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Lower Granite Dam Juvenile Fish Collection Channel Prototype Overflow Weir and Enlarged Orifice Biological Evaluation, 2013

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EXECUTIVE SUMMARY

In 2013, the U.S. Army Corps of Engineers, Walla Walla District, installed two prototype passage structures in Gatewell 5A at Lower Granite Dam (LGR). A prototype broad-crested overflow weir and an enlarged 14-inch orifice were installed within the juvenile bypass system to test for potential passage improvement measures between the gatewell and juvenile collection channel environments. The overflow weir was installed between existing fish passage orifices within Gatewell 5A while the existing southern orifice within the same Gatewell 5A was enlarged from 10 to 14 inches in diameter. During 2013, salmonid and lamprey passage through the prototype structures was evaluated to assess which passage structures warrant consideration during future Juvenile Fish Facility (JFF) upgrades.

In 2013, a study was conducted to assess the biological and debris passage characteristics associated with each style of passage structure (10-inch orifice, 14-inch orifice, and broad-crested overflow weir). More specifically, the objectives were to determine how the overflow weir and larger orifices affected orifice passage efficiency (OPE) and travel times through the juvenile bypass system (JBS) compared to current orifice configuration for juvenile salmonids and lampreys; determine fish condition (including injury and descaling) impacts of the overflow weir and/or larger orifices compared to current orifice configuration for juvenile salmonids; determine debris passage impacts of the overflow weir and/or larger orifices; and investigate salmonid fish behavior patterns in the gatewells with the overflow weir relative to current orifice configuration. Additional objectives specific to juvenile lampreys were to determine the effective collection methods for juvenile lampreys at LGR, Little Goose (LGS), and Lower Monumental (LMN) dams; determine collection efficiency for juvenile lampreys designated for re-collection at the Sort by Code (SxC) system at LGR; and to evaluate PIT-tag retention using two different surgical tagging techniques described by Mesa et al. (2011) compared to PIT tags injected with a 16-gauge needle.

Releases of yearling Chinook (*n* = 11,000) and steelheads (*n* = 11,657) were completed between April 20 and May 25. Releases of sub-yearling Chinook (*n* = 12,130) were completed between May 26–June 21. Juvenile lampreys (*n* = 1,498) were released from May 16 to June 5. A subset of each salmonid species/age class was photographed to assess external health metrics. Fish were released in the morning into Gatewell 5A during operation of the weir or 14-inch orifice, Gatewell 5B during operation of the 10-inch orifice or directly into the bypass channel. Fish selected for health assessments were re-collected at the SxC system at the JFF. While fish were examined for several categories of external health metrics (adapted from Hostetter et al. 2011), descaling was the only commonly encountered malady. Descaling on the right side was more common than the left side of all release groups of yearling Chinook and steelheads. The only species and passage routes linked with significantly increased descaling were yearling Chinook released during operation of the weir and 10-inch orifice. Other types of injuries, such as to the eye, head, or trunk, were extremely rare; <1% of re-collected fish sustained these types of injuries while passing the through the JBS. Sub-yearling Chinook did not have increased descaling scores for any passage route.

Overall, fish passage efficiency from the gatewell to the JFF was high; OPE for each salmonid species/age class ranged from 98.6% to 100% and for lampreys ranged from 95.7% to 99.0%, depending on the release location, which indicated that after reaching the gatewells, the JBS at LGR was effective for these species/age classes. Salmonids had the lowest mean travel times when released during operation of the 14-inch orifice (1.2 h, 2.8 h, and 1.2 h for yearling Chinook, steelheads, and sub-yearling Chinook, respectively). The greatest mean travel times occurred when salmonids were released during weir operation (3.6 h, 4.9 h, and 2.9 h for yearling Chinook, steelheads, and sub-yearling Chinook, respectively). Juvenile lampreys were released at night and had the lowest travel times when released during weir operation (0.3 h). The greatest mean travel times for lampreys occurred when fish were released directly into the bypass channel (0.5 h). The biological relevance of these results should be considered in terms of outmigration delay. The differences in travel times between groups of fish released during operation of the various passage structures were statistically significant but not necessarily biologically meaningful.

Results of multiple regression models indicated species-specific effects of mean fork length on mean travel time through the JFF. Travel time increased for sub-yearling Chinook (14-inch and 10-inch orifice releases) with increased mean fork length (R^2=0.63 and 0.26, respectively). For steelheads (14-inch orifice), the opposite relationship was observed for mean fork length (R^2 = 0.75). Julian day of release was related to decreasing mean travel times for steelheads released during operation of the 10-inch orifice and weir. There was a slight relationship between decreasing mean travel time and flow through Turbine Unit 5 for both yearling and sub-yearling Chinook salmon released during operation of the weir. Regression models were confounded by high levels of correlation between independent variables and small operating ranges of several independent variables.

In addition to evaluating passage through the prototype structures in Gatewells 5A and 5B, juvenile lampreys were included to determine feasible methods of collection, tagging, handling, and release. Some juvenile lampreys were collected at smolt monitoring program (SMP) facilities at LGR, LGS, and LMN dams. The most successful collection efforts occurred in the JBS raceways at LGR and LMN using dip nets. At LMN, lampreys were captured during barge loading after the juvenile salmonids were crowded out of the raceways and also during the night when free swimming lampreys were observed. At LGR, lampreys were captured in the head boxes (upstream end) of the raceways. Most tagging was completed using methods described by Mesa et al. (2011) using a scalpel to create a 2–3-mm incision on the ventral side of the fish and manually inserting a 9-mm-L x 2.1-mm-dia. PIT tag. A tag retention comparison was conducted with 75 fish tagged with scalpels and 75 tagged by injecting an 8.5-mm-L x 1.4-mm-dia PIT tag with a 16-gauge needle. Each group was held for 96 h, then inspected for tag sheds and healing of surgical wounds. No mortalities occurred during the holding period. The group tagged with scalpels had 2 shed tags and 66.7% had unhealed tag wounds. The group injected with PIT tags had no shed tags and 5.7% had unhealed tag wounds. During holding periods, lampreys were kept in perforated 5-gallon buckets placed in tanks plumbed with flow-through river water. Releases of juvenile lampreys were completed by placing tagged fish into a 300-gallon fish transport tank filled to 20% capacity; then opening a release valve allowing the fish to be entrained into a 4-inch diameter flexible release pipe and into the appropriate release location. Three releases of 50 juvenile lampreys into the bypass channel were used to test collection efficiency at the SxC system. The overall proportion recovered from the SxC net partitions was 65%.

The rate of debris obstruction in the passage structures and direct juvenile fish interactions with the passage structure (i.e., strikes) observed with optical video was low for all passage routes. Debris obstructions were only observed in the 10-inch orifice with obstruction of 10–20% of the 10-inch orifice most common, occurring during 7.5% of subsampled video periods. The rate of fish strike was greatest during operation of the 14-inch diameter orifice (0.8% of passing juvenile fish) and lowest during weir operation (0.3% of passing juvenile fish). Video observations of fish strikes did not correlate with fish condition scoring after passage recapture. The frequency and extent of debris obstruction vary between years, with 2013 appearing to be a relatively low debris year within the LGR JBS. The number of adult salmonids observed passing from the gatewells into the bypass channel with the optical video and DIDSON during subsampled monitoring periods was limited (n = 5 and n = 12 for the optical video and DIDSON, respectively).

The 2013 LGR JBS study indicated that yearling and sub-yearling Chinook as well as juvenile steelheads that were released in the morning traveled through the JBS most quickly during operation of the 14-inch orifice. Questions about diel passage are proposed to be addressed in future studies planned for spring 2014. Future studies should include the ability to detect PIT-tagged fish within the bypass collection channel for the purpose of portioning time spent in the gatewell versus collection channel. The rates of injury and descaling among fish released into each release location were mostly benign with the exception of yearling Chinook released during operation of the weir and 10-inch orifice.

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INTRODUCTION

A primary focus of recovery efforts for depressed stocks of Pacific salmon *Oncorhynchus spp.* and steelhead trout *O. mykiss* in the Columbia River Basin has been assessing and improving fish passage conditions at dams (Williams 2008). As such, the 2008 National Oceanic Atmospheric Administration (NOAA) Biological Opinion and the 2010 Supplemental Federal Columbia River Power System (FCRPS) Biological Opinion (NOAA 2008; 2010) calls for the Action Agencies to investigate and implement reasonable and effective measures that will reduce passage delay and increase survival of juvenile fish passing through the forebay, dam, and tailrace as warranted. Juvenile Bypass Systems (JBS) have been identified as a viable method for increasing survival and fish passage efficiency at hydroelectric dams on the Snake and Columbia Rivers (Muir et al. 2001). As a result, modifications to the Lower Granite Dam (LGR) JBS have been proposed to improve fish survival and fish passage efficiency. Initial modifications proposed for the LGR JBS include orifice configuration changes, primary dewatering structures, improved holding facilities for transport, and primary bypass improvements that will improve direct and indirect survival for all fish bypassed through the JBS. Furthermore, the BiOp calls for monitoring and evaluating the effectiveness of traditional juvenile bypass systems and modifications on smolt survival and condition (RPA 54.2).

Contemporary JBSs consist of numerous components, including diversion screens, flumes, barrier screens, orifices, and fish sampling and holding facilities. For example, at LGR, extended-length submersible bar screens (ESBSs) are used to guide fish upward and away from turbine intakes. Guided fish then enter gatewells, where vertical barrier screens confine fish near underwater orifices. Fish currently pass through one of two 10-inch diameter orifices into a juvenile collection channel, which extends along the length of the powerhouse and into the juvenile fish facility (JFF). From the JFF, fish may be returned to the river below the dam, diverted to holding raceways for transport, or diverted and sampled within the JFF. Each component of this system may contribute to delay in the downstream migration of juvenile salmonids. The condition of migrating juvenile salmonids diverted from turbines into JBSs at hydroelectric projects is an ongoing concern because the operating criteria for turbines or the JBS may influence passage timing as well as injury or mortality rates.

At McNary Dam, two studies found that the majority of juvenile fish passage delay was associated with gatewell residence. Beeman and Maule (2001) found that juvenile spring Chinook salmon *O. tshawytscha* and steelheads spent 83% and 96%, respectively, of their total time in the JBS, specifically within the upper 11 m of the gatewells. Axel and Dey (2001) found similar results for sub-yearling Chinook salmon at McNary Dam, when gatewell residence accounted for 90 to 98% of the total passage time through the JBS. Since the majority of passage delay within the JBS was in the gatewell, modifications that could potentially reduce gatewell residence time may have the greatest opportunity to decrease passage times for bypassed fish.

Juvenile Pacific lampreys (*Lampetra tridentata*) also pass the federal mainstem hydroelectric projects in the course of downstream migration. While lampreys typically swim lower in the water column than anadromous salmonids (Long 1968), a portion are guided away from turbine intakes by screens and into the juvenile bypass systems. Laboratory studies conducted in 1999 demonstrated that juvenile lampreys have a distinct activity period that is almost entirely limited to periods of darkness (Moursund et al. 2000). While current limitations in tagging and tracking technology (i.e., size of tag and battery life) limit direct measurement of passage efficiency of juvenile lampreys, it is believed that surface-oriented collection structures are more effective for juvenile salmonids.

Study Area

The study area, LGR, is located at river kilometer (rkm) 695 on the Snake River in southeast Washington (Figure 1). Construction of the dam began in 1965, was completed in 1984, and the project is operated by the U.S. Army Corps of Engineers, Walla Walla District (USACE). The dam is 3,200 feet long with an effective height of 100 feet. A navigation lock is present on the north side. The powerhouse has six 135,000 KW turbines, numbered from south to north. Each turbine has three intake slots, designated A, B, and C from south to north. The spillway contains eight bays, each with a 50-foot by 60.5-foot radial gate.

To test structural modifications that could reduce passage delays and increase survival of fish through the upper portion of the LGR JBS, a prototype broad-crested overflow weir and an enlarged 14-inch diameter orifice were installed into Gatewell 5A during the winter of 2012–2013. The overflow weir was installed between the current orifices and created a new passage structure within the gatewell. The existing southern 10-inch diameter orifice in Gatewell 5A was enlarged to a 14-inch diameter. The northern 10-inch orifice was left as-is without any modifications as part of prototype modifications.

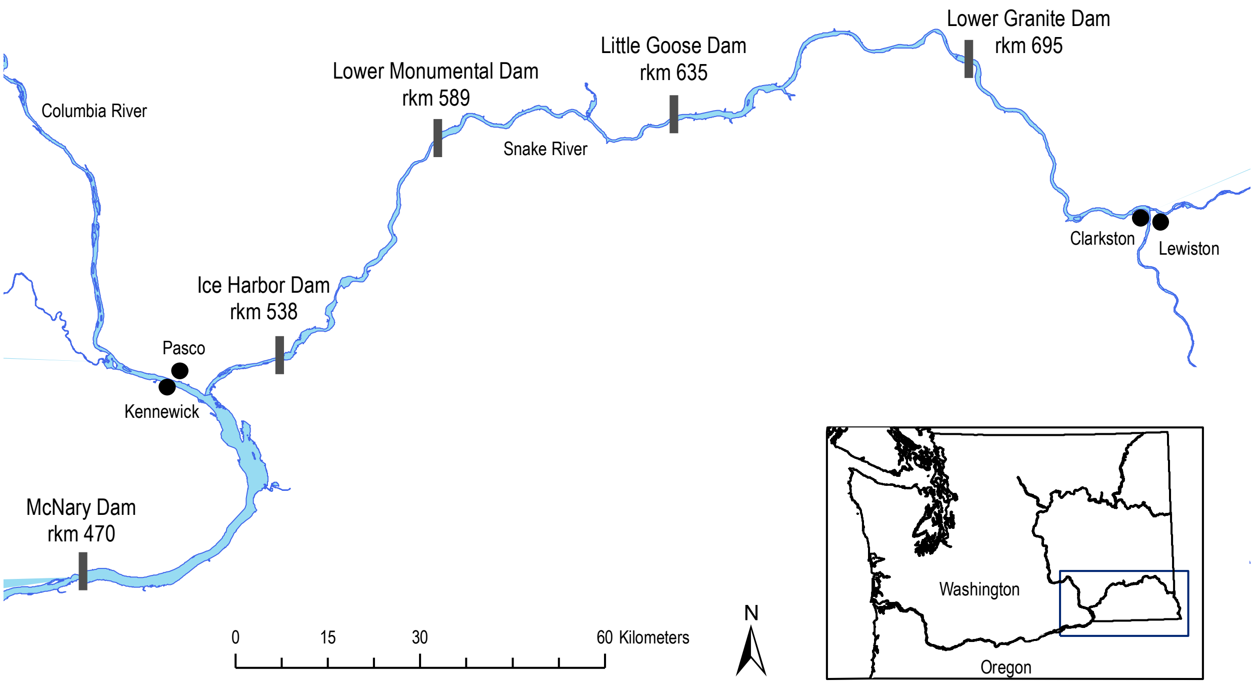

Figure 1. Study area, highlighting Lower Granite Dam at rkm 695, on the lower Snake River in southwest Washington.

River Environment

The Snake River at LGR in 2013 was characterized by below average river flow with a freshet that peaked earlier and did not persist as late into the season as was common over the past ten years (Figure 1). Peak flow downstream of LGR reached 137 Kcfs on May 13. Total dissolved gas (TDG) levels were approximately average compared to the past ten years with early levels exceeding the average but later levels falling below average. Peak TDG reached 115% on June 21. River temperature was below average in April then climbed to above average for part of May and all of June, peaking at 16 °C on June 20.

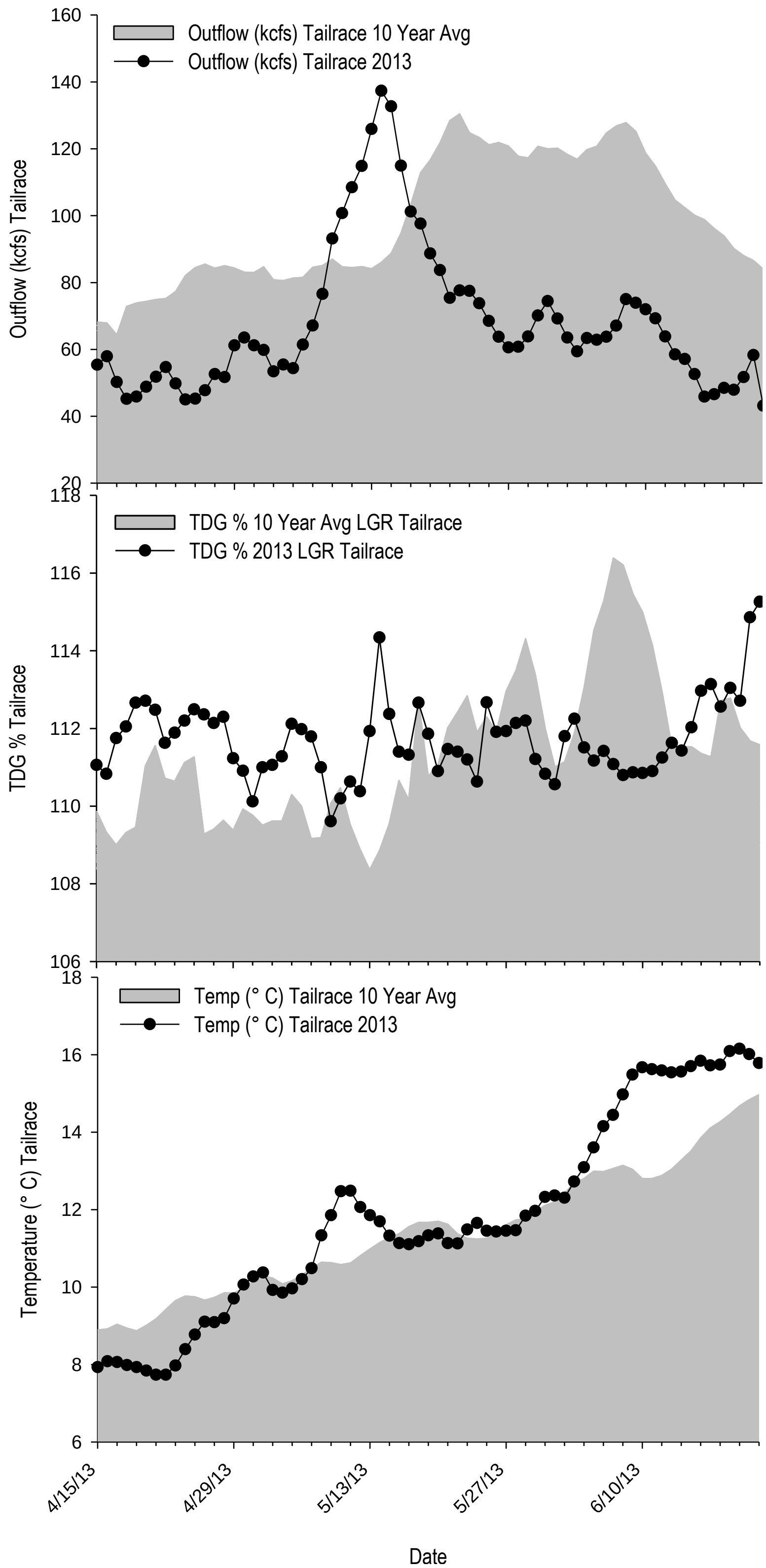

Figure 2. Environmental conditions at Lower Granite Dam in spring 2013. The dotted line plots represent conditions in 2013 and the area plots (gray) represent the 2003–2012 ten-year average.

Research Objectives

The purpose of this study was to assess the biological and debris passage characteristics associated with each style of passage structure (10-inch orifice, 14-inch orifice, and broad-crested overflow weir). More specifically, the objectives were to

1) Determine how the overflow weir and larger orifice affected orifice passage efficiency (OPE) and travel times through the JBS compared to current orifice configuration for juvenile salmonids and lampreys;
2) Determine fish condition (including injury and descaling) impacts of the overflow weir and larger orifice compared to current orifice configuration for juvenile salmonids;
3) Determine debris passage impacts of the overflow weir and larger orifice; and
4) Investigate salmonid fish behavior patterns in gatewells with the overflow weir relative to current orifice configuration.

Additional objectives specific to juvenile lampreys were to determine effective collection methods for juvenile lampreys at LGR, Little Goose (LGS), and Lower Monumental (LMN) dams, determine collection efficiency for juvenile lampreys designated for re-collection at the Sort by Code (SxC) system at LGR, and to evaluate PIT-tag retention using two different tagging techniques: surgical methods described by Mesa et al. (2011) and injecting PIT tags with a 16-gauge needle.

METHODS

The methods are described per research objective.

Objective 1: Determine how the overflow weir and larger orifice affected orifice passage efficiency (OPE) and travel times through the Juvenile Bypass System (JBS) compared to the current orifice configuration for juvenile salmonids and lampreys.

Study Design

The experimental design contained four treatments (10-inch orifice, 14-inch orifice, prototype overflow weir, and bypass channel) of four fish species/age classes (yearling Chinook salmon, steelhead trout, sub-yearling Chinook salmon, and juvenile Pacific lamprey). For a given fish species/age class, the travel times across all replicate releases were combined into one dataset for each treatment and all statistical analyses were performed using NCSS software (Kaysville, Utah). Descriptive statistics were used to summarize sample sizes, mean, median, standard deviation, minimum, maximum, and the Shapiro–Wilk W test for normality. The closer W is to one, the more normal the sample is. Differences in the median travel times for a given fish species/age class between the treatments were evaluated using the Kruskal–Wallis one-way analysis of variance. The null hypothesis (H_0) for the tests was that all median travel times were equal. The alternate hypothesis (H_a) was that at least two median travel times were different. When significant differences were found ($\alpha \leq 0.05$), H_0 was rejected.

In cases where statistically significant differences were found in median travel times between treatments using a Kruskal–Wallis one-way analysis of variance (ANOVA), a multiple comparison procedure (MCP) was used to determine which treatments were different. The Kruskal–Wallis Z (Dunn's test) was used to determine differences between pairs of medians following the Kruskal–Wallis test. This MCP is a distribution-free multiple comparison, meaning that the assumption of normality is not necessary. The Bonferroni test was used to determine significant differences in medians when the z value was greater than 2.64. The Bonferroni test is a conservative estimate of significance compared to the standard z test and appropriate for MCPs. Test power (β) was determined *post hoc* with actual values of sample sizes and standard deviations for all release groups using power analysis pairwise multiple comparisons.

Due to distribution issues with the data, we also explored differences in travel times between treatment pairs using a stratified bootstrapping approach. The test statistic used was the difference of the mean travel times over the season for the two treatments being contrasted. Because of the heterogeneous distributions involved, bootstrapping was stratified by release date and passage type (Efron and Tibshirani [1993] e.g., section 8.3; Davison and Hinkley [1997] e.g., section 3.2; Davison et al. [2003]). For each bootstrap contrast replicate, data sets were constructed for the two passage treatments by joining random samples from each release date's travel times. The samples were of equal size to the original number of released fish for each date, and were drawn with replacement. This algorithm properly accounted for changes over the season of the mean and distribution of travel times. The test pairs for the bootstrapping analysis were 10-inch orifice versus 14-inch orifice, 10-inch orifice versus prototype overflow weir, and 14-inch orifice versus prototype overflow weir. Significant differences between test pairs were determined by two-tailed contrast quantiles. If the interval between the $\alpha/2$ quantile and the $1 - \alpha/2$ quantile did not contain 0, the hypothesis test of no difference between the groups was rejected at the α significance level.

Analyses of potential covariates that impacted fish travel time through the system were explored using multiple regression. Variables were screened using a scatterplot matrix to provide a visual tool to identify linear relationships among covariates. In addition, descriptive statistics were used to summarize mean, standard deviation, median, minimum, maximum, and range for each potential covariate. Finally, a correlation matrix was created for each species/age-class and release location to display a quantitative estimate of correlation among covariates. Highly correlated ($|r| > 0.5$) pairs of independent variables were treated individually to identify the best fit in each model. The independent variable with the lesser relationship to the dependent variable was excluded from the model. Potential multiple regression models were identified using a variable selection algorithm (all possible regressions). Covariates that were considered for potential impacts on travel time included fork length of released fish, water elevation in the bypass channel, Unit 5 turbine discharge, forebay elevation, release date (Julian day), water temperature, and calculated flow through the weir, 10-inch orifice, and 14-inch orifice (as appropriate for each release). Multiple regression analyses were performed for each combination of species/age class and passage route. A Box–Cox transformation of mean travel time for each release was used to optimize the distribution of regression residuals of travel time versus Julian day of release for each species/age class. The transformed mean travel time for each replicate release was regressed against the mean fork length of the release group and the covariate values at the time of each release. The mean travel times, rather than medians, were used to meet the assumptions of the multiple regression models.

We released yearling Chinook salmon (n = 11,000) and steelheads (n = 11,657) during April 20–May 25, sub-yearling Chinook salmon (n = 12,130) during May 26–June 21, and lampreys (n = 1,498) during May 20–June 3 (see Appendix A for detailed release information and Figure 5 for release and exit operations). Fish were released into one of four treatments (10-inch orifice in Gatewell 5B, prototype broad-crested overflow weir in Gatewell 5A, 14-inch orifice in Gatewell 5A, or directly into the Juvenile Bypass Channel [hereafter bypass channel]). Each release of juvenile salmonids into Gatewell 5A (weir or 14-inch orifice) was paired with a release into Gatewell 5B (10-inch orifice) and bypass channel release. Because the treatment structures in Gatewell 5A were operated separately (to provide only one possible passage route), there were half as many total releases for each juvenile salmonid species/age class in Gatewell 5A compared to Gatewell 5B or the bypass channel. For purposes of covariate analysis, each release was treated as a replicate. Because we collected lampreys opportunistically, we lacked sufficient quantities to pair each release into Gatewell 5A with releases into Gatewell 5B and the bypass channel. All lampreys were released at night (after 21:30). The experimental passage structures (weir or 14-inch orifice) in Gatewell 5A were operated on an alternating 48-hour schedule throughout the study period (Table 1). Releases occurred six days per week, Monday through Saturday. The travel time of each fish in each release group was monitored from release to the first detection within the JBS over a 24-hour period prior to the next release (Figures 3 and 4). Fish may have been delayed for a number of reasons (or may have exited the gatewell through the turbine unit); therefore, fish that were not redetected within 24 hours were excluded from statistical analysis. The number of fish withheld from analysis due to passage delay is summarized in the Results.

Table 1. Schedule of operation for each passage structure in Gatewells 5A and 5B at Lower Granite Dam, spring 2013.

Date	Day of Week	Gatewell 5A	Gatewell 5B
4/20/2013	Saturday	Weir	10" orifice -north
4/21/2013	Sunday	Weir	10" orifice -north
4/22/2013	Monday	Weir	10" orifice -north
4/23/2013	Tuesday	14" orifice	10" orifice -north
4/24/2013	Wednesday	14" orifice	10" orifice -north
4/25/2013	Thursday	Weir	10" orifice -north
4/26/2013	Friday	Weir	10" orifice -north
4/27/2013	Saturday	14" orifice	10" orifice -north
4/28/2013	Sunday	14" orifice	10" orifice -north
4/29/2013	Monday	14" orifice	10" orifice -north
4/30/2013	Tuesday	Weir	10" orifice -north
5/1/2013	Wednesday	Weir	10" orifice - north
5/2/2013	Thursday	14" orifice	10" orifice - north
5/3/2013	Friday	14" orifice	10" orifice - north
5/4/2013	Saturday	Weir	10" orifice - north
5/5/2013	Sunday	Weir	10" orifice - north
5/6/2013	Monday	Weir	10" orifice - north
5/7/2013	Tuesday	14" orifice	10" orifice - north
5/8/2013	Wednesday	14" orifice	10" orifice - north
5/9/2013	Thursday	Weir	10" orifice - north
5/10/2013	Friday	Weir	10" orifice - north
5/11/2013	Saturday	14" orifice	10" orifice - north
5/12/2013	Sunday	14" orifice	10" orifice - north
5/13/2013	Monday	14" orifice	10" orifice - north
5/14/2013	Tuesday	Weir	10" orifice - north
5/15/2013	Wednesday	Weir	10" orifice - north
5/16/2013	Thursday	14" orifice	10" orifice - north
5/17/2013	Friday	14" orifice	10" orifice - north
5/18/2013	Saturday	Weir	10" orifice - north
5/19/2013	Sunday	Weir	10" orifice - north
5/20/2013	Monday	Weir	10" orifice - north
5/21/2013	Tuesday	14" orifice	10" orifice - north
5/22/2013	Wednesday	14" orifice	10" orifice - north
5/23/2013	Thursday	Weir	10" orifice - north
5/24/2013	Friday	Weir	10" orifice - north
5/25/2013	Saturday	14" orifice	10" orifice - north

Table 1. (*continued).* Schedule of operation for each passage structure in Gatewells 5A and 5B at Lower Granite Dam, spring 2013.

Date	Day of Week	Gatewell 5A	Gatewell 5B
5/26/2013	Sunday	14" orifice	10" orifice - north
5/27/2013	Monday	14" orifice	10" orifice - north
5/28/2013	Tuesday	Weir	10" orifice - north
5/29/2013	Wednesday	Weir	10" orifice - north
5/30/2013	Thursday	14" orifice	10" orifice - north
5/31/2013	Friday	14" orifice	10" orifice - north
6/1/2013	Saturday	Weir	10" orifice - north
6/2/2013	Sunday	Weir	10" orifice - north
6/3/2013	Monday	Weir	10" orifice - north
6/4/2013	Tuesday	14" orifice	10" orifice - north
6/5/2013	Wednesday	14" orifice	10" orifice - north
6/6/2013	Thursday	Weir	10" orifice - north
6/7/2013	Friday	Weir	10" orifice - north
6/8/2013	Saturday	14" orifice	10" orifice - north
6/9/2013	Sunday	14" orifice	10" orifice - north
6/10/2013	Monday	14" orifice	10" orifice - north
6/11/2013	Tuesday	Weir	10" orifice - north
6/12/2013	Wednesday	Weir	10" orifice - north
6/13/2013	Thursday	14" orifice	10" orifice - north
6/14/2013	Friday	14" orifice	10" orifice - north
6/15/2013	Saturday	Weir	10" orifice - north
6/16/2013	Sunday	Weir	10" orifice - north
6/17/2013	Monday	Weir	10" orifice - north
6/18/2013	Tuesday	14" orifice	10" orifice - north
6/19/2013	Wednesday	14" orifice	10" orifice - north
6/20/2013	Thursday	Weir	10" orifice - north
6/21/2013	Friday	Weir	10" orifice - north

Figure 3. Location of Gatewells 5A and 5B along the Lower Granite Dam powerhouse. The location of the Juvenile Fish Facility (JFF), where the entrained bypassed fish are routed to, is highlighted in the upper portion of the figure.

Figure 4. The red arrow represents the path of travel for fish released into Gatewells 5A, 5B, and the bypass channel. Fish were entrained in the bypass channel and routed to the Juvenile Fish Facility (JFF), approximately 0.25 miles downstream of Lower Granite Dam.

Figure 5. The red circles represent the locations of the three fish passage routes in Gatewell 5A. Fish were entrained in one route per operation mode and routed to the Juvenile Fish Facility (JFF), approximately 0.25 miles downstream of Lower Granite Dam. The 10-inch diameter orifice is represented here for the purpose of displaying relative location within the gatewell. Gatewell 5B was used for releases to test travel time through the 10-inch orifice.

Fish Collection and Tagging

Juvenile Salmonids

Steelheads and Chinook salmon that were tagged for this project were collected at the JFF operated by USACE with staff assistance from the Pacific States Marine Fisheries Commission (PSMFC) or NOAA. This ensured that fish were available for tagging every day of the week (except Saturdays, when no fish were tagged). Methods and the timing of fish handling are detailed below. The research group took custody of the fish following anesthetization, sorting, and counting by PSMFC or NOAA.

The USACE typically operates the JBS and JFF from March 25 through December 15. Beginning May 1, the PSMFC were required to complete sampling by 08:30 each morning so that fish could be loaded onto waiting barges for downstream transport. Thus, all fish that were collected at the JFF for this study were diverted from the morning sample into recirculating holding tanks and tagged the following day. The quantity of fish collected each day was dependent on both the quantity of each species/age class in the river and the daily sample rate. Fish were selected for the study based on size as well as condition. Each fish within the predetermined size categories (Table 2) was scrutinized for descaling and other injuries and excluded if obviously already injured (see Physical Condition Criteria, Appendix B). Rejected fish were immediately returned to the JFF recovery tank with the rest of the PSMFC post-processed juveniles.

Juvenile steelheads and Chinook salmon (both yearling and sub-yearling) were collected by PSMFC during routine sampling of fish passing LGR. Any fish of appropriate species and condition that did not have a PIT tag was placed in an aerated 5-gallon bucket and transported to one of four flow-through holding tanks located outside on the north side of the JFF. Temperature and dissolved oxygen levels in the tanks were monitored regularly in the holding tanks. The following morning, fish were removed from the recirculating holding tanks and brought into the JFF via aerated 5-gallon buckets for anesthesia with MS-222, PIT-tagging, and (for a subsample of fish) photography of condition. Prior to tagging, all fish that were injured, deformed, previously PIT-tagged, severely descaled, or below minimum size criteria were removed from the study. In addition, only hatchery stocks of Chinook salmon and steelheads were marked. The selected fish were PIT-tagged using techniques described by Prentice et al. (1990). The USACE provided 12.5-mm PIT tags (TX1411 SST) to the team who preloaded the tags into single use needles. Following tagging, fish were transferred into the flow-through holding tanks mounted on the release vehicle where they were held until release the following morning. Finally, all salmonids were released into the study gatewell at approximately 08:00 with the exception of four releases of sub-yearling Chinook salmon completed at night (21:30), per a USACE request for a pilot investigation of diel travel time differences.

If the necessary number of fish were not available from PSMFC, fish were collected from the NOAA research group during their daily sorting of raceway-held salmonids. This was common during the end of the steelhead and yearling Chinook salmon run. When we received fish from the NOAA group, the sampling and collection methods that were used have been outlined below.

The long-term juvenile fish monitoring project conducted at LGR by NOAA operated two days a week from April 1–30; then five days a week (Monday–Friday) from May 1 to June 15. Up to 750 steelheads, yearling or sub-yearling Chinook salmon were diverted from the NOAA sampling effort for PIT- tagging in this study.

Fish to be included in the study were removed from the sorting process at the NOAA fish processing trailer via aerated 5-gallon bucket to one of the four large flow-through holding tanks outside the north side of the JFF. Temperature and dissolved oxygen levels in the holding tanks were monitored regularly. The sorting process was typically competed by 10:00. Once fish were in the custody of the research team, handling and release protocols were identical to those used for fish received from PSMFC staff.

Table 2. Minimum length criteria for species included in the enlarged orifice and overflow weir biological evaluation at Lower Granite Dam, spring 2013. Length criteria for salmonids were recommended by Tiffany Marsh, NOAA Fisheries (pers. comm.). The length criterion for juvenile Pacific lampreys was adapted from Mesa et al. (2011).

Species	Minimum Length Criterion (mm)
Juvenile steelhead	90
Yearling Chinook	90
Sub-yearling Chinook	65
Juvenile Pacific lamprey	120

Juvenile Lampreys

Juvenile lampreys were collected from three locations, LMN, LGS and LGR. The collection methods are further described at each location.

Lower Monumental Dam (LMN) — Juvenile lampreys were collected at LMN on eight occasions beginning May 16 (see Appendix C for detailed illustrations of collection areas). Fish were collected from two locations; the daily smolt monitoring program (SMP) sample and fish raceways. SMP staff collected macropthalmia present in the sample and held them in a perforated 5-gallon bucket. The quantities of macropthalmia collected during the SMP sort ranged from 8 to 64. As the raceways were being drawn down for barge loading we collected fish from the raceways using dip nets. The greatest quantities of juvenile lampreys were collected from the top (north) end of the raceways. During the crowding process the water level in the raceway was lowered and salmonids were crowded from the top to the bottom (north to south end) of the raceway for loading onto the barge. Immediately after the USACE tech crowded the salmonids from the top end of the raceway, we inspected the corners at the top end and located groups of macropthalmia entwined together in a tennis ball-sized clump. We used dip nets to scoop up these fish and then followed the tech down the raceway looking for individual macropthalmia. We typically collected fewer than 10 free swimming macropthalmia in the 2 to 3 minutes before the raceway was refilled with water.

USACE staff reported seeing juvenile lampreys swimming near the water's surface after dark in the raceways at LMN. We made three attempts, beginning on May 25, to collect free swimming macropthalmia from the raceways during the night. We used dip nets to capture approximately 27 macropthalmia during the three attempts. Our collection effort began around 23:00 and ended at 04:00 during each attempt. Most of the fish were captured at the lower end of the raceways as they were observed swimming towards the tail screens. A few were caught by netting along the concrete walls of the raceway near the tail screens.

All macropthalmia were transported to LGR inside of 5-gallon perforated buckets with no more than 75 fish per bucket placed in a 300-gallon fish transport tank filled with river water from a hose bib at LMN. Stress Coat™ was added (250 µl/L) after filling the transport tank and prior to beginning the return trip to LGR.

Little Goose Dam (LGS) — We collected macropthalmia from LGS on May 23, 2013. SMP staff collected four fish during the daily sort. We were unsuccessful at capturing the single juvenile lamprey that was observed in the raceways during barge loading. We were not granted permission to attempt night collection of juvenile lampreys at LGS. The methods used to transport fish were the same as described for fish collected from LMN.

Lower Granite Dam (LGR) — We collected macropthalmia from LGR beginning on May 20, 2013. The first 15 we encountered were bycatch in the SxC nets. An additional three were collected by SMP staff during the daily sample. The majority came from dip netting behind the head screens in both the east and west raceways. The large collection (*n* = 453) on May 24 was completed in the evening hours, concluding around 21:00. Collection totals from May 26–31 2013 reflect combined day and night collection effort. Day effort began around 07:00 and night effort concluded around 02:00. We were generally more successful during evening and night collection periods.

The collection effort at LGR involved using a dip net handle to "stir up" the water in the head box then quickly dipping the net into the head box and sweeping it from one side to the other before drawing it out. This process was repeated in the head box of each raceway (6 in the east raceway and 6 in the west raceway for a total of 12 head boxes). If juvenile lampreys were caught, they were typically in the head boxes of one or two raceways (out of 12). On some days, more were caught from either the east or west raceways. The head box in the southernmost raceway of the east raceways was the most consistent location we found macropthalmia. When any juvenile lampreys were caught, we attempted to catch more before moving on to the next head box. We completed several "rounds" of collection effort each day/night.

The juvenile lampreys collected at LGR, LGS and LMN were used to evaluate travel time through the JBS. Juvenile lampreys were removed from the holding tank and placed into MS-222 at 100 ppm and buffered to a neutral pH using sodium bicarbonate, as described by Christiansen et al. (2012). Once the fish became unresponsive, they were placed ventral side up in a groove cut into a moist, closed-cell foam pad that was saturated with 150 $\mu g\ L^{-1}$ poly Aqua (Mesa et. al. 2011). An 8.5-mm x 1.4-mm HPT8 Minichip PIT tag was used to tag a subsample of the juvenile lampreys for a tag-retention test *in situ*. All other juvenile lampreys for gatewell residence time evaluations were tagged with a 9-mm x 2.1-mm PIT tag following the scalpel tagging procedure outlined by Mesa et al. (2011). After tagging, juvenile lampreys were held for approximately 20 hours prior to release. A subsample of both 9-mm scalpel-tagged and 8.5-mm needle-tagged fish was retained for 72 hours to test tag retention and wound healing.

Prior to releases of live lampreys, detection efficiency of the 8.5-mm x 1.4-mm PIT tags was assessed, with the assistance of PSMFC staff, using test sticks on April 30, 2013. Ten test sticks were released immediately downstream of the separator screen at the LGR JFF and re-collected using the SxC system. A second test using 10 test sticks with 9-mm x 2.1-mm PIT tags occurred on May 13, 2013. Both tests resulted in 100% detection.

