Comparison of Alternative Steelhead Smolt Release Groups from Rock Island Dam Tailrace in 2007

Prepared for:
Public Utility District No. 2 of Grant County
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. Brown
Corey D. Wright
Bruce H. Ransom
Hydroacoustic Technology, Inc.
715 NE Northlake Way
Seattle, Washington 98105

November 1, 2007

Executive Summary

Three separate groups of acoustic-tagged steelhead smolts were released below Rock Island Dam to compare survival and migration dynamics of alternative fish sources and handling methods. One release consisted of smolts collected at the Wanapum Dam gatewell and tagged by an LGL Limited Environmental Research Associates crew (identified as, LGL/LGL). The two other release groups consisted of smolts collected at the Public Utility No. 1 of Chelan PUD (Chelan) Rocky Reach juvenile fish bypass and tagged by either LGL (i.e., Chelan/LGL) or Chelan PUD personnel (i.e., Chelan/Chelan).

Smolt survival from Rock Island tailrace to Vernita Bridge was highest for the LGL/LGL release group (0.7055, $\widehat{SE}$ = 0.0209), intermediate for the Chelan/LGL release group (0.6518, $\widehat{SE}$ = 0.0231), and lowest for the Chelan/Chelan fish (0.6190, $\widehat{SE}$ = 0.0216). Fish condition factor was the lowest for the Chelan/Chelan release group but similar to that for the LGL/LGL and Chelan/LGL release groups. A significant ($P < 0.001$) and appreciable difference in survival was observed for fish tagged by different individuals in the LGL crew. From release to Vernita Bridge, the difference in survival estimates for fish from different taggers exceeded 0.20. No information was available on fish survival for the individual Chelan PUD taggers.

At Wanapum Dam, the fish collected from the Wanapum gatewell source used the gatewell significantly more (6.65%, $\widehat{SE}$ = 0.55%) than the Chelan source fish (2.80 %, $\widehat{SE}$ = 0.62%). Steelhead smolts used the powerhouse most frequently (59.6–64.1%), followed by the sluiceway (18.1–24.0%) and then top spill (9.8–15.0%).

At Priest Rapids Dam, all three release groups used the passage routes in similar proportions. Of the fish arriving at the dam, 75.4% used the powerhouse, 18.7% used the top spill, 5.5% used the gatewell, and only 0.4% used the spillway.

Table of Contents

List of Figures

List of Tables

List of Appendices

1.0 Introduction

The effects of fish source and tagging crew on subsequent downstream survival of steelhead smolts at Public Utility District No. 2 of Grant County (Grant PUD) were investigated in 2007. Three treatments of smolts were released below Rock Island Dam to evaluate their downstream survival and migration dynamics. The three treatment groups consisted of the following fish sources and handling combinations:

Groups	Fish Source	Tagging Crew	Abbreviation
Release 1	Rocky Reach juvenile fish bypass	Chelan PUD	Chelan/Chelan
Release 2	Rocky Reach juvenile fish bypass	LGL	Chelan/LGL
Release 3	Wanapum gatewells	LGL	LGL/LGL

The objectives of the study included the following:

1. Compare downstream survival of the three treatment groups from Rock Island tailrace to Vernita Bridge.

2. Comparison of arrival distributions and travel times to downstream detection sites.

3. Comparison of arrival proportions through the various passage routes at downstream dams.

4. Evaluation of the influence of individual tagging crew on downstream survival of tagged smolts.

The results of this investigation will be used to help guide the conduct of future acoustic-tag, release-recapture studies at the Priest Rapids Project.

2.0 Methods

Capture, handling and release procedures, release-recapture design and statistical analysis methodology are described in sections 2.1, 2.2 and 2.3 below.

2.1 Capture, Handling, and Release Procedures

The acoustic tagging and tracking methods employed are described in detail by Timko et al. (2007b). To compare fish handling techniques between the Public Utility District No. 1 of Chelan County (Chelan PUD) and Grant PUD run-of-river steelhead smolts, release groups identified as LGL/LGL, Chelan/LGL, and Chelan/Chelan were collected at different locations and transported by Chelan or Grant PUD personnel. Steelhead smolts were collected from April 23 to May 22, 2007.

The first release group, LGL/LGL, was collected from samples collected at the Wanapum Dam gatewells, using methods similar to those employed in 2006 (Timko et al. 2007a). Gatewell dipping involved removing fish from the gatewells with a large net. The net was lowered by a crane into the gatewells, the side panels of the net were released, and the net was lifted. The panels remained unfolded as the net was lifted, and fish were collected in a sanctuary box that was positioned at the base of the net. Fish were then transferred by a water-to-water technique into the transport tank which was located on the back of a flatbed truck.

During the 2007 emigration season, fish were collected daily by Grant PUD staff, typically beginning at 0700 hr, from within the turbine gatewells at Wanapum Dam. The acoustic tag systems could not distinguish fish that had entered the gatewells from fish that passed through the turbines. Therefore, all gatewell collected fish were scanned for acoustic tags on the deck of the dam.

Fish collected in the gatewells were either transported to the right (west) bank of Wanapum Dam for potential use in tagging for the study (typically before 1000 hr) or they were released into the tailrace through a 6-inch diameter pipe at the sluiceway. Fish transported to the west bank of Wanapum Dam for potential use in this study were transported in a newly designed transport tank. The transport tank, designed and manufactured by Grant PUD staff, was 4-ft wide by 8-ft long and was filled with ambient river water at a depth of 40 in. The tank was baffled and the bottom was sloped from the front to rear by 4 inches with the posterior 2 ft of the tank angled at 45 degrees to aid in fish exit of the tank via 6 in. diameter outfall. Oxygen was supplied to the tank by an agitator, and supplemented by air stones when necessary, during holding and transport.

During transport (to the west bank of Wanapum Dam), temperature and dissolved oxygen measurements were recorded before fish were transferred into a temporary 10-ft wide by 20-ft long collection tank. To decrease netting and handling stress on transported fish, all transfers were completed through water-to-water transfers into the 4,000-gal collection tank which was filled with circulating ambient river water at a depth of approximately 36 inches.

At the southern end of the temporary collection tank, a Pescalator was installed. The Pescalator is a fish transport device that utilizes the Archimedes screw to lift fish gently out of holding areas, such as ponds, raceways, and net pens. Fish were slowly crowded toward the Pescalator and fish volitionally swam into the Pescalator which transferred them into the sorting facility. Once fish entered the sorting facility they were placed in a light sedation of MS-222 and sorted for use in the study.

The remaining two release groups, Chelan/LGL and Chelan/Chelan, were collected at the Rocky Reach Dam juvenile fish bypass by Chelan PUD personnel. The second release group, Chelan/LGL, was trucked from Rocky Reach Dam. Steelhead were transported every other day and typically arrived on-site by 1400 hr.

The third release group, Chelan/Chelan, was collected and transported using Chelan PUD protocols. All fish in the Chelan/Chelan release group were captured and transferred into a 275-gal (1,041 L) tank for transport to the fish tagging sites daily throughout the study. Oxygen was added to the tank to maintain dissolved oxygen levels of 7-12 ppm. Upon arrival at Rock Island Dam, fish were transferred through a 4 inch (10.2 cm) diameter flex hose, directly from the transport tank into 35-gal (132 L) tanks at each of the tagging sites. All transfers occurred in the morning, and to minimize handling and reduce transport injuries, all fish transfers were water-to-water. Chelan PUD personnel were on-site 24 hrs to monitor the holding tanks for adequate flow and to ensure that dissolved oxygen levels remained at 7-12 ppm.

2.2 Release-Recapture Design

For each treatment, 15 releases of approximately 30 fish each were completed over the course of the study, from 23 April to 22 May 2007. The steelhead releases were detected downstream at seven locations to estimate reach survivals (Figure 1). The single release-recapture model was used to estimate reach survivals and compare reach survivals and detection probabilities downstream of Rock Island Dam. The same analysis procedures were used when the effects of individual tagging crews were examined.

At both Wanapum (Figure 2) and Priest Rapids (Figure 3) dams, double detection arrays were used to estimate route-specific passage proportions for fish known to have arrived at the dams. Using downstream detections, route-specific survivals were calculated relative to the powerhouse.

2.3 Statistical Analysis

For the steelhead releases, the single-recapture model (Skalski et al. 1998) was used to estimate reach passage survival probabilities. For each of the steelhead releases, six reach passage survivals were estimated (Figure 1). 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. That is, tagged animals have the same probabilities as untagged animals.

A3. All sampling events are “instantaneous.” That is, 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.

A7. All tags are correctly identified and the status of smolts (i.e., alive or dead), correctly assessed.

The first assumption (A1) concerns making inferences from the sample to the target population. For example, if inferences are sought to steelhead smolts, then the sample of tagged fish should be drawn from that class of fish. Otherwise, nonstatistical inferences are necessary, justifying the similarity between the target population and the representatives of the tagged fish. These assumptions could also be violated if smolts selected for tagging were, on the average, larger than the population of smolts in general.

Assumption (A2) again relates to making inferences to the population of interest (i.e., untagged fish). If tagging has a detrimental effect on survival, then survival estimates from the single-release model will tend to be negatively biased (i.e., underestimated).

