshold settings.

Capacity Used (%)	Frequency
0-20	30
21-40	11
41-60	2
61-80	2
81-100	3

Table D.2. Frequency of valid smiolt detections at in-river arrays in the Priest Rapids Reservoir recorded from Teknologic and Lotek JSATS receivers that were deployed *and* recovered for the 2011 analysis of juvenile steelhead survival and behavior. Detection frequency is partially a function of ambient noise and detection threshold settings on individual receivers. The detection range of a Lotek receiver(s) is estimated to be approximately 100 m and Teknologic receiver(s) is approximately 250-300 m (based on acoustic tag 2011 testing in the field). Asterisk at array P403_0 for Lotek receiver indicates no valid smolt detections were recorded; however, valid detections of predators were recorded.

	Lotek		Teknologic	
Array	**Valid Detections**	**Receivers**	**Valid Detections**	**Receivers**
P395_0	0	0	7,499	1
P396_0	0	0	11,617	1
P397_0	0	0	311,821	7
P398_5	0	0	107,770	3
P400_0	2,977	1	70,595	3
P401_0	0	0	61,276	2
P402_0	0	0	65,875	2
P403_0	0	1*	75,922	2
P404_0	0	0	58,125	2
P405_0	0	0	32,583	2
P406_0	0	0	27,848	2
P407_0	0	0	18,240	2
P407_5	0	0	2,080	1
P408_0	0	0	27,521	2
P409_0	0	0	15,219	1
P410_0	0	0	9,418	1
P410_5	0	0	9,721	1
P411_0	0	0	358	1
P411_5	0	0	5,405	1
P412_0	0	0	3,819	1
P413_0	2,364	1	14,136	2
P413_5	0	0	3,695	1
P414_0	0	0	0	0
P415_0	0	0	126,950	2
P416_0	0	0	388,459	5
Total	**5,341**	**3**	**1,455,952**	**48**

Appendix E

Juvenile Steelhead Travel and Residence Time Statistics

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Table E.1. ***Slowest* 10% travel time** statistics for steelhead smolts which traveled from Wanapum Dam to Priest Rapids Dam, by array. Median travel time (measured in days) between arrays is used as a filtering criteria for identifying abnormal behavior patterns in steelhead smolts which are suspected of having experienced predation by piscivorous predators.

Detection Arrays		Travel Time (days)			
From	To	Minimum	Average	Median	Maximum
P413_5	P413_0	0.09	0.11	0.11	0.21
P413_0	P412_0	0.23	0.31	0.26	0.98
P412_0	P411_5	0.11	0.13	0.12	0.29
P411_5	P411_0	0.14	0.15	0.15	0.16
P411_0	P410_5	0.12	0.16	0.13	0.27
P410_5	P410_0	0.15	0.20	0.17	0.60
P409_0	P408_0	0.29	0.34	0.33	0.64
P408_0	P407_5	0.10	0.16	0.11	0.82
P407_5	P407_0	0.18	0.20	0.19	0.23
P407_0	P406_0	0.37	1.47	0.42	67.03
P406_0	P405_0	0.47	0.73	0.53	7.13
P405_0	P404_0	0.57	0.86	0.68	11.14
P404_0	P403_0	0.82	1.37	1.03	7.08
P403_0	P402_0	1.36	2.28	1.68	8.54
P402_0	P401_0	1.65	3.18	2.39	12.06
P401_0	P400_0	2.38	4.65	3.92	11.56
P400_0	P398_5	7.16	9.82	9.03	15.82
P398_5	P397_0	0.61	2.26	1.08	18.76

Table E.2. ***Longest*** **10% residence time** statistics of steelhead smolts which traveled from Wanapum Dam to Priest Rapids Dam, by array. Median residence time (measured in days) at arrays is used as a filtering criteria for identifying abnormal behavior patterns in steelhead smolts which are suspected of having experienced predation by piscivorous predators.

Detection	Residence Time (days)			
Array	Minimum	Average	Median	Maximum
P413_5	0.03	0.06	0.04	0.54
P413_0	0.08	0.72	0.10	36.04
P412_0	0.03	0.04	0.04	0.06
P411_5	0.03	0.04	0.03	0.06
P411_0	0.02	0.03	0.04	0.04
P410_5	0.04	0.05	0.04	0.09
P410_0	0.04	0.05	0.05	0.11
P409_0	0.05	0.07	0.05	1.31
P408_0	0.08	0.15	0.10	2.12
P407_5	0.03	0.03	0.03	0.04
P407_0	0.05	0.06	0.06	0.09
P406_0	0.07	0.50	0.08	23.03
P405_0	0.17	0.39	0.20	6.15
P404_0	0.16	1.23	0.19	89.74
P403_0	0.23	1.58	0.29	89.77
P402_0	0.30	0.89	0.43	11.27
P401_0	0.34	1.46	0.58	18.17
P400_0	0.69	4.88	2.73	25.92
P398_5	3.25	8.26	6.46	30.88
P397_0	4.27	10.20	9.02	36.73

Appendix F

Piscivorous Fish Characteristics Collected, Tagged and Released in the Priest Rapids Reservoir

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Table F.1. Release quantities, tagging locations, capture methods, and release dates for piscivorous fishes including northern pikeminnow, smallmouth bass, and walleye that were tagged and released into the Priest Rapids Reservoir during the spring of 2011.

Release	Northern Pikeminnow	Smallmouth Bass	Walleye	Tagging Location	River Mile	Capture method	Date
PO01	1			Wanapum Boat Launch	415	Angling	8-Apr
PO02		1	3	Wanapum Boat Launch	415	Angling	9-Apr
PO03			3	Wanapum Boat Launch	415	Angling	10-Apr
PO04	26	1		Desert Aire, Mattawa	400, 408	Set line, angling	20-Apr
PO05	50			Desert Aire, Mattawa	400, 408	Set line	21-Apr
PO06		2		Buckshot Slough	403	Angling	22-Apr
PO07	4			Wanapum Boat Launch	415	Angling	25-Apr
PO08	8		1	Wanapum Transformer Deck	415	Angling	27-Apr
PO09		16		Buckshot Slough	403	Angling	28-Apr
PO10		13		Buckshot Slough	403	Angling	29-Apr
PO11		8		Desert Aire	400	Electrofishing	1-May
PO12		2		Desert Aire, Buckshot Slough	400, 403	Angling	2-May
PO13	36	2		Wanapum Boat Launch, Buckshot Slough	415, 403	Set line, angling	3-May
PO14	9	7		Wanapum Boat Launch, Buckshot Slough	415, 403	Set line, angling	4-May
ΣPO	**134**	**52**	**7**	*Total no. fish tagged and released:*	*193*		