Lamprey Tag Retention Experiment

On May 18, Biomark staff tagged 75 juvenile lampreys with 8.5-mm x 1.4-mm PITs injected with 16-gauge needles and 75 lampreys with 9-mm × 2.1-mm PITs using methods described by Mesa et al. (2011). The method employed by Mesa et al. (2011) used a scalpel to create a 2–3-mm incision through which the PIT tag is manually inserted into the body cavity (Figure 6). An additional 50 fish (control) were subjected to the identical handling protocol but without surgery. The fish were kept in perforated buckets placed in tanks plumbed for flow-through river water. After 96 hours (on May 22) the buckets were opened and all fish were inspected. No mortalities occurred during the holding period. The groups with PIT tags were anesthetized with MS-222 at 100mg/L concentration and photographed to document the condition of the PIT incision.

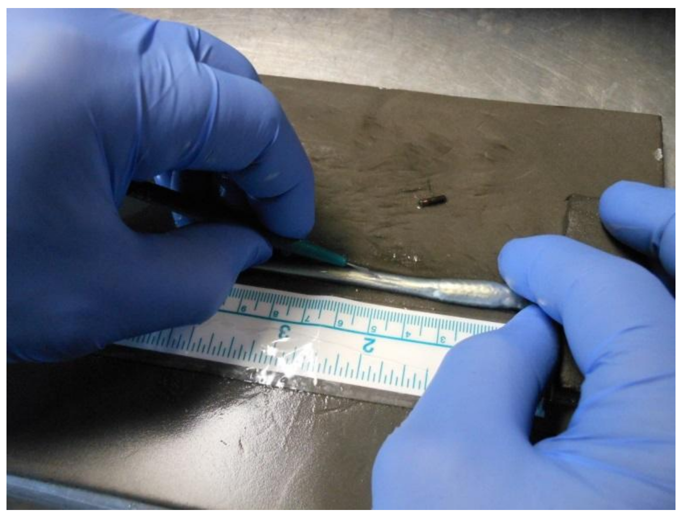

Figure 6. Project staff surgically implanting PIT tags into juvenile lampreys at Lower Granite Dam, spring 2013.

Fish Releases

Juvenile Salmonids

All releases were conducted directly from the recovery/holding tanks into their appropriate treatment location (Figure 7). Prior to releases, temperature and dissolved oxygen levels in each tank were measured using an Oakton 110 series meter. Each tank was also visually inspected for mortalities and swept for shed tags using a large magnet. Any mortalities or shed tags were returned to the JFF for accounting. Following pre-release tank inspections, the transport truck outfitted with fish recovery/holding tanks was driven from the LGR JFF to Gatewells 5A and 5B. Tagged fish were drafted into their release locations through a 4-inch diameter flexible release pipe to a depth of approximately 20 feet within the gatewells or directly into the bypass channel through the experimental weir opening (Figure 8).

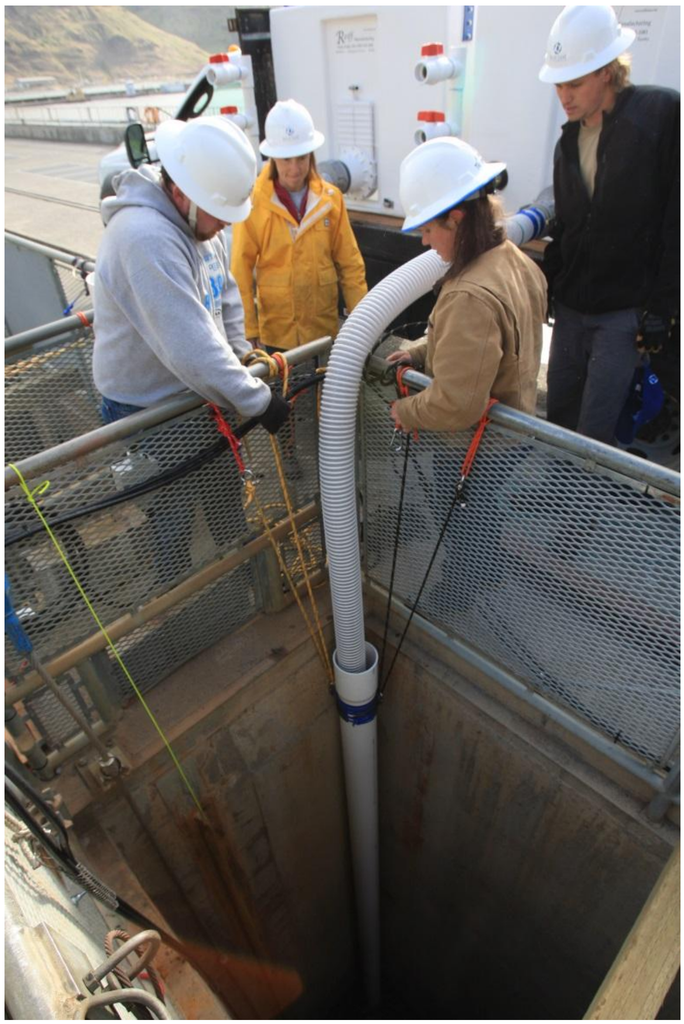

Figure 7. Project staff completing a fish release into Gatewell 5A at Lower Granite Dam, spring 2013.

Gatewell Releases

An 6-inch x 20-foot-long stabilizing PVC pipe on a pulley system was used to keep the release pipe rigid underwater for gatewell releases in 5A and 5B (Figure 8). The release pipe was fed into the stabilizing pipe to its full extension and cam-coupled to the release tank. The stabilizing pipe was then lowered down into the water to within two feet of the release pipe end and secured at the railing. Prior to April 23, fish releases were completed without the 6-inch x 20 foot long PVC pipe stabilizing the release pipe. This resulted in inconsistent release depths as the release pipe moved within the gatewell. During treatments to test the 14-inch orifice, the experimental weir opening was closed prior to releasing fish into Gatewell 5A.

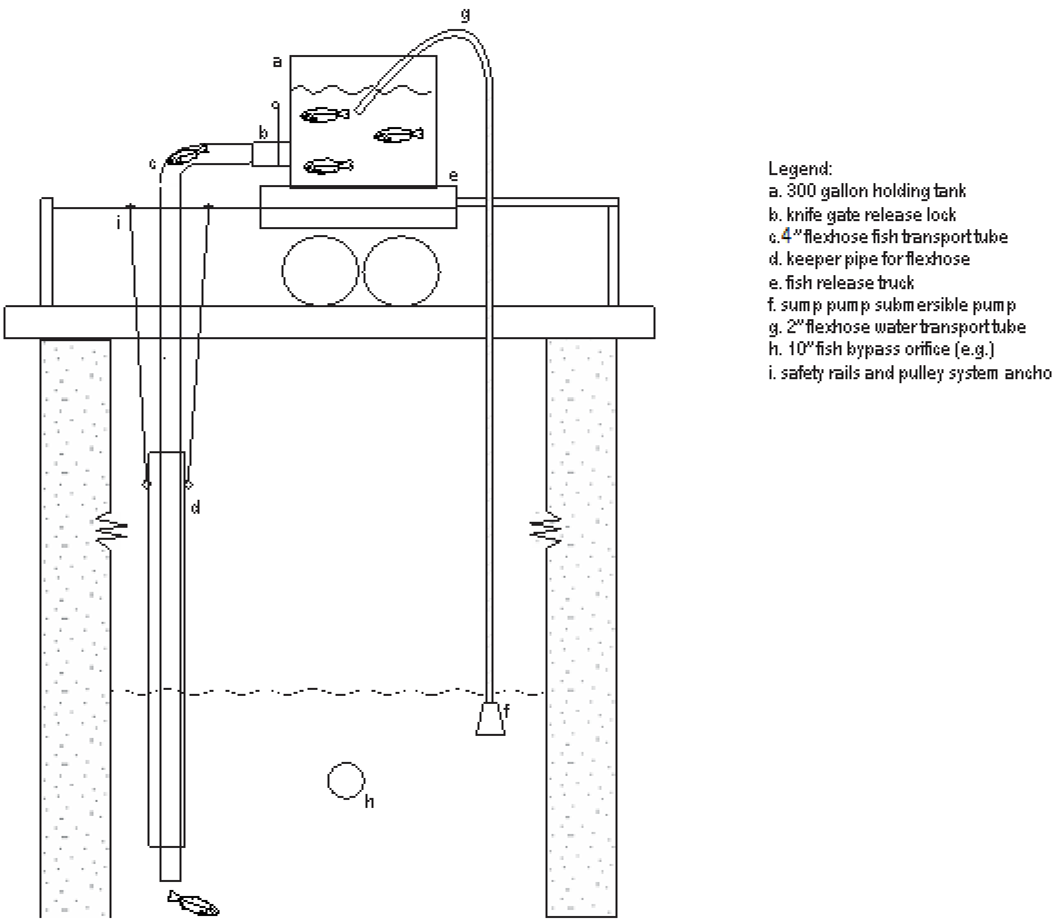

Figure 8. Fish release strategy for Gatewell 5A and 5B releases. All fish were transported in one of three release tanks (a) on the release truck (e). The water level in the tank was decreased and fish were introduced into the gatewell at ~20' depth via a wetted flexible 4" release pipe (c).

Fish were transported in the release tanks with the tanks at full capacity (approximately 300 gallons). Prior to release, the water level was drawn down in the tanks to the level of top of the release valve, approximately 20% full, which was observed to reduce the time required for all fish to swim out of the tank and down the pipe. River water from the gatewells was added to the release tank through a submersible pump to produce adequate flow through the tank and pipe to ensure sufficient water in the release pipe, and that all fish left the tank. At the time of release, the exact time was noted, the submersible pump turned on, and the knife gate opened. Fish were gently crowded toward the exit with a foam squeegee until all fish had exited. At the completion of the release, the knife gate was closed and water from the pump was used to refill the tank to approximately 20% full. Then the knife gate was reopened to allow the extra water to flush down the release pipe, ensuring that no fish remained in the tank or pipe. Finally, the tank and pipe connections were inspected for any remaining fish. After releases were complete the transport truck was driven back to the fish sorting facility. We did not draw down the water level in the transport tanks for releases completed prior to April 23. Fish were instead released from a nearly full tank. This resulted in a slower release process as it took more time for all the water to drain out and required more effort to crowd fish out of the release tank when compared to releases completed after drawing down the water in the tank to the 20% full level.

Bypass Channel Releases

Fish that were to be released directly into the bypass channel underwent identical treatment to experimental study fish until release. Release into the bypass channel from Gatewell 5A was achieved by feeding the release pipe directly into the bypass channel when the prototype overflow weir was in the open position (Figures 9 and 10). A tennis ball with an eight-foot section of rope (tracer line) was slip-knotted to the end of the release pipe. The tennis ball, when lowered into the gatewell was entrained in the flow through the weir. A person standing by inside the gallery captured the tennis ball as it passed through the weir and used the tracer line to guide the release pipe into position. Three strong hook-and-loop (Velcro®) quick release attachment points were installed on the railing around the overflow weir outflow to hold the release pipe in place during releases. The position of the release pipe during release was such that the end of the pipe was just outside the outflow spill from the weir. Fish release then proceeded identically to that for gatewell-released fish. We did not use hook-and-loop quick release attachment points at the hand rail on the release pipe for releases completed prior to April 23. This resulted in inconsistent release location and depth in the bypass channel as the release pipe moved within the channel during release.

Figure 9. Project staff securing the release pipe in the bypass channel gallery at Lower Granite Dam prior to completing a fish release, spring 2013.

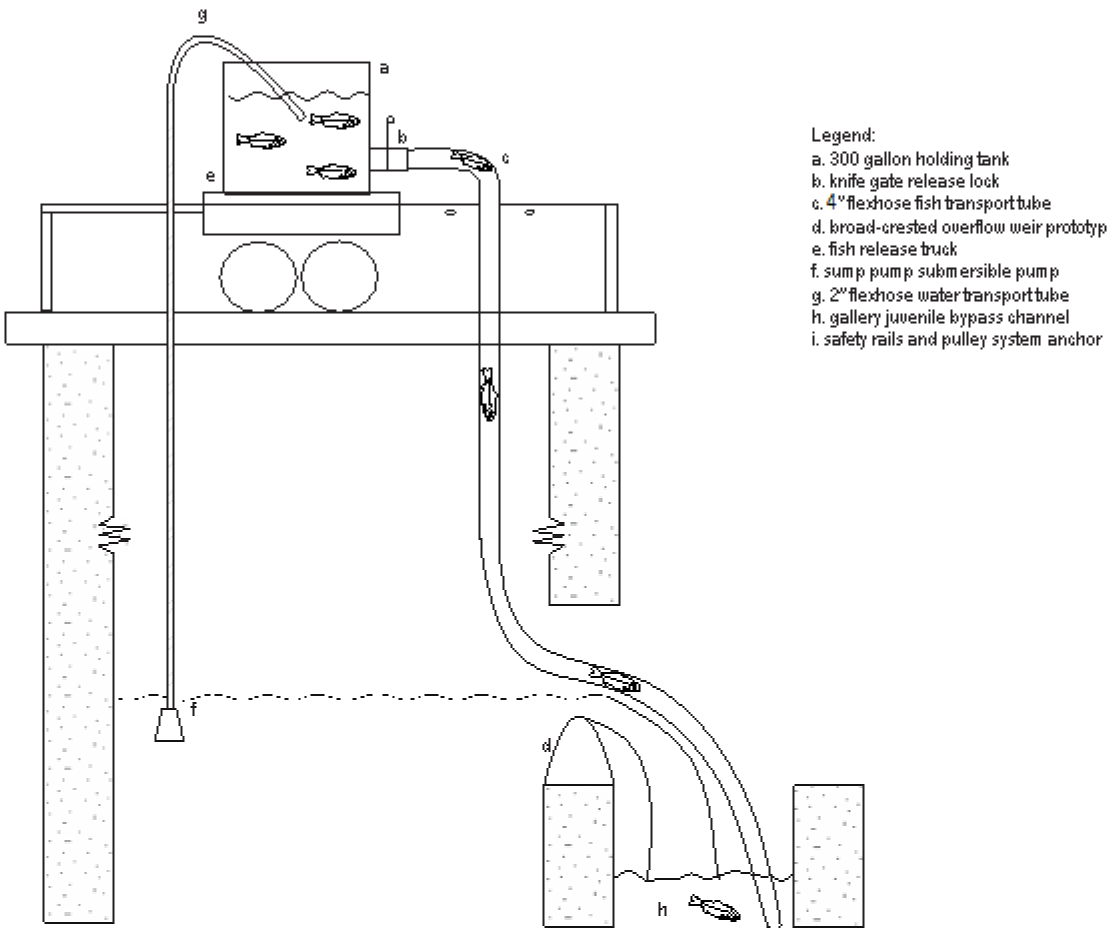

Figure 10. Fish release strategy for juvenile bypass channel releases via Gatewell 5A. Fish were released into the release pipe (c) which was fed through the prototype overflow weir (d) and into the bypass channel flow.

Lamprey Releases

PIT-tagged lampreys were kept in perforated 5-gallon buckets placed in circular tanks plumbed with flow-through river water located on the north side of the JFF. In preparation for release, a 300-gallon fish transport tank was filled with river water and the buckets containing the fish designated for release were placed in the tank. After driving to the deck of LGR and stopping at the designated release location (Gatewell 5A or 5B), the water level in the transport tank was drained to the level of the knife gate (approximately 20% full). The buckets containing the lampreys were opened and the fish were emptied into the release tank. The knife gate was opened and the fish were drafted through a 4-inch diameter release pipe into the gatewells to a depth of approximately 20 feet. During bypass channel releases, the release pipe was routed directly into the bypass channel through the opening of the broad-crested overflow weir. A submersible pump was used to add river water to the transport tank during the release to ensure all fish swam out of the tank. After all fish left the tank, the knife gate was closed and the tank refilled to the 20%-full level. The release gate was opened again to allow the additional water to flush out any fish remaining in the release pipe. All releases were completed after dark (after 21:30).

Objective 2. Determine fish condition (including injury and descaling) impacts of the overflow weir and larger orifice compared to current orifice configuration for juvenile salmonids.

Study Design

The experimental design contained four treatments (10-inch orifice, 14-inch orifice, prototype overflow weir, and bypass channel) for three fish species/age classes (yearling Chinook salmon, steelheads, and sub-yearling Chinook salmon). A subset of each release group was re-collected using the SxC system at LGR for external condition assessment. The change in injury and descaling scores before release and after re-collection were assessed across all species/age class and release locations using external condition criteria described in Hostetter and Evans (2012); observations and recordings were combined into one dataset for each treatment. Each fish that was assessed for changes in external condition was given a categorical score that ranged from 0 to 3 for descaling (i.e. loss of scales at <5% of body = 0, 5–20% of body = 1, 21–50% of body = 2, and >50% of body = 3) and 0 to 2 for operculum injury, head injury, eye injury, and trunk injury, with increasing scores representing increasing injury.

An additional method for determining whether a smolt was descaled was completed as described in Ceballos et al. (1992). Briefly, the fish was visually divided into five equally sized partitions on each side of the body, with the partitions beginning near the operculum and extending to the caudal fin. The deeper parts of the body (near the head and dorsal fin) had narrower partitions (horizontally) than the body areas near the adipose and caudal fins. If 40% or more of the scales were missing from two adjacent partitions on one side of a fish (20% of the fish on one side), the fish was considered to be descaled. The incidence of descaling was determined by subtracting the percentage of fish in each treatment that were descaled prior to release from the percentage of fish that were descaled after re-collection.

Each photograph of each side of each fish was given a suite of fish condition scores ranging from 0 to 3 for descaling as described above (Hostetter and Evans 2012) and 0 to 2 for operculum injury, head injury, eye injury, and trunk injury (see detailed scoring criteria, Appendix B). The difference in score from before release and after re-collection was the basis for comparison. This “ranked difference” indicated the magnitude of change in external condition from before release to after re-collection. For example, a ranked difference of 0 indicated that any change in condition was insufficient to require an increase in score. A ranked difference of 1 indicated that the fish sustained sufficient injury between the initial condition assessment and re-collection for an increase in score of 1 for a given category (i.e. a change from a score before release of 1 to a score after re-collection of 2), and so on. To maintain the highest possible consistency in assessment of descaling and injuries, two technicians were trained to assess fish condition scores.

Differences in the injury and descaling scores by fish species/age class and between the treatments (all pairs) were evaluated using the Kruskal–Wallis ANOVA, because injury and descaling was relatively rare and not normally distributed. The null hypothesis (H_0) for the test was that all median changes in injury and descaling scores before release and after re-collection were equal. The alternate hypothesis (H_a) was that the median change in injury and descaling scores for at least two release locations were different. When significant differences were found ($\alpha \leq 0.05$), H_0 was rejected. In cases where statistically significant differences were found between treatments with an ANOVA, a multiple comparison procedure (MCP) was used to determine which treatments were different. The Kruskal–Wallis Z (Dunn’s test) was used to determine differences between tested pairs following the Kruskal–Wallis test. This MCP is a distribution-free multiple comparison, meaning that the assumption of normality is not necessary. The Bonferroni test was used to determine significant difference between tested pairs when the z-value was > 2.64. The Bonferroni test is a conservative estimate of significance compared to the standard z test.

We also used the Kruskal–Wallis one-way ANOVA (any pair) to test for differences in fish scores before release and after re-collection for all combinations of species/age class and passage route. The null hypothesis (H_0) for the tests was that the median score for each category of injury/descaling did not change from before release to after re-collection. The alternate hypothesis (H_a) was that median scores from before release to after re-collection were different. When significant differences were found ($\alpha \leq 0.05$), H_0 was rejected.

For significant differences in rates of injury across passage routes identified with ANOVA tests, analysis of potential covariates impacting the injury and descaling rate was explored using Poisson regression. A forward variable selection procedure was used to determine the best covariates for each model. Covariates that were considered for potential impacts on rates of injury included water elevation in the bypass channel, Unit 5 turbine discharge, forebay elevation, release date, water temperature, and calculated flow through the weir, 10-inch orifice, and 14-inch orifice. Poisson regression analysis was performed for each species and passage route that was identified as significant in the all pairs ANOVA tests. A correlation matrix was used to exclude highly correlated ($|r| > 0.5$) variables. Independent variables not significantly related to the dependent variable were also excluded from the models. The dispersion Phi was used to allow for over-dispersion for each model.

Fish Photography for Injury Assessment

Sample fish were collected at LGR as part of daily collections from either the JFF or from NOAA. Fish were tagged, measured, photographed, assessed for injury and descaling, and released as part of Objective 2. Sample groups consisted of a subset of the overall release group for a particular release (i.e. the total release group may have consisted of 250 individuals; however, only a subset of approximately 30% were re-collected for fish condition assessment). To hedge against re-collection of study fish during daily sampling by PSMFC staff, we photographed more than the quantity we intended to re-collect at the SxC facility. The SxC system was programmed to divert all tags designated for re-collection that were detected between 07:00 and 15:30 each day (when team staff were assigned to monitor the SxC net partitions) and to avoid prolonged residence (i.e., overnight) of re-collected fish in the nets. Each week a pool of tags was designated for use in SxC fish and the SxC system was programmed to divert each tag in the pool. All fish tagged with SxC tags were photographed prior to release (Figure 11). When necessary, we increased the number of fish photographed and assessed for injury and descaling on a week-by-week basis to ensure that a sufficient sample was re-collected at the SxC facility. Fish selected for photography and SxC re-collection came from the initial pool of all suitable fish in each release group. While we tried to use only fish in good-to-excellent condition, when sample sizes were limited we included all fish in a release for photography and re-collection in the SxC system.

Two species were evaluated for injury and descaling rates during the first half of the study (yearling Chinook salmon and steelheads) and sub-yearling Chinook salmon were evaluated during the second half of the study. A total of 4,587 yearling Chinook salmon, 5,847 steelheads, and 5,043 sub-yearling Chinook salmon were released for re-collection at the SxC system. All fish released for SxC re-collection were a full or partial set of fish from the releases completed for Objective 1; there were no releases specifically completed for the purposes of Objective 2.

After the releases for the day were completed (approximately 09:00), staff began transferring fish from the SxC net partitions to the 300-gallon flow-through tanks in the work trailer located in the truck pit on the south side of the JFF. Fish were dip-netted from the SxC partitions, placed in aerated 5-gallon buckets and transported on a utility vehicle to the work trailer. Fish were anesthetized with MS-222, then photographed on both the left and right sides using the Real Time Research fish photography system; TagTracker software was used to assess descaling and injury rates that resulted from passage per release location to the JFF. All injuries were noted, including those to the head, operculum, eye, and body of the fish. Fin erosion was not included for analysis primarily because the photo system was not intended for detecting minor changes to fin condition (i.e. the extra time required to manually inspect all fins was not practical for this study and would have resulted in increased handling of sample fish). After images were taken, all fish were allowed to recover in a flow-through tank and where later transferred to the large recovery tank located on the north side of the JFF. At the beginning of the season (April 20–26), all fish were flushed back to the river at the end of the work day (approximately 16:30). After April 27, all fish in the recovery tank outside the JFF were loaded for downstream barge transport at the convenience of the barge crew and the USACE project biologist.

Figure 11. Project staff photographing an anesthetized juvenile steelhead prior to its release at Lower Granite Dam, spring 2013. These images were used to assess external condition prior to release and after re-collection at the SxC system.

Arrival of study fish into the SxC partition was monitored throughout the work day (ending at approximately 15:30). Counts of bycatch of non-target PIT-tagged fish at the SxC were recorded on daily report forms and provided to PSMFC and USACE staff daily.

During the period of lamprey collection and release (May 20–June 3), three complete releases into the bypass channel were designated for re-collection at the SxC. The purpose of re-collection was to determine re-collection efficiency of juvenile lampreys. All juvenile lampreys collected at the SxC were transferred to the recovery tank outside the north side of the JFF.

An additional metric collected was the vertical barrier screen (VBS) differential. To measure VBS differential Onset HOBO loggers were deployed in Gatewell 5A, Operating Slot 5A, Gatewell 5B, Operating Slot 5B, and the Juvenile Bypass Channel on April 26. In the experimental gatewells, HOBOs were deployed in Schedule 40 PVC casings on a weighted (10-lb.) static line in the northwest corner of each slot where they would be free from interference with release apparatus and other infrastructure in the gatewells. HOBOs were deployed such that the sensors were at least 6 ft. under water. In operating slots, HOBOs were deployed without PVC casings or additional weights due to the narrow gaps in the grate over the slot, which allowed only the HOBOs themselves to fit through. HOBOs were tied to the grate at the surface level of the deck. The one HOBO in the juvenile bypass channel was housed in a 6-ft.-long Schedule 40 PVC pipe with multiple holes drilled in it to allow the water level to equilibrate with the channel. This PVC pipe was hose-clamped to the railing around the prototype overflow weir. A line of known length was used to tether the HOBO inside the pipe such that the instrument was a minimum of 12 inches under the water at all times.

Elevations of deployed HOBO loggers were calculated by subtracting the length of deployment line from the known elevation at which the line was affixed (i.e. 751 ft. at the deck of the dam). The HOBOS were retrieved and downloaded several times over the course of the season, necessitating re-tying deployment knots. Thus, the elevations at which HOBOs were deployed throughout the season varied by the amount of line used to complete the knot, with the exception of the unit in the bypass channel. The water depth above the instrument was calculated by converting the measured pressure units (PSI) to depth of water (inches). The elevation of the water surface was then calculated by adding the depth of water measurement to deployed elevation.

Objective 3. Determine debris passage impacts of overflow weirs and/or larger orifices

And

Objective 4. Investigate salmonid fish behavior patterns in gatewells with overflow weirs relative to current orifice configuration.

Camera Frame Structures

Camera support frames were designed to deploy both optical and DIDSON cameras in Unit 5 turbine intake Gatewells 5A and 5B (Figure 12). The equipment consisted of an aluminum I-beam (camera pole), steel fulcrums, and various support structures. The frames functioned by bowing the camera pole slightly to develop friction against the walls of the gatewell. The pole was then anchored at the top deck with a screw, at 8 ft. down the gatewell and at 16 ft. down with friction to the wall. The camera pole was lowered to the correct depth in the gatewell and a screw mechanism at the top of the gatewell that pulls the pole approximately 1.5" to bend the pole 0.75" over a span of 16 ft. down into the gatewells. A hand winch was placed near the top of the I-beam to raise and lower camera trolleys, which ride down the pole into position for viewing gatewell structures.

Figure 12. Camera frame structures at Gatewells 5A and 5B, Lower Granite Dam, spring 2013. The left image is of the camera pole being lowered into gatewell using a crane; the middle image is of the camera pole in place within the gatewell (The steel supports brace the pole within the gatewell. The short steel channel midway up serves as a fulcrum); and the right image is of a threaded rod that applies a force to the pole, bending the pole and bracing it within the gatewell slot.

Video Cameras and Infrared Lights

SPECO CVC320 video cameras were used during underwater video monitoring of Gatewells 5A and 5B at the fish passage structures. Each camera was paired with two external infrared lights (*Model 42, Seaviewer Inc., Tampa, FL*) to provide sufficient illumination during night observations. Cameras and lights were fitted to camera trolleys designed to slide down the I-beam surface and contained a 10-pound weight for stabilization (Figure 13).

Figure 13. Image of video camera trolley system deployed at Lower Granite Dam in Gatewells 5A and 5B to monitor the orifices and overflow weir from a distance of ~48". The trolley included a stabilization weight (black), upper armored cable, and camera housing (black cylinder) with one or two IR lights. Trolley dimensions were 18" x 6" x 2".

Video Acquisition and Processing

BNC cable ends from video cameras were routed to a ventilated, NEMA 4-rated electrical enclosure. The enclosure housed a personal computer-based digital video recorder (DVR; Intel dual-core processor, 2 GB RAM, PCI slot, 2 SATA hard-drive ports, Windows 7 OS), using an 8-channel Hikvision video capture card (Model DS-4008HCI; Hikvision USA, City of Industry, CA) and 2 TB of hard-drive space dedicated to video recording. Video cameras were set to record with the following parameters: 704 x 480 resolution, normal record, video quality 250 KB/sec, 10 frames per second (fps), grayscale color scheme, and no audio.

One video camera was used to image each structure (5A overflow weir, 5A 14-inch orifice, 5B 10-inch orifice) and was situated to provide the best viewing angle of fish behavior at the openings. These placements permitted enumeration of fish passage as well as captured fish behavior (i.e. the orientation of fish during passage) (Figure 14).

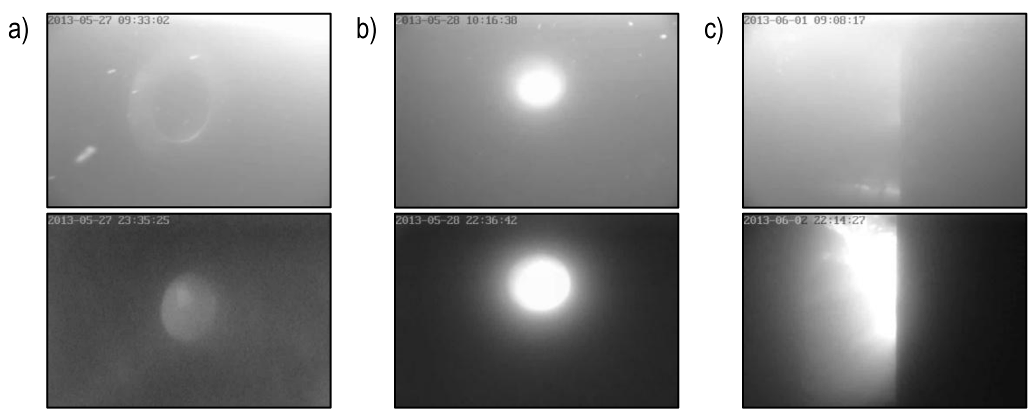

Figure 14. Still images of camera angles used to view fish passage structures during the day (top row) and night (bottom row) at: a) 14-inch orifice in Gatewell 5A, b) 10-inch orifice in Gatewell 5B, c) broad-crested overflow weir in Gatewell 5A.

Video data were periodically retrieved from the DVR's hard drive by exporting it to a 2-TB external drive using the Hikvision export utility. Video was subsequently compressed using the MPEG-4 (ISO/IEC 14496-2) and H.264 (ISO/IEC 14496-10) video codecs. Compressed video was reviewed by technicians to determine counts of fish and rates of debris obstruction.

Video Data Analyses

Observational periods, listed in Table 3, were selected to permit comparisons between open fish passage structures in Gatewells 5A and 5B. Prior to May 22, these comparisons were not possible, due to the 5B 10-inch orifice being located in a different location than construction documents indicated (orifice was not visible in camera), thus the 5B camera frame was removed and repositioned in the gatewell on May 22.

Processed video clips of the gatewell structures were manually reviewed at a playback speed of 1–2x using the open-source VLC Media Player, version 1.1.11 (www.videolan.org). Fish interactions at the structures were defined as a fish striking the edge of either the orifices or the overflow weir. Debris obstruction of the structures was recorded by estimating the occluded proportion of the visible structure opening and recording the duration of the obstruction. Observations for adult and juvenile fish were separated, although the majority of fish observed in the passage structures were juveniles.

Metrics describing the proportion of observations (day and night), interaction rate, and debris obstruction of each fish passage structure were calculated using the following equations:

$$\text{Interaction rate} = \frac{\text{number interactions}}{\text{total number passing structure}} \quad (1)$$

$$\text{Debris obstruction rate} = \frac{\text{time blocked (min)}}{\text{observational period (min)}} \quad (2)$$

For Eq. 2, the debris obstruction rate was calculated for three blockage percentages: 10–20%, 20–50%, and 50–80%.

Table 3. Summary of dates and times (hours) of recorded video reviewed at Gatewell 5A and 5B, Lower Granite Dam, spring 2013. The camera frame was moved into the proper position in Gatewell 5B to view the 10-inch orifice on May 22, 2013; therefore, comparisons between Gatewell 5A and 5B could not be conducted prior this date.

Date	Hours Reviewed	Total Hours Reviewed	Comparison
23 May	0700–1200 2200–2400	Day: 29 Night: 22 Total: 51	5A overflow weir/5B 10-inch orifice
24 May	0700–1200 2200–2400		
29 May	0800–1100 2200–2400		
1 June	0800–1200 2200–2400		
2 June	0700–1100 2200–2400		
3 June	0700–1100 2200–0100		
6 June	0800–1000 2200–2400		
7 June	0800–1000 2200–2400		
11 June	2200–2400		
12 June	2200–2400		
25 May	0700–1200 2200–2400	Day: 29 Night: 22 Total: 51	5A 14-inch orifice/5B 10-inch orifice
26 May	0700–1100 2200–2400		
27 May	0700–1200 2200–2400		
28 May	0700–1100 2200–2400		
29 May	1000–1100		
30 May	0800–1200 2200–2400		
1 June	0700–0800		
4 June	0800–1000 2200–2400		
5 June	0700–0900 2200–2400		
8 June	0700–1200 2200–2400		
9 June	2200–2400		
10 June	2200–2400		
13 June	0800–1000 2200–2400		

DIDSON Analysis

DIDSON analysis was completed by reviewing the first 15 minutes of each hour recorded throughout the study period. Files were reviewed in double time (frame rate of 20 frames sec^{-1}) until an event of interest was noted. Then the frame rate was slowed or paused as needed to review and mark the event of interest. Events of interest included the presence of adult fish (>30 cm in length); adult fish passage at the weir, 10-inch, or 14-inch orifices; lampreys;

and debris. Adult fish passage was determined by observing the fish approaching the passage route, disappearing from the field of view and remaining absent for the remainder of the hourly file. The events marked were automatically saved into a database including the file name and passage route, information regarding measured marked fish (number and species of adult fish observed, length, motion, range, and comment), the date/time of the file, and the frame number of the observation.

A total of 1,300 hours of DIDSON footage were recorded in Gatewell 5B (10-inch orifice) and 1,158 hours were recorded in Gatewell 5A (529 hours oriented towards the 14-inch orifice and 626 hours oriented towards the weir). The DIDSON cameras operated continuously from May 1 to June 24. The DIDSON in Gatewell 5A was oriented towards the weir or 14-inch orifice as appropriate based on the operations schedule for each structure. The minimum hours reviewed for each system was a quarter of the total recorded hours. However, when an adult salmonid was observed, additional files were reviewed in an effort to confirm the passage route. Approximately 325 hours of footage were reviewed for the 10-inch orifice, 132.5 hours for the 14-inch orifice, and 156.5 hours for the weir.

RESULTS

For organizational purposes, the results have been categorized generally by research objective.

Objective 1. Determine how the overflow weir and larger orifice affected orifice passage efficiency (OPE) and travel times through the Juvenile Bypass System (JBS) compared to the current orifice configuration for juvenile salmonids and lampreys.

Salmonid Releases

Travel time data was not normally distributed for any species/age class or release location (Figures 15, 16, and 17). Among all gatewell passage structures, all salmonid species/age classes released during operation of the 14-inch orifice had the lowest travel times (i.e. egressed quickly after release) and fish released during operation of the weir had the highest travel times (i.e. experienced increased residence) (Table 4). Salmonids released directly into the bypass channel had lower travel times than fish released into gatewells.

Immediately after release, an initial surge of fish passage occurred within the first few hours. For all release locations, there was a second, smaller group of fish detected 10–12 h after release (between 18:00 and 20:00), particularly for fish released during weir operation. It is unknown whether these fish remained in the gatewell until evening or passed into the bypass channel after release and remained within the bypass channel or in the area of the separator until evening. Travel times for steelheads were greater than travel times for yearling and sub-yearling Chinook for each release location.

In addition to morning releases, three releases of sub-yearling Chinook were completed at night during weir operation to investigate diel differences in travel time. This group exited more quickly (median travel time 0.6 h) compared to those fish released in the morning (median travel time 2.1 h) (Figure 18).

The OPE was high for all species/age classes and release locations (Table 5). Among salmonids, all releases had a minimum overall detection rate of 98.6%. The minimum detection rate within 24 hours of release was 92% for steelheads released during operation of the 10-inch orifice and weir. Fish released into the gatewells that were never detected were assumed to have either 1) avoided the JBS by sounding or passing through the turbine; 2) exited the gatewell upstream of the dam to reach the forebay; 3) shed their PIT tag; or 4) passed through the JBS but were not detected. However, detection probability within the JBS typically exceeds 99.9% (Nicole Tranceto, PSMFC, pers. comm.)

Dunn's test, a multiple comparison procedure used after ANOVA testing (Kruskal–Wallis), was used to determine significant differences in travel times among all release locations. The minimum detectable difference for all salmonids was <0.01 h and test power (beta, β) was 1.0 in all cases. All species were found to have significant differences in travel times for at least two release locations (Table 6). For all salmonids, travel times for fish released into all release locations were significantly different except yearling Chinook salmon released during operation of the 10-inch orifice, which were not significantly different than those released during weir operation (Table 6).

To account for the heterogeneous distributions of travel times, a stratified bootstrapping approach was used to test for significant differences in travel times between test pairs including 10-inch orifice versus 14-inch orifice, 10-inch orifice versus weir, and 14-inch orifice versus weir for all daytime releases of juvenile salmonids. All test pairs were significantly different at at least the 1% level. See Appendix D for details.

For yearling Chinook salmon, the largest difference in mean travel time among the gatewell passage structures was between fish that were released during operation of the weir and 14-inch orifice (2.4 h) (Figure 15). The smallest difference was between fish released during the operation of the 10-inch orifice and weir (0.9 h). For steelheads, differences ranged from a high of 2.1 h for fish released during operation of the weir and 14-inch orifice to a low of 0.4 h for fish released during operation of the 10-inch orifice and 14-inch orifice (Figure 16). For sub-yearling Chinook salmon, differences ranged from 1.7 h for fish released during operation of the weir and 14-inch orifice to 1.0 h for fish released during operation of the 10-inch orifice and 14-inch orifice (Figures 17 and 18).

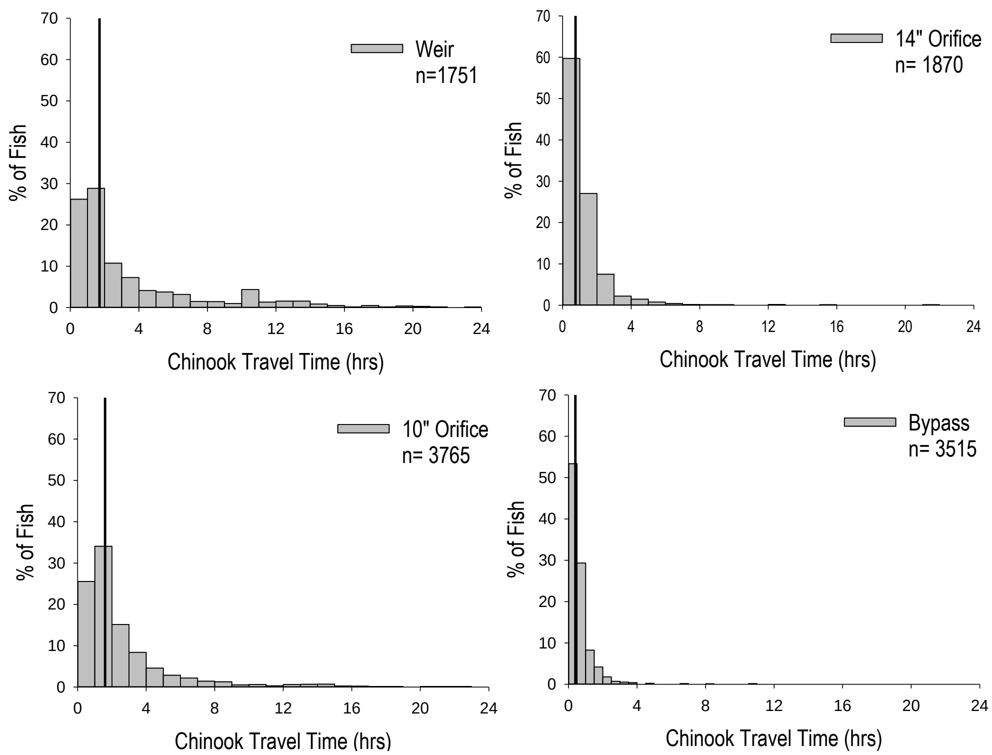

Figure 15. Travel-time histograms for yearling Chinook salmon released during the day into Gatewells 5A and 5B during operation of the broad-crested overflow weir, 14-inch diameter orifice, 10-inch diameter orifice, and directly into the bypass channel at Lower Granite Dam, spring 2013. The reference line represents the 50th percentile.