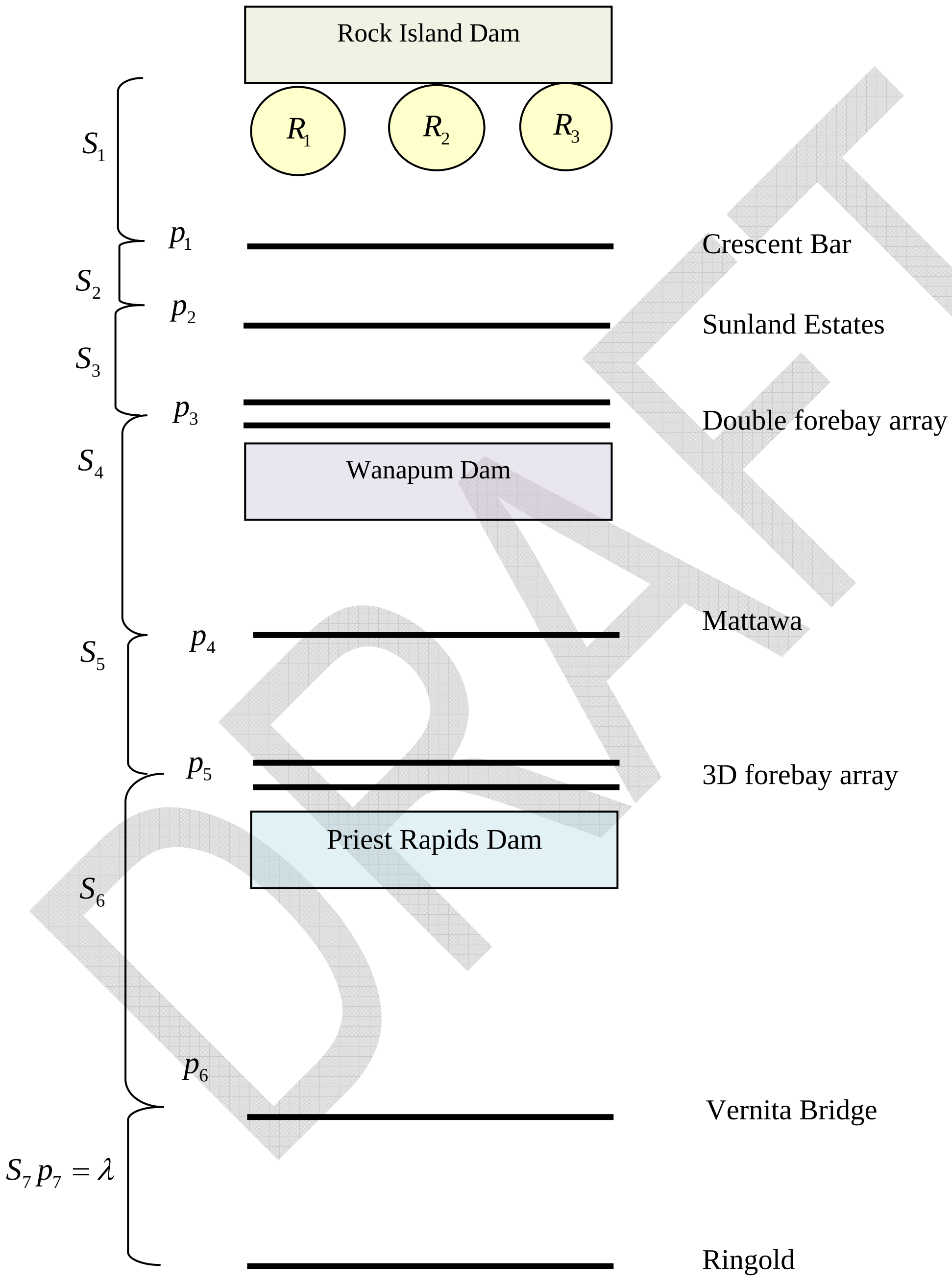


Figure 1 Schematic of steelhead releases *(R_1, R_2, and R_3)* and detection arrays used to estimate downstream reach survivals *(S)* and detection probabilities *(p)*.

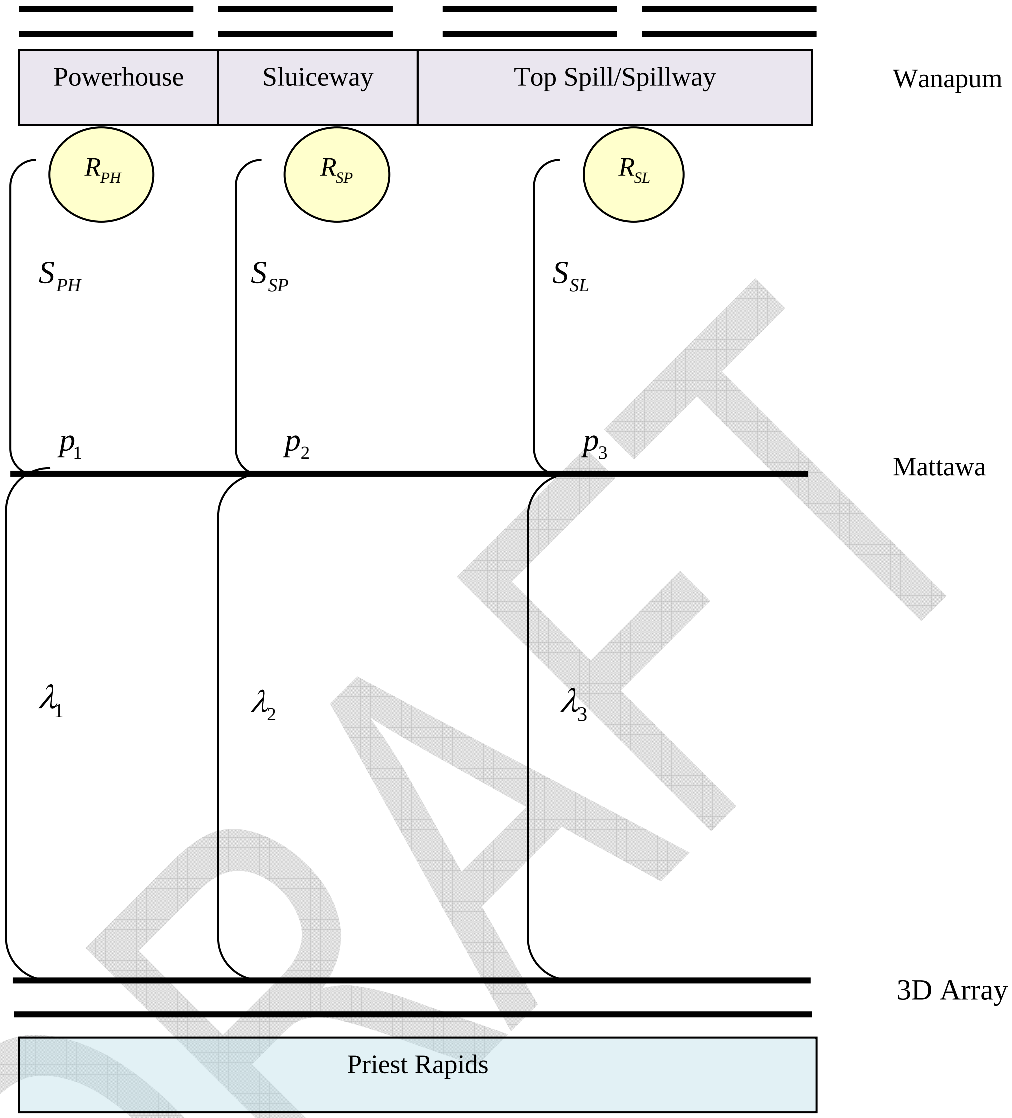
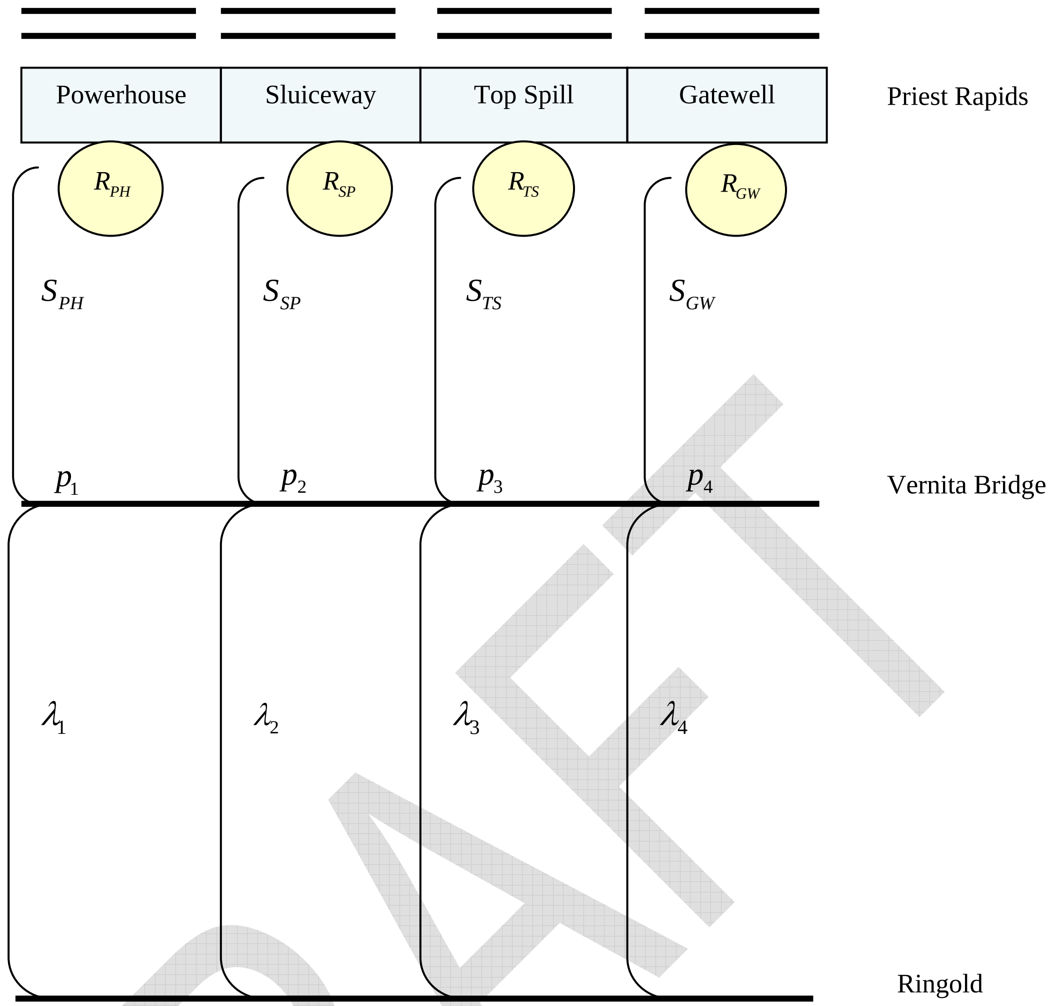


Figure 2 Schematic of route-specific detection at Wanapum Dam into powerhouse, spillway, and top-spill/spillway passage proportions and estimates of downstream survival *(S)* and relative survival *(RS)*.



Relative survival

Spillway:Powerhouse $RS_{SP/PH} = \dfrac{S_{SP}}{S_{PH}}$

Top Spill:Powerhouse $RS_{TS/PH} = \dfrac{S_{TS}}{S_{PH}}$

Gatewell:Powerhouse $RS_{GW/PH} = \dfrac{S_{GW}}{S_{PH}}$

Figure 3 Schematic of route-specific detections at Priest Rapids Dam into powerhouse, spillway, top-spill, and gatewell proportions and estimates of downstream survival *(S)* and relative survival *(RS)*.

The third assumption (A3) specifies that mortality is negligible immediately in the vicinity of the sampling stations, so that the estimated mortality is related to the river reaches in question and not during the sampling event. For acoustic-tagged smolts, the time spent in the vicinity of a hydrophone array is brief and narrow, relative to the size of the river reaches in question. This assumption should be fulfilled by the nature of the outmigration dynamics and deployment of hydrophone arrays.

The assumption of independence (A4) implies that the survival or death of one smolt has no effect on the fates of others. In the larger river system with tens of thousands of smolts, this is likely true. Furthermore, this assumption is common to all tag analyses with little or no evidence collected to suggest it is not generally true. Nevertheless, violations of assumption (A4) have little effect on the point estimate but might bias the variance estimate with precision being less than calculated.

Assumption (A5) specifies that a smolt's prior detection history has no effect on subsequent survival. This could be violated if some smolts were self-trained to repeatedly go through turbine or spill routes or, alternatively, to avoid routes because of prior experience. This occurrence is unlikely and can be assessed from the detection histories of the individual smolts. For acoustic-tagged smolts, the lack of handling following initial release further minimizes the risk that subsequent detections influence survival. Similarly, assumption (A6) could be violated if downstream detections were influenced by upstream passage routes taken by the smolts. For acoustic-tagged smolts, this assumption is minimized by placing hydrophone arrays across the breadth of the river or below the mixing zones for smolts following different passage routes at the dam.

Assumption (A7) implies that smolts do not lose their tags and are subsequently misidentified as dead or not captured, nor are dead fish falsely recorded as alive at detection locations. Tag loss or tag failure would tend to result in a negative bias (i.e., underestimation) of smolt survival rates. For acoustic-tagged smolts, tag failure will depend on travel times relative to battery life. If tag failure occurs, it will negatively bias the perceived survival estimates. Acoustic-tagged dead fish drifting downstream could result in false-positive detections and upwardly bias survival estimates. Tailrace hydrophone arrays were not proposed because of this concern.

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 will be performed to determine the validity of the model (i.e., goodness-of-fit). Burnham et al.'s (1987) tests T2 and T3 will be used to test goodness-of-fit of the acoustic-tag data to the release-recapture model. In these analyses, the release-recapture data will be pooled across the replicates within a season.

For purposes of identifying those reaches with the greatest source of mortality, the reach survival estimates $\left(S_j\right)$ will be converted into instantaneous mortality rates $\left(r_j\right)$ when

$$\hat{S}_j = e^{\hat{r}_j t_j}$$

or

$$\ln \hat{S}_j = \hat{r}_j t_j .$$

Consequently, overall survival $\left(S_{\text{Total}}\right)$ can be estimated as the product over *k* reaches,

$$\hat{S}_{\text{Total}} = \prod_{j=1}^{k} \hat{S}_j ,$$

or the sum of the instantaneous mortality rates,

$$\hat{S}_{\text{Total}} = e^{\sum_{j=1}^{k} \hat{r}_j t_j} .$$

Hence, the fraction of total integrated mortality that occurred in the *i*th reach can be estimated by the fraction (FM_i)

$$FM_i = \frac{\hat{r}_i t_j}{\sum_{j=1}^{k} \hat{r}_j t_j} = \frac{\ln \hat{S}_i}{\sum_{j=1}^{k} \ln \hat{S}_j} . \quad (1)$$

Using the delta method, the variance of $\hat{FM}_i$ can be approximated by the quantity

$$\widehat{\mathrm{Var}}\left(\hat{FM}_i\right) = \widehat{\mathrm{Var}}\left(\hat{S}_i\right)\left(\frac{\left(\sum_{j=1}^{k}\ln \hat{S}_j\right) - \ln \hat{S}_i}{\left(\sum_{j=1}^{k}\ln \hat{S}_j\right)^2 \hat{S}_i}\right)^2$$

$$+ \sum_{\substack{j=1 \\ j\neq i}}^{k}\left[\widehat{\mathrm{Var}}\left(\hat{S}_j\right)\left(\frac{\ln \hat{S}_i}{S_j\left(\sum_{j=1}^{k}\ln \hat{S}_j\right)^2}\right)^2\right]$$

$$+ 2\sum_{\substack{j=1 \\ j\neq i}}^{k}\left[\widehat{\mathrm{Cov}}\left(\hat{S}_i, \hat{S}_j\right)\left(\frac{\left(\sum_{j=1}^{k}\ln \hat{S}_j\right) - \ln \hat{S}_i}{\left(\sum_{j=1}^{k}\ln \hat{S}_j\right)^2 \hat{S}_i}\right)\left(\frac{\ln \hat{S}_i}{\hat{S}_j\left(\sum_{j=1}^{k}\ln \hat{S}_j\right)^2}\right)\right]$$

$$+ 2\sum_{\substack{j=1 \\ j\neq 1}}^{k}\sum_{\substack{g>1 \\ g\neq 1}}^{k}\left[\mathrm{Cov}\left(\hat{S}_j, \hat{S}_g\right)\left(\frac{\ln \hat{S}_i}{\hat{S}_j\left(\sum_{j=1}^{k}\ln \hat{S}_j\right)^2}\right)\left(\frac{\ln \hat{S}_i}{\hat{S}_g\left(\sum_{g=1}^{k}\ln \hat{S}_j\right)^2}\right)\right].$$

(2)

Fish known to have arrived at Wanapum Dam were used to estimate route-specific passage proportions and relative passage survivals. At each route within Wanapum Dam, a double hydroacoustic array was deployed to detect acoustic-tagged smolts during dam passage. The double detection data was used to estimate the absolute abundance (*N*) of tagged smolt passage through the different routes. Define for any particular passage route the following variables (Figure 2):

n_{10} = number of tagged smolts detected at the 1st array but not the 2nd,

n_{01} = number of tagged smolts detected at the 2nd array but not the 1st,

n_{11} = number of tagged smolts detected at both the 1st and 2nd arrays.

From these counts of smolts with various route-specific detections histories, absolute passage abundance $(\hat{N})$ of tagged smolts was estimated as

$$\hat{N} = \frac{(n_{10} + n_{11} + 1)(n_{01} + n_{11} + 1)}{(n_{11} + 1)} - 1$$

or

$$\hat{N} = \frac{(n_1 + 1)(n_2 + 1)}{(n_{11} + 1)} - 1 \qquad (3)$$

where $n_1 = n_{10} + n_{11}$ and $n_2 = n_{01} + n_{11}$ with associated variance estimate (Seber 1982:60)

$$\mathrm{Var}(\hat{N}) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - n_{11})(n_2 - n_{11})}{(n_{11} + 1)^2 (n_{11} + 2)}. \qquad (4)$$

The estimated probability of detection (p_1) in the first array was calculated as

$$\hat{p}_1 = \frac{n_{11}}{n_2},$$

and the probability of detection (p_2) in the second array as

$$\hat{p}_1 = \frac{n_{11}}{n_1}.$$

The overall probability of a smolt being detected in the double array system was then estimated by

$$\hat{P} = 1 - (1 - \hat{p}_1)(1 - \hat{p}_2) = \frac{n_{11}(n_1 + n_2 + n_{11})}{n_1 n_2}$$

Passage abundance was estimated for the powerhouse $(\hat{N}_{PH})$, spillway $(\hat{N}_{SP})$, and sluiceway $(\hat{N}_{SL})$.

The proportion of the acoustic-tagged smolts passing through the powerhouse $(\hat{P}_{PH})$ was estimated by

$$\hat{P}_{PH} = \frac{\hat{N}_{PH}}{\hat{N}_{PH} + \hat{N}_{SP} + \hat{N}_{SL}}\ . \qquad (5)$$

Using the delta method (Seber 1982:7-9), the variance of $\hat{P}_{PH}$ was approximated by

$$\widehat{\text{Var}}\left(\hat{P}_{PH}\right) = \frac{\hat{P}_{PH}\left(1-\hat{P}_{PH}\right)}{N_{PH}} + \hat{P}_{PH}^2\left(1-\hat{P}_{PH}\right)^2\left[\frac{\widehat{\text{Var}}\left(\hat{N}_{PH}\right)}{\hat{N}_{PH}^2} + \frac{\widehat{\text{Var}}\left(\hat{N}_{SP}\right)+\widehat{\text{Var}}\left(\hat{N}_{SL}\right)}{\left(\hat{N}_{SP}+\hat{N}_{SL}\right)^2}\right]. \qquad (6)$$

Values of $\hat{P}_{SP}$ and $\hat{P}_{SL}$ and associated variances were estimated analogously to Eq. (6).