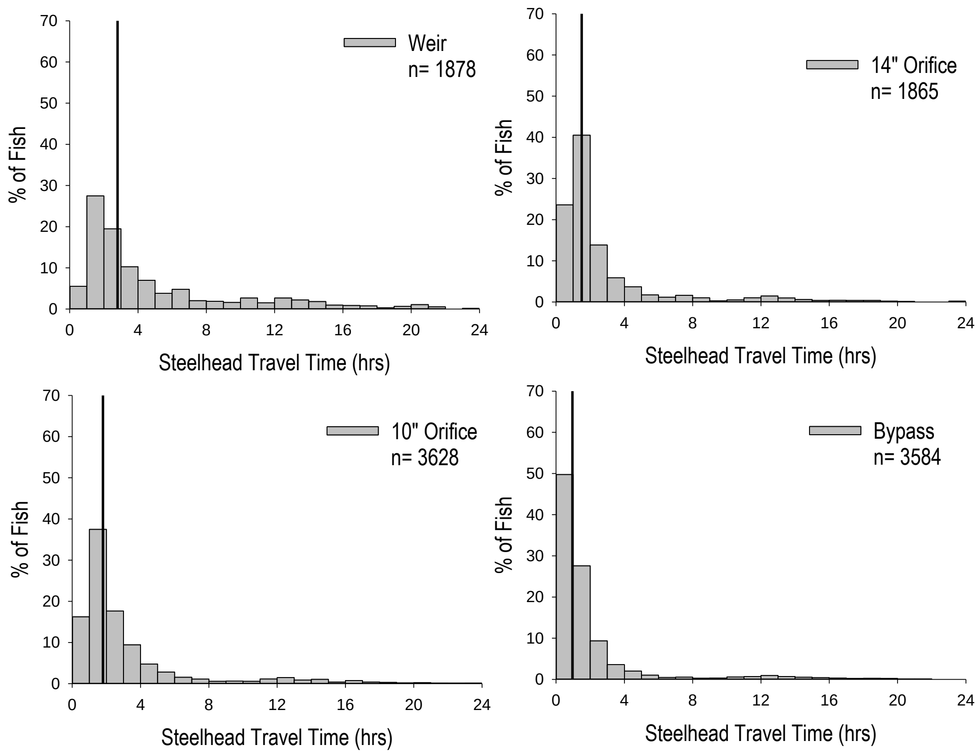

Figure 16. Travel-time histograms for juvenile steelheads released during the day into Gatewells 5A and 5B during operation of the broad-crested overflow weir, 14-inch diameter orifice, 10-inch diameter orifice, and directly into the bypass channel at Lower Granite Dam, spring 2013. The reference line represents the 50th percentile.

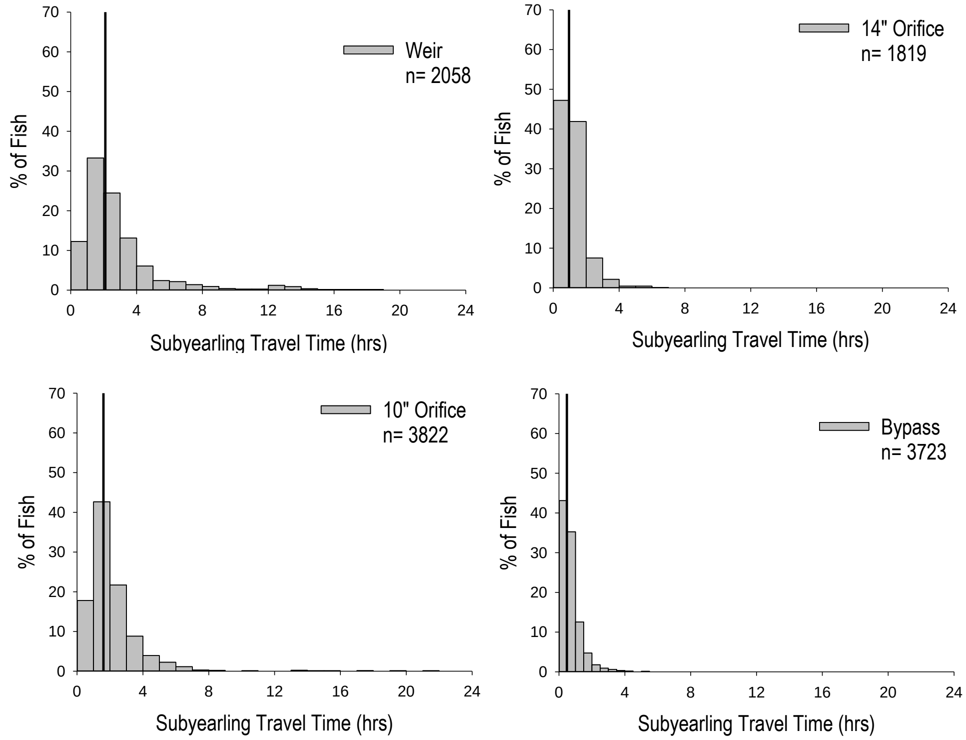

Figure 17. Travel-time histograms for sub-yearling Chinook released during the day into Gatewells 5A and 5B during operation of the broad-crested overflow weir, 14-inch diameter orifice, 10-inch diameter orifice, and directly into the bypass channel at Lower Granite Dam, spring 2013. The reference line represents the 50th percentile.

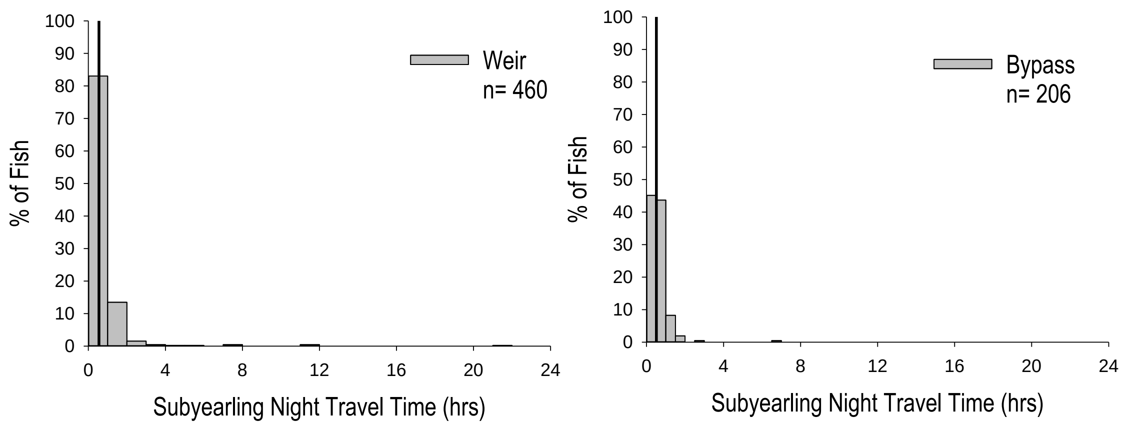

Figure 18. Travel-time histograms for sub-yearling Chinook released at night into Gatewell 5A during operation of the broad-crested overflow weir at Lower Granite Dam, spring 2013. The reference line represents the 50th percentile.

Table 4. Descriptive statistics for each release location at Lower Granite Dam, spring 2013. Mean, median, standard deviation, minimum, and maximum are representative of travel time, in hours, between release time and first detection at the JBS. Travel times exceeding 24 hours were redacted to avoid bias associated with fish releases or switching passage structures. Species abbreviations represent yearling Chinook (CH), steelheads (ST), sub-yearling Chinook (SY), and sub-yearling Chinook released at night (SY Night).

Release Location	Species	n	Mean	Median	SD	Min	Max	Shapiro-Wilk W	Decision (5%)
Bypass	CH	3,515	0.75	0.46	1.22	0.06	21.83	0.4	Reject Normality
14" Orifice	CH	1,870	1.19	0.79	1.54	0.06	21.97	0.52	Reject Normality
10" Orifice	CH	3,765	2.65	1.64	3.05	0.07	23.51	0.66	Reject Normality
Weir	CH	1,751	3.58	1.78	4.16	0.07	23.3	0.74	Reject Normality
Bypass	ST	3,584	2.03	1	3.17	0.07	23.07	0.51	Reject Normality
14" Orifice	ST	1,865	2.82	1.57	3.54	0.1	23.85	0.6	Reject Normality
10" Orifice	ST	3,628	3.21	1.85	3.74	0.08	23.96	0.64	Reject Normality
Weir	ST	1,878	4.91	2.86	4.78	0.13	23.89	0.77	Reject Normality
Bypass	SY	3,723	0.73	0.56	0.79	0.06	16.14	0.62	Reject Normality
14" Orifice	SY	1,819	1.21	1.03	1.04	0.07	22.33	0.55	Reject Normality
10" Orifice	SY	3,822	2.17	1.68	1.98	0.11	23.32	0.6	Reject Normality
Weir	SY	2,058	2.88	2.13	2.69	0.07	21.77	0.69	Reject Normality
Bypass	SY Night	206	0.59	0.53	0.58	0.08	6.51	0.62	Reject Normality
Weir	SY Night	460	0.79	0.58	1.4	0.09	21.77	0.03	Reject Normality

Table 5. Quantities of fish released into Gatewells 5A, 5B and the bypass channel at Lower Granite Dam, spring 2013; quantities and percentages of fish that were re-detected within 24 hours, detected after 24 hours, and never detected are listed. Orifice passage efficiency (OPE) is represented by the total percentage of fish detected after release. Species abbreviations represent yearling Chinook (CH), steelheads (ST), sub-yearling chinook (SY), sub-yearling Chinook released at night to investigate diel differences in travel time (SY N).

Species	Location	Total Qty Released	Total Qty Detected	Total % Detected	Qty Detected <24hrs	% Detected <24hrs	Qty Detected >24hrs	% Detected >24hrs	Qty Never Detected	% Never Detected
CH	Bypass	3,521	3,515	99.8%	3,515	99.8%	0	0.0%	6	0.2%
	14" Orifice	1,877	1,872	99.7%	1,870	99.6%	2	0.1%	5	0.3%
	10" Orifice	3,815	3,806	99.8%	3,765	98.7%	41	1.1%	9	0.2%
	Weir	1,787	1,784	99.8%	1,751	98.0%	33	1.8%	3	0.2%
	Total	*11,000*	*10,977*	*99.8%*	*10,901*	*99.1%*	*76*	*0.7%*	*23*	*0.2%*
ST	Bypass	3,695	3,688	99.8%	3,584	97.0%	104	2.8%	7	0.2%
	14" Orifice	1,971	1,943	98.6%	1,865	94.6%	78	4.0%	28	1.4%
	10" Orifice	3,950	3,915	99.1%	3,628	91.8%	287	7.3%	35	0.9%
	Weir	2,041	2,029	99.4%	1,878	92.0%	151	7.4%	12	0.6%
	Total	*11,657*	*11,575*	*99.3%*	*10,955*	*94.0%*	*620*	*5.3%*	*82*	*0.7%*
SY	Bypass	3,729	3,724	99.9%	3,723	99.8%	1	0.0%	5	0.1%
	14" Orifice	1,824	1,821	99.8%	1,819	99.7%	2	0.1%	3	0.2%
	10" Orifice	3,843	3,841	99.9%	3,822	99.5%	19	0.5%	2	0.1%
	Weir	2,063	2,062	100.0%	2,058	99.8%	4	0.2%	1	0.0%
	Total	*11,459*	*11,448*	*99.9%*	*11,422*	*99.7%*	*26*	*0.2%*	*11*	*0.1%*
SY N	Bypass	208	207	99.5%	206	99.0%	1	0.5%	1	0.5%
	Weir	463	462	99.8%	460	99.4%	2	0.4%	1	0.2%
	Total	*671*	*669*	*99.7%*	*666*	*99.3%*	*3*	*0.4%*	*2*	*0.3%*

Table 6. Differences in median travel times for each test pair and each species/age class at Lower Granite Dam, spring 2013. The Dunn's test *z* value indicates significance for the difference in median travel time for each test pair. A value greater than 2.64 (Bonferroni test) indicates a statistically significant difference.

Test Pair	Species	Δ Median Travel Time (h)	Dunn's Test *z* Value
Bypass (*n* = 3,515); 14" Orifice (*n* = 1,870)	Yearling Chinook	0.33	17.15
14" Orifice (*n* = 1,870); 10" Orifice (*n* = 3,765)		0.85	25.97
Bypass (*n* = 3,515); 10" Orifice (*n* = 3,765)		1.18	52.25
Bypass (*n* = 3,515); Weir (*n* = 1,751)		1.32	44.15
14" Orifice (*n* = 1,870); Weir (*n* = 1,751)		0.99	24.07
10" Orifice (*n* = 3,765); Weir (*n* = 1,751)		0.14	2.28
Bypass (*n* = 3,584); 14" Orifice (*n* = 1,865)	Steelhead	0.57	17.89
14" Orifice (*n* = 1,865); 10" Orifice (*n* = 3,628)		0.28	7.14
Bypass (*n* = 3,584); 10" Orifice (*n* = 3,628)		0.85	30.33
Bypass (*n* = 3,584); Weir (*n* = 1,878)		1.86	40.80
14" Orifice (*n* = 1,865); Weir (*n* = 1,878)		1.29	19.93
10" Orifice (*n* = 3,628); Weir (*n* = 1,878)		1.01	15.76
Bypass (*n* = 3,723); 14" Orifice (*n* = 1,819)	Sub-yearling Chinook	0.47	21.96
14" Orifice (*n* = 1,819); 10" Orifice (*n* = 3,822)		0.82	24.64
Bypass (*n* = 3,723); 10" Orifice (*n* = 3,822)		1.12	57.76
Bypass (*n* = 3,723); Weir (*n* = 2,058)		2.3	57.08
14" Orifice (*n* = 1,819); Weir (*n* = 2,058)		1.1	29.20
10" Orifice (*n* = 3,822); Weir (*n* = 2,058)		0.45	8.70

Covariate Analysis

We used multiple regression to identify significant relationships between a suite of covariates, including operations at LGR, and travel time for each species/age class that was released during operation of each treatment structure (14-inch orifice, 10-inch orifice, and weir). Analyses were confounded by strong correlation among most independent variables and the limited operating range of many independent variables (see Appendix E for scatterplots). As a result, the ability of the models to describe explanatory relationships was limited.

With the above said, the covariate regression models identified significant relationships between independent variables and mean travel time for all combinations of species/age class and release location, with the exception of yearling Chinook salmon released during operation of the 10-inch and 14-inch orifices (see Appendix F for detailed results of all regression models). Mean fork length and date of release were the most common significant independent variable followed by flow through Turbine Unit 5 (yearling and sub-yearling Chinook salmon only) and river elevation in the forebay (steelheads only). The quantity of replicates available to include for each model was limited to releases with complete covariate records. As such, calculated flow through each passage route in Gatewells 5A and 5B were not included in the regression analysis. Mean flows through each passage route, calculated using the available data from April 20 through June 19, 2013, were 14.9 cfs for the weir, 8.3 cfs for the 10-inch orifice, and 15.2 cfs for the 14-inch orifice.

Juvenile Lampreys

Travel times for juvenile lampreys that were released into the gatewells and bypass channel were not normally distributed for any release location (Figure 19). Among the lampreys released into the gatewells, fish released during weir operation had the lowest median travel times (0.19 h) and fish released during operation of the 10-inch orifice had the highest median travel times (0.25 h) (Table 7). Lampreys released directly into the bypass channel did not have lower median travel times than those released into gatewells (0.30 h). Median travel times for all release locations varied by only ±6 min.

Juvenile lamprey OPE was high at all release locations; the minimum overall detection rate of PIT-tagged juvenile lampreys was 95.7% (Table 8). The minimum detection rate within the first 24 hours of release was 88.1% for lampreys released during operation of the 14-inch orifice. Compared to the salmonid release groups, Lampreys had a relatively high rate of fish never detected, ranging from 1% of lampreys released into the bypass channel to 4.3% of lampreys released during operation of the 10-inch orifice. It was assumed that fish released into gatewells could have escaped detection either by sounding and passing through the turbine or moving upstream to reach the forebay. Additionally, the PIT tag could have been shed from the fish or not detected within the JBS.

Dunn's test, a multiple comparison procedure used after ANOVA testing (Kruskal–Wallis), similar to the same methods used for the salmonid release groups, was used to determine significant differences in travel times for lampreys among all release locations. The minimum detectable difference for lampreys was <0.09 h. Travel times for lampreys released into the bypass channel were not significantly different than those released during 10-inch orifice operation. Travel times for juvenile lampreys released during weir operation were not significantly different than lampreys released during operation of the 14-inch orifice (Table 9). All other pairs were significantly different.

The mean differences in travel times were relatively small for lampreys compared to salmonids. Among releases into the gatewells, the largest difference was between lampreys released during 14-inch orifice operation and lampreys released during 10-inch orifice operation (0.13 h).

Downstream Detections of Tagged Juvenile Lampreys

Of the 1,498 juvenile lampreys PIT-tagged and released during this study, an estimated 1,150 were assumed to have continued downstream in-river migration and the remainder were assumed to have been loaded onto a barge at LGR. Of fish that migrated in-river, 29 tagged lampreys were detected passing downstream in the lower Snake and Columbia rivers (31 were detected at LGO, 11 at LMN, 7 at Ice Harbor Dam, and one at McNary Dam; two had multiple detections). One tag was recovered from a double-crested cormorant colony on East Sand Island in the Columbia River estuary (rkm 8).

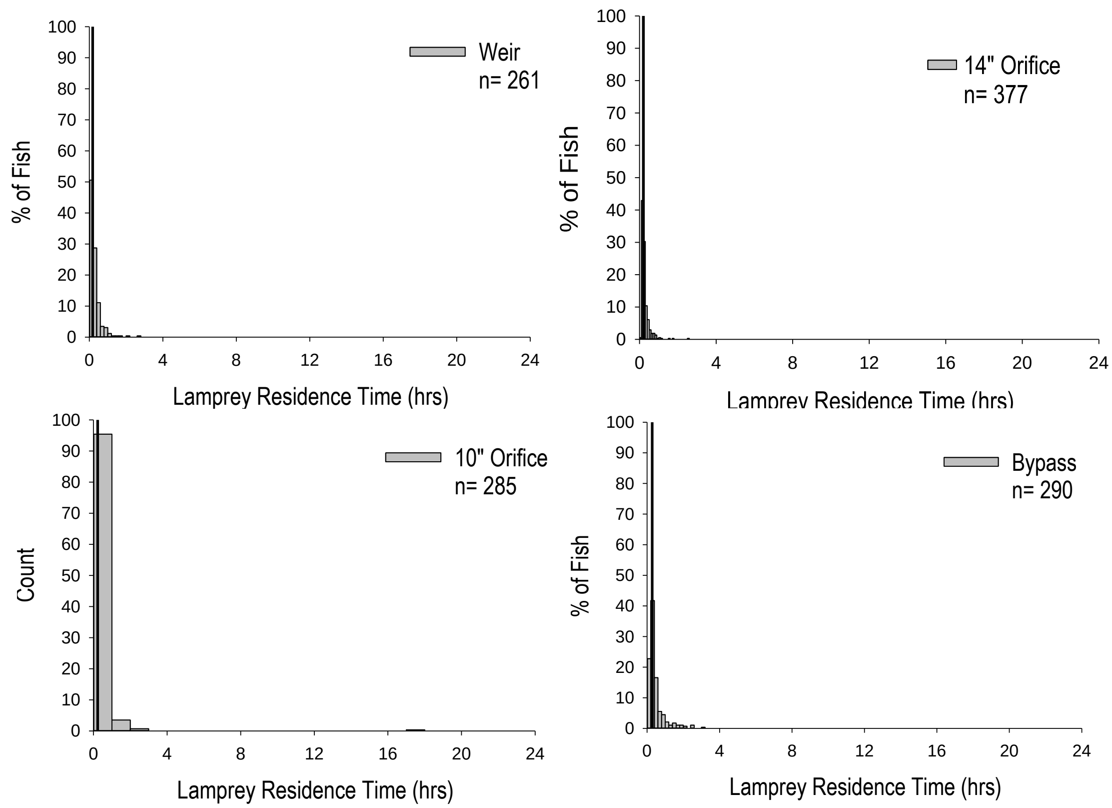

Figure 19. Travel-time histograms for juvenile lampreys released into Gatewells 5A and 5B during operation of the broad-crested overflow weir, 14-inch diameter orifice, 10-inch diameter orifice, and directly into the bypass channel at Lower Granite Dam, spring 2013.

Table 7. Descriptive statistics for juvenile lampreys at each release location at Lower Granite Dam, spring 2013. Mean, median, standard deviation, minimum, and maximum are representative of travel time, in hours, between release time and first detection at the JFF. Travel times exceeding 24 hours were redacted to avoid bias associated with fish releases or switching passage structures.

Release Location	n	Mean	Median	SD	Min	Max	Shapiro–Wilk *W*	Decision (5%)
Bypass	290	0.45	0.30	0.46	0.07	3.15	0.70	Reject Normality
14" Orifice	377	0.28	0.21	0.23	0.09	2.52	0.63	Reject Normality
10" Orifice	285	0.40	0.25	1.09	0.10	17.97	0.15	Reject Normality
Weir	261	0.30	0.19	0.30	0.09	2.71	0.61	Reject Normality
Total	1,213							

Table 8. Quantities of juvenile lampreys released into Gatewells 5A, 5B and the bypass channel at Lower Granite Dam, spring 2013, detected within 24 hours, detected after 24 hours, and never detected. Orifice passage efficiency (OPE) is represented by the total percentage of fish detected after release.

Location	Total Qty Released	Total Qty Detected	Total % Detected	Qty Detected <24hrs	% Detected <24hrs	Qty Detected >24hrs	% Detected >24hrs	Qty Never Detected	% Never Detected
Bypass	294	291	99.0%	290	98.6%	1	0.3%	3	1.0%
14" Orifice	428	413	96.5%	377	88.1%	36	8.4%	15	3.5%
10" Orifice	305	292	95.7%	285	93.4%	7	2.3%	13	4.3%
Weir	271	261	96.3%	261	96.3%	0	0.0%	10	3.7%
Total	*1,298*	*1,257*	*96.8%*	*1,213*	*93.5%*	*44*	*3.4%*	*41*	*3.2%*

Table 9. Differences in median travel times for each test pair of juvenile lampreys released at Lower Granite Dam, spring 2013. The Dunn's test *z* value indicates significance for the difference in median travel time for each test pair. A value greater than 2.64 (Bonferroni test) indicates a statistically significant difference.

Test Pair	Δ Median Travel Time (h)	Dunn's Test *z* Value
Bypass (*n* = 290); 14" Orifice (*n* = 377)	0.09	6.33
14" Orifice (*n* = 377); 10" Orifice (*n* = 285)	0.04	4.22
Bypass (*n* = 290); 10" Orifice (*n* = 285)	0.05	1.96
Bypass (*n* = 290); Weir (*n* = 261)	0.11	6.43
14" Orifice (*n* = 377); Weir (*n* = 261)	0.02	0.67
10" Orifice (*n* = 285); Weir (*n* = 261)	0.06	4.50

Objective 2. Determine fish condition (including injury and descaling) impacts of the overflow weir and larger orifice compared to current orifice configuration for juvenile salmonids.

Fish handled for this objective were photographed prior to release then re-collected at the SxC system and photographed again to document each fish's external condition. The proportion of fish successfully diverted to the SxC system was different for each species and release location, ranging from 68% for steelheads released during weir operation to 93% for yearling Chinook salmon released during 14-inch orifice operation (Table 8).

The primary fish condition metric associated with this objective was descaling, because it was much more common than other categories of injury. Descaling was measured with two approaches: ranked differences in categories from before release to after re-collection on each side of the fish, using categories adapted from Hostetter and Evans (2012), and a binary threshold of descaling (like Ceballos et al. 1992) to establish an overall incidence of descaling. The results describing the overall incidence of descaling are reported after the results describing the ranked-difference approach.

Using the ranked-difference approach, we found all release groups of yearling Chinook salmon and steelheads were more descaled on their right sides than on their left sides (Table 11) after re-collection at the SxC system. Conversely, there was very little difference in descaling scores between the left and right sides for sub-yearling Chinook salmon. Occurrence of other injuries including operculum damage, eye injury, head injury, and trunk injury were rare (<1% of fish scored changed categories from before release to after re-collection. See Appendix G for additional detail).

We used the Kruskall–Wallis one-way ANOVA to identify significant differences in external condition scores by species and among all release sites. Using this "all-pair" comparison, we identified a significant difference in descaling on the right side for yearling Chinook salmon (Table 14). We used Dunn's test to determine that yearling Chinook salmon which passed the 14-inch orifice had a significantly lower rate of descaling on their right side than yearling Chinook salmon that had passed through the 10-inch orifice or weir (Table 14). Yearling Chinook salmon that passed the weir and 10-inch orifice were also significantly more descaled on the right side than fish that were released directly into the bypass channel. No other salmonids had significant differences in external condition scores among all release sites.

Furthermore, we also used the Kruskal–Wallis one-way ANOVA to test for differences in ranked scores for each fish health metric before release and after re-collection (Table 15). Significant differences were limited to left- and right-side descaling for all species. Yearling Chinook salmon were more descaled after re-collection than before release on both the left and right sides for each release site. Steelheads were more descaled after re-collection than before release on the right side for each release site and on the left side when released directly into the bypass channel and during operation of the 10-inch orifice. Sub-yearling Chinook salmon had no significant differences in any external condition scores for any release locations.

The overall incidence of descaling, determined using methods described by Ceballos et al. 1992 varied between species/age-class and release location. Yearling Chinook salmon released during operation of the 14-inch orifice had the lowest incidence of descaling at 3% (i.e. there was a difference of 3.0% between the quantity of fish categorized as descaled before releases and the quantity categorized as descaled after re-collection) (Table 12). Yearling Chinook salmon released during weir operation had the greatest incidence of descaling with a 6.3% difference from before release to after re-collection. Steelheads had less variability in descaling incidence; fish released in all locations were descaled between 3.7% and 4.1% from before release to after re-collection. Sub-yearling Chinook salmon had the lowest incidence of descaling which ranged from 0.2% of fish released during operation of the 10-inch orifice to 0.6% of fish released into the bypass channel.

Poisson Regression

After obtaining the results from the Dunn's test described above, we used the Poisson regression to test the relationships between covariates and right-side descaling for yearling Chinook salmon that passed the 10-inch orifice, weir, and 14-inch orifice (See Appendix H for detailed results of the Poisson regression models). Poisson regression results were confounded by the same factors previously described during the covariate analysis in Objective 1. Additionally, we were unable to use VBS differential for covariate analysis due to in-season errors in data collection that occurred after May 14, 2013 that included the loss of one logger in Gatewell 5B and entanglement of another logger in Gatewell 5A (2013 VBS data is currently being corrected and is not displayed).

For yearling Chinook salmon that passed the 10-inch orifice, forebay elevation was mildly associated with right-side descaling (α = 0.07). Forebay elevation was also associated with right-side descaling of yearling Chinook salmon released during operation of the weir (α = 0.01). Right-side descaling of yearling Chinook salmon released during the operation of the 14-inch orifice was associated with mean fork length and travel time (α = 0.02 and 0.01, respectively).

Table 10. Quantities of yearling Chinook salmon, steelheads, and sub-yearling Chinook salmon released for Sort by Code (SxC) re-collection, quantities detected at the SxC gate, and quantities successfully photographed both prior to release and after re-collection at Lower Granite Dam, spring 2013.

Species	Release Location	Qty SxC Released	SxC Detected	Qty Photographed Before and After Release
Yearling Chinook	Bypass	1,313	1,168	1,089
	14" orifice	805	745	691
	10" orifice	1,659	1,371	1,260
	Weir	810	604	536
	Total	4,587	3,888	3,576
Steelhead	Bypass	1,608	1,380	1,275
	14" orifice	1,091	875	797
	10" orifice	2,053	1,613	1,454
	Weir	1,095	742	645
	Total	5,847	4,610	4,171
Sub-yearling Chinook	Bypass	1,613	1,414	1,203
	14" orifice	800	719	564
	10" orifice	1,707	1,509	1,287
	Weir	923	768	696
	Total	5,043	4,410	3,750

Table 11. Descaling scores for all salmonid release groups re-collected at the Sort by Code (SxC) system at Lower Granite Dam, spring 2013. Ranked differences were the change in descaling category from before to release to after re-collection.

Release Location	Species	Descaling Left Side Ranked Difference	Descaling Left Side Quantity	Descaling Left Side Percent	Descaling Right Side Ranked Difference	Descaling Right Side Quantity	Descaling Right Side Percent
Weir	Yearling Chinook	0	483	90.1%	0	448	83.6%
		1	46	8.6%	1	80	14.9%
		2	7	1.3%	2	8	1.5%
		Total	*536*		*Total*	*536*	
14" Orifice		0	649	93.3%	0	633	90.7%
		1	44	6.3%	1	59	8.5%
		2	5	0.7%	2	6	0.9%
		Total	*698*		*Total*	*698*	
10" Orifice		0	1,145	90.1%	0	1,092	85.9%
		1	113	8.9%	1	157	12.4%
		2	12	0.9%	2	22	1.7%
		Total	*1,270*		*Total*	*1,271*	
Bypass		0	998	91.4%	0	982	89.9%
		1	86	7.9%	1	102	9.3%
		2	8	0.7%	2	8	0.7%
		Total	*1,092*		*Total*	*1,092*	
Weir	Steelhead	0	613	94.6%	0	565	87.2%
		1	34	5.2%	1	78	12.0%
		2	1	0.2%	2	5	0.8%
		Total	*648*		*Total*	*648*	
14" Orifice		0	761	95.4%	0	714	89.7%
		1	36	4.5%	1	78	9.8%
		2	1	0.1%	2	6	0.8%
		Total	*798*		*Total*	*798*	
10" Orifice		0	1,393	95.4%	0	1,295	88.7%
		1	64	4.4%	1	156	10.7%
		2	3	0.2%	2	9	0.6%
		Total	*1,460*		*Total*	*1,460*	
Bypass		0	1,211	94.8%	0	1,136	88.9%
		1	66	5.2%	1	137	10.7%
		2	1	0.1%	2	5	0.4%
		Total	*1,278*		*Total*	*1,278*	

Table 11. (*continued*)

Release Location	Species	Descaling Left Side: Ranked Difference	Quantity	Percent	Descaling Right Side: Ranked Difference	Quantity	Percent
Bypass	Sub-yearling Chinook	0	1,194	97.5%	0	1,207	98.5%
		1	30	2.4%	1	15	1.2%
		2	1	0.1%	2	3	0.2%
		Total	*1,225*		*Total*	*1,225*	
14" Orifice		0	565	98.4%	0	561	97.7%
		1	9	1.6%	1	12	2.1%
		2	0		2	1	0.2%
		Total	*574*		*Total*	*574*	
10" Orifice		0	1,302	99.1%	0	1,295	98.6%
		1	12	0.9%	1	18	1.4%
		2	0		2	1	0.1%
		Total	*1,314*		*Total*	*1,314*	
Weir		0	693	98.2%	0	697	98.7%
		1	13	1.8%	1	9	1.3%
		2	0		2	0	
		Total	*706*		*Total*	*706*	

Table 12. Overall descaling rates using scoring criteria described by Ceballos et al. (1992) where the threshold for descaling was defined as missing at least 20% of scales on the entire fish. The total percent difference was calculated by subtracting the percentage of fish in each release scored as descaled prior to release from the percentage scored as descaled after re-collection.

Species	Release Location	Qty Scored for Condition Analysis	Qty Descaled Before Release	Qty Descaled After Re-Collection	Total % Difference
Yearling Chinook	Bypass channel	2178	12	112	4.6
	14" orifice	1386	6	48	3
	10" orifice	2528	14	150	5.4
	Weir	1072	4	72	6.3
Steelhead	Bypass channel	2550	18	112	3.7
	14" orifice	1594	8	74	4.1
	10" orifice	2910	28	136	3.7
	Weir	1290	26	78	4
Sub-yearling Chinook	Bypass channel	2410	6	20	0.6
	14" orifice	1130	0	6	0.5
	10" orifice	2578	0	6	0.2
	Weir	1400	0	4	0.3

Table 13. Matrix of results for Kruskal–Wallis one-way ANOVA on the ranked difference in fish external condition scores by species among all release sites. A "+" signifies that at least two medians were significantly different. A "0" signifies no significant difference.

Species/Year Class	Descale left side	Descale right side	Operculum left side	Operculum right side	Head	Eye left	Eye right	Trunk
Yearling Chinook	0	+	0	0	0	0	0	0
Steelhead	0	0	0	0	0	0	0	0
Sub-yearling Chinook	0	0	0	0	0	0	0	0

Table 14. Dunn's test matrix of results detailing significant differences in median descaling scores for yearling Chinook salmon, right side. A "+" signifies that medians were significantly different. Bold text indicates the passage structure associated with the greater level of descaling (i.e. 10" orifice > bypass and Weir > 14" orifice).

Descale right side	Bypass Chinook	14" Orifice Chinook	**10" Orifice Chinook**	**Weir Chinook**
Bypass Chinook	n/a	0	+	+
14" Orifice Chinook	0	n/a	+	+
10" Orifice Chinook	+	+	n/a	0
Weir Chinook	+	+	0	n/a

Table 15. Matrix of results for Kruskal–Wallis one-way ANOVA differences in fish external condition scores for each species and release site from before release to after re-collection. A "+" signifies a significant increase in median score from before release to after re-collection.

Release Location	Species	Descale left side	Descale right side	Operculum left side	Operculum right side	Head	Eye left	Eye right	Trunk
Bypass	Yearling Chinook	+	+	0	0	0	0	0	0
14" Orifice		+	+	0	0	0	0	0	0
10" Orifice		+	+	0	0	0	0	0	0
Weir		+	+	0	0	0	0	0	0
Bypass	Steelhead	+	+	0	0	0	0	0	0
14" Orifice		0	+	0	0	0	0	0	0
10" Orifice		+	+	0	0	0	0	0	0
Weir		0	+	0	0	0	0	0	0
Bypass	Sub-yearling Chinook	0	0	0	0	0	0	0	0
14" Orifice		0	0	0	0	0	0	0	0
10" Orifice		0	0	0	0	0	0	0	0
Weir		0	0	0	0	0	0	0	0

Lamprey Re-collection at the SxC System

The proportion of juvenile lampreys successfully recovered at the SxC nets ranged from 56 to 76% across three releases (Table 16). The overall proportion recovered was 65%.

Lampreys Released after the Tag Retention Comparison

No mortalities occurred during the 96-h holding period of PIT-tagged juvenile lampreys as part of the tag retention comparison study. The group tagged with 16-gauge needles and 8.5-mm × 1.4-mm PIT tags shed no tags and only 5.6% had unhealed tagging wounds at the end of the 96-h period. The group tagged with scalpels and 9-mm × 2.1-mm PIT tags had two shed tags and 66.7% had unhealed tagging wounds. After release onto the separator at the LGR JFF, 97% of the fish in each group were detected.

Table 16. Quantities of juvenile lampreys released for SxC re-collection, quantities detected at the SxC gate, and quantities recovered from the SxC nets at Lower Granite Dam, spring 2013.

Release Location	Qty SxC Released	Qty Detected SxC Gate	Qty Re-Collected in SxC Nets
Bypass	50	45	32
Bypass	50	41	28
Bypass	50	43	38
Total	150	129	98

Objective 3. Determine debris passage impacts of overflow weirs and/or larger orifices

And

Objective 4. Investigate salmonid fish behavior patterns in gatewells with overflow weirs relative to current orifice configuration.

Video Observation Results

A total of 5,842 fish were observed passing through all of the fish passage structures in Gatewells 5A and 5B at LGR during the subsampled video monitoring periods (Table 17). Interactions (or strikes) of juvenile salmonids with the fish passage structures were recorded and the interaction rates as a percentage of the total passing through each opening are reported in Table 17. For example, at the 10-inch orifice in Gatewell 5B, 13 out of 2,643 juvenile fish interacted, or struck the edge of the orifice structure for an interaction rate of 0.5%.

Submerged debris (logs, branches, plant matter) was observed only partially blocking the 10-inch orifice in Gatewell 5A (Table 18). For the 14-inch orifice and weir, no debris was observed at any time during subsampled video observation periods. For the 10-inch orifice, the percentage of the opening blocked by debris was estimated visually from video footage and the obstructed area divided into three ranges (10–20%, 21–50%, or 51–80% blocked). The most common rate of debris obstruction was 10–20% blockage, which occurred during 7.5% of subsampled video observation periods, followed by 21–50% blockage (5.7% of observed periods), and finally, blockage of 51–80% occurred during only 1.3% of observed periods.

In contrast to juvenile salmonids, adult salmonids and juvenile lampreys were infrequently observed in the vicinity of gatewell fish passage openings (Table 19). In total, nine adult salmonids were observed at these openings, with two fish at the 14-inch orifice and three fish at the 10-inch orifice going completely through the orifices. The remaining seven fish were observed swimming near the openings but not passing through them. Juvenile lampreys were sighted at each opening, with the most observed at the 10-inch orifice. The 21 juvenile lampreys that were counted at the 10-inch diameter orifice were observed on May 27 within a 10-minute period during the night hours shortly after a release of lampreys into the gatewell. None of the lampreys were observed to pass through the fish passage structures.

Table 17. Rate of juvenile fish striking or interacting with the edges of the passage structures during 102 hours of observed video footage recorded at the openings of the 14-inch orifice, 10-inch orifice, and broad-crested overflow weir located in Gatewells 5A and 5B at Lower Granite Dam, spring 2013.

Gatewell Opening	Total No. Passing	No. of Interactions	Interaction Rate (%)
5A 14-inch orifice	611	5	0.8
5B 10-inch orifice	2,643	13	0.5
5A overflow weir	2,588	8	0.3

Table 18. Rate of obstruction from debris in the fish passage structures observed using 102 hours of video footage recorded at the openings of the 14-inch orifice, 10-inch orifice, and broad-crested overflow weir located in Gatewells 5A and 5B at Lower Granite Dam, spring 2013.

Gatewell Opening	Range of Area Obstructed (%)	Time Obstructed (hr)	Debris Obstruction Rate (%)
5B 10-inch orifice	10–20	7.7	7.5
	21–50	5.8	5.7
	51–80	1.3	1.3
5A 14-inch orifice	0	0	0
5A overflow weir	0	0	0

Table 19. Summary of video observations of adult salmonids and juvenile lampreys at each passage structure using 102 hours of video footage recorded at the openings of the 14-inch orifice, 10-inch orifice, and broad-crested overflow weir located in Gatewells 5A and 5B at Lower Granite Dam, spring 2013**.** Not all observed fish passed the structure into the bypass collection channel.

Gatewell Opening	Adult Salmonids	Juvenile Lampreys
5A 14-inch orifice	2	1
5A overflow weir	2	1
5B 10-inch orifice	5	21

DIDSON Results

Technicians reviewed approximately 25% of the 1,300 total hours of DIDSON footage. The observation of adult fish with the DIDSON camera was rare; however, Pacific lampreys, white sturgeon, common carp, northern pikeminnow, and adult salmonids (likely Chinook salmon and steelheads) were observed while reviewing the subsampled DIDSON data. Twelve adult salmonids were observed passing through the structures in Gatewells 5A and 5B; four passed over the weir and eight passed through the 10-inch orifice.

DISCUSSION

Juvenile Bypass System Travel Time

Previous studies in the Columbia River basin have measured median gatewell residence with passage through an orifice into a bypass collection channel. Axel and Dey (2001) reported a median residence time of 2.8 h for sub-yearling Chinook salmon released into a gatewell at McNary Dam. Beeman and Maule (2001) reported a median residence time of 9.2 h for yearling Chinook salmon also released into a gatewell at McNary Dam. The median travel times for yearling and sub-yearling Chinook salmon released for this study at LGR during operation of both the 14-inch diameter (0.79 h and 1.03 h, respectively) and 10-inch diameter (1.64 h and 1.68 h, respectively) orifices were less than those reported in previous studies at other dams. Moreover, results of this study indicate that yearling Chinook salmon, juvenile steelheads, and sub-yearling Chinook salmon traveled through the JBS more quickly when released into Gatewell 5A during operation of the 14-inch diameter orifice than those that were released during operation of the broad-crested overflow weir and 10-inch diameter orifice. The greater travel times for juvenile steelheads compared with yearling and sub-yearling Chinook salmon were consistent for all release locations.

The difference in travel time we observed for sub-yearling Chinook salmon released in the morning versus night was also observed by Beeman and Maule (2001), who reported a 8.7 h difference in median travel time for yearling Chinook salmon released at mid-day versus those released at night into a gatewell at McNary Dam. The night releases for this study were limited to three release groups of one species/age class during the operation of the weir, which limited the ability to make quantitative comparisons with other routes and species. We did observe a pulse of fish detections that occurred 10–12 h after release, which suggested a portion of the fish remained in either the gatewell or bypass channel until evening. Future studies should include night releases for all species/age classes and release locations.

The primary purpose of the releases into the bypass channel was to show contrast in travel times with releases into Gatewells 5A and 5B. Because the first downstream detection site was located at the JFF, rather than within the bypass channel, the proportion of travel time spent only in the gatewell could not be measured. The original intent of this study was to use the releases into the bypass collection channel as a control, but the non-normal distribution of median travel times for those releases made that approach problematic. In addition, we were unable to complete enough replicate releases to achieve the test power required for that approach. Therefore, releases into the bypass were handled as a fourth treatment group. Future studies would benefit from an ability to detect PIT-tagged fish within the bypass collection channel for the purpose of allowing travel time to be divided by the time spent in the gatewell versus the collection channel.

Biological Relevance of the Results

One purpose of this study was to assess the biological characteristics associated with each style of passage structure and an important metric to consider was passage delay, more specifically residence time in the gatewell and JBS. The ANOVA tests we used to assign statistical significance to differences in pairs of releases showed significant differences between nearly all possible pairs for yearling Chinook salmon, juvenile steelheads, and sub-yearling Chinook salmon. The power of the tests (β) was 1.0 in all cases and was a result of large sample sizes and relatively low standard deviation for each group tested. However, biological significance should be considered by USACE biologists and regional stakeholders. For example, the question may be asked regarding yearling Chinook salmon, whether a median difference of 0.9 h in travel time between fish released during the operation of the 14-inch orifice versus the weir is of concern from the standpoint of outmigration delay. For comparison, the difference in median travel time of steelheads that were released during operation of the10-inch orifice versus 14-inch orifice was 0.3 h (17 min). While the ANOVA test indicated a significant difference, the biological interpretation of a significant outmigration delay should be taken into account during the decision process of choosing which passage structure is best.

Covariate Analyses

Results from covariate models completed for this study may be useful for considering effects of dam operations on travel time through the LGR JBS; however, the results do not explain the statistically different travel times between release locations. The limitations of these analyses were the relatively small number of replicates and limited operational range for most variables that were associated with operations of LGR. Also, many covariates were highly correlated with each other, limiting the number of independent variables available for inclusion in the regression models. These results should serve to further the discussion of covariate impacts on fish travel time and health rather than measure specific impacts.

Our analyses identified species-specific differences in relationships between travel time and the covariates in the regression models (Table 20). Mean fork length was the most common significant independent variable in the models. The mean fork length of steelheads and sub-yearling Chinook salmon tagged for this study increased over the course of the study period but lengths were largely representative of in-river migrants and run timing for each species/age class (Figures 20–24). The effect of fish size during the study period was different for steelheads than sub-yearling Chinook salmon. Travel times decreased with increasing mean fork length for steelheads but increased for sub-yearling Chinook salmon. For steelheads, Julian day of release was associated with both increasing river flow in the early part of the study and increasing fork length of fish. The model coefficients describe decreasing travel time for steelheads as Julian day increased. Later in the study period, after the spring freshet had subsided and we switched to releases of sub-yearling Chinook salmon, the only highly significant ($\alpha < 0.05$) independent variable was mean fork length, which was associated with increasing travel time. Flow through Turbine Unit 5 was a mildly significant ($\alpha < 0.1$) independent variable for both yearling and sub-yearling Chinook salmon. Interpretation of this relationship is difficult because the range of flows during turbine operation was relatively small (13.6–16.6 kcfs). The relationship between increase in turbine flow and decreased travel time indicate the hydrodynamics within the gatewell environment do affect travel times for yearling and sub-yearling Chinook salmon. Forebay elevation was only a significant independent variable for steelheads released during 14-inch orifice operation. While the number of replicate releases with calculated flow through the 14-inch orifice was limited (*n* = 5), there was a correlation between increasing forebay elevation and increasing orifice flow. Steelheads passed through the JBS more quickly with increases in forebay elevation, flow through the passage structure, and mean fork length. Yearling and sub-yearling Chinook salmon had opposite relationships to these factors.

The deployment of the U20 HOBO data loggers in 2013 did not provide reliable data collection for calculating VBS differential. Two of the four loggers deployed from the deck were lost due to turbulence, line breakage, or debris interference. Additionally, loggers were deployed on static lines, with 10-lb. weights to stabilize the deployment but resulted in line stretching that could not accurately be measured. In the future, loggers should only be deployed on cable, or should be affixed permanently to a structure in the gatewells that does not move. There were several instances where it was evident that the deployed units were tangled in other apparatus, meaning the deployment depth was incorrect based on sensor data.

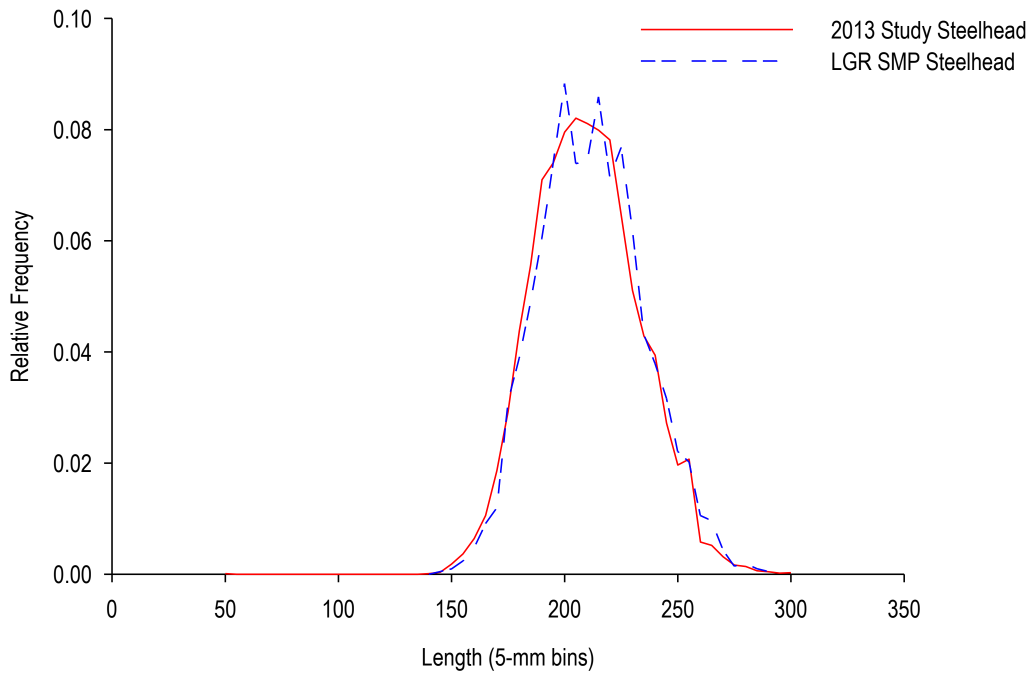

Figure 20. Fork-length frequency of juvenile steelheads PIT-tagged between April 21 and May 25, 2013 for inclusion in the Lower Granite Dam JBS evaluation compared with fork-length frequency of juvenile steelheads in the daily SMP sample during the same period.

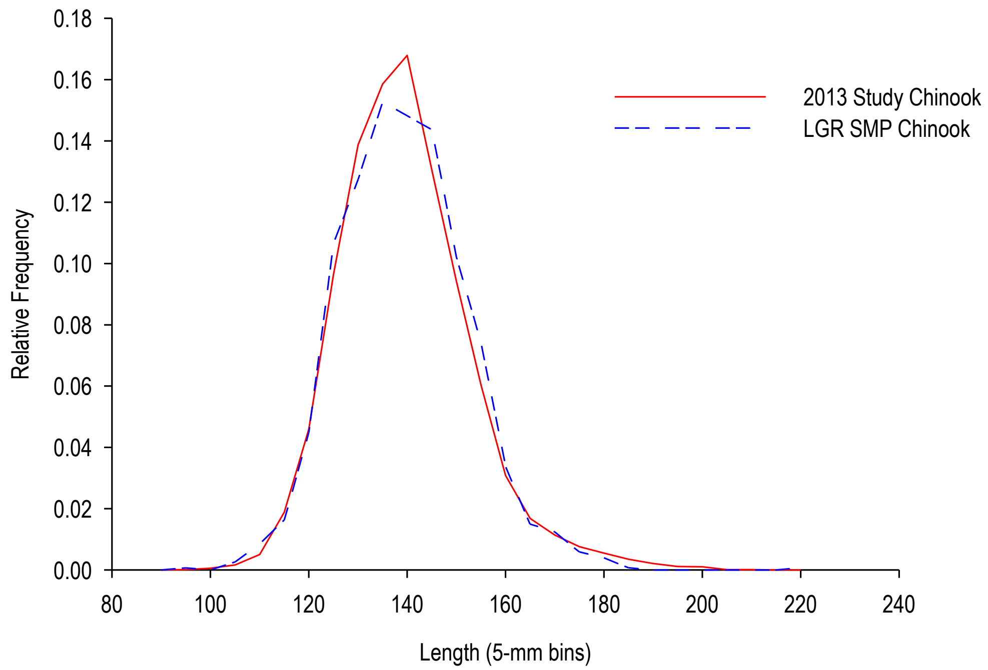

Figure 21. Fork-length frequency of yearling Chinook salmon PIT-tagged between April 21 and May 25, 2013 for inclusion in the Lower Granite Dam JBS evaluation compared with fork-length frequency of yearling Chinook salmon in the daily SMP sample during the same period.

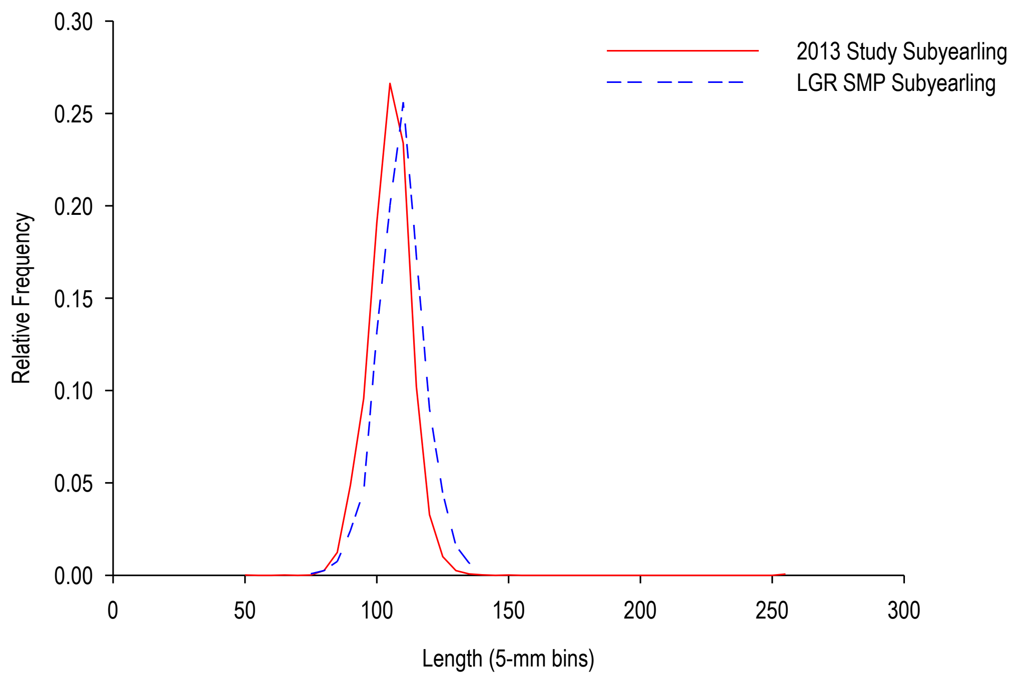

Figure 22. Fork-length frequency of sub-yearling Chinook salmon PIT-tagged between April 21 and May 25, 2013 for inclusion in the Lower Granite Dam JBS evaluation compared with fork-length frequency of sub-yearling Chinook salmon in the daily SMP sample during the same period.

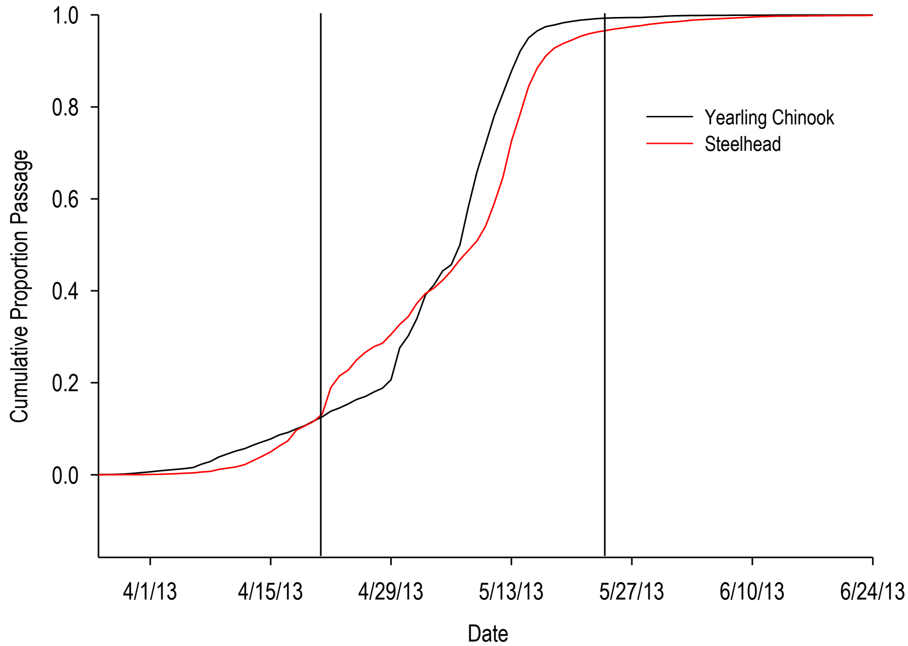

Figure 23. Cumulative proportion of fish passage for yearling Chinook salmon and juvenile steelheads at Lower Granite Dam in spring 2013. The reference lines define the period of April 21 through May 25 during which fish were PIT-tagged and released for the JBS evaluation.

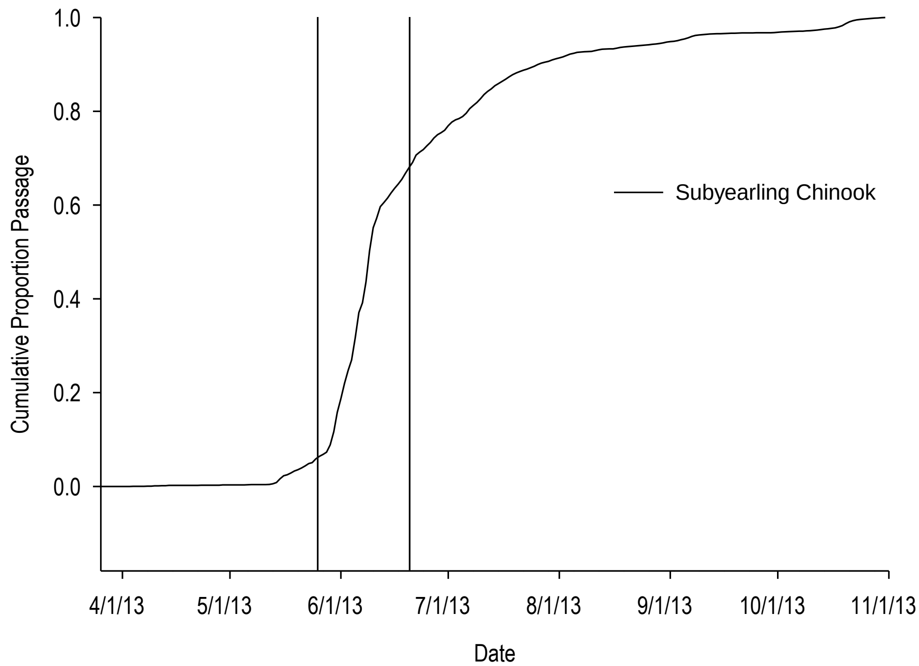

Figure 24. Cumulative proportion of fish passage for sub-yearling Chinook salmon at Lower Granite Dam in spring 2013. The reference lines define the period of May 26 through June 21 during which fish were PIT-tagged and released for the JBS evaluation.

Table 20. Relationships between independent variables and Box–Cox transformed mean travel time in the gatewell determined with regression models for each release location at Lower Granite Dam, spring 2013. Positive and negative relationships with mean travel were interpreted with the Model Coefficient.

Species	Release Location	Independent Variable	Model Coefficient	Significant α = 0.1?	Significant α = 0.05?	Variable Relationship
Yearling Chinook	14" orifice	no significant covariates				
	10" orifice	no significant covariates				
	Weir	Unit 5 kcfs	–0.165	Yes	No	Negative
Steelhead	14" orifice	Mean fork length	–0.032	Yes	Yes	Negative
		Forebay elevation	0.289	Yes	Yes	Positive
	10" orifice	Julian day	–0.030	Yes	Yes	Negative
	Weir	Julian day	–0.038	Yes	Yes	Negative
Sub-yearling Chinook	14" orifice	Mean fork length	0.026	Yes	Yes	Positive
	10" orifice	Mean fork length	0.021	Yes	Yes	Positive
	Weir	Unit 5 kcfs	–0.103	Yes	No	Negative

Fish Impingement on the Broad-Crested Weir

Over the course of the study period we observed approximately 38 juvenile steelheads and 30 yearling Chinook salmon impinged between the wall and broad-crested structure of the weir (Figure 25). In all cases, our observation of fish impingement occurred as the weir was raised (closed) after it had been in operation for 48 to 72 hours. This suggests the broad-crested structure should be modified to either create a larger gap on the edges or include a gasket that eliminates the gap altogether.

Figure 25. Impinged juvenile salmonid at the opening of the broad-crested overflow weir at Lower Granite Dam on April 27, 2013.

Fish Condition Analyses

The only species/age class that had significant differences in external condition scores between release locations was yearling Chinook salmon, which were more likely to be descaled on their right sides when released during operation of the 10-inch orifice and weir than other release locations. Steelheads and sub-yearling Chinook salmon were equally affected regardless of release location. Descaling was the only external health metric with statistically significant results. While the incidence of descaling was statistically significant (i.e. enough to detect a change in ranked difference scores from before release to after re-collection), the actual proportion of test fish affected was <20%. The other metrics, such as injuries to eye, operculum, and body were quite rare, affecting <1% of test fish.

We explored the linkage between covariates and right-side descaling of yearling Chinook salmon using Poisson regression and identified a significant independent variable for each model, but we are unable to explain how forebay elevation may increase the rate of descaling. The low pseudo-R^2 values for each model suggest other factors were associated with the variability in right-side descaling scores. Sub-yearling Chinook salmon had lower travel times and were physically smaller than the other salmonids, which may explain the lower rates of descaling. Because nearly all release groups of yearling Chinook salmon and steelheads were equally likely to be more descaled after re-collection than prior to release, the issue may lie within the JBS itself.

Debris and Fish Passage Observational Data

Results from optical video and DIDSON observation in the test gatewells were intended to reveal potential design flaws in the experimental passage structures resulting in unacceptable levels of debris buildup or harm to fish passing into the bypass channel. Such findings were largely absent from the analyses. This is primarily due to the relatively low quantities of debris in the gatewells at LGR in 2013 and the confounding effect of not knowing the total quantity of juvenile fishes present in the gatewells during observation periods. As such, it was impossible to make quantitative estimates of fish passage rates. Instead, the value of the results is qualitative observation useful in further discussions of how the experimental passage structures function for debris and fish passage.

River discharge at LGR in 2013 peaked earlier and the duration of the freshet was shorter than the combined average over the past ten years (Figure 26). This contributed to the infrequent occurrence of debris occluding the fish passage structures in Gatewells 5A and 5B. The infrequent occurrence of debris in the orifices resulted in a low (<1%) rate of direct interaction (strikes) between juvenile fish and debris recorded with optical video. Even with the relatively low occurrence of debris buildup, the results indicate that the 14-inch orifice and weir may be less prone to debris occlusion than the 10-inch orifice, which was the only passage structure observed to clog. The DIDSON cameras were not useful for observing fish interaction with debris at the fish passage structures. We were able to observe adult salmonid passage using both optical video and DIDSON. However, given the limited quantity of video and DIDSON data reviewed, the value for observing adult salmonids was limited.

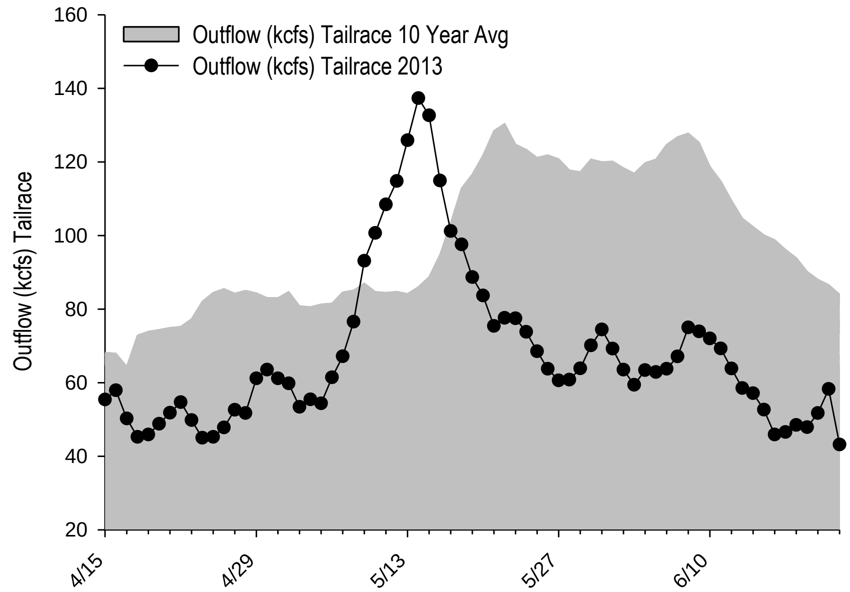

Figure 26. River discharge in the tailrace of Lower Granite Dam, spring 2013.

Lamprey Releases

We set out to determine feasible methods of collection, handling, tagging, and release for juvenile lampreys. We were successful in all of these tasks. A total of 96.8% of lampreys released for this study were detected in the LGR JBS. This is comparable to the detection rate of 99.4% reported by Bleich and Moursund (2006) for juvenile lampreys released into the JBS at McNary Dam. The low rate of loss indicated that the tagging method was effective and that juvenile lampreys are suitable for future JBS evaluations. The relatively low travel times and standard deviations compared to salmonids will allow for statistical comparisons among release groups in future studies, assuming that enough lampreys can be collected to complete several replicate releases for each treatment.

Given the identical detection rates of 9-mm L x 2.1-mm dia. PIT and 8.5-mm L x 1.4-mm dia. PIT tags used in this study, the frequency of unhealed tagging wounds and tag shedding rates should be considered when making decisions regarding tagging techniques for juvenile lampreys in future studies. At the conclusion of the 96-h holding period of our tag retention experiment, the group tagged with scalpels had 61.1% more unhealed tagging wounds and 2.7% more tag sheds compared with the group tagged with 16-gauge needles.

We began collecting juvenile lampreys on May 16 at the peak freshet at LGR (Figure 27). Staff at LGR and other Snake River dams reported encountering lampreys in the smolt monitoring program (SMP) sample and JBS raceways approximately one week prior to the start of our efforts. While we were successful in collecting enough lampreys to complete several releases, beginning collection efforts at the first indication of their presence would have resulted in more fish collected, particularly in the raceways at LMN. Our collection methods in the raceways and SMP samples at LMN were consistently successful but staff there commented that many more lampreys were observed free swimming at night in the raceways in the week prior to our collection effort. We were not granted permission to attempt collections at night at LGS in 2013. Collecting lampreys with a dip net behind the head screens in the raceways at LGR was our most successful method for capturing the most lampreys.

Only 2.5% (29 of 1,150) of tagged juvenile lampreys that were assumed to have continued in-river downstream migration were detected at downstream interrogation points in the mainstem Snake and Columbia Rivers. This low detection rate suggests either 1) juvenile lamprey behavior limits their availability for detections at existing facilities, 2) outmigration survival is poor; potentially, both 1 and 2 are true. In addition, only one tag from this study was detected at areas monitored for PIT-tag deposition at bird colonies, specifically a double-crested cormorant colony on East Sand Island in the Columbia River estuary.

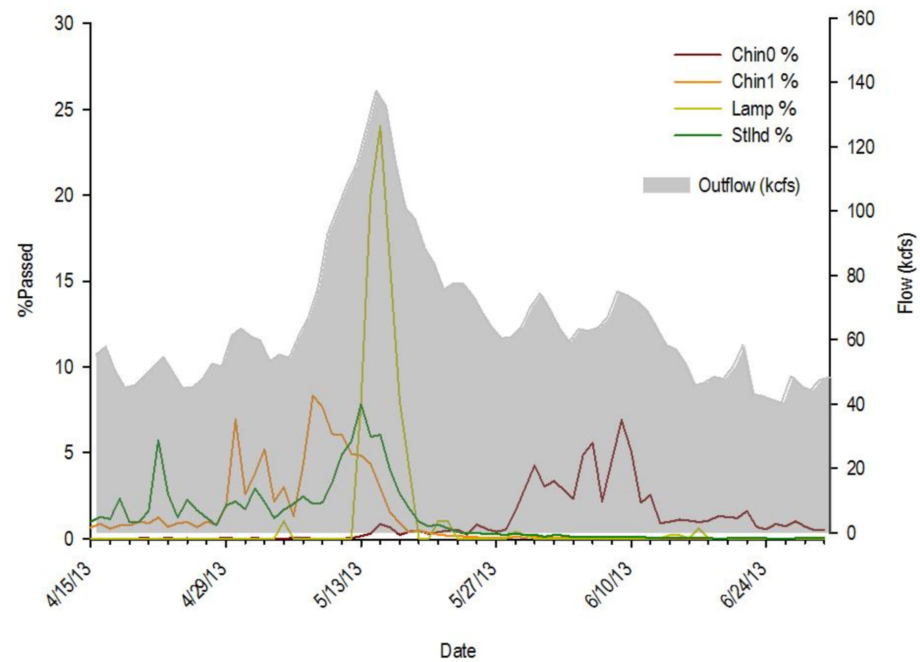

Figure 27. River flow versus juvenile fish passage at Lower Granite Dam, spring 2013.

Future Planned Research and Lessons Learned

In 2014, there are study plans to continue work at LGR and address objectives related to travel time and fish condition assessment for juvenile salmonids and lampreys passing through the JBS. There are several proposed modifications to the 2013 study, such as diel releases of salmonids, installation of temporary PIT-detection antennas in the bypass collection channel, and installation of a light ring at the opening of the 14-inch diameter orifice. All of these modifications should serve to incrementally improve understanding of fish passage through the JBS.

Some of the challenges we encountered in 2013 included difficulty measuring VBS differential with U20 HOBO loggers suspended in the gatewells. Future efforts should include the installation of these sensors using semi-permanent fixtures, preferably armored against battering by swirling debris. We were not able to obtain a complete record of calculated flows through the fish passage structures. Covariate models of fish travel times will improve with this metric. Another improvement to covariate analysis might be the use of “blocked” operations (i.e. operate the turbine unit associated with the experimental passage structures in descending blocks of 1 kcfs during consecutive releases while holding as many other operations as possible constant). This arrangement in operations would aid researchers in gaining a better understanding of the effects of dam operations on fish travel time and injury rates as juvenile fish pass through the JBS. Finally, installation of PIT antennas within the bypass channel is recommended and would improve estimates of the portion of travel time spent in the gatewell versus inside the bypass channel.

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Appendix A: Lower Granite Dam Release Data, Spring 2013

Table 21. Yearling Chinook released by location, per day at Lower Granite Dam, spring 2013.

Species	Release Code	Release Date	Location	Number Released	Daily total
CH	BC01	4/20/2013	Bypass Channel	40	
CH	WC01	4/20/2013	Gatewell 5A, Broad-Crest Overflow Weir	88	
CH	OC01	4/20/2013	Gatewell 5B, 10" Orifice (Original)	91	219
CH	BC02	4/22/2013	Bypass Channel	70	
CH	WC02	4/22/2013	Gatewell 5A, Broad-Crest Overflow Weir	112	
CH	OC02	4/22/2013	Gatewell 5B, 10" Orifice (Original)	112	294
CH	BC03	4/23/2013	Bypass Channel	81	
CH	EC01	4/23/2013	Gatewell 5A, 14" Orifice (Enlarged)	110	
CH	OC03	4/23/2013	Gatewell 5B, 10" Orifice (Original)	111	302
CH	BC04	4/24/2013	Bypass Channel	54	
CH	EC02	4/24/2013	Gatewell 5A, 14" Orifice (Enlarged)	77	
CH	OC04	4/24/2013	Gatewell 5B, 10" Orifice (Original)	81	212
CH	BC06	4/26/2013	Bypass Channel	21	
CH	WC04	4/26/2013	Gatewell 5A, Broad-Crest Overflow Weir	35	
CH	OC06	4/26/2013	Gatewell 5B, 10" Orifice (Original)	35	91
CH	BC07	4/27/2013	Bypass Channel	127	
CH	EC03	4/27/2013	Gatewell 5A, 14" Orifice (Enlarged)	137	
CH	OC07	4/27/2013	Gatewell 5B, 10" Orifice (Original)	140	404
CH	BC08	4/29/2013	Bypass Channel	67	
CH	EC04	4/29/2013	Gatewell 5A, 14" Orifice (Enlarged)	59	
CH	OC08	4/29/2013	Gatewell 5B, 10" Orifice (Original)	65	191
CH	BC09	4/30/2013	Bypass Channel	53	
CH	WC05	4/30/2013	Gatewell 5A, Broad-Crest Overflow Weir	55	
CH	OC09	4/30/2013	Gatewell 5B, 10" Orifice (Original)	52	160
CH	BC10	5/1/2013	Bypass Channel	152	
CH	WC06	5/1/2013	Gatewell 5A, Broad-Crest Overflow Weir	156	
CH	OC10	5/1/2013	Gatewell 5B, 10" Orifice (Original)	143	451
CH	BC11	5/2/2013	Bypass Channel	143	
CH	EC05	5/2/2013	Gatewell 5A, 14" Orifice (Enlarged)	158	
CH	OC11	5/2/2013	Gatewell 5B, 10" Orifice (Original)	170	471
CH	BC12	5/3/2013	Bypass Channel	151	
CH	EC06	5/3/2013	Gatewell 5A, 14" Orifice (Enlarged)	154	
CH	OC12	5/3/2013	Gatewell 5B, 10" Orifice (Original)	159	464
CH	BC13	5/4/2013	Bypass Channel	158	
CH	WC07	5/4/2013	Gatewell 5A, Broad-Crest Overflow Weir	156	
CH	OC13	5/4/2013	Gatewell 5B, 10" Orifice (Original)	153	467
CH	BC14	5/5/2013	Bypass Channel	156	
CH	WC08	5/5/2013	Gatewell 5A, Broad-Crest Overflow Weir	156	
CH	OC14	5/5/2013	Gatewell 5B, 10" Orifice (Original)	155	467
CH	BC15	5/7/2013	Bypass Channel	162	
CH	EC07	5/7/2013	Gatewell 5A, 14" Orifice (Enlarged)	144	
CH	OC15	5/7/2013	Gatewell 5B, 10" Orifice (Original)	168	474
CH	BC15	5/8/2013	Bypass Channel	165	
CH	EC08	5/8/2013	Gatewell 5A, 14" Orifice (Enlarged)	145	
CH	OC16	5/8/2013	Gatewell 5B, 10" Orifice (Original)	157	467

Species	Release Code	Release Date	Location	Number Released	Daily total
CH	BC17	5/9/2013	Bypass Channel	200	
CH	WC09	5/9/2013	Gatewell 5A, Broad-Crest Overflow Weir	219	
CH	OC17	5/9/2013	Gatewell 5B, 10" Orifice (Original)	216	635
CH	BC18	5/10/2013	Bypass Channel	213	
CH	WC10	5/10/2013	Gatewell 5A, Broad-Crest Overflow Weir	223	
CH	OC18	5/10/2013	Gatewell 5B, 10" Orifice (Original)	219	655
CH	BC19	5/11/2013	Bypass Channel	219	
CH	EC09	5/11/2013	Gatewell 5A, 14" Orifice (Enlarged)	203	
CH	OC19	5/11/2013	Gatewell 5B, 10" Orifice (Original)	219	641
CH	BC20	5/12/2013	Bypass Channel	214	
CH	EC10	5/12/2013	Gatewell 5A, 14" Orifice (Enlarged)	206	
CH	OC20	5/12/2013	Gatewell 5B, 10" Orifice (Original)	222	642
CH	BC21	5/14/2013	Bypass Channel	95	
CH	WC11	5/14/2013	Gatewell 5A, Broad-Crest Overflow Weir	90	
CH	OC21	5/14/2013	Gatewell 5B, 10" Orifice (Original)	100	285
CH	BC22	5/15/2013	Bypass Channel	205	
CH	WC12	5/15/2013	Gatewell 5A, Broad-Crest Overflow Weir	218	
CH	OC22	5/15/2013	Gatewell 5B, 10" Orifice (Original)	219	642
CH	BC23	5/16/2013	Bypass Channel	208	
CH	EC11	5/16/2013	Gatewell 5A, 14" Orifice (Enlarged)	206	
CH	OC23	5/16/2013	Gatewell 5B, 10" Orifice (Original)	243	657
CH	BC24	5/17/2013	Bypass Channel	226	
CH	EC12	5/17/2013	Gatewell 5A, 14" Orifice (Enlarged)	202	
CH	OC24	5/17/2013	Gatewell 5B, 10" Orifice (Original)	221	649
CH	BC25	5/18/2013	Bypass Channel	114	
CH	WC13	5/18/2013	Gatewell 5A, Broad-Crest Overflow Weir	111	
CH	OC25	5/18/2013	Gatewell 5B, 10" Orifice (Original)	110	335
CH	BC26	5/19/2013	Bypass Channel	48	
CH	WC14	5/19/2013	Gatewell 5A, Broad-Crest Overflow Weir	45	
CH	OC26	5/19/2013	Gatewell 5B, 10" Orifice (Original)	45	138
CH	BC27	5/22/2013	Bypass Channel	19	
CH	EC13	5/22/2013	Gatewell 5A, 14" Orifice (Enlarged)	14	
CH	OC27	5/22/2013	Gatewell 5B, 10" Orifice (Original)	16	49
CH	BC28	5/23/2013	Bypass Channel	105	
CH	WC15	5/23/2013	Gatewell 5A, Broad-Crest Overflow Weir	120	
CH	OC28	5/23/2013	Gatewell 5B, 10" Orifice (Original)	120	345
CH	BC29	5/25/2013	Bypass Channel	49	
CH	EC14	5/25/2013	Gatewell 5A, 14" Orifice (Enlarged)	57	
CH	OC29	5/25/2013	Gatewell 5B, 10" Orifice (Original)	64	170

Table 22. Steelheads released by location, per day at Lower Granite Dam, spring 2013.

Species	Release Code	Release Date	Location	Number Released	Daily total
ST	BS01	4/20/2013	Bypass Channel	115	
ST	WS01	4/20/2013	Gatewell 5A, Broad-Crest Overflow Weir	165	
ST	OS01	4/20/2013	Gatewell 5B, 10" Orifice (Original)	165	445
ST	BS02	4/22/2013	Bypass Channel	82	
ST	WS02	4/22/2013	Gatewell 5A, Broad-Crest Overflow Weir	113	
ST	OS02	4/22/2013	Gatewell 5B, 10" Orifice (Original)	109	304
ST	BS03	4/23/2013	Bypass Channel	119	
ST	ES01	4/23/2013	Gatewell 5A, 14" Orifice (Enlarged)	164	
ST	OS03	4/23/2013	Gatewell 5B, 10" Orifice (Original)	149	432
ST	BS04	4/24/2013	Bypass Channel	108	
ST	ES02	4/24/2013	Gatewell 5A, 14" Orifice (Enlarged)	134	
ST	OS04	4/24/2013	Gatewell 5B, 10" Orifice (Original)	168	410
ST	BS05	4/25/2013	Bypass Channel	105	
ST	WS03	4/25/2013	Gatewell 5A, Broad-Crest Overflow Weir	158	263
ST	BS06	4/26/2013	Bypass Channel	39	
ST	WS04	4/26/2013	Gatewell 5A, Broad-Crest Overflow Weir	39	
ST	OS06	4/26/2013	Gatewell 5B, 10" Orifice (Original)	40	118
ST	BS07	4/27/2013	Bypass Channel	113	
ST	ES03	4/27/2013	Gatewell 5A, 14" Orifice (Enlarged)	187	
ST	OS07	4/27/2013	Gatewell 5B, 10" Orifice (Original)	150	450
ST	BS08	4/29/2013	Bypass Channel	77	
ST	ES04	4/29/2013	Gatewell 5A, 14" Orifice (Enlarged)	76	
ST	OS08	4/29/2013	Gatewell 5B, 10" Orifice (Original)	81	234
ST	BS09	4/30/2013	Bypass Channel	53	
ST	WS05	4/30/2013	Gatewell 5A, Broad-Crest Overflow Weir	52	
ST	OS09	4/30/2013	Gatewell 5B, 10" Orifice (Original)	51	156
ST	BS10	5/1/2013	Bypass Channel	155	
ST	WS06	5/1/2013	Gatewell 5A, Broad-Crest Overflow Weir	151	
ST	OS10	5/1/2013	Gatewell 5B, 10" Orifice (Original)	152	458
ST	BS11	5/2/2013	Bypass Channel	198	
ST	ES05	5/2/2013	Gatewell 5A, 14" Orifice (Enlarged)	150	
ST	OS11	5/2/2013	Gatewell 5B, 10" Orifice (Original)	156	504
ST	BS12	5/3/2013	Bypass Channel	157	
ST	ES06	5/3/2013	Gatewell 5A, 14" Orifice (Enlarged)	175	
ST	OS12	5/3/2013	Gatewell 5B, 10" Orifice (Original)	175	507
ST	BS13	5/4/2013	Bypass Channel	167	
ST	WS07	5/4/2013	Gatewell 5A, Broad-Crest Overflow Weir	169	
ST	OS13	5/4/2013	Gatewell 5B, 10" Orifice (Original)	169	505
ST	BS14	5/5/2013	Bypass Channel	136	
ST	WS08	5/5/2013	Gatewell 5A, Broad-Crest Overflow Weir	170	
ST	OS14	5/5/2013	Gatewell 5B, 10" Orifice (Original)	169	475
ST	BS15	5/7/2013	Bypass Channel	78	
ST	ES07	5/7/2013	Gatewell 5A, 14" Orifice (Enlarged)	73	
ST	OS15	5/7/2013	Gatewell 5B, 10" Orifice (Original)	77	228
ST	BS16	5/8/2013	Bypass Channel	163	
ST	ES08	5/8/2013	Gatewell 5A, 14" Orifice (Enlarged)	163	
ST	OS16	5/8/2013	Gatewell 5B, 10" Orifice (Original)	170	496

Species	Release Code	Release Date	Location	Number Released	Daily total
ST	BS17	5/9/2013	Bypass Channel	177	
ST	WS09	5/9/2013	Gatewell 5A, Broad-Crest Overflow Weir	162	
ST	OS17	5/9/2013	Gatewell 5B, 10" Orifice (Original)	171	510
ST	BS18	5/10/2013	Bypass Channel	139	
ST	WS10	5/10/2013	Gatewell 5A, Broad-Crest Overflow Weir	128	
ST	OS18	5/10/2013	Gatewell 5B, 10" Orifice (Original)	135	402
ST	BS19	5/11/2013	Bypass Channel	141	
ST	ES09	5/11/2013	Gatewell 5A, 14" Orifice (Enlarged)	160	
ST	OS19	5/11/2013	Gatewell 5B, 10" Orifice (Original)	170	471
ST	BS20	5/12/2013	Bypass Channel	161	
ST	ES10	5/12/2013	Gatewell 5A, 14" Orifice (Enlarged)	162	
ST	OS20	5/12/2013	Gatewell 5B, 10" Orifice (Original)	171	494
ST	BS21	5/14/2013	Bypass Channel	84	
ST	WS11	5/14/2013	Gatewell 5A, Broad-Crest Overflow Weir	72	
ST	OS21	5/14/2013	Gatewell 5B, 10" Orifice (Original)	81	237
ST	BS22	5/15/2013	Bypass Channel	150	
ST	WS12	5/15/2013	Gatewell 5A, Broad-Crest Overflow Weir	160	
ST	OS22	5/15/2013	Gatewell 5B, 10" Orifice (Original)	170	480
ST	BS23	5/16/2013	Bypass Channel	157	
ST	ES11	5/16/2013	Gatewell 5A, 14" Orifice (Enlarged)	162	
ST	OS23	5/16/2013	Gatewell 5B, 10" Orifice (Original)	158	477
ST	BS24	5/17/2013	Bypass Channel	175	
ST	ES12	5/17/2013	Gatewell 5A, 14" Orifice (Enlarged)	162	
ST	OS24	5/17/2013	Gatewell 5B, 10" Orifice (Original)	174	511
ST	BS25	5/18/2013	Bypass Channel	138	
ST	WS13	5/18/2013	Gatewell 5A, Broad-Crest Overflow Weir	163	
ST	OS25	5/18/2013	Gatewell 5B, 10" Orifice (Original)	173	474
ST	BS26	5/19/2013	Bypass Channel	138	
ST	WS14	5/19/2013	Gatewell 5A, Broad-Crest Overflow Weir	164	
ST	OS26	5/19/2013	Gatewell 5B, 10" Orifice (Original)	173	475
ST	BS27	5/22/2013	Bypass Channel	30	
ST	ES13	5/22/2013	Gatewell 5A, 14" Orifice (Enlarged)	33	
ST	OS27	5/22/2013	Gatewell 5B, 10" Orifice (Original)	35	98
ST	BS28	5/23/2013	Bypass Channel	176	
ST	WS15	5/23/2013	Gatewell 5A, Broad-Crest Overflow Weir	163	
ST	OS28	5/23/2013	Gatewell 5B, 10" Orifice (Original)	172	511
ST	BS29	5/25/2013	Bypass Channel	157	
ST	ES14	5/25/2013	Gatewell 5A, 14" Orifice (Enlarged)	142	
ST	OS29	5/25/2013	Gatewell 5B, 10" Orifice (Original)	151	450

Table 23. Sub-yearling Chinook released by location, per day at Lower Granite Dam spring 2013.