Smolts known to have passed through the various routes at Wanapum Dam (Figure 2) were also monitored downriver to obtain their capture histories. Define the following variables:

R_{PH} = number of smolts known to have passed through powerhouse,

n_{PH} = number of smolts among R_{PH} detected downriver,

R_{SP} = number of smolts known to have passed through spillway,

n_{SP} = number of smolts among R_{SP} detected downriver,

R_{SL} = number of smolts known to have passed through sluiceway,

n_{SL} = number of smolts among R_{SL} detected downriver.

Using the relative recoveries of smolts through the various routes compared to the powerhouse, relative route-specific survival probabilities was estimated for the spillbay, i.e.,

$$RS_{SP/PH} = \frac{\left(\frac{n_{SP}}{R_{SP}}\right)}{\left(\frac{n_{PH}}{R_{PH}}\right)}. \qquad (7)$$

The variance of $RS_{SP/PH}$ was estimated by

$$\widehat{\text{Var}}\left(\widehat{RS}_{SP/PH}\right) = \widehat{RS}_{SP/PH}^{\,2}\left[\frac{1}{n_{PH}} - \frac{1}{R_{PH}} + \frac{1}{n_{SP}} - \frac{1}{R_{SP}}\right]. \qquad (8)$$

The estimator of relative survival of the sluiceway compared to the powerhouse (i.e., $RS_{SL/PH}$) was estimated analogously to Eq. (7) with the variance estimator analogous to Eq. (8).

Route-specific passage survivals at Priest Rapids Dam were estimated using methods analogous to those used at Wanapum Dam.

3.0 Results

3.1 Distribution of Size and Condition Factors at Time of Release

One factor that might influence the downstream migration success of steelhead smolts is their size and condition factor at time of release. For this reason, the distribution of the fish size and condition factor was compared between the three treatment groups (Figure 4). The treatment groups tagged by LGL (i.e., LGL/LGL and Chelan/LGL) have the most similar condition factor distributions (Table 1). The smolts tagged by Chelan PUD had a higher proportion of smolts with lower condition factors $\left(\text{i.e., } \sqrt[3]{\text{weight}}\big/\text{length}\right)$.

3.2 Arrival Distribution and Travel Times

The distribution of travel times from time of release to arrival at a detection site for the three treatments were compared at all seven detection locations (Figure 5). Although R × C contingency table tests of homogeneity are significant ($P < 0.001$), visual inspection of the arrival curves show remarkable similarity. The arrival curves suggest good mixing and comparable travel times for all three treatments. Mean travel times (Table 2) are very similar at all sites for the three treatment groups.

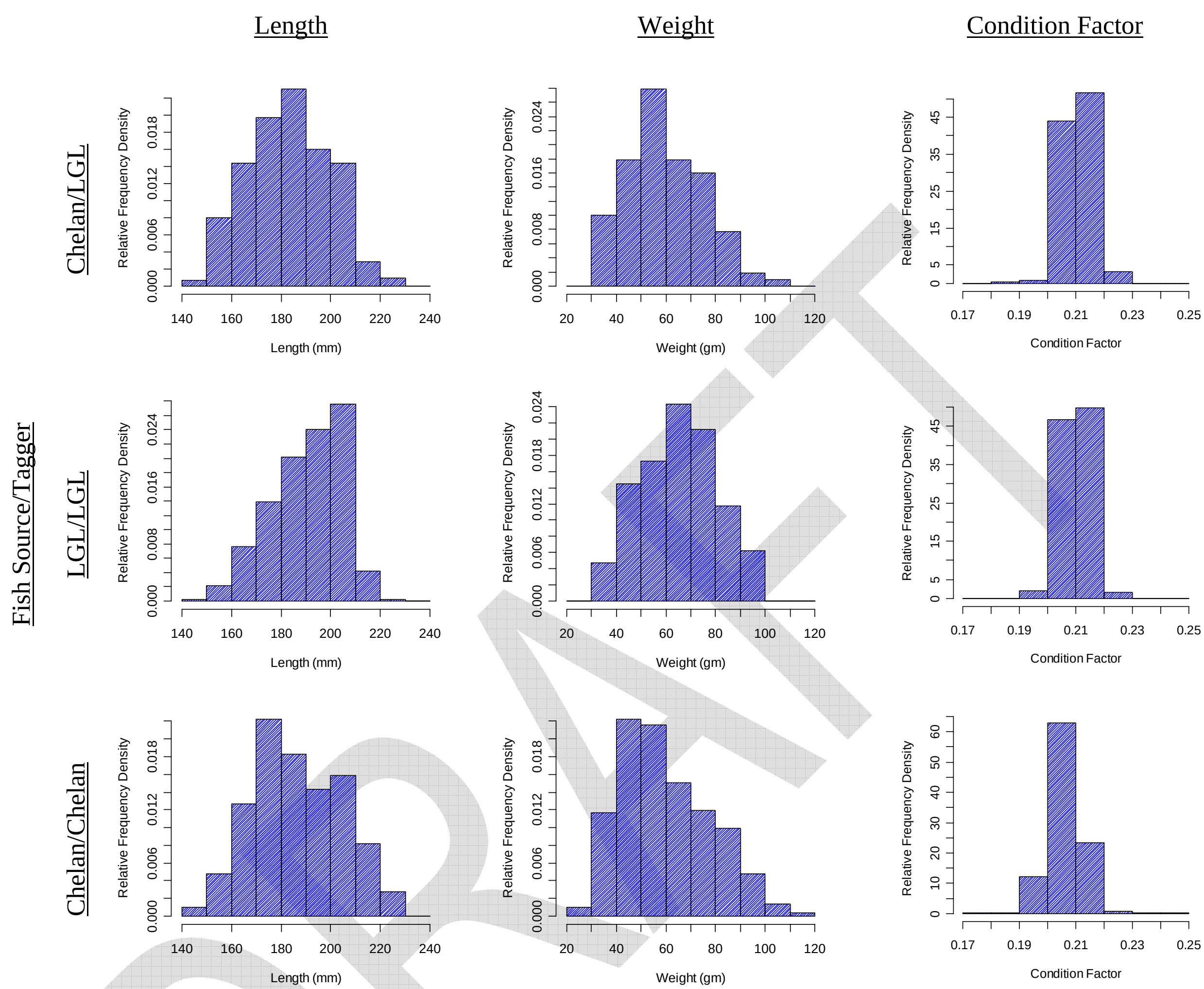


Figure 4 Comparison of length, weight, and condition factor of steelhead used in each of the three releases from Rock Island tailrace in 2007.

Table 1 ***P*-values of Kolmogorov-Smirnov tests for similarity of length, weight, and condition factor of steelhead smolts used in each of the three releases from Rock Island tailrace in 2007.**

Test	Length	Weight	Condition Factor
Chelan/Chelan vs. LGL/LGL	<0.0001	<0.0001	<0.0001
Chelan/Chelan vs. Chelan/LGL	0.0174	0.0844	<0.0001
LGL/LGL vs. Chelan/LGL	<0.0001	<0.0001	0.2116

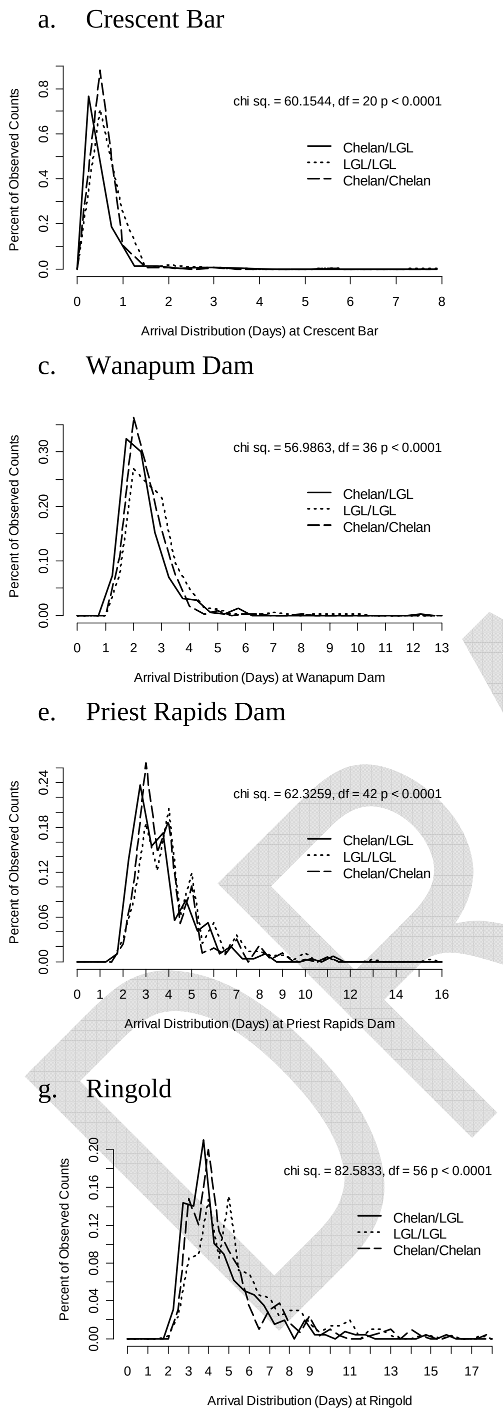


Figure 5 Comparison of arrival distributions to downstream acoustic arrays for the three releases of steelhead from Rock Island tailrace in 2007.

Table 2 Comparison of harmonic mean travel times to each acoustic array site by release group. Standard errors are in parentheses.