Species	Release Code	Release Date	Location	Number Released	Daily total
SY	BY01	5/26/2013	Bypass Channel	55	
SY	EY01	5/26/2013	Gatewell 5A, 14" Orifice (Enlarged)	56	
SY	OY01	5/26/2013	Gatewell 5B, 10" Orifice (Original)	59	170
SY	BY03	5/29/2013	Bypass Channel	11	
SY	WY02	5/29/2013	Gatewell 5A, Broad-Crest Overflow Weir	18	
SY	OY03	5/29/2013	Gatewell 5B, 10" Orifice (Original)	16	45
SY	BY04	5/30/2013	Bypass Channel	167	
SY	EY02	5/30/2013	Gatewell 5A, 14" Orifice (Enlarged)	156	
SY	OY04	5/30/2013	Gatewell 5B, 10" Orifice (Original)	157	480
SY	BY05	5/31/2013	Bypass Channel	354	
SY	EY03	5/31/2013	Gatewell 5A, 14" Orifice (Enlarged)	365	
SY	OY05	5/31/2013	Gatewell 5B, 10" Orifice (Original)	365	1084
SY	BY06	6/1/2013	Bypass Channel	341	
SY	WY03	6/1/2013	Gatewell 5A, Broad-Crest Overflow Weir	399	
SY	OY06	6/1/2013	Gatewell 5B, 10" Orifice (Original)	398	1138
SY	BY07	6/2/2013	Bypass Channel	290	
SY	WY04	6/2/2013	Gatewell 5A, Broad-Crest Overflow Weir	331	
SY	OY07	6/2/2013	Gatewell 5B, 10" Orifice (Original)	334	955
SY	BY08	6/4/2013	Bypass Channel	65	
SY	EY04	6/4/2013	Gatewell 5A, 14" Orifice (Enlarged)	72	
SY	OY08	6/4/2013	Gatewell 5B, 10" Orifice (Original)	71	208
SY	BY09	6/5/2013	Bypass Channel	230	
SY	EY05	6/5/2013	Gatewell 5A, 14" Orifice (Enlarged)	233	
SY	OY09	6/5/2013	Gatewell 5B, 10" Orifice (Original)	233	696
SY	BY10	6/6/2013	Bypass Channel	220	
SY	WY05	6/6/2013	Gatewell 5A, Broad-Crest Overflow Weir	235	
SY	OY10	6/6/2013	Gatewell 5B, 10" Orifice (Original)	233	688
SY	BY11	6/7/2013	Bypass Channel	233	
SY	WY06	6/7/2013	Gatewell 5A, Broad-Crest Overflow Weir	237	
SY	OY11	6/7/2013	Gatewell 5B, 10" Orifice (Original)	237	707
SY	BY12	6/8/2013	Bypass Channel	241	
SY	EY06	6/8/2013	Gatewell 5A, 14" Orifice (Enlarged)	241	
SY	OY12	6/8/2013	Gatewell 5B, 10" Orifice (Original)	202	684
SY	BY13	6/9/2013	Bypass Channel	240	
SY	EY07	6/9/2013	Gatewell 5A, 14" Orifice (Enlarged)	240	
SY	OY13	6/9/2013	Gatewell 5B, 10" Orifice (Original)	240	720
SY	BY14	6/11/2013	Bypass Channel	230	
SY	WY07	6/11/2013	Gatewell 5A, Broad-Crest Overflow Weir	237	
SY	OY14	6/11/2013	Gatewell 5B, 10" Orifice (Original)	235	702
SY	BY15	6/12/2013	Bypass Channel	179	
SY	WY08	6/12/2013	Gatewell 5A, Broad-Crest Overflow Weir	182	
SY	OY15	6/12/2013	Gatewell 5B, 10" Orifice (Original)	182	543
SY	BY16	6/13/2013	Bypass Channel	193	
SY	EY08	6/13/2013	Gatewell 5A, 14" Orifice (Enlarged)	193	
SY	OY16	6/13/2013	Gatewell 5B, 10" Orifice (Original)	189	575
SY	BY17	6/14/2013	Bypass Channel	184	
SY	EY09	6/14/2013	Gatewell 5A, 14" Orifice (Enlarged)	196	

SY	OY17	6/14/2013	Gatewell 5B, 10" Orifice (Original)	197	577
SY	BY18	6/15/2013	Bypass Channel	142	
SY	WY09	6/15/2013	Gatewell 5A, Broad-Crest Overflow Weir	143	
SY	OY18	6/15/2013	Gatewell 5B, 10" Orifice (Original)	143	428
SY	BY19	6/16/2013	Bypass Channel	193	
SY	WY10	6/16/2013	Gatewell 5A, Broad-Crest Overflow Weir	191	
SY	OY19	6/16/2013	Gatewell 5B, 10" Orifice (Original)	193	577
SY	BY20	6/18/2013	Bypass Channel	32	
SY	EY10	6/18/2013	Gatewell 5A, 14" Orifice (Enlarged)	34	
SY	OY20	6/18/2013	Gatewell 5B, 10" Orifice (Original)	33	99
SY	BY21	6/19/2013	Bypass Channel	36	
SY	EY11	6/19/2013	Gatewell 5A, 14" Orifice (Enlarged)	35	
SY	OY21	6/19/2013	Gatewell 5B, 10" Orifice (Original)	35	106
SY	BY22	6/20/2013	Bypass Channel	55	
SY	WY11	6/20/2013	Gatewell 5A, Broad-Crest Overflow Weir	56	
SY	OY22	6/20/2013	Gatewell 5B, 10" Orifice (Original)	56	167
SY	BY23	6/21/2013	Bypass Channel	33	
SY	WY12	6/21/2013	Gatewell 5A, Broad-Crest Overflow Weir	33	
SY	OY23	6/21/2013	Gatewell 5B, 10" Orifice (Original)	33	99

Table 24. Night release sub-yearling Chinook released by location, per day at Lower Granite Dam, spring 2013.

Species	Release Code	Release Date	Location	Number Released	Daily total
SYN	BN01	6/2/2013	Bypass Channel (Night)	207	207
SYN	WN01	6/6/2013	Gatewell 5A, Broad-Crest Overflow Weir (Night)	162	162
SYN	WN02	6/12/2013	Gatewell 5A, Broad-Crest Overflow Weir (Night)	150	150
SYN	WN03	6/15/2013	Gatewell 5A, Broad-Crest Overflow Weir (Night)	150	150

Table 25. Lampreys released by location, per day at Lower Granite Dam spring 2013.

Species	Release Code	Release Date	Location	Number Released	Daily total
LY	BL01	5/20/2013	Bypass Channel	96	
LY	WL01	5/20/2013	Gatewell 5A, Broad-Crest Overflow Weir	97	193
LY	EL01	5/22/2013	Gatewell 5A, 14" Orifice (Enlarged)	54	54
LY	BL02	5/24/2013	Bypass Channel	52	
LY	OL01	5/24/2013	Gatewell 5B, 10" Orifice (Original)	60	112
LY	EL02	5/27/2013	Gatewell 5A, 14" Orifice (Enlarged)	210	
LY	OL02	5/27/2013	Gatewell 5B, 10" Orifice (Original)	198	408
LY	BL03	5/28/2013	Bypass Channel	64	64
LY	WL02	5/29/2013	Gatewell 5A, Broad-Crest Overflow Weir	164	164
LY	BL04	5/30/2013	Bypass Channel	55	
LY	EL03	5/30/2013	Gatewell 5A, 14" Orifice (Enlarged)	69	124
LY	EL04	5/31/2013	Gatewell 5A, 14" Orifice (Enlarged)	80	
LY	OL03	5/31/2013	Gatewell 5B, 10" Orifice (Original)	34	114
LY	BL05	6/3/2013	Bypass Channel	24	24

Appendix B: Physical Condition Selection Criteria

While the great majority of fish included in the 2013 LGR JBS evaluation conformed to the criteria described below, some fish of lesser physical condition were included when the supply of fish that met criteria was low. In those incidences, the value of including fish that would have otherwise been excluded was increasing the sample size and improving statistical power.

Table 26. Physical condition criteria for selecting juvenile steelheads, yearling Chinook, and sub-yearling Chinook for inclusion in the enlarged orifice and overflow weir biological evaluation at Lower Granite Dam, spring 2013. Physical condition criteria adapted from Hostetter and Evans 2012.

		Residence-Time Analysis		Condition Assessment	
		Accept	Reject	Accept	Reject
Descaling	Loss of scales <5% of body	x		x	
	Loss of scales 5–20% of body	x			x
	Loss of scales 21–50% of body		x		x
	Loss of scales >50% of body		x		x
Bird Marks	No marks associated with a bird beak	x		x	
	Descaling or healed scars, due to bird beaks, covering <20% of the body	x			x
	Visible descaling or healed scars covering >20% of the body, or open wounds or hemorrhaging due to bird beaks		x		x
Fish Marks	No marks from fish bites present	x		x	
	Visible descaling or healed scars, due to fish bites, covering <20% of the body	x			x
	Visible descaling or healed scars covering >20% of the STHD, or open wounds or hemorrhaging due to fish bites		x		x
Operculum Injury	Operculum has no visible damage	x		x	
	Physical damage to operculum, but operculum still completely covers lamellae	x			x
	Physical damage to operculum; operculum does not completely cover lamellae		x		x
Head Injury	No visible physical damage to the head	x		x	
	Visible surface injury covering <10% of head; no internal or external hemorrhage associated with the injury	x		x	
	Visible surface injury covering >10% of head, any injury with internal or external hemorrhage; or if any bones are broken or dislocated (i.e., lower jaw)		x		x
	Visible hemorrhaging, bubbles, infection, or other trauma in <25% of the eye		x		x
	Visible hemorrhaging, bubbles, pop-eye, infection, or other trauma to >25% of the eye		x		x

			Residence-Time Analysis		Condition Assessment	
			Accept	Reject	Accept	Reject
Trunk injury	No visible signs of hemorrhaging, scarring, or other trunk injuries		x		x	
	Visible closed or healed marks/scars on <20% of the trunk		x		x	
	Visible closed or healed marks revealing hemorrhaging on >20% of the trunk, or any open wounds.			x		x
Spine	Backbone visually appears to be normal		x		x	
	Backbone visually appears to have a deformity or injury			x		x
Tagging injury	PIT-tag scar was not bleeding		x		x	
	PIT-tag scar was bleeding			x		x
Origin	Adipose fin clipped (clipped)	Hatchery	x		x	
	Adipose fin unclipped; fins not eroded (unclipped)	Wild		x		x
	Adipose fin unclipped; fins eroded (unknown)	Hatchery		x		x

Appendix C: Juvenile Lamprey Collection Locations

Juvenile lamprey collection locations at Lower Monumental, Little Goose, and Lower Granite dams in spring 2013.

Lower Monumental Dam

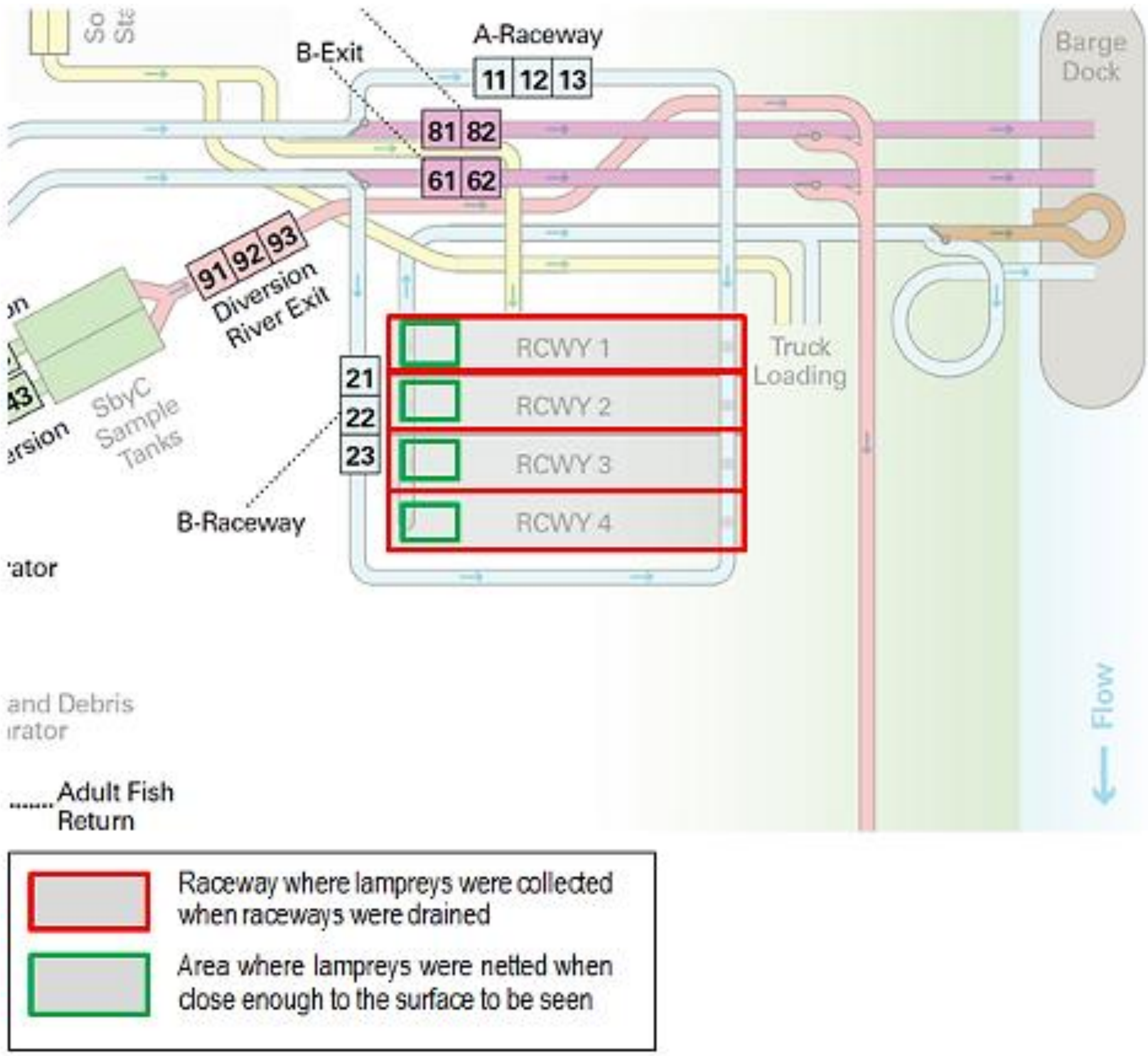


Figure 28. Lamprey collection location at Lower Monumental Dam, spring 2013

Little Goose Dam

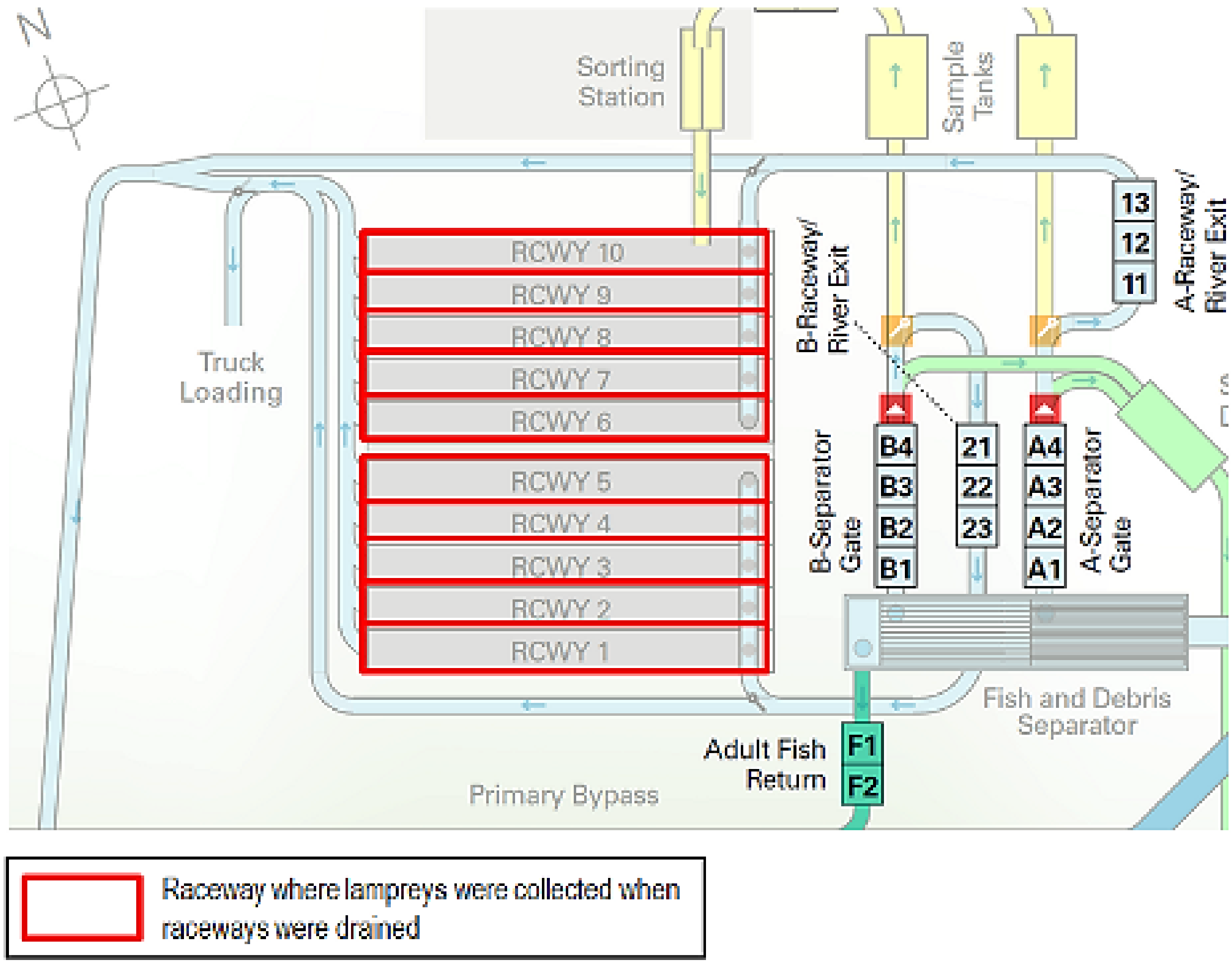


Figure 29. Lamprey collection location at Little Goose Dam, spring 2013.

Lower Granite Dam

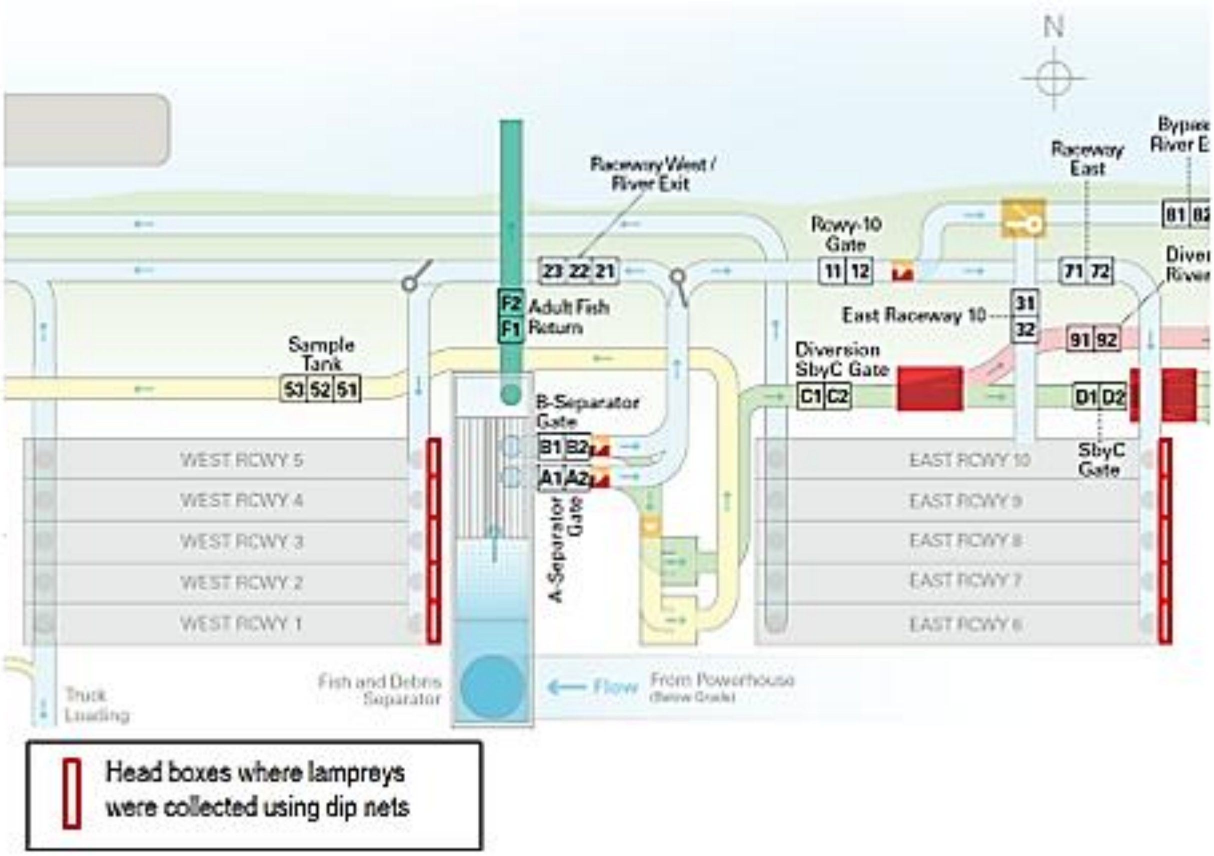


Figure 30. Lamprey collection location at Lower Granite Dam, spring 2013.

Appendix D: Contrasts between passage treatments in travel times through the juvenile bypass system for daytime releases of yearling and sub-yearling Chinook salmon and juvenile steelheads at Lower Granite Dam, spring 2013

The inferential question of interest is: Does the mean (over the season) travel time of juveniles differ between prototype passage types? The data present a number of challenges: 1) Travel time is not normally distributed. 2) Travel-time distributions vary with time of season. 3) Travel-time distributions differ among passage types. 4) Juveniles do not arrive at the dam at a constant rate over the season. We use a bootstrap approach to construct a test that is valid under all of these problems. All contrasts are within fish species.

As pointed out by Hall and Wilson (1991) the power of a bootstrap test is maximized if the bootstrap distribution is constructed under a true null. The most straightforward way to accomplish this is to create bootstrap confidence intervals around the observed test statistic and see if they overlap the null hypothesis of 0 (no difference). Hypothesis tests and confidence intervals are deeply related (Casella and Berger 1990, Efron and Tibshirani 1993, Davison et al. 2003), and either can be inverted to construct the other.

The test statistic used was the difference of the mean travel times over the season for the two treatments being contrasted. Because of the heterogeneous distributions involved, bootstrapping was stratified by release date and passage type (Efron and Tibshirani 1993, e.g. section 8.3; Davison and Hinkley 1997, e.g. section 3.2; Davison et al. 2003). For each bootstrap contrast replicate, data sets were constructed for the two passage types by joining random samples from each release date's travel times. The samples were of size equal to the original number of released fish for each date, and were drawn with replacement. This algorithm properly accounts for changes over the season of the mean and distribution of travel times.

We used 2000 replicate data sets to estimate the distribution of each contrast. The test pairs for the bootstrapping analysis were 10-inch orifice versus 14-inch orifice, 10-inch orifice versus prototype overflow weir, and 14-inch orifice versus prototype overflow weir for each species/age class. We tested contrast for yearling and sub-yearling Chinook salmon and juvenile steelheads released during the day. Travel times greater than 24 hours were truncated to 24 hours for the analysis to accommodate the operation schedule for each passage route in Gatewells 5A and 5B. Significant differences between test pairs were determined by two-tailed contrast quantiles. If the interval between the $\alpha/2$ quantile and the $1 - \alpha/2$ quantile did not contain 0, the hypothesis test of no difference between the groups was rejected at the α significance level. All test pairs were significantly different at at least the 1% level (Table 27). The values of all quantile intervals represent the difference in mean travel times in hours for the 2000 replicate bootstrap resamples.

Tables 27–35 present bootstrap test outputs for test pairs of juvenile salmonids released into Gatewells 5A and 5B at Lower Granite Dam in spring 2013. Abbreviations for each treatment are defined with a treatment code and species code.

Treatment codes are defined as:

- E = Enlarged 14-inch diameter orifice
- O = Original 10-inch diameter orifice, and
- W = Broad-crested overflow weir.

Species codes are defined as:

- C = Yearling Chinook salmon
- S = Juvenile steelhead, and
- Y = Sub-yearling Chinook salmon

Thus, "EC," for example, indicates "Enlarged 14-inch diameter orifice, yearling Chinook salmon."

Table 27. Summary of contrast of Release Type EC against Release Type OC on variable RT_h.

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–1.676038	–1.661011	–1.641669	–1.623015	–1.531212	–1.444899	–1.431630	–1.411399	–1.400560

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for EC = 1.146173 . Mean RT_h for OC = 2.676765
Contrast = –1.530592 .Contrast quantiles for EC > OC

Table 28. Summary of contrast of Release Type EC against Release Type WC on variable RT_h.

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–2.658517	–2.641236	–2.598207	–2.573605	–2.429172	–2.287484	–2.258169	–2.222658	–2.208406

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for EC = 1.146173 . Mean RT_h for WC = 3.574797
Contrast = –2.428624. Contrast quantiles for EC > WC

Table 29. Summary of contrast of Release Type OC against Release Type WC on variable RT_h.

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–1.1431155	–1.1131897	–1.0822700	–1.0506480	–0.8951275	–0.7405435	–0.7102321	–0.6771124	–0.6510169

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for OC = 2.676765 . Mean RT_h for WC = 3.574797
Contrast = –0.8980328. Contrast quantiles for OC > WC

Table 30. Summary of contrast of Release Type ES against Release Type OS on variable RT_h.

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–1.2585858	–1.2395085	–1.1934886	–1.1502279	–0.9601783	–0.7805050	–0.7445456	–0.7039197	–0.6665314

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for ES = 3.285595 . Mean RT_h for OS = 4.246464
Contrast = –0.9608688 . Contrast quantiles for ES > OS

Table 31. Summary of contrast of Release Type ES against Release Type WS on variable RT_h.

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–2.738235	–2.693376	–2.621062	–2.582570	–2.354681	–2.134600	–2.095574	–2.036877	–2.014105

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for ES = 3.285595 . Mean RT_h for WS = 5.646238
Contrast = –2.360643. Contrast quantiles for ES > WS

Table 32. Summary of contrast of Release Type OS against Release Type WS on variable RT_h.

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–1.755843	–1.713569	–1.661702	–1.621502	–1.396317	–1.185377	–1.153227	–1.105287	–1.083659

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for OS = 4.246464 . Mean RT_h for WS = 5.646238
Contrast = –1.399774 . Contrast quantiles for OS > WS

Table 33. Summary of contrast of Release Type EY against Release Type OY on variable RT_h .

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–1.0883523	–1.0775352	–1.0613769	–1.0493235	–0.9879333	–0.9225277	–0.9129308	–0.8968525	–0.8843678

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for EY = 1.205239 . Mean RT_h for OY = 2.192403.
Contrast = –0.9871641. Contrast quantiles for EY > OY

Table 34. Summary of contrast of Release Type EY against Release Type WY on variable RT_h

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–1.695052	–1.685985	–1.669534	–1.650028	–1.558858	–1.468678	–1.450114	–1.432687	–1.418615

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for EY = 1.205239 . Mean RT_h for WY = 2.765308.
Contrast = –1.560069 .Contrast quantiles for EY > WY

Table 35. Summary of contrast of Release Type OY against Release Type WY on variable RT_h

0.5%	1%	2.5%	5%	50%	95%	97.5%	99%	99.5%
–0.7241944	–0.7051628	–0.6848498	–0.6656619	–0.5715667	–0.4810600	–0.4619320	–0.4442174	–0.4262854

Inference based on a stratified bootstrap of 2000 replicates.
RT_h truncated at 24 hrs. Mean RT_h for OY = 2.192403 . Mean RT_h for WY = 2.765308.
Contrast = –0.5729045. Contrast quantiles for OY > WY

References

Davison, A. C. and D. V. Hinkley. 1997. *Bootstrap Methods and their Application*. Cambridge University Press, Cambridge, UK.

Davison, A. C., D. V. Hinkley, and G. A. Young. 2003. Recent developments in bootstrap methodology. *Statistical Science* 18:141–157.

Efron, B. and R. Tibshirani. 1993. *An Introduction to the Bootstrap*. Chapman and Hall, London, UK.

Hall, P. and S. R. Wilson. 1991. 2 Guidelines for Bootstrap Hypothesis-Testing. *Biometrics* 47:757–762.

R code to perform passage type contrasts:

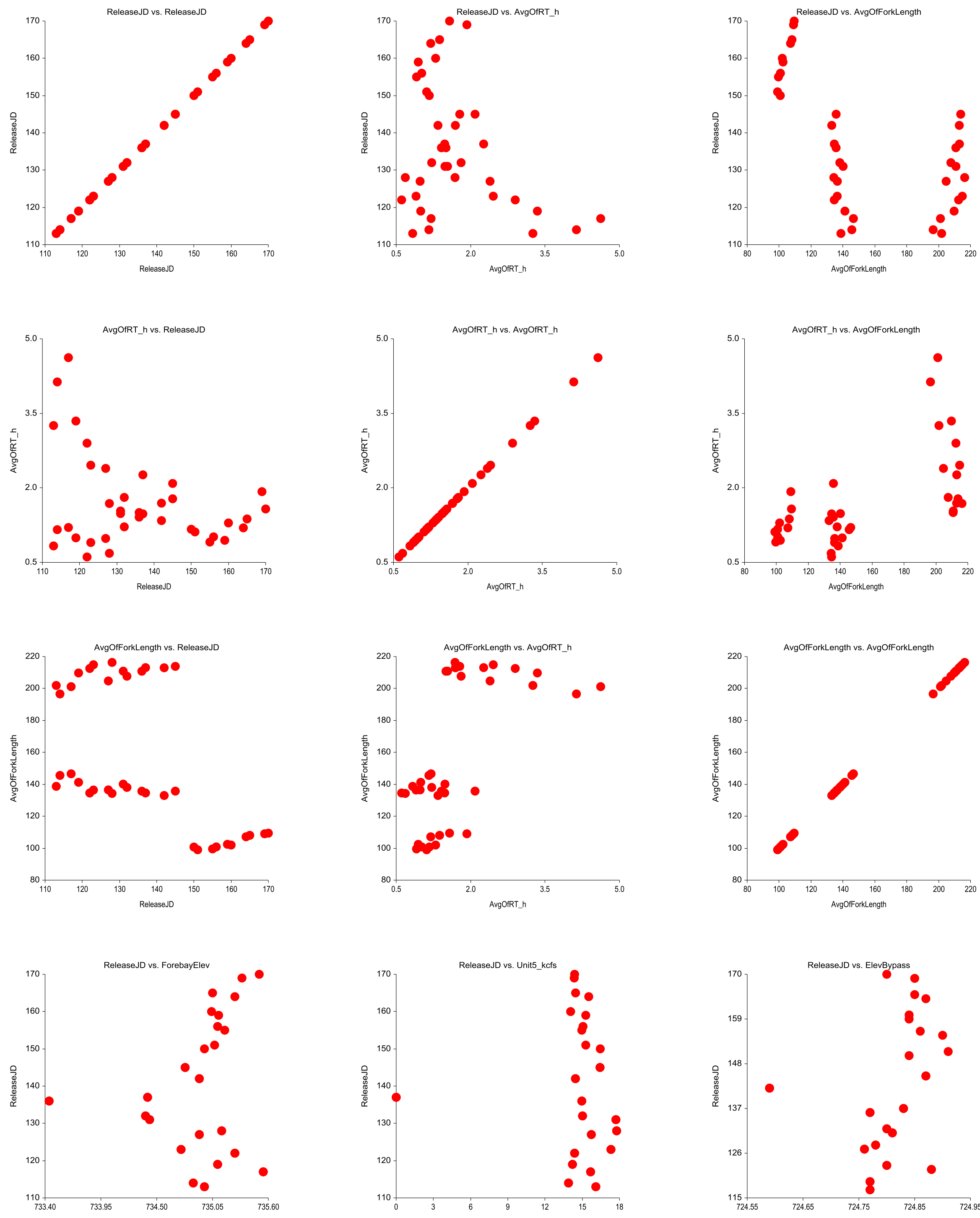
```
# Mark L. Taper: Environmental & Ecological Analysis, MarkLTaper@gmail.com
(406) 451-9542

loadlib=function(){
 library(boot)
 library(plyr)
}

loadlib()

passageT=read.csv(file="LGR_TravelTime_AllSpecies_BeforeAfterRecords_030714.c
sv")
passT.trunc24h=passageT
passT.trunc24h$RT_h=ifelse(passageT$RT_h<24,passageT$RT_h,24)
passT.trunc24h$RT_m=passT.trunc24h$RT_h*60

BtMnCon=function(df,Rel.type1,Rel.type2,v2c,R=2000){
  df1=df[df$ReleaseSite==Rel.type1,]
  df2=df[df$ReleaseSite==Rel.type2,]
  mn1=rep(NA,R)
  mn2=rep(NA,R)
  con=rep(NA,R)
  mn1[1]=mean(df1[,v2c]) #first element is the observed mean Rel.type1
  mn2[1]=mean(df2[,v2c]) #first element is the observed mean Rel.type2
  uniqR1=unique(df1$Release) #list of release events for Rel.type1
  uniqR2=unique(df2$Release) #list of release events for Rel.type1
  for (b in 2:R){
    T1=NULL
    T2=NULL
    for (r in uniqR1){
      idx=which(df1$Release==r)
      rss=length(idx)
      T1=c(T1,df1[sample(x=idx,size=rss,replace=TRUE),v2c])
    }
    mn1[b]=mean(T1)
    for (r in uniqR2){
      idx=which(df2$Release==r)
      rss=length(idx)
      T2=c(T2,df2[sample(x=idx,size=rss,replace=TRUE),v2c])
    }
      mn2[b]=mean(T2)
  }
    con=mn1-mn2

out=list(mn1=mn1,mn2=mn2,con=con,Rel.type1=Rel.type1,Rel.type2=Rel.type2,v2c=
v2c,R=R)
  class(out)="BtMnCon"
  return(out)
}

summary.BtMnCon=function(bmc.out,probs=c(.005,.01,.025,.05,.5,.95,.975,.99,.9
95)){
  cat("\nSummary of contrast of Release Type=",bmc.out$Rel.type1,"against
Release Type",bmc.out$Rel.type2,"on variable",bmc.out$v2c,".\nInference based
on a stratified bootstrap of",bmc.out$R,"replicates.\n")
  cat("Mean",bmc.out$v2c,"for",bmc.out$Rel.type1,"=",bmc.out$mn1[1],".
Mean",bmc.out$v2c,"for",bmc.out$Rel.type1,"=",bmc.out$mn2[1],".
Contrast=",bmc.out$con[1],".\n")
  cat("Contrast quantiles for",bmc.out$Rel.type1,">",bmc.out$Rel.type2,"\n")
  print(quantile(bmc.out$con,probs))
  cat("\n")
}
```

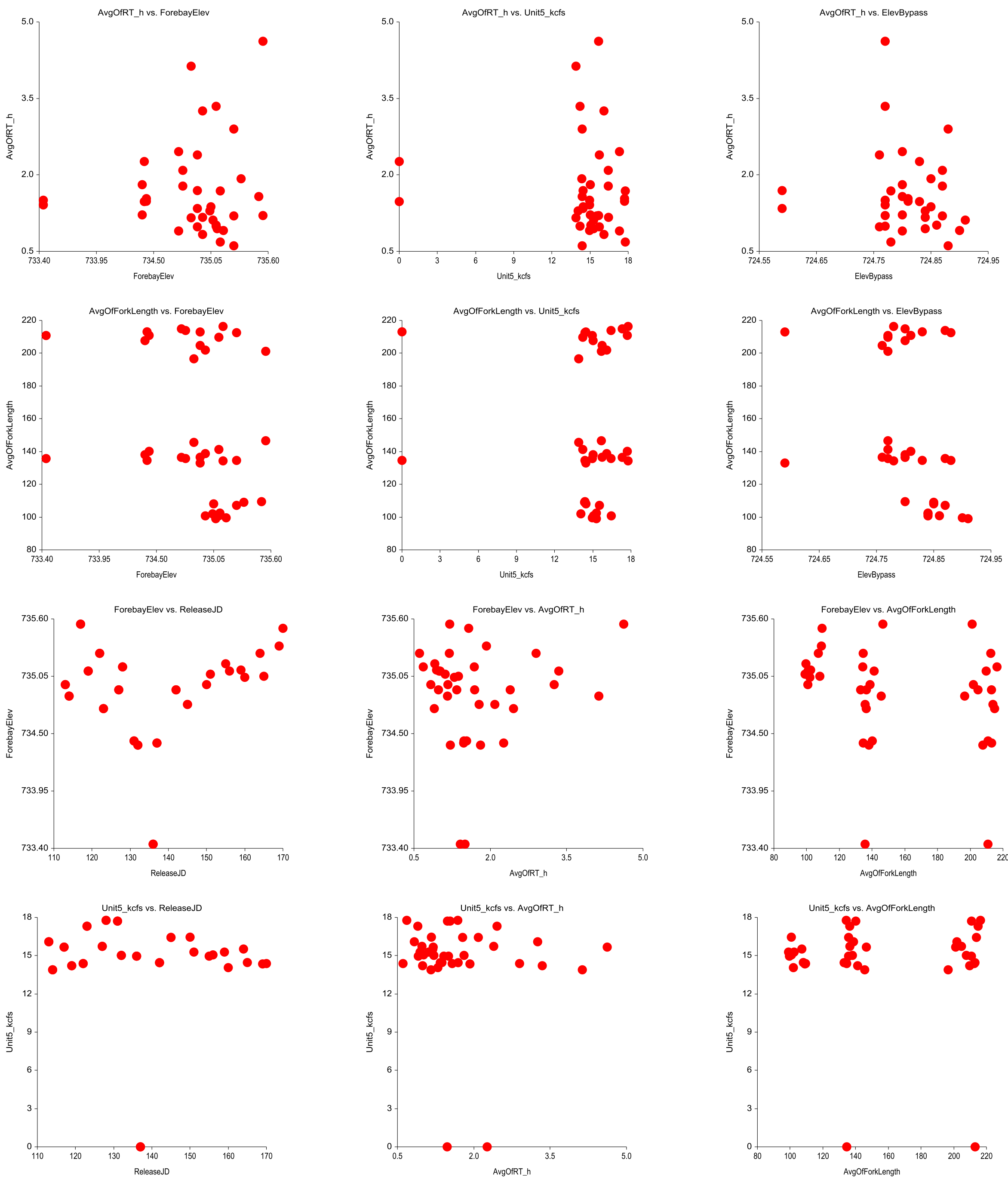
```
summarytrunc=function(bmc.out,probs=c(.005,.01,.025,.05,.5,.95,.975,.99,.995)
){
  cat("\nSummary of contrast of Release Type=",bmc.out$Rel.type1,"against
Release Type",bmc.out$Rel.type2,"on variable",bmc.out$v2c,".\nInference based
on a stratified bootstrap of",bmc.out$R,"replicates. RT_h truncated at
24hrs\n")
  cat("Mean",bmc.out$v2c,"for",bmc.out$Rel.type1,"=",bmc.out$mn1[1],".
Mean",bmc.out$v2c,"for",bmc.out$Rel.type1,"=",bmc.out$mn2[1],".
Contrast=",bmc.out$con[1],".\n")
  cat("Contrast quantiles for",bmc.out$Rel.type1,">",bmc.out$Rel.type2,"\n")
  print(quantile(bmc.out$con,probs))
  cat("\n")
}

RT1=c("EC","EC","OC","ES","ES","OS","EY","EY","OY")
RT2=c("OC","WC","WC","OS","WS","WS","OY","WY","WY")
V2C=c("RT_h","RT_m")

R.con.lst=list()
i=0
for (v in V2C){
  for (c in 1:9){
    i=i+1

R.con.lst[[i]]=BtMnCon(df=passageT,Rel.type1=RT1[c],Rel.type2=RT2[c],v2c=v,R=
2000)
  }
}

l_ply(R.con.lst,.fun=summary)

sink(file="Release.Contrasts.txt")
l_ply(R.con.lst,.fun=summary)
sink()

R.trunc.con.lst=list()
i=0
for (v in V2C){
  for (c in 1:9){
    i=i+1

R.trunc.con.lst[[i]]=BtMnCon(df=passT.trunc24h,Rel.type1=RT1[c],Rel.type2=RT2
[c],v2c=v,R=2000)
  }
}

l_ply(R.trunc.con.lst,.fun=summarytrunc)

sink(file="Release.Contrasts.trunc24.txt")
l_ply(R.trunc.con.lst,.fun=summarytrunc)
sink()
```

Appendix E: Scatterplot Matrices for Variables Considered in Covariate Analysis

Scatterplots were used to visually determine relationships between pairs of variables, including Julian date of release, mean of travel time from release to the JFF, mean fork length, forebay elevation, flow through Turbine Unit 5, and water elevation within the bypass channel.

Table 36. Scatterplot matrix for yearling Chinook salmon, steelheads, and sub-yearling Chinook salmon released during operation of the 14-inch diameter orifice.





AvgOfRT_h vs. ForebayElev
AvgOfRT_h
ForebayElev
AvgOfRT_h vs. Unit5_kcfs
AvgOfRT_h
Unit5_kcfs
AvgOfRT_h vs. ElevBypass
AvgOfRT_h
ElevBypass
AvgOfForkLength vs. ForebayElev
AvgOfForkLength
ForebayElev
AvgOfForkLength vs. Unit5_kcfs
AvgOfForkLength
Unit5_kcfs
AvgOfForkLength vs. ElevBypass
AvgOfForkLength
ElevBypass
ForebayElev vs. ReleaseJD
ForebayElev
ReleaseJD
ForebayElev vs. AvgOfRT_h
ForebayElev
AvgOfRT_h
ForebayElev vs. AvgOfForkLength
ForebayElev
AvgOfForkLength
Unit5_kcfs vs. ReleaseJD
Unit5_kcfs
ReleaseJD
Unit5_kcfs vs. AvgOfRT_h
Unit5_kcfs
AvgOfRT_h
Unit5_kcfs vs. AvgOfForkLength
Unit5_kcfs
AvgOfForkLength

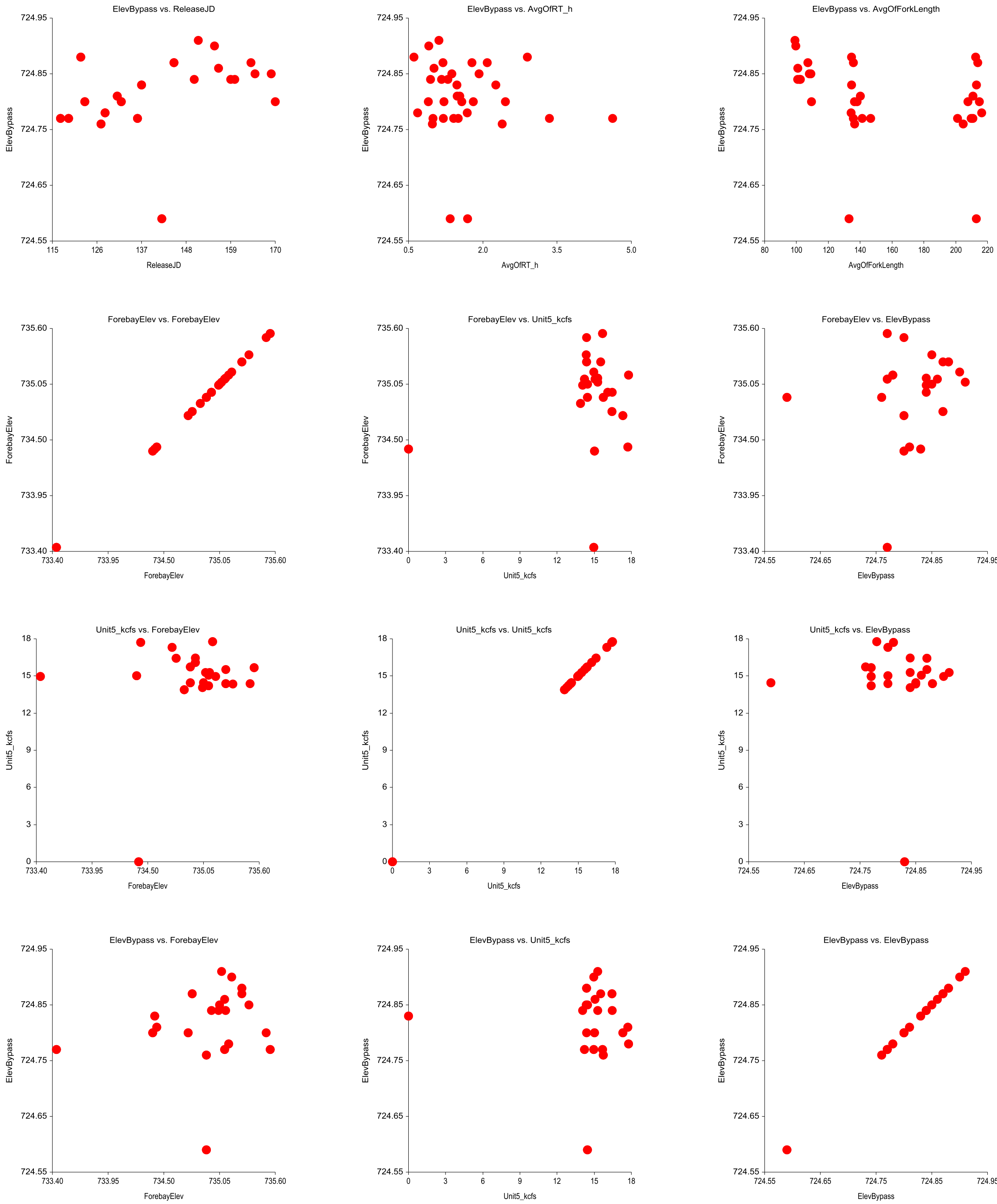
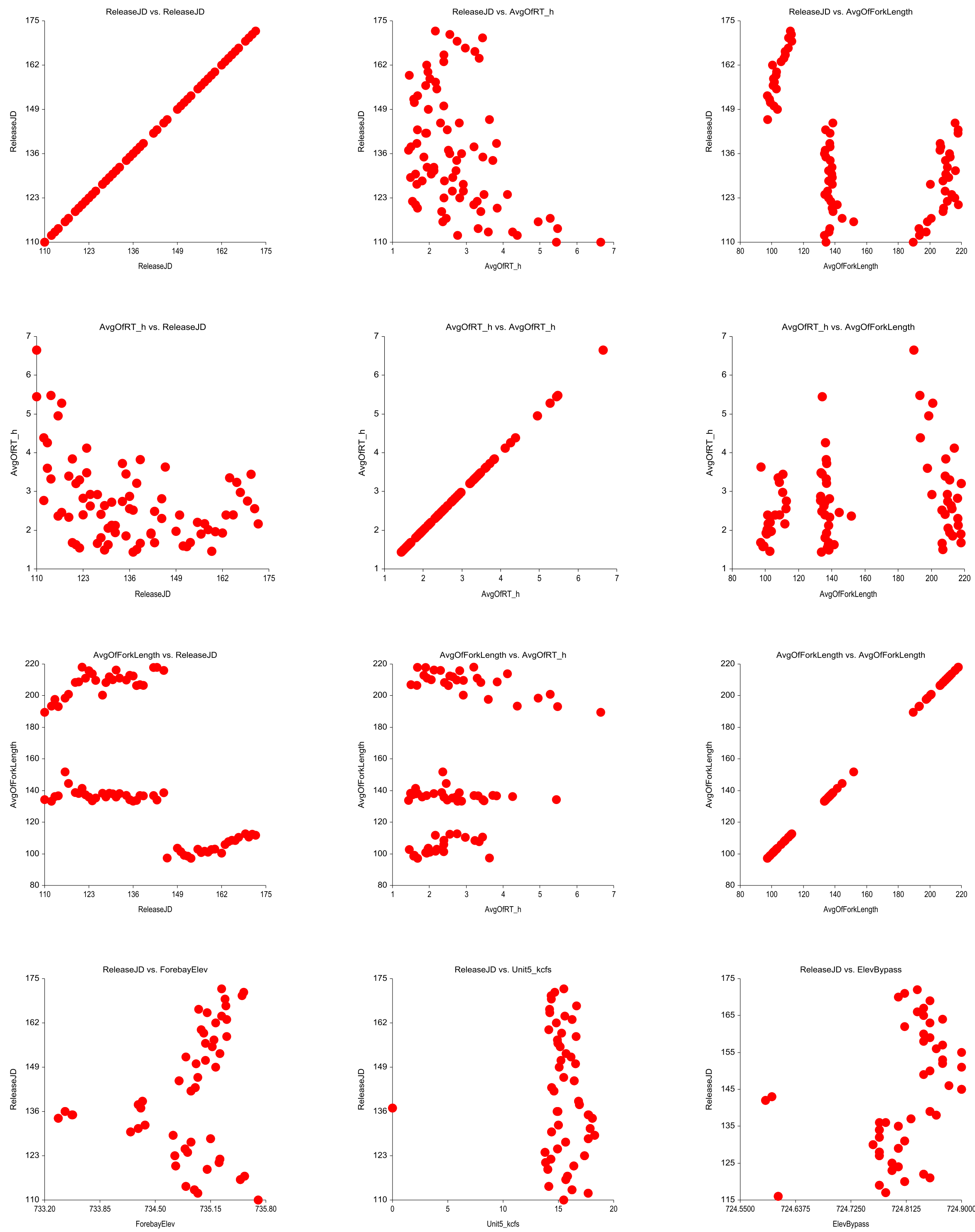
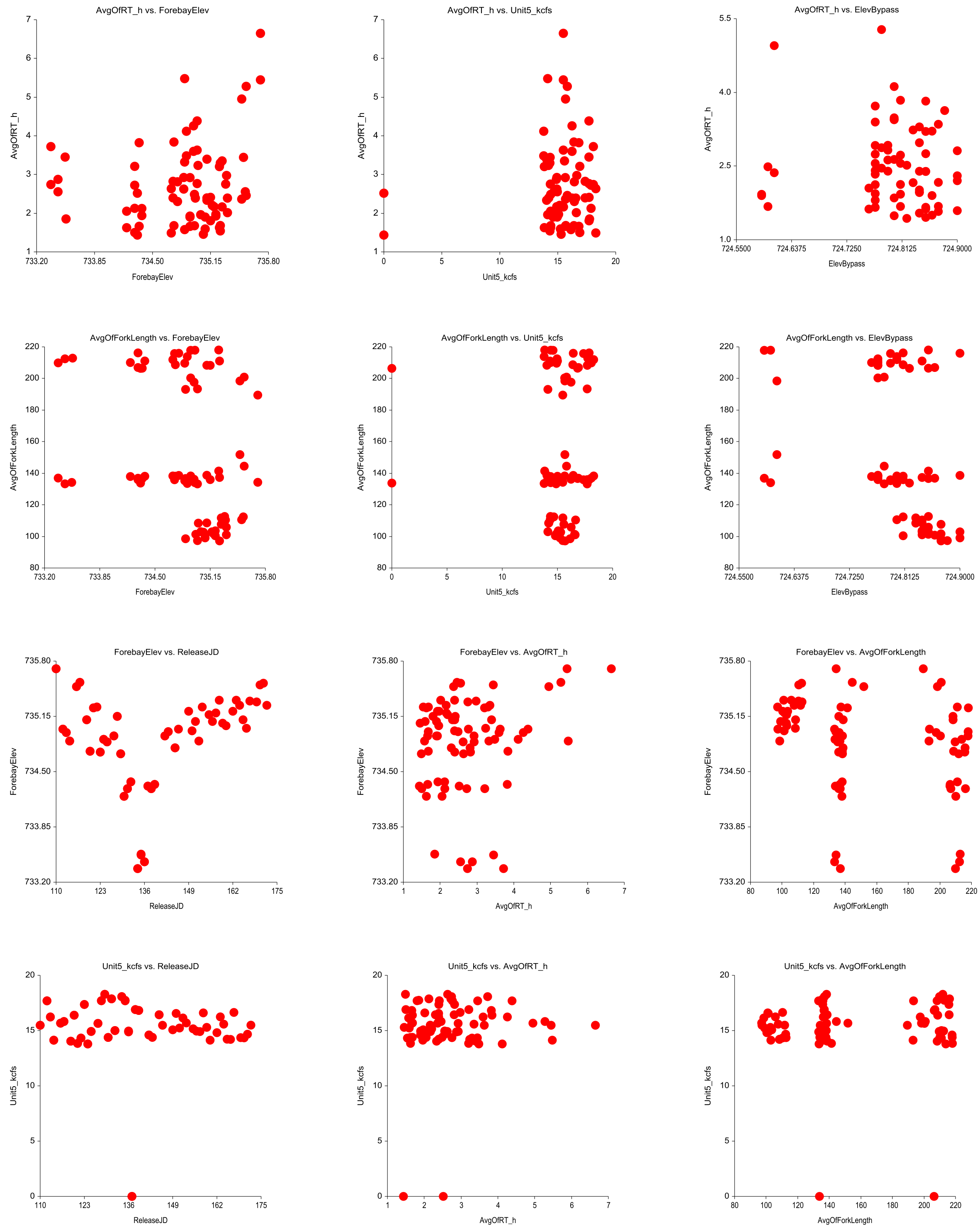

ElevBypass vs. ReleaseJD
ElevBypass
724.95
724.85
724.75
724.65
724.55
115
126
137
148
159
170
ReleaseJD
ElevBypass vs. AvgOfRT_h
0.5
2.0
3.5
5.0
AvgOfRT_h
ElevBypass vs. AvgOfForkLength
80
100
120
140
160
180
200
220
AvgOfForkLength
ForebayElev vs. ForebayElev
ForebayElev
735.60
735.05
734.50
733.95
733.40
ForebayElev vs. Unit5_kcfs
Unit5_kcfs
ForebayElev vs. ElevBypass
Unit5_kcfs vs. ForebayElev
18
15
12
9
6
3
0
Unit5_kcfs vs. Unit5_kcfs
Unit5_kcfs vs. ElevBypass
ElevBypass vs. ForebayElev
ElevBypass vs. Unit5_kcfs
ElevBypass vs. ElevBypass

Table 37. Scatterplot matrix for yearling Chinook salmon, steelheads, and sub-yearling Chinook salmon released during operation of the 10-inch diameter orifice.




AvgOfRT_h vs. ForebayElev
AvgOfRT_h
ForebayElev
AvgOfRT_h vs. Unit5_kcfs
AvgOfRT_h
Unit5_kcfs
AvgOfRT_h vs. ElevBypass
AvgOfRT_h
ElevBypass
AvgOfForkLength vs. ForebayElev
AvgOfForkLength
ForebayElev
AvgOfForkLength vs. Unit5_kcfs
AvgOfForkLength
Unit5_kcfs
AvgOfForkLength vs. ElevBypass
AvgOfForkLength
ElevBypass
ForebayElev vs. ReleaseJD
ForebayElev
ReleaseJD
ForebayElev vs. AvgOfRT_h
ForebayElev
AvgOfRT_h
ForebayElev vs. AvgOfForkLength
ForebayElev
AvgOfForkLength
Unit5_kcfs vs. ReleaseJD
Unit5_kcfs
ReleaseJD
Unit5_kcfs vs. AvgOfRT_h
Unit5_kcfs
AvgOfRT_h
Unit5_kcfs vs. AvgOfForkLength
Unit5_kcfs
AvgOfForkLength

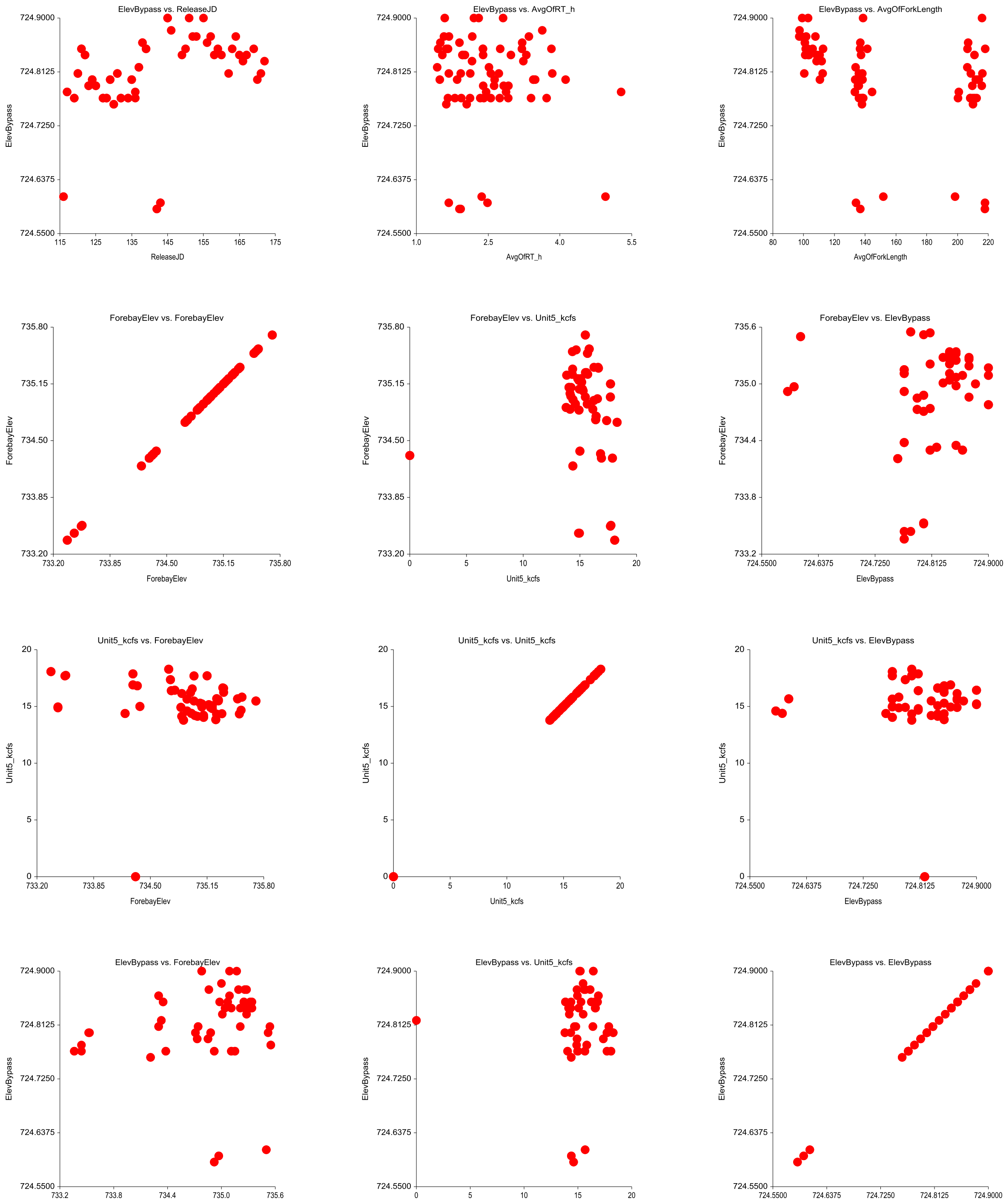
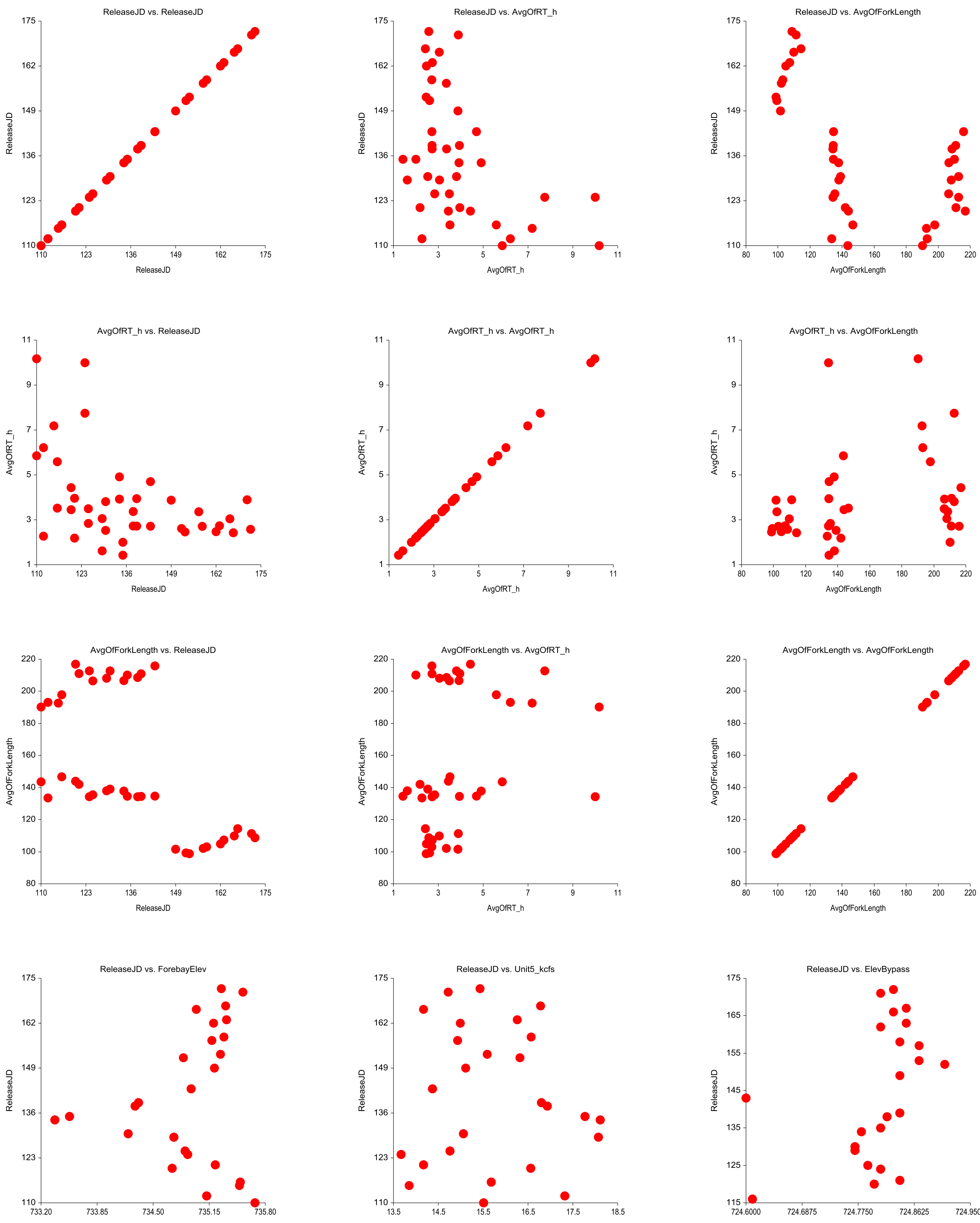
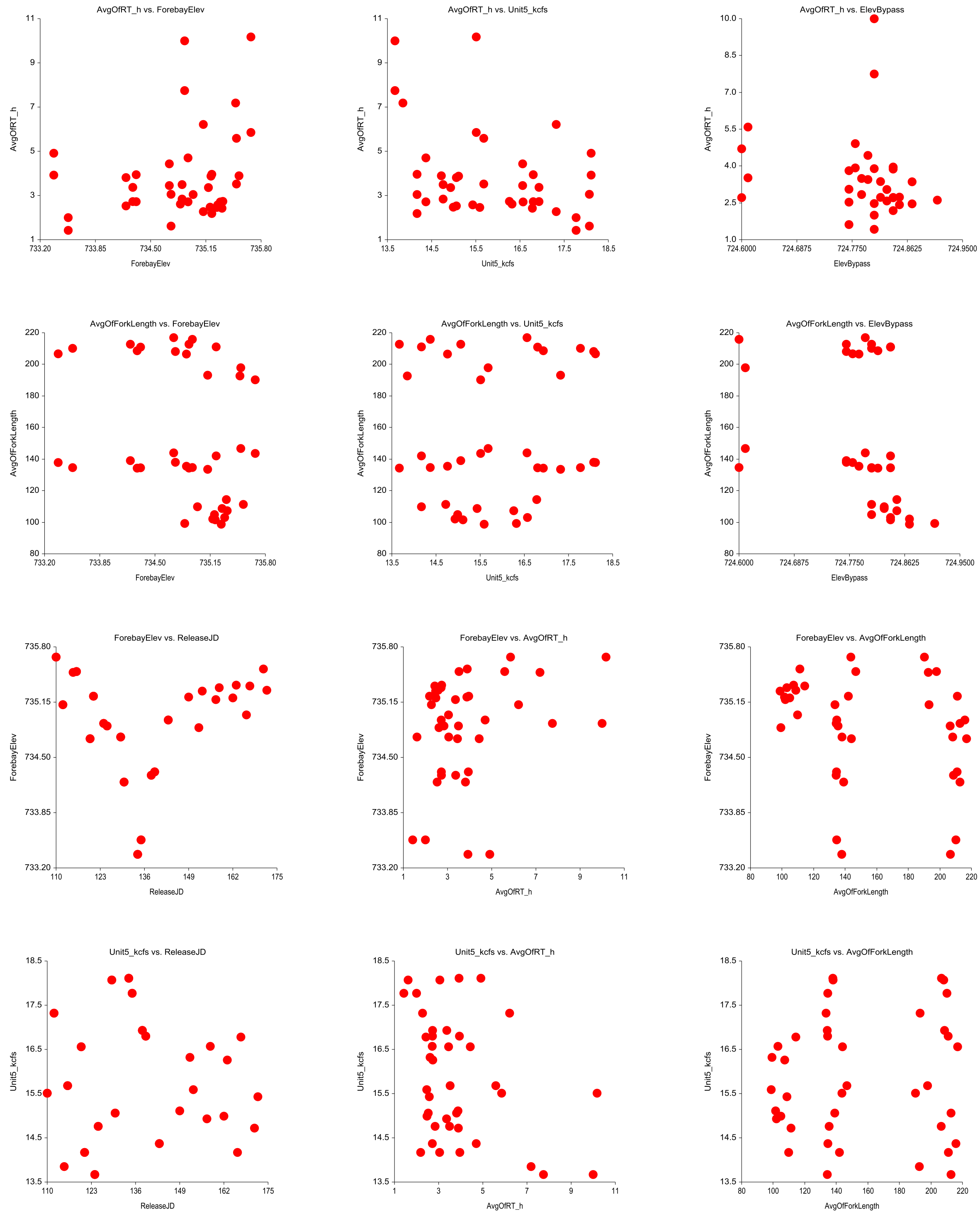
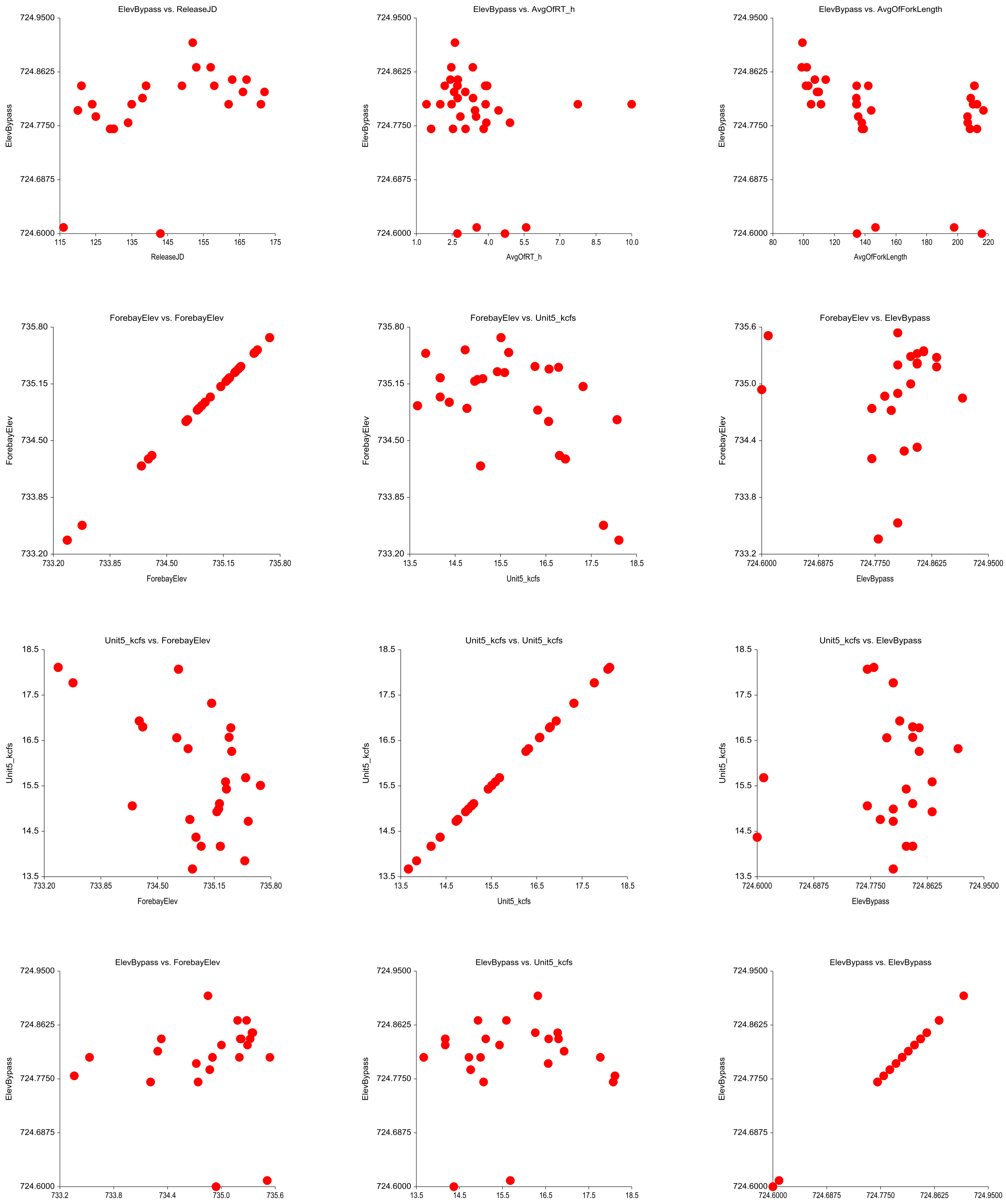

ElevBypass vs. ReleaseJD
ElevBypass
ReleaseJD
ElevBypass vs. AvgOfRT_h
ElevBypass
AvgOfRT_h
ElevBypass vs. AvgOfForkLength
ElevBypass
AvgOfForkLength
ForebayElev vs. ForebayElev
ForebayElev
ForebayElev
ForebayElev vs. Unit5_kcfs
ForebayElev
Unit5_kcfs
ForebayElev vs. ElevBypass
ForebayElev
ElevBypass
Unit5_kcfs vs. ForebayElev
Unit5_kcfs
ForebayElev
Unit5_kcfs vs. Unit5_kcfs
Unit5_kcfs
Unit5_kcfs
Unit5_kcfs vs. ElevBypass
Unit5_kcfs
ElevBypass
ElevBypass vs. ForebayElev
ElevBypass
ForebayElev
ElevBypass vs. Unit5_kcfs
ElevBypass
Unit5_kcfs
ElevBypass vs. ElevBypass
ElevBypass
ElevBypass

Table 38. Scatterplot matrix for yearling Chinook salmon, steelheads, and sub-yearling Chinook salmon released during operation of the broad-crested overflow weir.




AvgOfRT_h vs. ForebayElev
AvgOfRT_h
ForebayElev
AvgOfRT_h vs. Unit5_kcfs
AvgOfRT_h
Unit5_kcfs
AvgOfRT_h vs. ElevBypass
AvgOfRT_h
ElevBypass
AvgOfForkLength vs. ForebayElev
AvgOfForkLength
ForebayElev
AvgOfForkLength vs. Unit5_kcfs
AvgOfForkLength
Unit5_kcfs
AvgOfForkLength vs. ElevBypass
AvgOfForkLength
ElevBypass
ForebayElev vs. ReleaseJD
ForebayElev
ReleaseJD
ForebayElev vs. AvgOfRT_h
ForebayElev
AvgOfRT_h
ForebayElev vs. AvgOfForkLength
ForebayElev
AvgOfForkLength
Unit5_kcfs vs. ReleaseJD
Unit5_kcfs
ReleaseJD
Unit5_kcfs vs. AvgOfRT_h
Unit5_kcfs
AvgOfRT_h
Unit5_kcfs vs. AvgOfForkLength
Unit5_kcfs
AvgOfForkLength


ElevBypass vs. ReleaseJD
ElevBypass
724.9500
724.8625
724.7750
724.6875
724.6000
115 125 135 145 155 165 175
ReleaseJD
ElevBypass vs. AvgOfRT_h
1.0 2.5 4.0 5.5 7.0 8.5 10.0
AvgOfRT_h
ElevBypass vs. AvgOfForkLength
80 100 120 140 160 180 200 220
AvgOfForkLength
ForebayElev vs. ForebayElev
ForebayElev
735.80
735.15
734.50
733.85
733.20
ForebayElev vs. Unit5_kcfs
13.5 14.5 15.5 16.5 17.5 18.5
Unit5_kcfs
ForebayElev vs. ElevBypass
735.6
735.0
734.4
733.8
733.2
724.6000 724.6875 724.7750 724.8625 724.9500
ElevBypass
Unit5_kcfs vs. ForebayElev
Unit5_kcfs
18.5
17.5
16.5
15.5
14.5
13.5
733.20 733.85 734.50 735.15 735.80
ForebayElev
Unit5_kcfs vs. Unit5_kcfs
Unit5_kcfs vs. ElevBypass
ElevBypass vs. ForebayElev
733.2 733.8 734.4 735.0 735.6
ForebayElev
ElevBypass vs. Unit5_kcfs
ElevBypass vs. ElevBypass

Appendix F: Covariate analysis of travel times for yearling Chinook salmon, juvenile steelheads, and sub-yearling Chinook salmon at Lower Granite Dam, spring 2013

Regression residuals for plots of mean travel time versus Julian day of release were normalized with a Box–Cox optimization procedure. Raw mean travel times for releases of yearling and sub-yearling Chinook salmon and juvenile steelheads into Gatewells 5A and 5B were transformed using a range of lambda values from –5 to 5. The resulting residuals were tested for normality using the Shapiro–Wilk test statistic. Then a new plot was generated to display the Shapiro–Wilk test statistic versus the range of Box–Cox lambda values. The greatest (closest value to 1.0) Shapiro–Wilk test score indicated which residuals were closest to a normal distribution. The associated transformed travel time data was used for the covariate regression models. The Box–Cox lambda value 0 resulted in the highest Shapiro–Wilk score for yearling Chinook salmon and 0.5 resulted in the highest Shapiro–Wilk scores for both juvenile steelheads and sub-yearling Chinook salmon (Figure 31).

All significant covariates were related to increasing or decreasing travel time across release locations for each species. Increasing mean fork length was related to increasing travel times for sub-yearling Chinook salmon but decreasing travel times for steelheads. Increasing Julian date of release was related to decreasing travel times for steelheads. Increasing flow through turbine unit 5 was related to decreasing travel times for yearling and sub-yearling Chinook salmon but was not a significant variable for steelheads. And increasing forebay elevation was related to increasing travel times for steelheads (Table 39).

This is not an exclusive list of significant covariates; highly correlated pairs ($|r| > 0.5$) were tested individually and the less significant of the pair excluded. The Spearman correlation section in each detailed regression report (Tables 40–46) contains the correlation values for each covariate. Row-wise deletion means that only covariates with data from all releases were included for analysis.

Regression residual reports (Figures 32–53) were included to provide a visual tool to assess appropriate distribution of residuals.

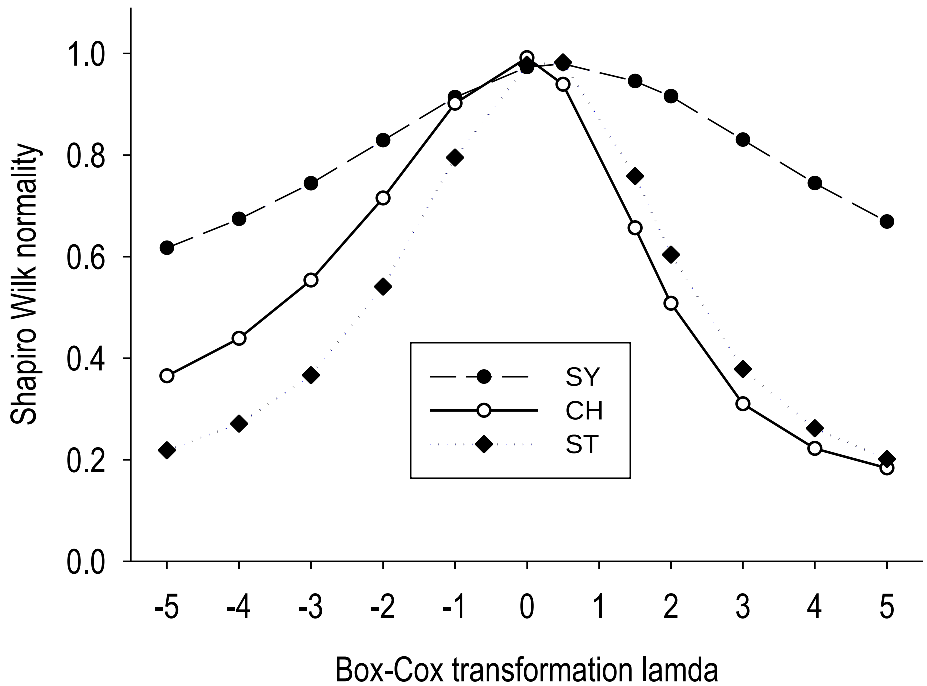


Figure 31. Shapiro–Wilk normality test statistic values plotted against Box–Cox transformation lambda values used to transform mean travel times for yearling and sub-yearling Chinook salmon and juvenile steelheads released into Gatewells 5A and 5B at Lower Granite Dam, spring 2013. Mean travel times for each release were transformed to normalize the distribution of residuals when regressed against Julian release day. The transformed travel times (using the Box–Cox lambdas) with most normally distributed residuals (highest Shapiro–Wilk test score) were included in the covariate regression models. SY = sub-yearling Chinook salmon; CH = yearling Chinook salmon; and ST = juvenile steelhead.