	Travel Times from Release to (in Days)						
Source/Tagger	Crescent Bar	Sunland Estates	Wanapum Dam	Mattawa	Priest Rapids Dam	Vernita Bridge	Ringold
Chelan/Chelan	0.236 (0.004)	0.707 (0.008)	2.014 (0.027)	2.481 (0.044)	3.261 (0.055)	3.695 (0.074)	4.078 (0.081)
LGL/LGL	0.301 (0.007)	0.831 (0.013)	2.210 (0.033)	2.703 (0.053)	3.507 (0.066)	4.105 (0.094)	4.521 (0.100)
Chelan/LGL	0.291 (0.006)	0.813 (0.012)	2.128 (0.033)	2.544 (0.053)	3.271 (0.060)	3.620 (0.072)	3.978 (0.080)

3.3 Reach Survivals

The seven downstream detection sites permitted the estimation of reach passage survival through six locations (Figure 1). Capture histories were compiled by treatment groups to compare passage survival probabilities (Table 3). The single release-recapture model was used to estimate survivals on a reach-by-reach basis (Table 4). Only in the third reach, from Sunland Estates to Wanapum Dam, was survival significantly different ($P < 0.0003$) between treatment groups, with the LGL/LGL group experiencing the highest survival (Table 5). Cumulatively over the six estimable reaches, the LGL/LGL treatment had the highest survival ($\hat{S}$ = 0.7055, $\widehat{SE}$ = 0.0209), while the Chelan/Chelan treatment had the lowest ($\hat{S}$ = 0.6190, $\widehat{SE}$ = 0.0216) (Table 3.6). The cumulative effect of treatment groups on survival was statistically significant between LGL/LGL and Chelan/Chelan ($P = 0.0040$). Cumulative survival curves for the three treatments indicate the overall better survival of the LGL/LGL treatment group (Figure 6).

A number of factors ultimately distinguished the three treatment groups (see Section 2.1). However, one factor identified as statistically significant (Chelan/Chelan vs. LGL/LGL, $P < 0.0001$; Chelan/Chelan vs. Chelan/LGL, $P = 0.0174$; Chelan/LGL vs. Chelan/LGL, $P < 0.0001$) was a difference in length distribution of the steelhead smolts. The LGL/LGL treatment fish were proportionately larger than the fish from the other two treatments. One individual covariate analysis which examined the relationship between size at time of release and the probability of survival from Rock Island tailrace to Vernita Bridge found a nonsignificant ($P = 0.1963$) positive relationship. The largest fish were estimated to have about a 0.10 higher survival probability than the smallest fish.

3.3.1 Fractional Mortality

The fraction of total integrated mortality was estimated on a reach-by-reach basis (Table 7). Two reaches, Sunland Estates – Wanapum forebay and Wanapum forebay – Mattawa, were found to compose the largest fractions of overall mortality (Figure 8), approximately 32% and 26%, respectively.

Table 3 Detection histories used in estimating steelhead smolt survival from releases in the Rock Island tailrace. "1" denotes detection; "0," nondetections at Crescent Bar, Sunland Estates, Wanapum Dam, Mattawa, Priest Rapids Dam, Vernita Bridge, and Ringold arrays.

Fish Source	Chelan PUD	LGL	Chelan PUD
Tagging Group	Chelan PUD	LGL	LGL
Detection Histories			
1111111	273	272	228
0111111	0	9	4
1101111	11	7	9
1110111	5	15	15
1100111	1	0	0
1111011	0	1	1
1111101	0	1	0
1111110	20	24	19
0111110	0	1	0
1101110	1	2	0
1001110	1	0	0
1110110	0	1	1
1111010	0	1	0
1110010	0	1	0
1111100	22	30	16
1101100	1	0	0
1111000	23	23	14
1101000	3	1	0
1110000	50	35	34
1100000	77	36	60
0100000	1	1	1
1000000	6	8	12
0000000	9	6	11
Total	504	475	425

Table 4 Survival and detection probability estimates of steelhead smolts released from the Rock Island tailrace. The joint probability of surviving from Vernita Bridge to, and being detected at, Ringold (λ) is reported in the last column. Standard errors are reported in parentheses.

	Survival					
Source/Tagger	Rock Island to Crescent Bar	CB to Sunland Estates	Sunland Estates to Wanapum	Wanapum to Mattawa	Mattawa to Priest Rapids	Priest Rapids to Vernita Bridge
Chelan/Chelan	0.9822 (0.0059)	0.9882 (0.0049)	0.8455 (0.0168)	0.8739 (0.0168)	0.9268 (0.0138)	0.9313 (0.0138)
LGL/LGL	0.9878 (0.0051)	0.9825 (0.0061)	0.9217 (0.0127)	0.9182 (0.0137)	0.9362 (0.0128)	0.9174 (0.0145)
Chelan/LGL	0.9745 (0.0077)	0.9707 (0.0083)	0.8508 (0.0180)	0.9000 (0.0167)	0.9521 (0.0125)	0.9452 (0.0133)

	Detection at					
Source/Tagger	Crescent Bar	Sunland Estates	Wanapum	Mattawa	Priest Rapids	Vernita Bridge
Chelan/Chelan	0.9980 (0.0020)	0.9976 (0.0024)	0.9501 (0.0115)	0.9821 (0.0072)	1.0000 (<0.0001)	1.0000 (< 0.0001)
LGL/LGL	0.9761 (0.0071)	1.0000 (< 0.0001)	0.9743 (0.0080)	0.9534 (0.0110)	0.9910 (0.0051)	0.9967 (0.0033)
Chelan/LGL	0.9876 (0.0055)	1.0000 (< 0.0001)	0.9707 (0.0096)	0.9454 (0.0133)	0.9964 (0.0036)	1.0000 (< 0.0001)

Source/Tagger	Detection and Survival (λ) to Ringold
Chelan/Chelan	0.9295 (0.0145)
LGL/LGL	0.9102 (0.0156)
Chelan/LGL	0.9278 (0.0156)

Table 5 Likelihood ratio tests of Rock Island tailrace releases of acoustic-tagged steelhead smolts.

Hypotheses	χ^2	DF	*P*-value
$S_1 \mid p_1, \underset{\sim}{S}_2, p_2, \underset{\sim}{S}_3, p_3, \underset{\sim}{S}_4, p_4, \underset{\sim}{S}_5, p_5, \underset{\sim}{S}_6, p_6, \underset{\sim}{\lambda}$	2.1070	2	0.3487
$S_2 \mid \underset{\sim}{S}_1, p_1, p_2, \underset{\sim}{S}_3, p_3, \underset{\sim}{S}_4, p_4, \underset{\sim}{S}_5, p_5, \underset{\sim}{S}_6, p_6, \underset{\sim}{\lambda}$	3.4448	2	0.1786
$S_3 \mid \underset{\sim}{S}_1, p_1, \underset{\sim}{S}_2, p_2, p_3, \underset{\sim}{S}_4, p_4, \underset{\sim}{S}_5, p_5, \underset{\sim}{S}_6, p_6, \underset{\sim}{\lambda}$	16.2085	2	0.0003
$S_4 \mid \underset{\sim}{S}_1, p_1, \underset{\sim}{S}_2, p_2, \underset{\sim}{S}_3, p_3, p_4, \underset{\sim}{S}_5, p_5, \underset{\sim}{S}_6, p_6, \underset{\sim}{\lambda}$	3.4402	2	0.1791
$S_5 \mid \underset{\sim}{S}_1, p_1, \underset{\sim}{S}_2, p_2, \underset{\sim}{S}_3, p_3, \underset{\sim}{S}_4, p_4, p_5, \underset{\sim}{S}_6, p_6, \underset{\sim}{\lambda}$	2.1015	2	0.3497
$S_6 \mid \underset{\sim}{S}_1, p_1, \underset{\sim}{S}_2, p_2, \underset{\sim}{S}_3, p_3, \underset{\sim}{S}_4, p_4, \underset{\sim}{S}_5, p_5, p_6, \underset{\sim}{\lambda}$	1.9427	2	0.3786
$\lambda \mid \underset{\sim}{S}_1, p_1, \underset{\sim}{S}_2, p_2, \underset{\sim}{S}_3, p_3, \underset{\sim}{S}_4, p_4, \underset{\sim}{S}_5, p_5, \underset{\sim}{S}_6, p_6$	0.9786	2	0.6131

Table 6 Comparison of survival from Rock Island tailrace to Vernita Bridge for the three steelhead release groups.

Source/Tagger	Survival, Rock Island Tailrace to Vernita Bridge
Chelan/Chelan	0.6190 (0.0216)
LGL/LGL	0.7055 (0.0209)
Chelan/LGL	0.6518 (0.0231)

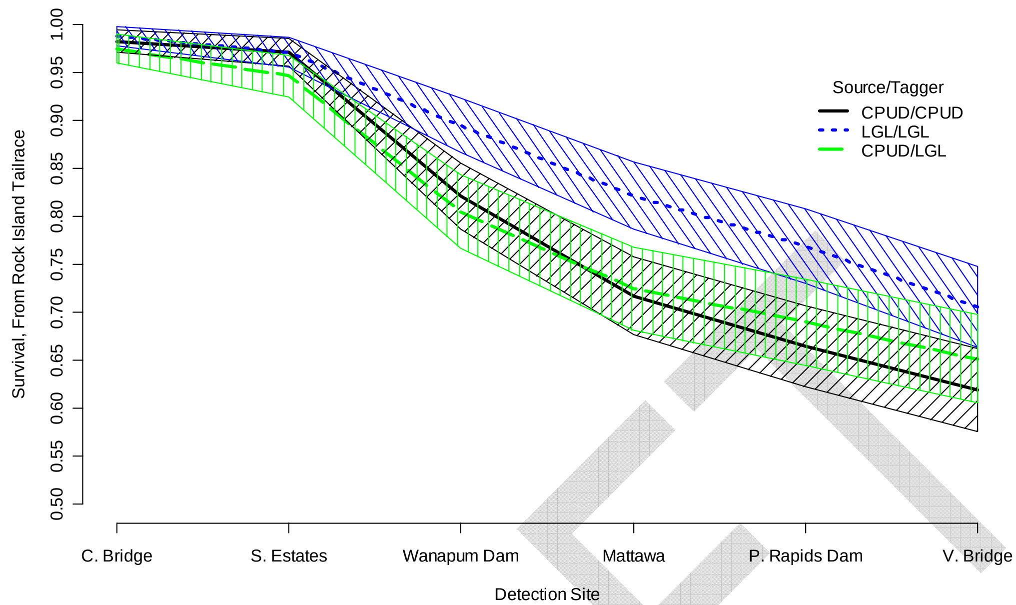


Figure 6 **Plot of cumulative survival for each of the three releases of steelhead smolts from Rock Island tailrace. Shaded area is the 95% confidence interval for the cumulative survival estimate.**