Table 39. Multiple regression model summary results for Box–Cox transformed travel time versus covariates for each species/age class and passage route tested at LGR, spring 2013. All non-significant effects were excluded from the models reported in the table.

Release Location	Species	Independent Variable	Model Coefficient	SE	Probability Level	R^2	Power	Qty replicates in model
14" Orifice	Chinook	no significant covariates						
10" Orifice	Chinook	no significant covariates						
Weir	Chinook	Unit 5 kcfs	–0.165	0.088	0.084	0.229	0.411	14
14" Orifice	Steelhead	Mean fork length	–0.032	0.008	0.002	0.751	0.956	14
		Forebay elev.	0.289	0.091	0.009		0.822	
10" Orifice	Steelhead	Julian day	–0.030	0.003	0.000	0.755	1.000	28
Weir	Steelhead	Julian day	–0.038	0.008	0.000	0.660	0.996	15
14" Orifice	Sub-yearling	Mean fork length	0.026	0.007	0.006	0.631	0.898	10
10" Orifice	Sub-yearling	Mean fork length	0.021	0.008	0.014	0.264	0.722	22
Weir	Sub-yearling	Unit 5 kcfs	–0.103	0.051	0.071	0.317	0.447	11

Table 40. Yearling Chinook regression model output and correlation matrix for passage through the broad-crested overflow weir at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|r| > 0.5) were excluded from the model.

Multiple Regression

Rows Used in Estimation	14
R^2	0.23

Regression Coefficients T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standard-ized Coefficient	T-Statistic to Test H0: β(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	3.829884	1.41212	0	2.712	0.0189	Yes	0.7023
Unit5_kcfs	-0.1652086	0.08759	-0.4782	-1.886	0.0837	No	0.4112

Spearman Correlations Section (Row-Wise Deletion)

	Julian Date	Avg RT_h	Avg FL	Elevation forebay	Unite 5 Kcfs	Elevation bypass	Temp
Julian Date	1	0.05594	-0.692308	-0.48951	0.307692	0.05624	0.594406
Avg RT_h	0.055944	1	-0.202797	0.167832	-0.258741	-0.15114	-0.1958
Avg FL	-0.692308	-0.2028	1	0.321678	-0.048951	-0.4218	-0.20979
Elevation forebay	-0.48951	0.16783	0.321678	1	-0.699301	-0.17926	-0.67832
Unite 5 Kcfs	0.307692	-0.25874	-0.048951	-0.699301	1	-0.03164	0.496503
Elevation bypass	0.05624	-0.15114	-0.421798	-0.179264	-0.031635	1	-0.22847
Temp	0.594406	-0.1958	-0.20979	-0.678322	0.496503	-0.22847	1

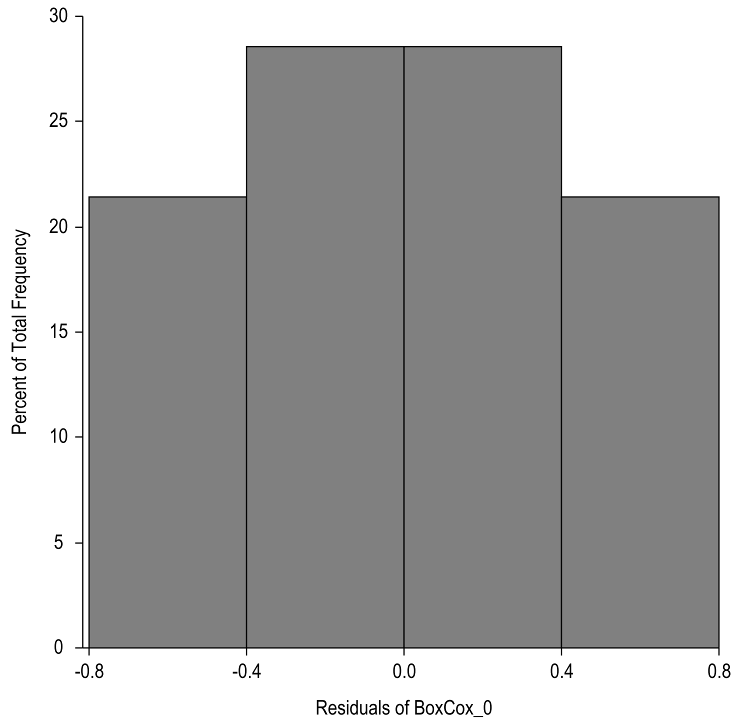


Figure 32. Histogram of residuals of the Box–Cox transformed mean of travel time of yearling Chinook salmon that passed though the broad-crested overflow weir at Lower Granite Dam, spring 2013.

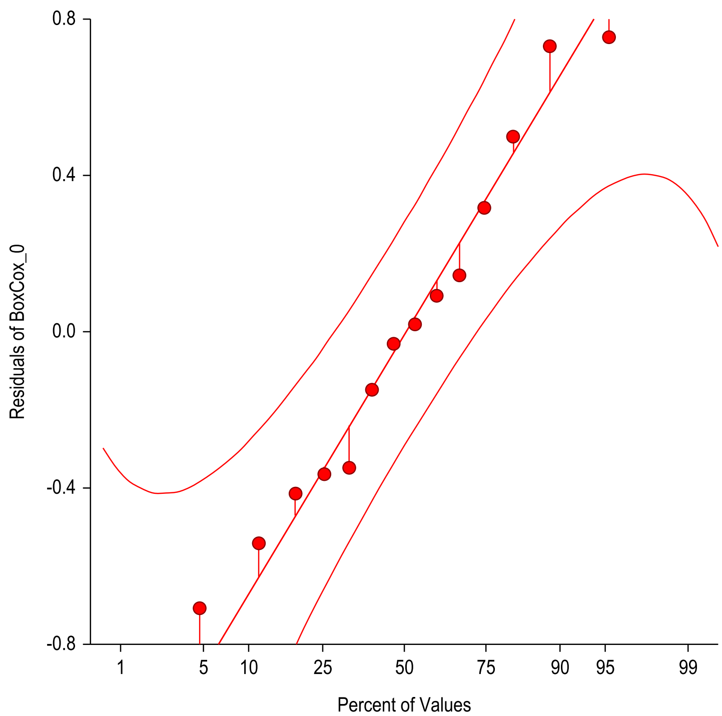


Figure 33. Normal probability plot of residuals of Box–Cox transformed mean travel time of yearling Chinook salmon that passed though the broad-crested overflow weir at Lower Granite Dam in spring 2013.

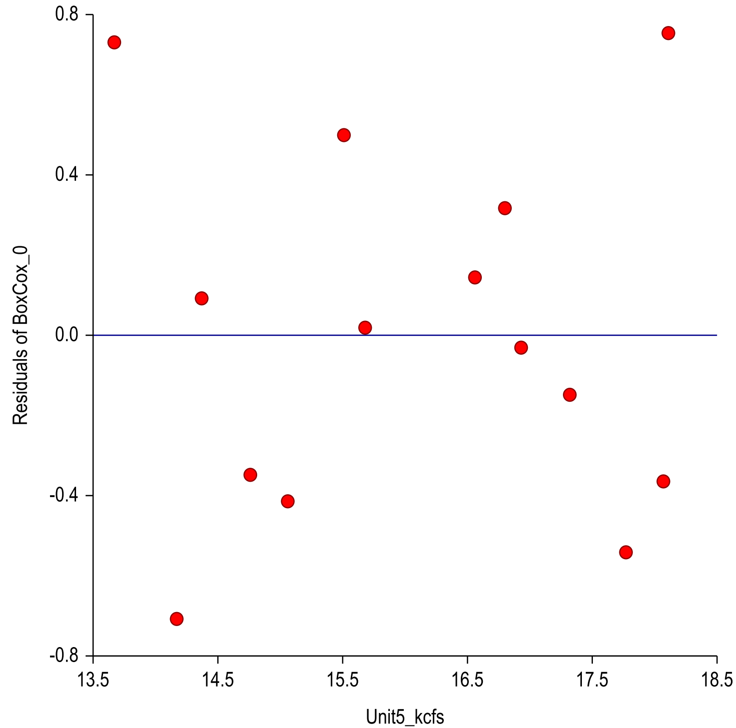


Figure 34. Residuals of Box–Cox transformed mean travel time of yearling Chinook salmon that passed though the broad-crested overflow weir versus flow through Turbine Unit 5 at Lower Granite Dam, spring 2013.

Table 41. Juvenile steelhead regression model output and correlation matrix for passage through the 14-inch diameter orifice at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|r| > 0.5) were excluded from the model.

Multiple Regression

Rows Used in Estimation	14
R^2	0.75

Regression Coefficients T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standard-ized Coefficient	T-Statistic to Test H0: β(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	-203.8682	67.3051	0	-3.029	0.0115	Yes	0.7873
AvgOfForkLength	-0.0317412	0.00787	-0.6212	-4.033	0.002	Yes	0.9556
ForebayElev	0.2886133	0.0911	0.4879	3.168	0.009	Yes	0.8219

Spearman Correlations Section (Row-Wise Deletion)

	Julian Date	Avg RT_h	Avg FL	Elevation Forebay	Unit 5 Kcfs	Elevation Bypass	Temp
Julian Date	1	-0.72727	0.405594	-0.623469	-0.020979	0.134044	0.540354
Avg RT_h	-0.727273	1	-0.34965	0.581437	-0.34965	0.017637	-0.75088
Avg FL	0.405594	-0.34965	1	-0.070053	0.272727	0.423297	0.147369
Elevation forebay	-0.623469	0.58144	-0.070053	1	0.042032	-0.14135	-0.51845
Unit 5 Kcfs	-0.020979	-0.34965	0.272727	0.042032	1	0.035275	0.512284
Elevation bypass	0.134044	0.01764	0.423297	-0.141346	0.035275	1	0.192923
Temp	0.540354	-0.75088	0.147369	-0.518454	0.512284	0.192923	1

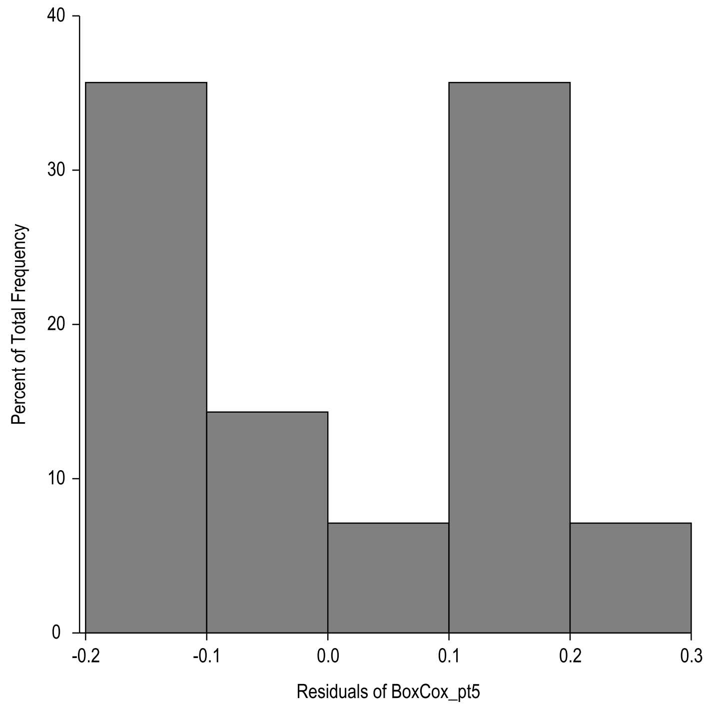


Figure 35. Histogram of residuals of the Box–Cox transformed mean of travel time of juvenile steelheads that passed though the 14-inch diameter orifice at Lower Granite Dam, spring 2013.

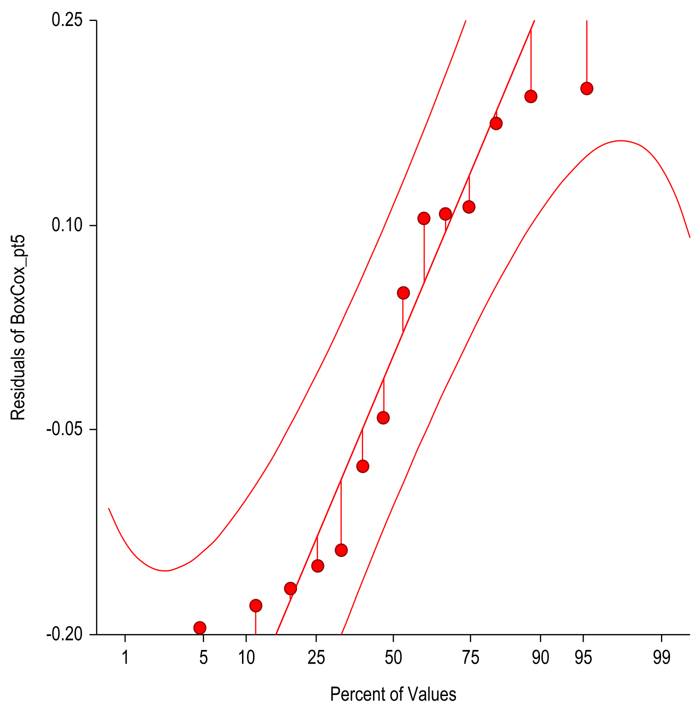


Figure 36. Normal probability plot of residuals of Box–Cox transformed mean travel time of juvenile steelheads that passed through the 14-inch diameter orifice at Lower Granite Dam, spring 2013.

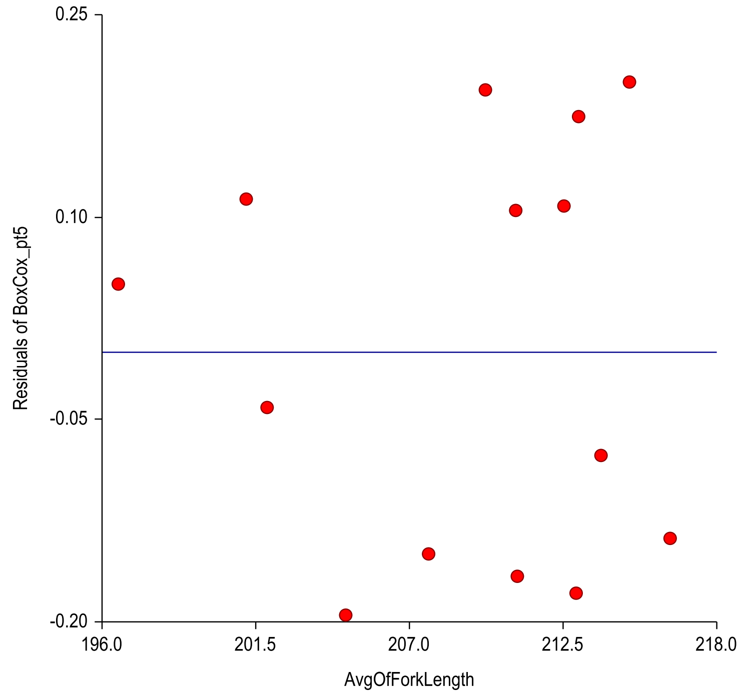


Figure 37. Residuals of Box–Cox transformed mean travel time of juvenile steelheads that passed though the 14-inch diameter orifice versus mean of fork length at Lower Granite Dam, spring 2013.

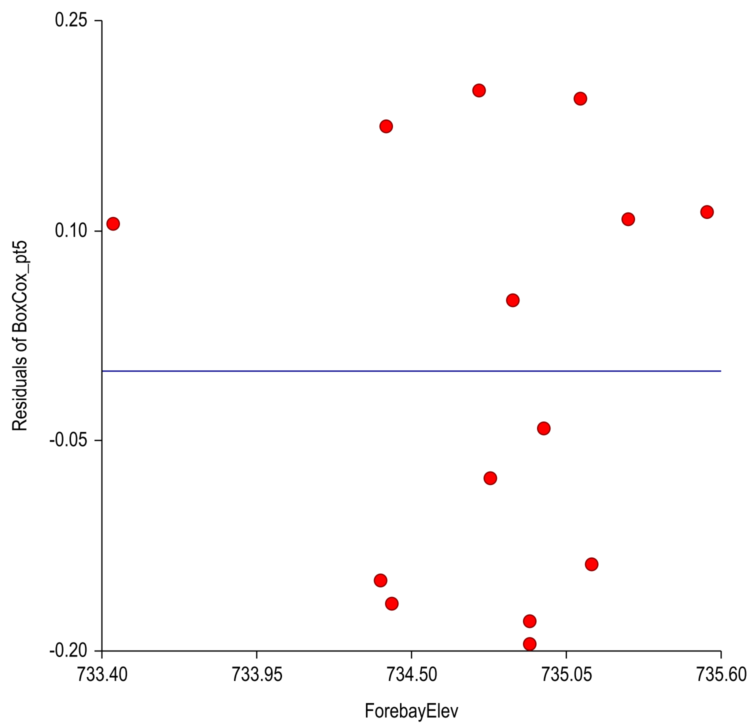


Figure 38. Residuals of Box–Cox transformed mean travel time of juvenile steelheads that passed though the 14-inch diameter orifice versus forebay elevation at Lower Granite Dam, spring 2013.

Table 42. Juvenile steelhead regression model output and correlation matrix for passage through the 10-inch diameter orifice at Lower Granite Dam, spring 2013. All highly correlated pairs of variables ($|r| > 0.5$) were excluded from the model.

Multiple Regression

Rows Used in Estimation	28
R^2	0.75

Regression Coefficients T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standard-ized Coefficient	T-Statistic to Test H0: β(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	5.573535	0.43119	0	12.926	0	Yes	1
ReleaseJD	-0.0302439	0.00338	-0.8689	-8.95	0	Yes	1

Spearman Correlations Section (Row-Wise Deletion)

	Julian Date	Avg RT_h	Avg FL	Elevation forebay	Unit 5 Kcfs	Elevation bypass	Temp
Julian Date	1	-0.87304	0.318261	-0.558504	0.155652	0.077669	0.584804
Avg RT_h	-0.873043	1	-0.269565	0.555024	-0.266957	-0.0373	-0.65883
Avg FL	0.318261	-0.26957	1	-0.123097	-0.05913	0.045636	0.242108
Elevation forebay	-0.558504	0.55502	-0.123097	1	-0.369726	-0.14794	-0.60967
Unit 5 Kcfs	0.155652	-0.26696	-0.05913	-0.369726	1	0.12155	0.423689
Elevation bypass	0.077669	-0.0373	0.045636	-0.147942	0.12155	1	-0.07515
Temp	0.584804	-0.65883	0.242108	-0.609671	0.423689	-0.07515	1

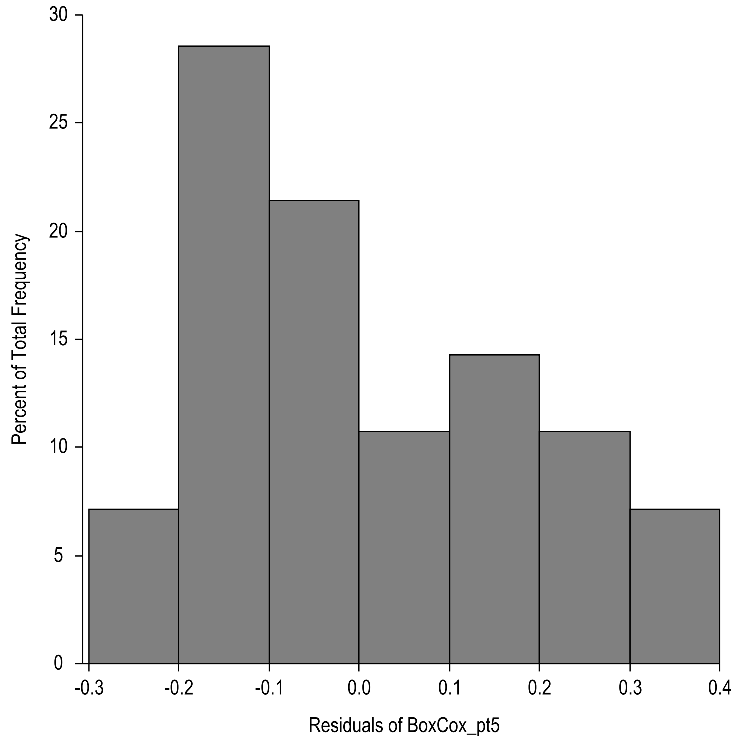


Figure 39. Histogram of residuals of the Box–Cox transformed mean of travel time of juvenile steelheads that passed though the 10-inch diameter orifice at Lower Granite Dam, spring 2013.

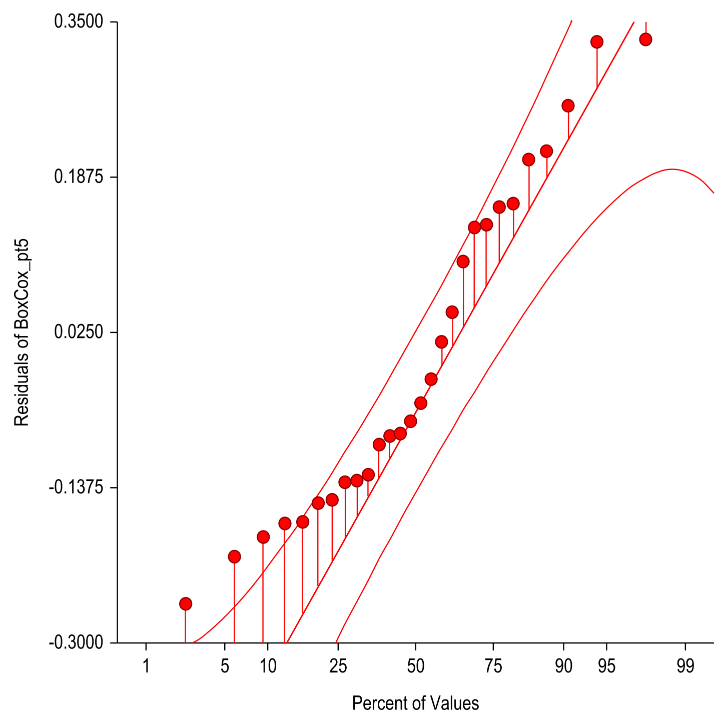


Figure 40. Normal probability plot of residuals of Box–Cox transformed mean travel time of juvenile steelheads that passed through the 10-inch diameter orifice at Lower Granite Dam, spring 2013.

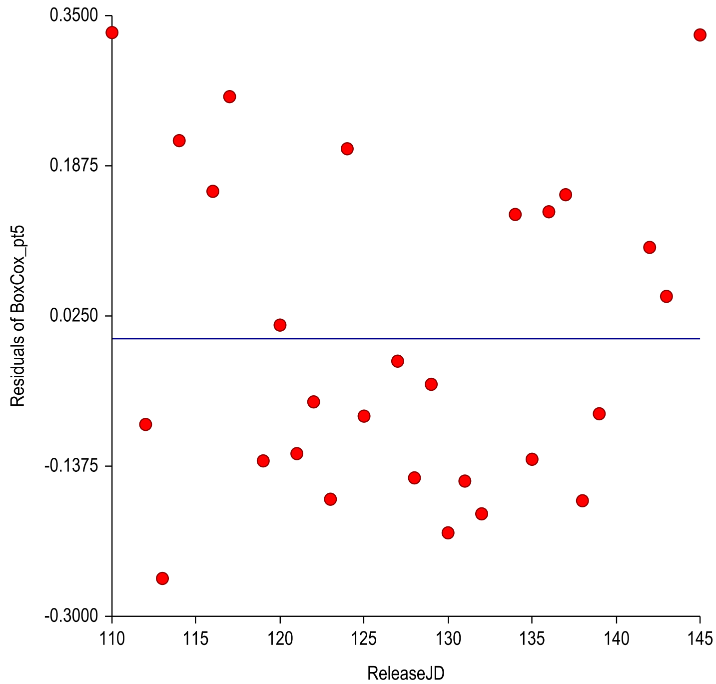


Figure 41. Residuals of Box–Cox transformed mean travel time of juvenile steelheads that passed though the 10-inch diameter orifice versus Julian date of release at Lower Granite Dam, spring 2013.

Table 43. Juvenile steelhead regression model output and correlation matrix for passage through the broad-crested overflow weir at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|r| > 0.5) were excluded from the model.

Multiple Regression

Rows Used in Estimation	15
R^2	0.66

Regression Coefficients T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standard-ized Coefficient	T-Statistic to Test H0: β(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	6.960052	0.96898	0	7.183	0	Yes	1
ReleaseJD	-0.0384463	0.00766	-0.8121	-5.018	0.0002	Yes	0.9961

Spearman Correlations Section (Row-Wise Deletion)

	Julian Date	Avg RT_h	Avg FL	Elevation forebay	Unite 5 Kcfs	Elevation bypass	Temp
Julian Date	1	-0.82518	0.132867	-0.48951	0.307692	0.05624	0.594406
Avg RT_h	-0.825175	1	0	0.377622	-0.398601	0	-0.51049
Avg FL	0.132867	0	1	0	-0.41958	0.11248	0.20979
Elevation forebay	-0.48951	0.37762	0	1	-0.699301	-0.17926	-0.67832
Unite 5 Kcfs	0.307692	-0.3986	-0.41958	-0.699301	1	-0.03164	0.496503
Elevation bypass	0.05624	0	0.11248	-0.179264	-0.031635	1	-0.22847
Temp	0.594406	-0.51049	0.20979	-0.678322	0.496503	-0.22847	1

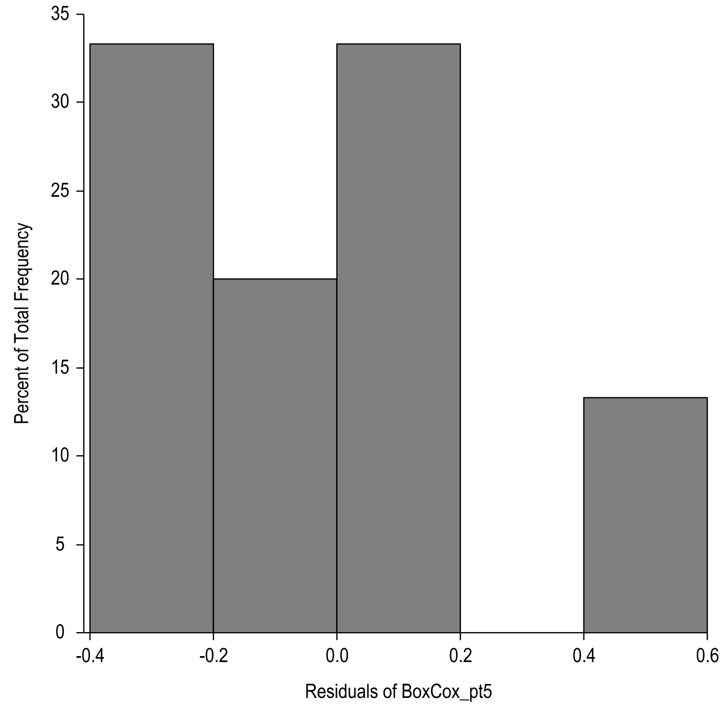


Figure 42. Histogram of residuals of the Box–Cox transformed mean of travel time of juvenile steelheads that passed though the broad-crested overflow weir at Lower Granite Dam, spring 2013.

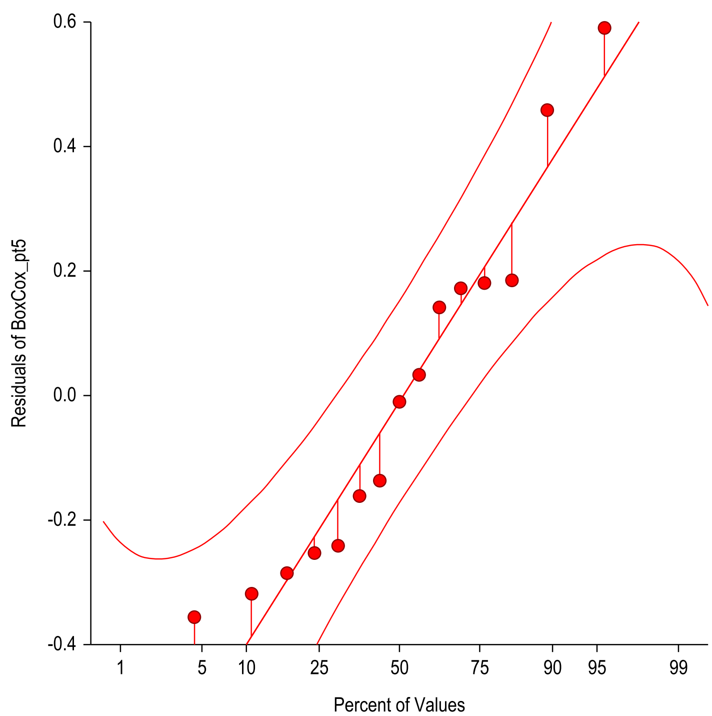


Figure 43. Normal probability plot of residuals of Box–Cox transformed mean travel time of juvenile steelheads that passed through the broad-crested overflow weir at Lower Granite Dam, spring 2013.

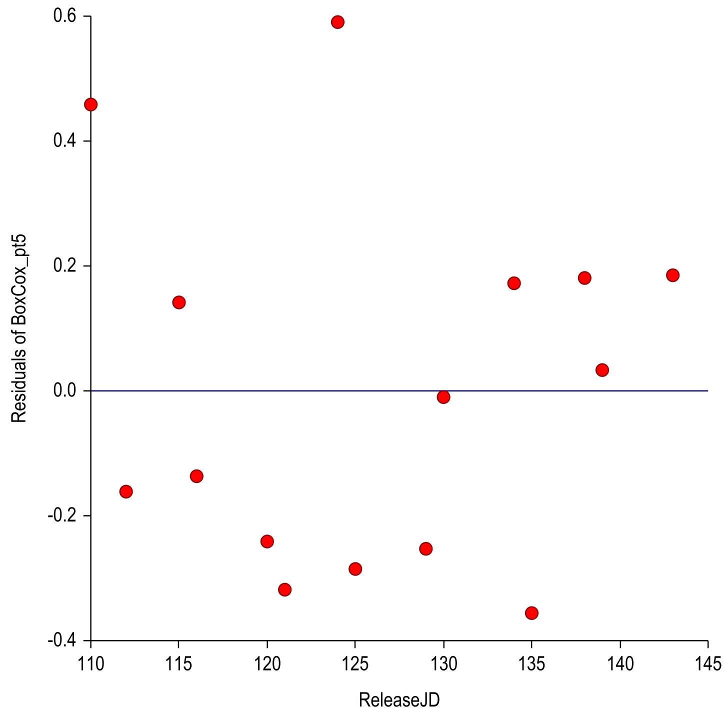


Figure 44. Residuals of Box–Cox transformed mean travel time of juvenile steelheads that passed though the broad-crested overflow weir versus Julian date of release at Lower Granite Dam, spring 2013.

Table 44. Sub-yearling Chinook salmon Regression model output and correlation matrix for passage through the 14-inch diameter orifice at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|r| > 0.5) were excluded from the model.

Multiple Regression

Rows Used in Estimation	10
R^2	0.63

Regression Coefficients T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standard-ized Coefficient	T-Statistic to Test H0: β(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	-1.566824	0.72422	0	-2.163	0.0625	No	0.4773
AvgOfForkLength	0.0257949	0.00697	0.7945	3.701	0.006	Yes	0.8982

Spearman Correlations Section (Row-Wise Deletion)

	Julian Date	Avg RT_h	Avg FL	Elevation forebay	Unite 5 Kcfs	Elevation bypass	Temp
Julian Date	1	0.7697	0.951515	0.612121	-0.632222	-0.39389	0.978728
Avg RT_h	0.769697	1	0.769697	0.224242	-0.541036	-0.42467	0.778119
Avg FL	0.951515	0.7697	1	0.551515	-0.462008	-0.55391	0.911858
Elevation forebay	0.612121	0.22424	0.551515	1	-0.224925	0.030773	0.534957
Unite 5 Kcfs	-0.632222	-0.54104	-0.462008	-0.224925	1	0.283972	-0.75
Elevation bypass	-0.393893	-0.42467	-0.553912	0.030773	0.283972	1	-0.47226
Temp	0.978728	0.77812	0.911858	0.534957	-0.75	-0.47226	1

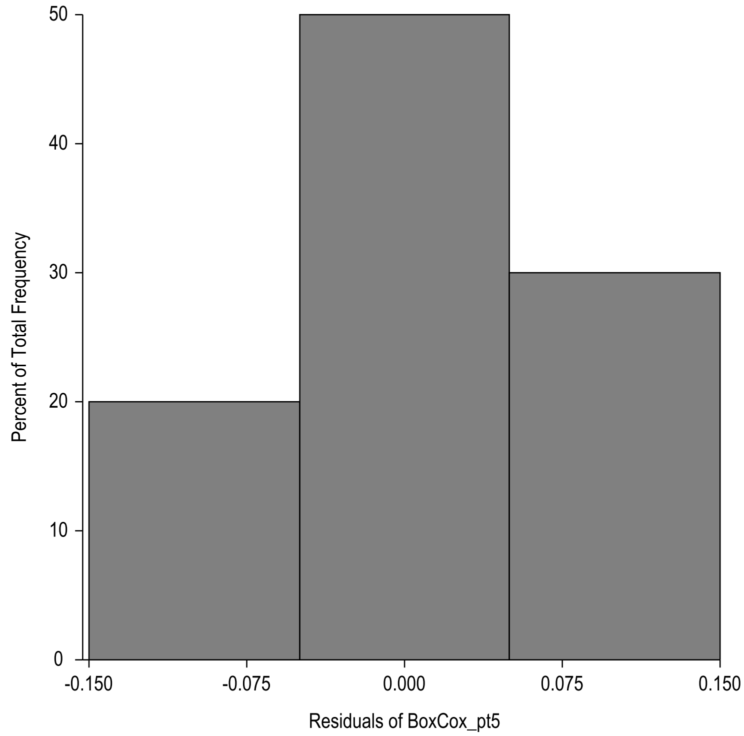


Figure 45. Histogram of residuals of the Box–Cox transformed mean of travel time of sub-yearling Chinook salmon that passed though the 14-inch diameter orifice at Lower Granite Dam, spring 2013.

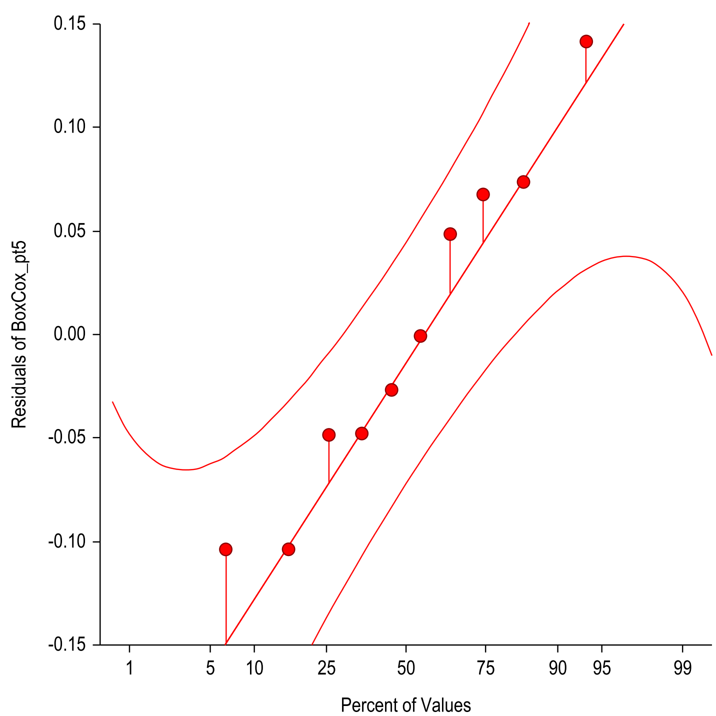


Figure 46. Normal probability plot of residuals of Box–Cox transformed mean travel time of sub-yearling Chinook salmon that passed through the 14-inch diameter orifice at Lower Granite Dam, spring 2013.

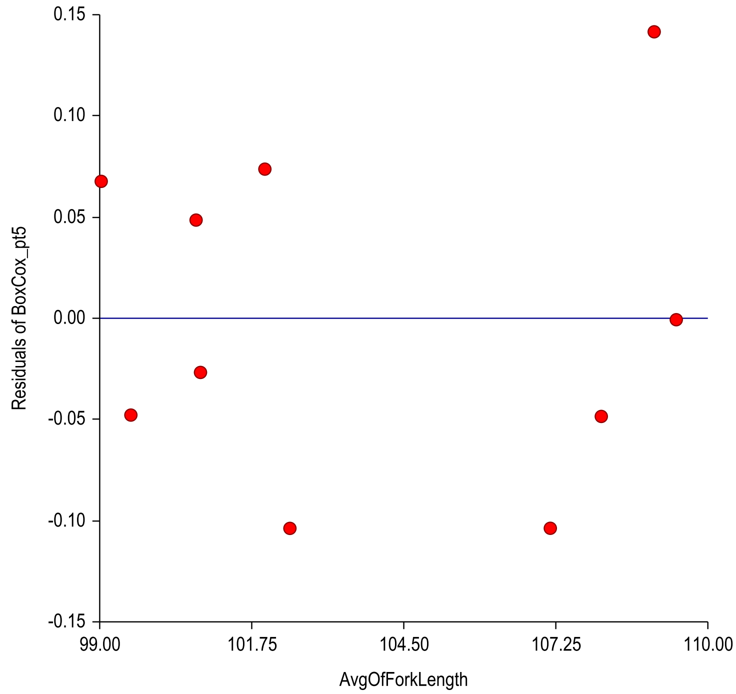


Figure 47. Residuals of Box–Cox transformed mean travel time of sub-yearling Chinook salmon that passed through the 14-inch diameter orifice versus mean fork length at Lower Granite Dam, spring 2013.

Table 45. Sub-yearling Chinook salmon regression model output and correlation matrix for passage through the 10-inch diameter orifice at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|*r*| > 0.5) were excluded from the model.

Multiple Regression

Rows Used in Estimation	22
R^2	0.26

Regression Coefficients T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standard-ized Coefficient	T-Statistic to Test H0: β(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	-0.6434568	0.80843	0	-0.796	0.4354	No	0.118
AvgOfForkLength	0.020719	0.00773	0.514	2.68	0.0144	Yes	0.7221

Spearman Correlations Section (Row-Wise Deletion)

	Julian Date	Avg RT_h	Avg FL	Elevation forebay	Unit 5 Kcfs	Elevation bypass	Temp
Julian Date	1	0.43083	0.838509	0.614472	-0.320158	-0.67281	0.975944
Avg RT_h	0.43083	1	0.565217	0.325608	-0.141728	-0.22808	0.427966
Avg FL	0.838509	0.56522	1	0.550029	-0.343874	-0.58307	0.836685
Elevation forebay	0.614472	0.32561	0.550029	1	0.081402	-0.42492	0.59252
Unite 5 Kcfs	-0.320158	-0.14173	-0.343874	0.081402	1	0.358987	-0.33116
Elevation bypass	-0.672814	-0.22808	-0.583068	-0.424919	0.358987	1	-0.68399
Temp	0.975944	0.42797	0.836685	0.59252	-0.331164	-0.68399	1

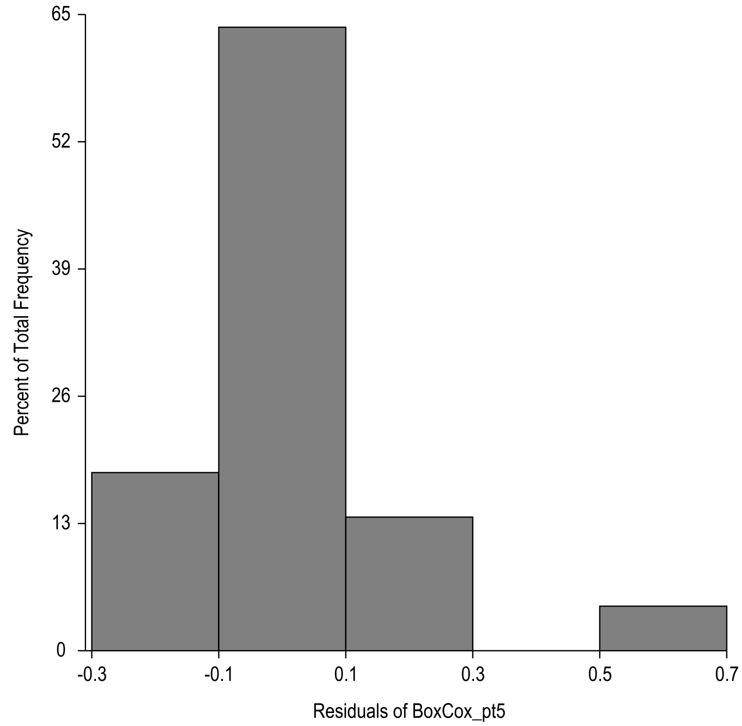


Figure 48. Histogram of residuals of the Box–Cox transformed mean of travel time of sub-yearling Chinook salmon that passed though the 10-inch diameter orifice at Lower Granite Dam, spring 2013.