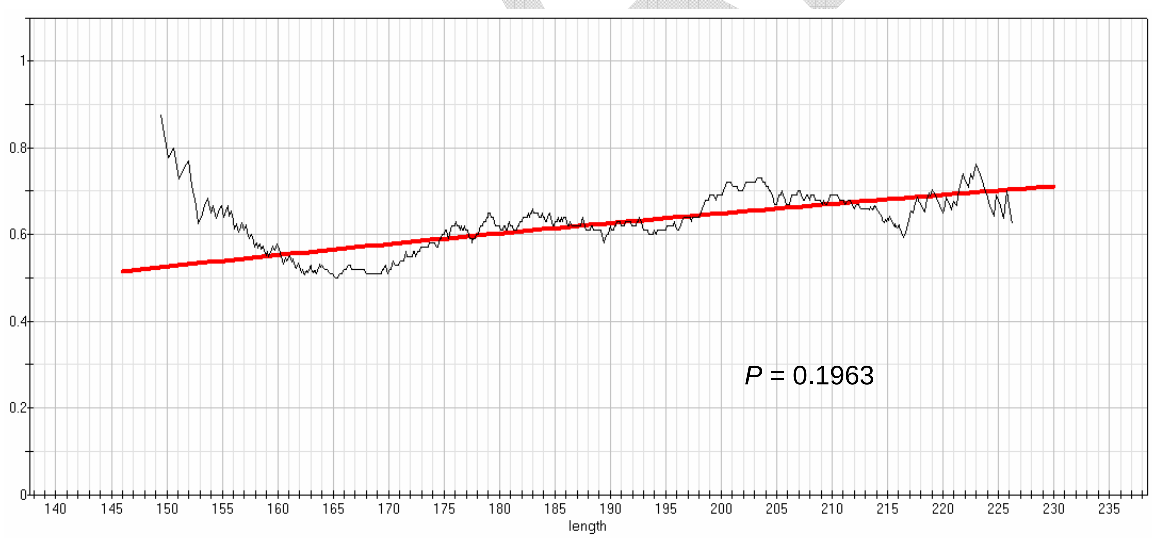


Figure 7 **Estimated steelhead smolt survival from Rock Island tailrace to Vernita Bridge versus length at the time of tagging for the Chelan/Chelan release group. The jagged line is the nonparametric estimate of survival.**

Table 7 Fraction of total mortality per reach for steelhead smolts released from the Rock Island tailrace. Standard errors are reported in parentheses.

	Fraction of Total Mortality					
Source/Tagger	Rock Island to Crescent Bar	Crescent Bar to Sunland Estates	Sunland Estates to Wanapum	Wanapum to Mattawa	Mattawa to Priest Rapids	Priest Rapids to Vernita Bridge
Chelan/Chelan	0.0374 (0.0123)	0.0247 (0.0103)	0.3499 (0.0338)	0.2810 (0.0332)	0.1585 (0.0281)	0.1484 (0.0281)
LGL/LGL	0.0352 (0.0146)	0.0506 (0.0175)	0.2337 (0.0348)	0.2446 (0.0367)	0.1889 (0.0345)	0.2471 (0.0384)
Chelan/LGL	0.0604 (0.0180)	0.0695 (0.0195)	0.3776 (0.0395)	0.2462 (0.0367)	0.1147 (0.0284)	0.1317 (0.0302)

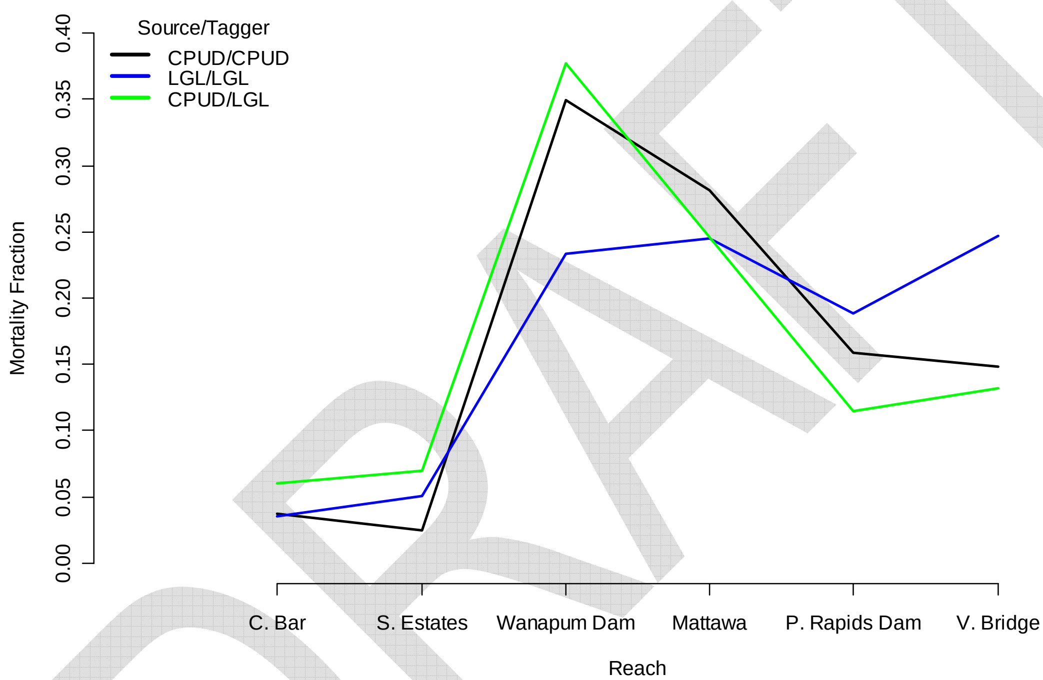


Figure 8 Fraction of total integrated mortality per reach for each steelhead smolt release from the Rock Island tailrace.

3.3.2 Individual Tagger Effects

For the two treatments (i.e., LGL/LGL and Chelan/LGL) where LGL tagged the fish, personnel who tagged specific fish were identified. These individuals— coded A, L, and M—tagged all the fish for these two treatment groups. Survivals were again estimated on a reach-by-reach basis for each tagger and treatment group (Table 8). Within individual reaches there was some anticipated random variability. However, in the two reaches with the greatest sources of mortality, Sunland Estates – Wanapum forebay and Wanapum forebay – Mattawa, tagger effects became more apparent. There was as much as a 0.20 spread in reach survival estimates between fish tagged by different crews. Fish tagged by A had consistently lower survival (Table 8). Across the length of the six reaches, survival estimates varied as much as 0.24 with fish tagged by tagger A with the lower estimates of survival; fish tagged by M, the highest; and fish tagged by L, intermediate. The results were consistent across the LGL/LGL and Chelan/LGL treatment groups.

3.4 Arrival Distribution at Downstream Dams

3.4.1 Arrival to Wanapum Dam

When possible, the passage routes taken by a steelhead smolt through Wanapum Dam were identified based on the arrays at which the detections occurred. Unfortunately, due to the side-by-side position of the top-spill and sluiceway, the exact route could not always be determined at these two locations, and the detection went into the category “Top-Spill/Sluiceway” (Table 10). The passage abundance of the fish in this unknown category was apportioned to the top spill and sluiceway routes in the proportions observed for those two categories. This apportionment approach assumes fish with identifiable and non-identifiable routes pass through the top-spill and sluiceway in the same proportions. However, there is no way to empirically test this assumption.

Table 8 Survival and detection probability estimates of steelhead smolts released from the Rock Island tailrace by tagger (A, L, or M). The joint probability of surviving from Vernita Bridge to, and being detected at, Ringold (λ) is reported in the last column. Standard errors are reported in parentheses.

		Survival						
Source/Tagger	Tagger Code	Rock Island to Crescent Bar	Crescent Bar to Sunland Estates	Sunland Estates to Wanapum	Wanapum to Mattawa	Mattawa to Priest Rapids	Priest Rapids to Vernita Bridge	Overall
LGL/LGL	A	0.9897 (0.0103)	0.9688 (0.0178)	0.8757 (0.0351)	0.8718 (0.0379)	0.9155 (0.0330)	0.9077 (0.0359)	0.6082 (0.0216)
	L	0.9812 (0.0086)	0.9798 (0.0089)	0.9171 (0.0177)	0.9226 (0.0183)	0.9316 (0.0180)	0.9176 (0.0199)	0.6954 (0.0286)
	M	1.0000 (<0.0001)	1.0000 (<0.0001)	0.9681 (0.0166)	0.9404 (0.0230)	0.9600 (0.0196)	0.9231 (0.0261)	0.8067 (0.0362)
Chelan/LGL	A	0.9545 (0.0199)	0.9714 (0.0163)	0.7425 (0.0443)	0.8714 (0.0400)	0.9545 (0.0256)	0.9365 (0.0307)	0.5364 (0.0475)
	L	0.9825 (0.0090)	0.9623 (0.0131)	0.8629 (0.0241)	0.8939 (0.0236)	0.9474 (0.0181)	0.9474 (0.0181)	0.6545 (0.0321)
	M	0.9791 (0.0147)	0.9891 (0.0108)	0.9457 (0.0236)	0.9350 (0.0274)	0.9596 (0.0233)	0.9481 (0.0253)	0.7789 (0.0426)

Table 9 Comparison of steelhead smolt survival from Rock Island tailrace to Vernita Bridge for the three steelhead release groups by tagger (A, L, and M). The Chelan/Chelan group did not have the tagger identified.

Source/Tagger	Tagger Code	Number Tagged	Number Cull Candidates	% Cull Candidates	Survival, Rock Island Tailrace to Vernita Bridge
Chelan/Chelan		504	Unknown	Unknown	0.6190 (0.0216)
LGL/LGL	A	97	9	9.3%	0.6082 (0.0496)
	L	259	56	21.6%	0.6954 (0.0286)
	M	119	22	18.5%	0.8067 (0.0362)
Chelan/LGL	A	110	11	10.0%	0.5364 (0.0475)
	L	220	62	28.2%	0.6545 (0.0321)
	M	95	29	30.5%	0.7789 (0.0426)

Table 10 Observed counts at each passage route at Wanapum Dam for each release of steelhead from Rock Island Dam.

Release Group	Gatewell	Powerhouse	Sluiceway	Spillway	Top Spill or Sluiceway
Chelan/Chelan	12	239	37	33	66
Chelan/LGL	8	219	27	20	53
LGL/LGL	27	242	49	20	68

A chi-square test of the observed detections at each route through Wanapum Dam show that the three steelhead release groups were non-homogeneous in their passage route distribution (*P* = 0.0224). Further analysis indicated that the LGL/LGL group had a greater proportion of detected fish in the Wanapum gatewell than the other two release groups. The Chelan/Chelan and Chelan/LGL groups had homogenous proportions through the five Wanapum passage routes (*P* = 0.5879). Therefore, these two latter groups were pooled together to estimate passage proportions and relative route survival, and the LGL/LGL group was analyzed separately.

Using the detection histories at the double arrays at each route, the passage abundance of tagged fish through each route was estimated using a Lincoln/Peterson Index, single mark-recapture model (Table 11). In turn, passage abundance estimates were converted to route-specific passage proportions (Table 12). For both the LGL/LGL treatment and the other two pooled treatments, the powerhouse passed the greatest proportion of fish, 64.14% and 59.61%, respectively. The sluiceway passed the next largest proportion of fish, estimated to be 18.08% and 23.96%, respectively, for the two groups of fish (Table 12). The LGL/LGL fish went through the gatewell and sluiceway at significantly greater proportions (*P* = 0.0055 and 0.0319, respectively) than the combined Chelan/LGL and Chelan/Chelan fish groups. The gatewells passed 6.65% (SE= 1.24) and 2.80% (SE = 0.62). Conversely, the LGL/LGL fish went through the top-spill at a significantly lower proportion (*P* = 0.0210) than the other fish (Table 12).

3.4.2 Arrival at Priest Rapids Dam

A chi-square test of the observed detections at each route through Priest Rapids Dam indicate that the three steelhead smolt release groups were homogeneous in their passage route distributions (*P* = 0.4122) (Table 13). The three groups were therefore pooled together to estimate passage proportions and relative route survival.

The double array at each passage route of Priest Rapids were used to generate capture histories (Table 3.14) that could then be converted to estimates of passage abundance of the tagged fish and subsequent passage proportions (Table 15). The powerhouse at Priest Rapids was estimated to have passed 75.35% ($\widehat{SE}$ = 1.387) of the tagged steelhead smolts, followed by the top-spill, 18.72% ($\widehat{SE}$ = 1.25%). The spillway passed the fewest proportion of fish at 0.41% ($\widehat{SE}$ = 0.20%) (Table 15).

Table 11 Capture histories at the route-specific double arrays at Wanapum Dam and the resulting abundance $(\hat{N})$ of tagged steelhead smolts. Standard errors are in parentheses.

Chelan-source release groups

Route	Capture Histories			$\hat{N}(\widehat{SE})$
	11	01	10	
Powerhouse	458	0	0	458 (0)
Gatewell	20	0	0	20 (0)
Sluiceway	64	0	0	64 (0)
Spillway	51	1	1	53.1 (0.1)
Top-Spill/Sluiceway	118	1	0	119 (0)

a. Wanapum-gatewell-source release groups

Route	Capture Histories			$\hat{N}(\widehat{SE})$
	11	01	10	
Powerhouse	242	0	0	242 (0)
Gatewell	27	0	0	27 (0)
Sluiceway	49	0	0	49 (0)
Spillway	19	1	0	20 (0)
Top-Spill/Sluiceway	68	0	0	68 (0)

Table 12 Estimates of proportional passage of steelhead smolts at Wanapum Dam. Standard errors are in parentheses. The *P*-value is for a two-tailed test of equality.

Route	Passage Proportion		*P*-value
	Chelan Source	Wanapum Gatewell Source	
Powerhouse	0.6414 (0.0192)	0.5961 (0.0255)	0.1558
Gatewell	0.0280 (0.0062)	0.0665 (0.0124)	0.0055
Sluiceway	0.1808 (0.0158)	0.2396 (0.0224)	0.0319
Top-Spill	0.1498 (0.0149)	0.0978 (0.0169)	0.0210

Table 13 **Observed counts at each passage route at Priest Rapids Dam for each release of steelhead smolts from Rock Island Dam.**

Release Group	Gatewell	Powerhouse	Spillway	Top Spill
Chelan/Chelan	14	255	2	62
Chelan/LGL	14	222	2	53
LGL/LGL	26	260	0	68

Table 14 **Capture histories at the route-specific double arrays at Priest Rapids Dam and the resulting abundance $(\hat{N})$ of tagged steelhead smolts. Standard errors are in parentheses.**

	Capture Histories			
Route	11	01	10	$\hat{N}(\widehat{SE})$
Powerhouse	703	0	34	737 (0)
Gatewell	52	0	2	54 (0)
Spillway	4	0	0	4 (0)
Top-Spill	172	1	10	183.1 (0.2)

Table 15 **Estimates of proportional passage of steelhead smolts at Priest Rapids Dam. Standard errors are in parentheses.**

Route	Passage Proportion
Powerhouse	0.7535 (0.0138)
Gatewell	0.0552 (0.0073)
Spillway	0.0041 (0.0020)
Top-Spill	0.1872 (0.0125)

3.5 Route-Specific Relative Survival Rates

3.5.1 Wanapum Dam

Using the steelhead smolts with known passage routes, downstream capture histories were compiled by category (Table 16). Relative survivals were computed for each route relative to the powerhouse, i.e., $S_{\text{Route}_i} / S_{\text{Powerhouse}}$. Only at the sluiceway did the Chelan and Wanapum gatewell-source fish exhibit different route-specific survivals $\left(P\left(\chi_1^2 \geq 6.5917\right) = 0.0102\right)$. At the other routes, *P*-values ranged from $0.2992 \leq P \leq 0.9028$. Both the LGL/LGL and the other two pooled treatments groups estimated relative survivals for the unspecified top-spill/sluiceway passed fish at greater than one (Table 17). For the other fish that passed through the gatewell, sluiceway, or spillway, the pattern of relative survivals is less clear (Table 17). In some instances, the relative survivals are greater than one; at other times, less than one, when comparing the two groups of fish sorted by source. Analysis using R × C contingency tables indicates the downstream survivals of the gatewell, sluiceway, and spillway passed fish are significantly different between routes (*P* = 0.04169 for Chelan-source fish and *P* = 0.1147 for Wanapum-source fish).

3.5.2 Priest Rapids Dam

Route-specific detections at Priest Rapids for the Chelan and Wanapum gatewell-source fish were homogeneous (*P* = 0.4122), permitting pooling of the alternative release groups (Table 18). Both the spillway and the top-spill had estimated greater relative survivals compared to the powerhouse, with values of 1.0697 ($\widehat{\text{SE}}$ = 0.0104) and 1.0287 ($\widehat{\text{SE}}$ = 0.0182), respectively (Table 19). The relative survival for the spillway was significantly greater than one (*P* < 0.0001).

Table 16 Detection histories for the pooled Chelan-source and Wanapum-gatewell-source, acoustic-tagged steelhead smolts released at Rock Island tailrace and detected at the Wanapum forebay arrays to estimate relative route survival at Wanapum Dam. Downstream detection sites were pooled. "1" indicates detection, "0" indicates not detected.

a. Chelan-source release group

	Detection Downstream		
Passage Route at Wanapum Dam	1	0	Total
Powerhouse	411	47	458
Gatewell	18	2	20
Sluiceway	56	8	64
Spillway	43	10	53
Top-Spill or Sluiceway	113	6	119
Total			929

b. Wanapum-gatewell-source release group

	Detection Downstream		
Passage Route at Wanapum Dam	1	0	Total
Powerhouse	223	19	242
Gatewell	24	3	27
Sluiceway	49	0	49
Spillway	18	2	20
Top-Spill or Sluiceway	65	3	68
Total			475

Table 17 Estimates of relative route-specific survival of steelhead smolts, comparing those that passed through other routes to those that passed through powerhouse route at Wanapum Dam. Standard errors are in parentheses.

	Relative Route-Specific Survival to the Powerhouse	
Parameter	Chelan Source	Wanapum Gatewell Source
$S_{Powerhouse}$	1	1
$S_{Gatewell}$	1.0029 (0.0764)	0.9646 (0.0681)
$S_{Sluiceway}$	0.9751 (0.0486)	1.0852 (0.0204)
$S_{Spillway}$	0.9041 (0.0616)	0.9767 (0.0751)
$S_{Top\text{-}Spill/Sluiceway}$	1.0582 (0.0279)	1.0373 (0.0333)

Table 18 Detection histories for the pooled acoustic-tagged steelhead smolts released at Rock Island tailrace and detected at the Priest Rapids forebay arrays to estimate relative route-specific survival at Priest Rapids Dam. Downstream detection sites were pooled. "1" indicates detection, "0" indicates not detected.

	Detection Downstream		
Passage Route at Wanapum Dam	1	0	Total
Powerhouse	689	48	737
Gatewell	50	4	54
Spillway	4	0	4
Top-Spill	176	7	183
Total			1404

Table 19 Estimates of relative route-specific survival of steelhead smolts compared to those passing through the powerhouse route at Priest Rapids Dam. Standard errors are in parentheses.

Parameter	Relative Route-Specific Survival to the Powerhouse
$S_{Powerhouse}$	1
$S_{Gatewell}$	0.9904 (0.0390)
$S_{Spillway}$	1.0697 (0.0104)
$S_{Top\text{-}Spill}$	1.0287 (0.0182)

4.0 Discussion

4.1 Comparison of Release Groups

The intent of the three different steelhead release groups was to assess the effects of fish source and tagging crew on the downstream migratory success of steelhead smolts. Results of the study were intended to provide guidance on the conduct of future paired release-recapture studies to estimate project passage survival. Results indicate the LGL/LGL release group had the best downstream survival success. However, the detailed description of handling and tagging procedures (Section 2.1) indicates perhaps more than just fish source and tagging crew were being compared in these trials. Individual tagging records of the fish indicate that the treatment group had proportionally larger fish than the other two release groups (Figure 4). The size differential could be a result of fish source (i.e., Rocky Reach juvenile fish bypass vs. Wanapum gatewell) or due to size selectivity. Analysis of route-specific size distributions of the 2007 acoustic-tagged groups of fish at Wanapum (i.e., Chelan/Chelan and Chelan/LGL groups) indicates a possible size bias at the powerhouse but not elsewhere (Figure 9). At the powerhouse, there is a tendency for more large fish and fewer small fish to pass. Therefore, having collected the LGL/LGL fish from the Wanapum gatewell should not have size-biased fish selection.

4.2 Tagger Effects

In 2006, significant and appreciable differences in the downstream migratory success of tagged fish were observed between members of the tagging crew (Skalski et al. 2006). It was a reasonable expectation that selection of the 2007 tagging crew was done cautiously to avoid problems experienced in 2006, however, significant and appreciable tagger effects were again evident in the 2007 study. For the Chelan-tagged fish, similar information on which fish were tagged by which taggers was unavailable. Consequently, it is important in paired releases to assure equal proportions of both upstream and downstream releases of fish tagged by the same tagging crew member. It is not sufficient just to have the same crews; it is necessary to have the same individuals tagging at both release locations.

Even then, a crew member-by-location interaction could bias paired release-recapture investigations. If a fish stressed by handling and tagging is more susceptible to mortality during dam passage than fish tagged by other crew members, a survival bias could still occur. For this reason, rigorous training sessions should be required to help raise the overall quality of tagging by all crew members.

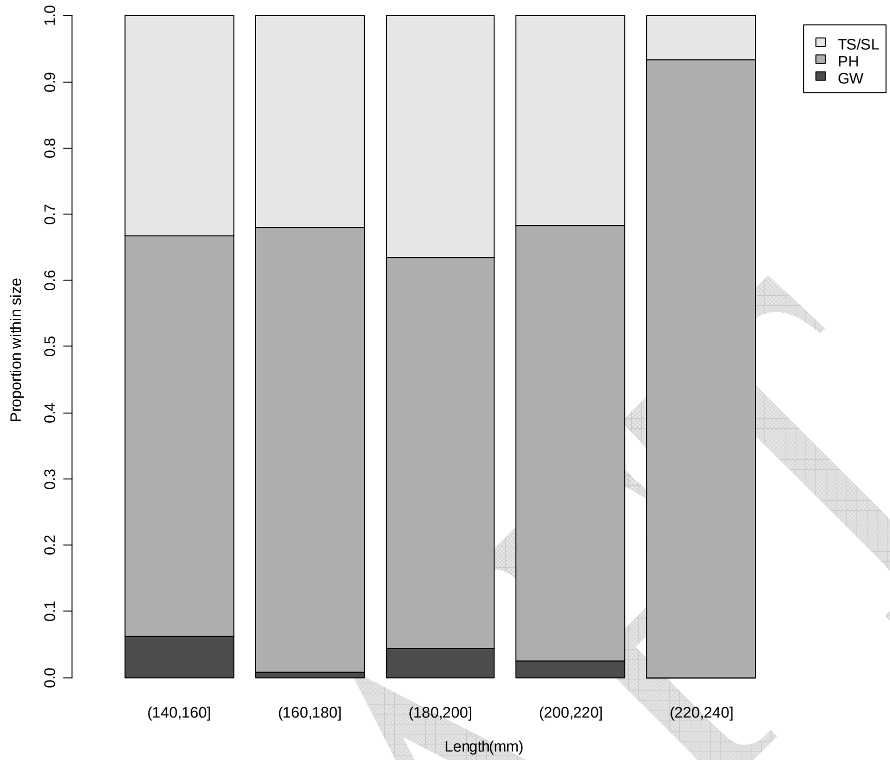


Figure 9 Proportions of fish passing through the Wanapum powerhouse, gatewell, and top spill/sluiceway by length class of steelhead smolts. Note constant proportions across all but the largest size class. Plot based on Chelan PUD as fish source (i.e., treatment groups Chelan/Chelan and Chelan/LGL).

5.0 List of Literature

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C., and Pollock, K.H. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5.

Seber, G.A.F. 1982. The estimation of animal abundance. MacMillan, New York, New York.

Skalski, J.R., Smith, S.G., Iwamoto, R.N., Williams, J.G., and Hoffmann, A. 1998. Use of PIT-tags to estimate survival of migrating juvenile salmonids in the Snake and Columbia Rivers. Canadian Journal of Fisheries and Aquatic Sciences 55: 1484-1493.

Skalski, J.R., Townsend, R.L., Timko, M.A., Brown, L.S. 2006. Statistical Analysis of the 2006 Grant PUD acoustic-Tag Survival Studies for Steelhead Smolts. Draft Report.

Timko, M.A., Brown, L.S., Wright, C.D., O'Connor, R.R., Fitzgerald, C.A., Meagher, M.L., Rizor, S.E., Nealson, P.A., and Johnston, S.V. 2007a. Analysis of juvenile Chinook, steelhead and sockeye salmon behavior using acoustic tags at Wanapum and Priest Rapids dams, 2006. Public Utility District No. 2 of Grant County, Ephrata, Washington. Final report by Hydroacoustic Technology, Inc.

Timko, M.A., Brown, L.S., Wright, C.D., Rizor, S.E., Fitzgerald, C.A., O'Connor, R.R., and Meagher, M.L. 2007b. Analysis of juvenile Chinook, steelhead and sockeye salmon behavior using acoustic tags at Wanapum and Priest Rapids dams, 2007. Public Utility District No. 2 of Grant County, Ephrata, Washington. Final report by Hydroacoustic Technology, Inc.

Appendix A
2007 Comparison of Alternative Steelhead Smolt Release Summary

Study Summary Sheet 1

Year: 2007

Study site(s): Wanapum and Priest Rapids Projects

Objective of study:
Compare downriver steelhead survivals resulting from alternative handling and fish sources

State hypothesis, if applicable: N/A

Fish
- Species-race: Run-of-river steelhead smolts
- Source: Wanapum gatewell and Rocky Reach juvenile fish bypass

Size (median & range) Release Group: Fish Source/Tagging Group

	Chelan/Chelan	Chelan/LGL	LGL/LGL
• eight (gm):	57.3 (28.8-117.7)	58.5 (32-107)	66 (33.5-98)
• ength (mm):	186 (146-230)	183 (150-227)	194 (150-221)

Tag
- Type/model: HTI Model 795E Acoustic Tag
- Weight (gm): 1.5 gm in air
- Implant procedure: Surgical

Survival estimate (per release group), Rock Island tailrace to Vernita Bridge

• Type: Combined Reaches	Chelan/Chelan	Chelan/LGL	LGL/LGL
• Value & SE:	0.6190 (0.02160)	0.6518 (0.0231)	0.7055 (0.0209)
• Sample sizes:	504	425	475

- Analytical model: Single release-recapture model

Hypothesis test and results (if applicable): N/A

Characteristics of estimate
- Effects reflected: Handling mortality
- Relative survival

Environmental/operating conditions

• Type: Project	Wanapum	Priest Rapids
• Discharge (kcfs):	170.9 (145.8-233.7)	171.1 (152.9-224.7)
• Temperature (C°):	9.1 (7.6-11.1)	9.5 (7.8-11.4)
• TDG (%)	116.45 (114.2-131.0)	116.9 (113.3-125.9)

Study Summary Sheet 2

Year: 2007

Study site(s): Wanapum and Priest Rapids Dams

Objective of study:
Compare route-specific proportions and relative survivals of steelhead at Wanapum and Priest Rapids Dams

State hypothesis, if applicable: N/A

Fish
- Species-race: Run-of-river steelhead smolts
- Source: Wanapum gatewell and Rocky Reach juvenile fish bypass

Tag
- See Summary Sheet 1

Route-specific survival relative to powerhouse survival estimate (per fish source)

Type: Relative route-specific survival

Wanapum	Gatewell	Sluiceway	Spillway	Top Spill/Sluiceway
• Chelan source	1.0029 (0.0764)	0.9751 (0.0486)	0.9041 (0.0616)	1.0582 (0.0279)
• LGL source	0.9646 (0.0681)	1.0852 (0.0204)	0.9767 (0.0751)	1.0373 (0.0333)

Priest Rapids	Gatewell	Spillway	Top Spill
• Combined	0.9904 (0.0390)	1.0697 (0.0104)	1.0287

- Analytical model: Single release-recapture model

Proportional route passage

Wanapum	Powerhouse	Gatewell	Sluiceway	Top Spill
• Chelan source	0.6414 (0.0192)	0.0280 (0.0062)	0.1808 (0.0158)	0.1498 (0.0149)
• LGL source	0.5961 (0.0255)	0.0665 (0.0124)	0.2396 (0.0224)	0.0978 (0.0169)

Priest Rapids	Powerhouse	Gatewell	Spillway	Top Spill
• Combined	0.7535 (0.0138)	0.0552 (0.0073)	0.0041 (0.020)	0.1872 (0.0125)

Hypothesis test and results (if applicable): N/A

Characteristics of estimate
- Effects reflected: Handling mortality
- Relative survival

Environmental/operating conditions
- See Summary Sheet 1