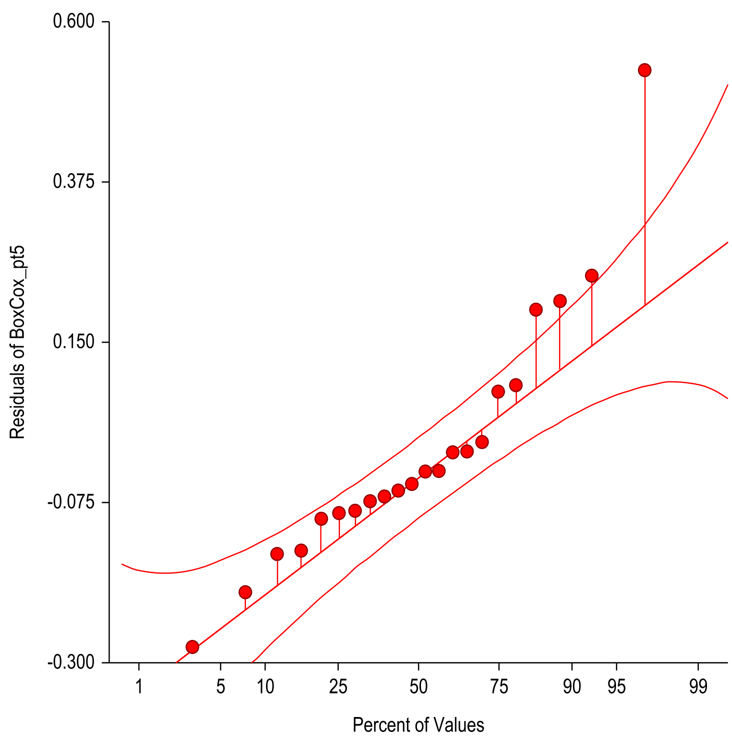


Figure 49. Normal probability plot of residuals of Box–Cox transformed mean travel time of sub-yearling Chinook salmon that passed through the 10-inch diameter orifice at Lower Granite Dam, spring 2013.

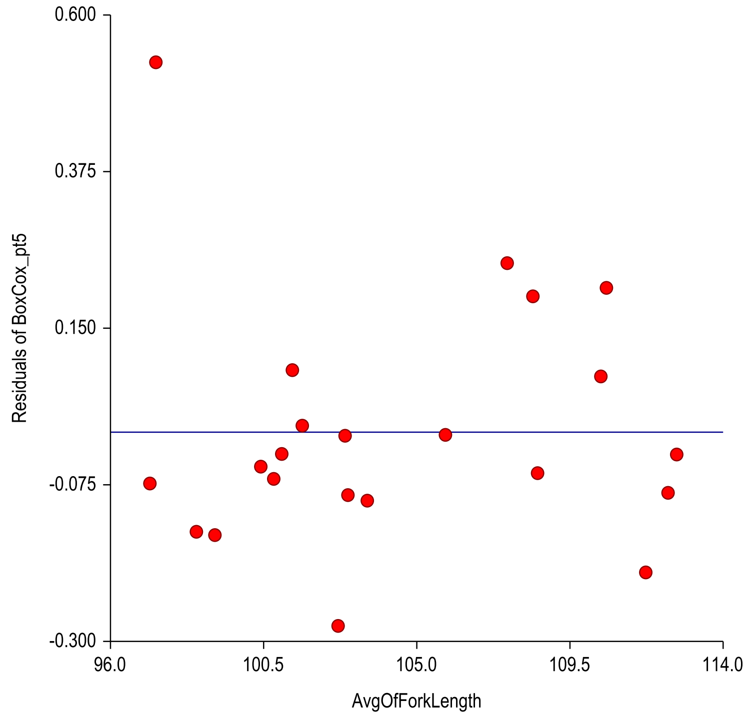


Figure 50. Residuals of Box–Cox transformed mean travel time of sub-yearling Chinook salmon that passed through the 10-inch diameter orifice versus mean fork length at Lower Granite Dam, spring 2013.

Table 46. Sub-yearling Chinook Multiple Regression model output and Correlation matrix for passage through the broad-crested overflow weir at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|r| > 0.5) were excluded from the model.

Multiple Regression

Rows Used in Estimation	11
R^2	0.32

Regression Coefficients T-Tests

Independent Variable	Regression Coefficient b(i)	Standard Error Sb(i)	Standard-ized Coefficient	T-Statistic to Test H0: β(i)=0	Prob Level	Reject H0 at 5%?	Power of Test at 5%
Intercept	3.310097	0.78734	0	4.204	0.0023	Yes	0.9612
Unit5_kcfs	-0.1034451	0.05062	-0.563	-2.044	0.0713	No	0.4466

Spearman Correlations Section (Row-Wise Deletion)

	Julian Date	Avg RT_h	Avg FL	Elevation	Unite 5 Kcfs	Elevation	Temp
Julian Date	1	-0.09091	0.9	0.536364	-0.154545	-0.58855	0.952166
Avg RT_h	-0.090909	1	0.036364	0.018182	-0.609091	-0.2345	-0.10478
Avg FL	0.9	0.03636	1	0.509091	-0.145455	-0.58855	0.961278
Elevation	0.536364	0.01818	0.509091	1	0.272727	-0.28967	0.505696
Unite 5 Kcfs	-0.154545	-0.60909	-0.145455	0.272727	1	0.519575	-0.07745
Elevation	-0.588545	-0.2345	-0.588545	-0.289674	0.519575	1	-0.48389
Temp	0.952166	-0.10478	0.961278	0.505696	-0.077449	-0.48389	1

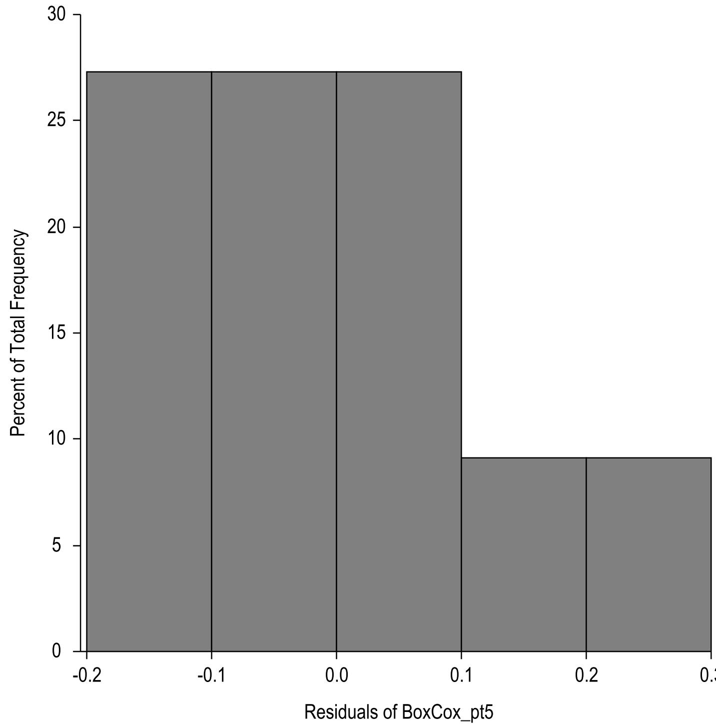


Figure 51. Histogram of residuals of the Box–Cox transformed mean of travel time of sub-yearling Chinook salmon that passed though the broad-crested overflow weir at Lower Granite Dam, spring 2013.

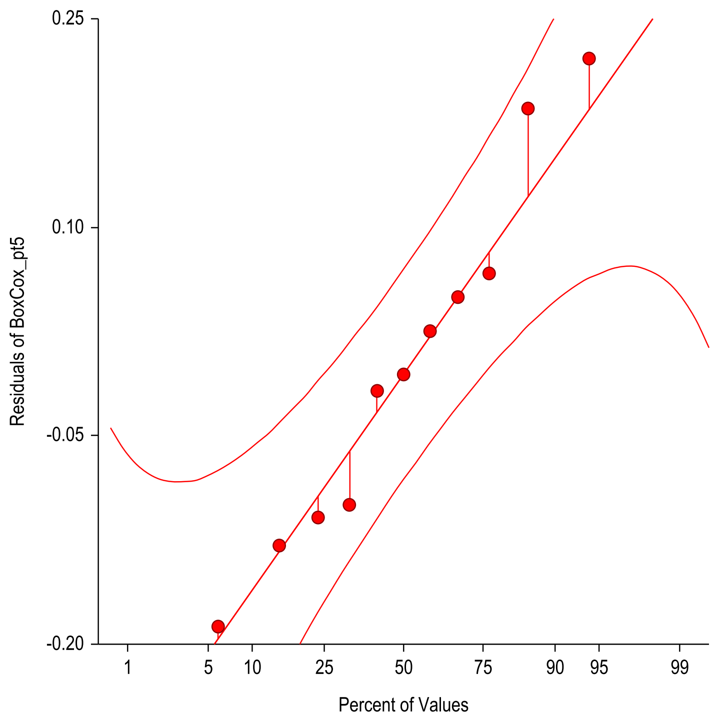


Figure 52. Normal probability plot of residuals of Box–Cox transformed mean travel time of sub-yearling Chinook salmon that passed through the broad-crested overflow weir at Lower Granite Dam, spring 2013.

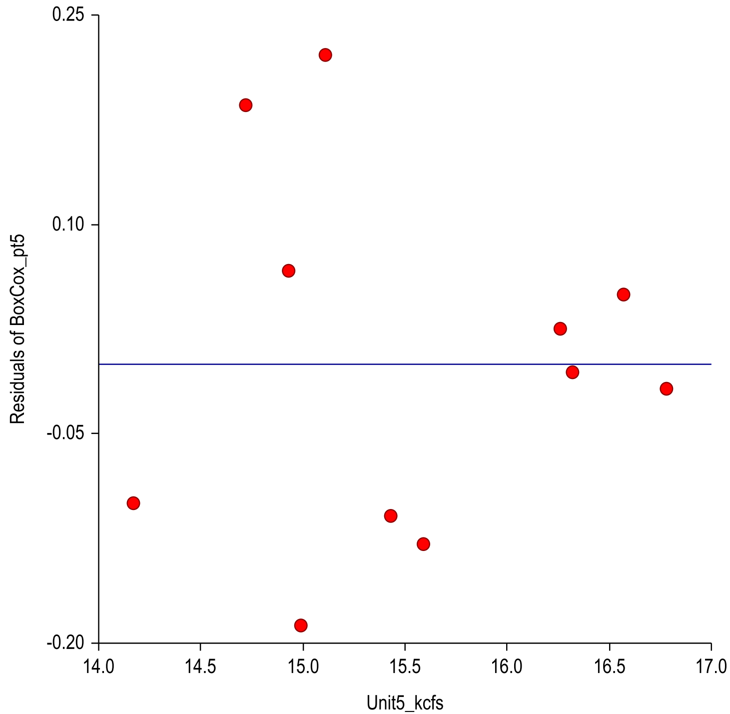


Figure 53. Residuals of Box–Cox transformed mean travel time of sub-yearling Chinook salmon that passed through the broad-crested overflow weir versus flow through Turbine Unit 5 at Lower Granite Dam, spring 2013.

Appendix G: Ranked Injury Difference Data

Each photograph of each side of each fish was given a suite of fish condition scores ranging from 0 to 3 for descaling (i.e. 0 = Loss of scales <5% of body, 1 = 5–20% of body, 2 = 21–50% of body, and 3 = >50% of body) and 0 to 2 for operculum injury, head injury, eye injury, and trunk injury (see detailed scoring criteria, Appendix B). The difference in score from before release and after re-collection was the basis for comparison. This "ranked difference" indicates the magnitude of change in external condition from before release to after re-collection. For example, a ranked difference of 0 indicates any change in condition was insufficient to require an increase in score. A ranked difference of 1 indicates the fish sustained sufficient injury between the initial condition assessment and re-collection to require an increase in score of 1 for a given category (i.e. a change from a score before release of 1 to a score after re-collection of 2), and so on. See Appendix B for the criteria used to describe each condition category.

Table 47. Ranked difference of scale loss, operculum injury, and eye injury for the left side of yearling Chinook, steelheads, and sub-yearling Chinook re-collected at the Sort by Code system at Lower Granite Dam, spring 2013.

			Left Side								
Release Location	**Species**	**Release Qty**	**Scale Loss Ranked Diff**	**Scale Loss Qty.**	**Scale Loss %**	**Oper. Ranked Diff**	**Oper. Qty**	**Oper. %**	**Eye Ranked Diff**	**Eye Qty**	**Eye %**
Weir	Chinook	536	0	483	90.1%	0	534	99.6%	0	536	100.0%
			1	46	8.6%	1	1	0.2%	1	0	
			2	7	1.3%	2	1	0.2%	2	0	
			Total	536		Total	536		Total	536	
14" Orifice	Chinook	697	0	648	93.0%	0	696	99.9%	0	695	99.7%
			1	44	6.3%	1	1	0.1%	1	1	0.1%
			2	5	0.7%	2	0		2	1	0.1%
			Total	697		Total	697		Total	697	
10" Orifice	Chinook	1271	0	1145	90.1%	0	1269	99.8%	0	1266	99.6%
			1	113	8.9%	1	1	0.1%	1	3	0.2%
			2	12	0.9%	2	0		2	2	0.2%
			Total	1270		Total	1270		Total	1271	
Bypass	Chinook	1092	0	998	91.4%	0	1089	99.7%	0	1087	99.5%
			1	86	7.9%	1	3	0.3%	1	1	0.1%
			2	8	0.7%	2	0		2	4	0.4%
			Total	1092		Total	1092		Total	1092	
Weir	Steelhead	648	0	613	94.6%	0	646	99.7%	0	648	100.0%
			1	34	5.2%	1	2	0.3%	1	0	
			2	1	0.2%	2	0		2	0	
			Total	648		Total	648		Total	648	
14" Orifice	Steelhead	798	0	761	95.4%	0	791	99.1%	0	797	99.9%
			1	36	4.5%	1	6	0.8%	1	0	
			2	1	0.1%	2	1	0.1%	2	1	0.1%
			Total	798		Total	798		Total	798	
10" Orifice	Steelhead	1460	0	1393	95.4%	0	1454	99.6%	0	1456	99.7%
			1	64	4.4%	1	6	0.4%	1	3	0.2%
			2	3	0.2%	2	0		2	1	0.1%
			Total	1460		Total	1460		Total	1460	
Bypass	Steelhead	1278	0	1211	94.8%	0	1273	99.6%	0	1277	99.9%
			1	66	5.2%	1	5	0.4%	1	1	0.1%
			2	1	0.1%	2	0		2	0	
			Total	1278		Total	1278		Total	1278	

Release Location	Species	Release Qty	Left Side: Scale Loss Ranked Diff	Scale Loss Qty.	Scale Loss %	Oper. Ranked Diff	Oper. Qty	Oper. %	Eye Ranked Diff	Eye Qty	Eye %
Weir	Sub-yearling	706	0	693	98.2%	0	702	99.4%	0	705	99.9%
			1	13	1.8%	1	3	0.4%	1	1	0.1%
			2	0		2	0		2	0	
			Total	706		Total	705		Total	706	
14" Orifice	Sub-yearling	574	0	565	98.4%	0	570	99.3%	0	574	100.0%
			1	9	1.6%	1	2	0.3%	1	0	
			2	0		2	1	0.2%	2	0	
			Total	574		Total	573		Total	574	
10" Orifice	Sub-yearling	1314	0	1302	99.1%	0	1311	99.8%	0	1314	100.0%
			1	12	0.9%	1	3	0.2%	1	0	
			2	0		2	0		2	0	
			Total	1314		Total	1314		Total	1314	
Bypass	Sub-yearling	1225	0	1194	97.5%	0	1222	99.8%	0	1225	100.0%
			1	30	2.4%	1	1	0.1%	1	0	
			2	1	0.1%	2	0		2	0	
			Total	1225		Total	1223		Total	1225	

Table 48. Ranked difference of scale loss, operculum injury, and eye injury for the right side of yearling Chinook, steelheads, and sub-yearling Chinook re-collected at the Sort by Code system at Lower Granite Dam, spring 2013.

		Right Side								
Release Location	Species	Scale Loss Ranked Diff	Scale Loss Qty.	Scale Loss %	Oper. Ranked Diff	Oper. Qty	Oper. %	Eye Ranked Diff	Eye Qty	Eye %
Weir	Chinook	0	448	83.6%	0	536	100.0%	0	535	99.8%
		1	80	14.9%	1	0		1	1	0.2%
		2	8	1.5%	2	0		2	0	
		Total	536		Total	536		Total	536	
14” Orifice	Chinook	0	632	90.7%	0	696	99.9%	0	696	99.9%
		1	59	8.5%	1	0		1	0	
		2	6	0.9%	2	1	0.1%	2	1	0.1%
		Total	697		Total	697		Total	697	
10” Orifice	Chinook	0	1092	85.9%	0	1270	99.9%	0	1266	99.6%
		1	157	12.4%	1	1	0.1%	1	3	0.2%
		2	22	1.7%	2	0		2	2	0.2%
		Total	1271		Total	1271		Total	1271	
Bypass	Chinook	0	982	89.9%	0	1090	99.8%	0	1090	99.8%
		1	102	9.3%	1	2	0.2%	1	1	0.1%
		2	8	0.7%	2	0		2	1	0.1%
		Total	1092		Total	1092		Total	1092	
Weir	Steelhead	0	565	87.2%	0	645	99.5%	0	648	100.0%
		1	78	12.0%	1	3	0.5%	1	0	
		2	5	0.8%	2	0		2	0	
		Total	648		Total	648		Total	648	
14” Orifice	Steelhead	0	714	89.5%	0	797	99.9%	0	797	99.9%
		1	78	9.8%	1	1	0.1%	1	1	0.1%
		2	6	0.8%	2	0		2	0	
		Total	798		Total	798		Total	798	
10” Orifice	Steelhead	0	1295	88.7%	0	1454	99.6%	0	1460	100.0%
		1	156	10.7%	1	6	0.4%	1	0	
		2	9	0.6%	2	0		2	0	
		Total	1460		Total	1460		Total	1460	
Bypass	Steelhead	0	1136	88.9%	0	1268	99.2%	0	1276	99.8%
		1	137	10.7%	1	9	0.7%	1	1	0.1%
		2	5	0.4%	2	0		2	1	0.1%
		Total	1278		Total	1277		Total	1278	
Weir	Sub-yearling	0	697	98.7%	0	704	99.7%	0	706	100.0%
		1	9	1.3%	1	1	0.1%	1	0	
		2	0		2	0		2	0	
		Total	706		Total	705		Total	706	
14” Orifice	Sub-yearling	0	561	97.7%	0	573	99.8%	0	574	100.0%
		1	12	2.1%	1	1	0.2%	1	0	
		2	1	0.2%	2	0		2	0	
		Total	574		Total	574		Total	574	
10” Orifice	Sub-yearling	0	1295	98.6%	0	1308	99.5%	0	1314	100.0%
		1	18	1.4%	1	6	0.5%	1	0	
		2	1	0.1%	2	0		2	0	
		Total	1314		Total	1314		Total	1314	

Table 48. (*continued*)

Release Location	Species	Scale Loss Ranked Diff	Scale Loss Qty.	Scale Loss %	Oper. Ranked Diff	Oper. Qty	Oper. %	Eye Ranked Diff	Eye Qty.	Eye %
		Right Side								
Bypass	Sub-yearling	0	1207	98.5%	0	1222	99.8%	0	1224	99.9%
		1	15	1.2%	1	3	0.2%	1	1	0.1%
		2	3	0.2%	2	0		2	0	
		Total	1225		Total	1225		Total	1225	

Table 49. Ranked difference of head injury and trunk injury of yearling Chinook, steelheads, and sub-yearling Chinook re-collected at the Sort by Code system at Lower Granite Dam in spring 2013.

Release Location	Species	Head Ranked Diff.	Head Qty.	Head %	Trunk Ranked Diff.	Trunk Qty.	Trunk %
Weir	Chinook	0	536	100.0%	0	536	100.0%
		1	0		1	0	
		2	0		2	0	
		Total	536		Total	536	
14" Orifice	Chinook	0	697	100.0%	0	695	99.7%
		1	0		1	2	0.3%
		2	0		2	0	
		Total	697		Total	697	
10" Orifice	Chinook	0	1271	100.0%	0	1267	99.7%
		1	0		1	4	0.3%
		2	0		2	0	
		Total	1271		Total	1271	
Bypass	Chinook	0	1091	99.9%	0	1091	99.9%
		1	1	0.1%	1	0	
		2	0		2	1	0.1%
		Total	1092		Total	1092	
Weir	Steelhead	0	647	99.8%	0	647	99.8%
		1	1	0.2%	1	1	0.2%
		2	0		2	0	
		Total	648		Total	648	
14" Orifice	Steelhead	0	797	99.9%	0	792	99.2%
		1	1	0.1%	1	5	0.6%
		2	0		2	1	0.1%
		Total	798		Total	798	
10" Orifice	Steelhead	0	1455	99.7%	0	1458	99.9%
		1	4	0.3%	1	2	0.1%
		2	0		2	0	
		Total	1459		Total	1460	
Bypass	Steelhead	0	1275	99.8%	0	1274	99.7%
		1	3	0.2%	1	3	0.2%
		2	0		2	1	0.1%
		Total	1278		Total	1278	
Weir	Sub-yearling	0	706	100.0%	0	706	100.0%
		1	0		1	0	
		2	0		2	0	
		Total	706		Total	706	
14" Orifice	Sub-yearling	0	572	99.7%	0	574	100.0%
		1	2	0.3%	1	0	
		2	0		2	0	
		Total	574		Total	574	
10" Orifice	Sub-yearling	0	1309	99.6%	0	1312	99.8%
		1	4	0.3%	1	1	0.1%
		2	1	0.1%	2	1	0.1%
		Total	1314		Total	1314	

Table 49. (*continued*)

Release Location	Species	Head Ranked Diff.	Head Qty.	Head %	Trunk Ranked Diff.	Trunk Qty.	Trunk %
Bypass	Sub-yearling	0	1224	99.9%	0	1224	99.9%
		1	1	0.1%	1	1	0.1%
		2	0		2	0	
		Total	1225		Total	1225	

Appendix H: Regression analysis of right-side descaling for yearling Chinook salmon released during orifice and weir operation at Lower Granite Dam, spring 2013

Poisson regression analysis was used to model the relationships between covariates and right-side descaling for yearling Chinook salmon released during operation of the 10-inch diameter orifice, 14-inch diameter orifice, and broad-crested overflow weir at Lower Granite Dam in spring 2013 (Table 50). The dependent variable was the change in fish condition score from before release to after re-collection at the SxC system at the LGR JFF. If there was no change, the score was 0 and the score increased to 1, 2, or 3 for increasing amounts of change. Phi was used to correct standard errors. Over-dispersion was not observed to be a problem in the analyses and dispersion Phi values ranged from 0.97 for yearling Chinook salmon that passed through the broad-crested overflow weir to 1.07 for yearling Chinook salmon that passed through the 14-inch diameter orifice (Tables 51–53).

This is not an exclusive list of tested covariates; highly correlated pairs ($|r| > 0.5$) were tested individually and the least significant of the pair excluded. The Spearman correlation section in each detailed regression report (Tables 51–53) contains the correlation values for each covariate. Row-wise deletion means that only covariates with data from all releases were included for analysis.

One covariate term was identified as significant for yearling Chinook salmon released during operation of the 10-inch orifice and weir, and two terms were significant for yearling Chinook salmon released during operation of the 14-inch orifice. Pseudo-R^2 values ranged from 0.004 for Chinook salmon that passed through the 10-inch orifice to 0.050 for Chinook salmon that passed the 14-inch orifice. For yearling Chinook salmon that passed the 10-inch orifice, forebay elevation was mildly associated with right-side descaling ($\alpha = 0.07$). Forebay elevation was also associated with right-side descaling of yearling Chinook salmon released during operation of the weir ($\alpha = 0.01$). Right-side descaling of Chinook salmon released during 14-inch orifice operation was associated with mean fork length and travel time ($\alpha = 0.03$ and .01, respectively).

Residual plots (Figures 54–60) were included to assess appropriate distributions. The Poisson-model Pearson residuals are the residuals divided by the square root of expected values. Those values are then plotted against the relevant covariates (Figures 55, 57, and 59).

Table 50. Poisson regression results testing relationships between seven covariates (see Obj. 1 covariate analysis) and right-side descaling for yearling Chinook salmon that passed through the 10-inch orifice, weir, and 14-inch orifice. All non-significant effects were excluded from the models reported in the table.

Release Location	Species	Pseudo R^2	Ind. Variables available	No. of X's in model	Count	Terms entered
10" Orifice	Chinook	0.004	5	1	1255	Forebay elevation
Weir	Chinook	0.02	5	1	531	Forebay elevation
14" Orifice	Chinook	0.05	5	2	690	Fork length, Travel time

Table 51. Poisson regression coefficients report and Pearson correlation matrix for yearling Chinook that passed through the 10-inch diameter orifice at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|r| > 0.5) were excluded from the model.

Regression Coefficients Report						
Independent Variable	**Regression Coefficient *b*(*i*)**	**Standard Error *Sb*(*i*)**	**Wald's Chi² *H*0: *β* = 0**	**Prob. Level**	**Lower 95.0% Confidence Limit**	**Upper 95.0% Confidence Limit**
Intercept	–187.25155	104.8513	3.19	0.0741	–392.75638	18.25328
Forebay Elev.	0.25231	0.14269	3.13	0.077	–0.02736	0.53198
Dispersion Phi		1.0607				

Pearson Correlations Section (Row-wise Deletion)					
	Julian Day	**Forebay Elev.**	**Unit 5 kcfs**	**Bypass Elev.**	**Temp**
Julian Day	1	0.5	–0.91538	0.327327	–0.99999
Forebay Elev.	0.5	1	–0.10904	0.981981	–0.49523
Unit 5 kcfs	–0.91538	–0.10904	1	0.080778	0.917582
Bypass Elev.	0.327327	0.981981	0.080778	1	–0.32213
Temp	–0.99999	–0.49523	0.917582	–0.32213	1

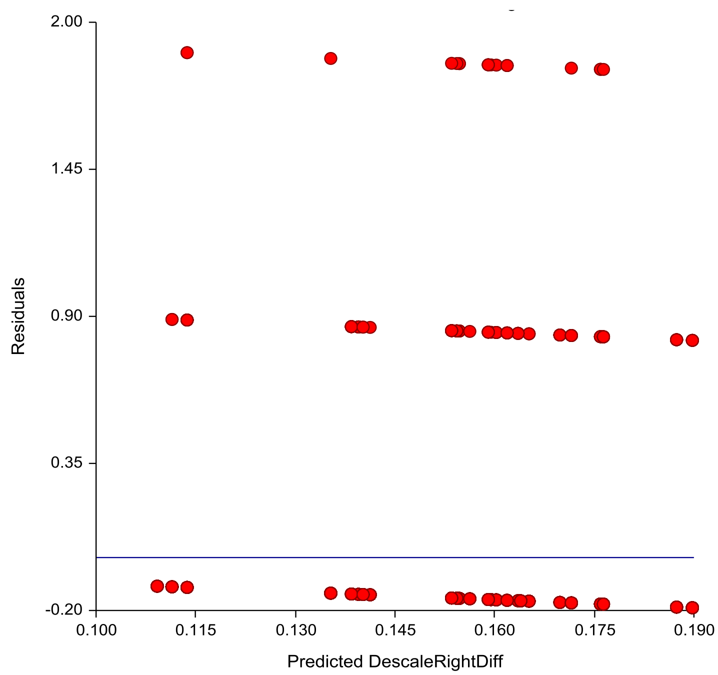


Figure 54. Poisson-model residuals versus predicted score for descaling on the right side for yearling Chinook salmon that passed through the 10-inch diameter orifice at Lower Granite Dam, spring 2013. An increasing score indicates greater severity of descaling.

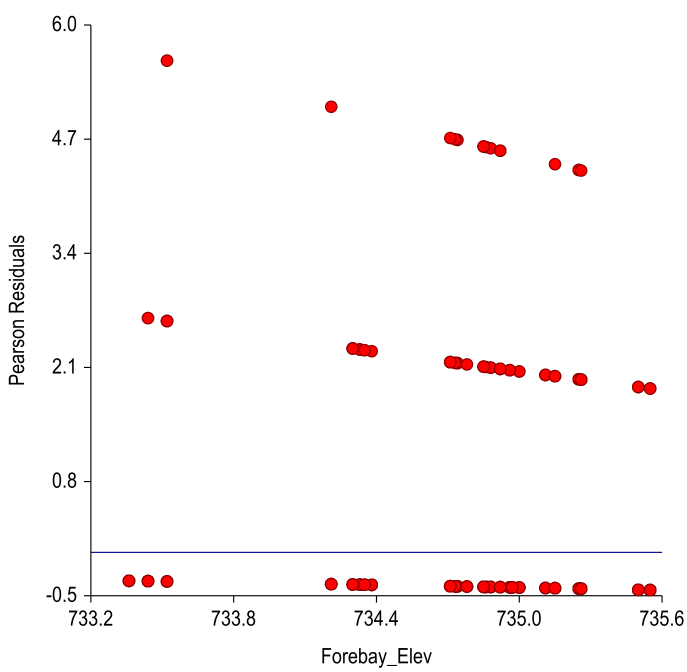


Figure 55. Poisson-model Pearson residuals versus forebay elevation for yearling Chinook salmon that passed through the 10-inch diameter orifice at Lower Granite Dam, spring 2013.

Table 52. Poisson regression coefficients report and Pearson correlation matrix for yearling Chinook that passed through the broad-crested overflow weir at Lower Granite Dam, spring 2013. All highly correlated pairs of variables ($|r| > 0.5$) were excluded from the model.

Regression Coefficients Report						
Independent Variable	**Regression Coefficient *b*(*i*)**	**Standard Error *Sb*(*i*)**	**Wald's Chi² *H0*: *β* = 0**	**Prob. Level**	**Lower 95.0% Confidence Limit**	**Upper 95.0% Confidence Limit**
Intercept	–357.62854	137.5521	6.76	0.0093	–627.22571	–88.03137
Forebay Elev.	0.48445	0.1872	6.7	0.0097	0.11753	0.85136
Dispersion Phi		0.9754				

Pearson Correlations Section (Row-wise Deletion)					
	Julian Day	**Forebay Elev.**	**Unit 5 kcfs**	**Bypass Elev.**	**Temp.**
Julian Day	1	0.98955	–0.99504	0.924185	–0.88157
Forebay Elev.	0.98955	1	–0.99536	0.878146	–0.89918
Unit 5 kcfs	–0.99504	–0.99536	1	–0.91978	0.919706
Bypass Elev	0.924185	0.878146	–0.91978	1	–0.89219
Temp.	–0.88157	–0.89918	0.919706	–0.89219	1

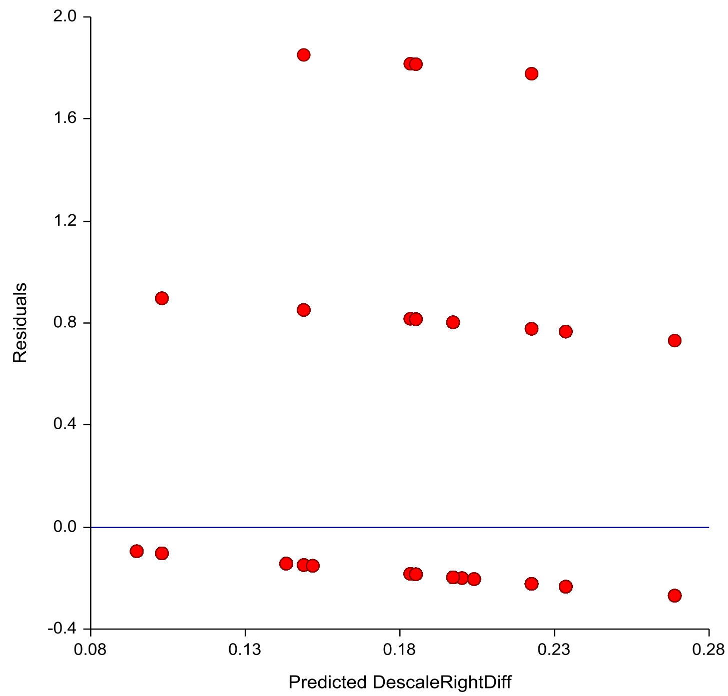


Figure 56. Poisson-model residuals versus predicted score for descaling on the right side for yearling Chinook salmon that passed through the broad-crested overflow weir at Lower Granite Dam, spring 2013. An increasing score indicates greater severity of descaling.

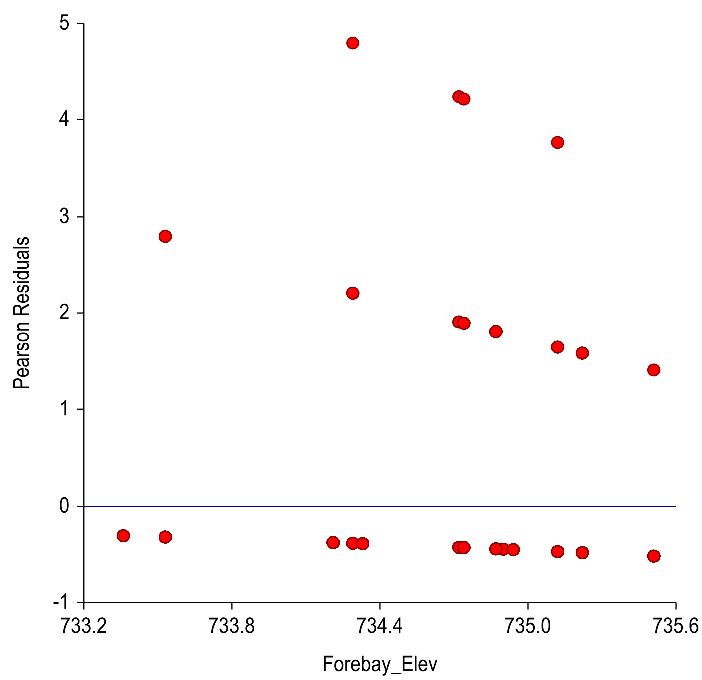


Figure 57. Poisson-model Pearson residuals versus forebay elevation for yearling Chinook salmon that passed through the broad-crested overflow weir at Lower Granite Dam, spring 2013.

Table 53. Poisson regression coefficients report and Pearson correlation matrix for yearling Chinook that passed through the 14-inch diameter orifice at Lower Granite Dam, spring 2013. All highly correlated pairs of variables (|*r*| > 0.5) were excluded from the model.

Regression Coefficients Report						
Independent Variable	**Regression Coefficient *b*(*i*)**	**Standard Error *Sb*(*i*)**	**Wald's Chi² H0: *β* = 0**	**Prob. Level**	**Lower 95.0% Confidence Limit**	**Upper 95.0% Confidence Limit**
Intercept	0.96289	1.2777	0.57	0.4511	–1.54135	3.46713
RT_h	–0.60959	0.24633	6.12	0.0133	–1.09239	–0.12679
Fork Length	–0.02047	0.00964	4.51	0.0337	–0.03936	–0.00158
Dispersion Phi		1.0752				

Pearson Correlations Section (Row-wise Deletion)					
	Julian Day	**Forebay Elev.**	**Unit 5 kcfs**	**Bypass Elev.**	**Temp.**
Julian Day	1	0.855138	0.33103	–0.92155	–0.92721
Forebay Elev.	0.855138	1	–0.2061	–0.58678	–0.98706
Unit 5 kcfs	0.33103	–0.2061	1	–0.67143	0.046504
Bypass Elev	–0.92155	–0.58678	–0.67143	1	0.709043
Temp.	–0.92721	–0.98706	0.046504	0.709043	1

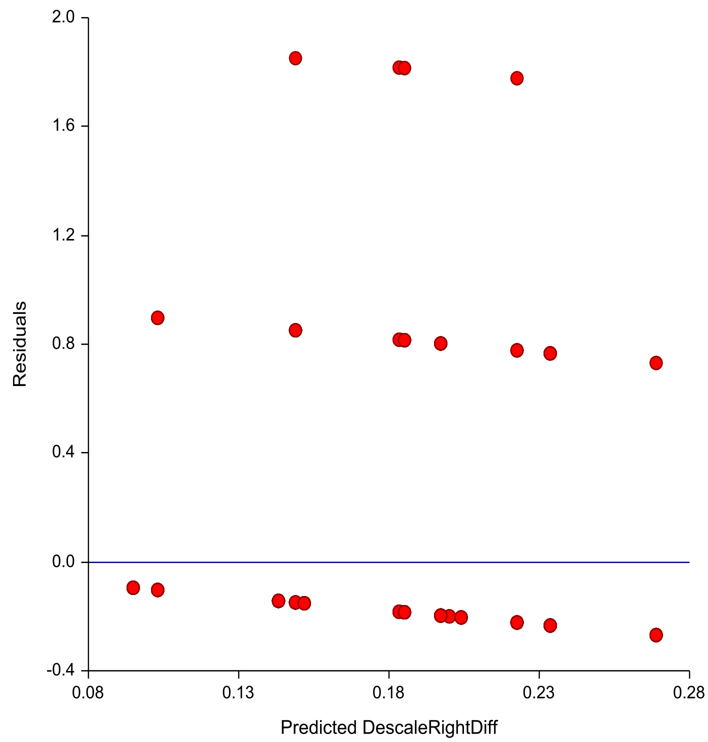


Figure 58. Poisson-model residuals versus predicted score for descaling on the right side for yearling Chinook salmon that passed through the 14-inch diameter orifice at Lower Granite Dam, spring 2013. An increasing score indicates greater severity of descaling.

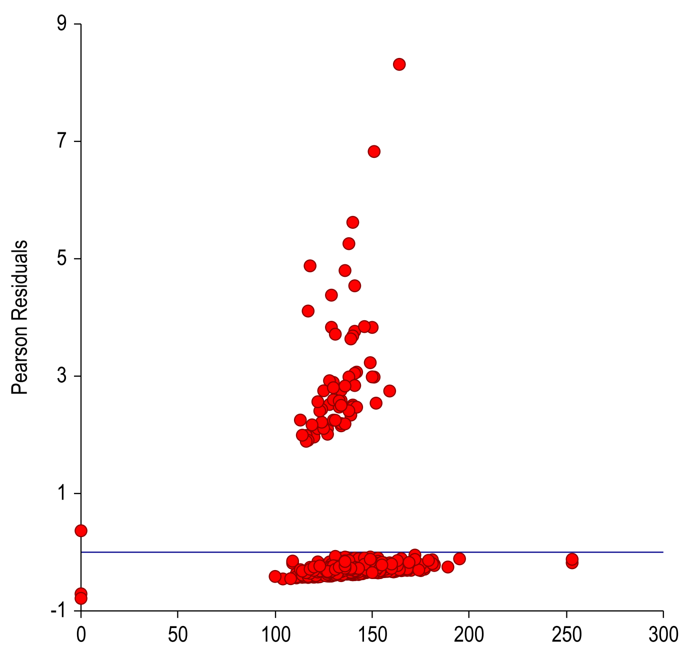


Figure 59. Poisson-model Pearson residuals versus fork length (mm) for yearling Chinook salmon that passed through the 14-inch diameter orifice at Lower Granite Dam, spring 2013.

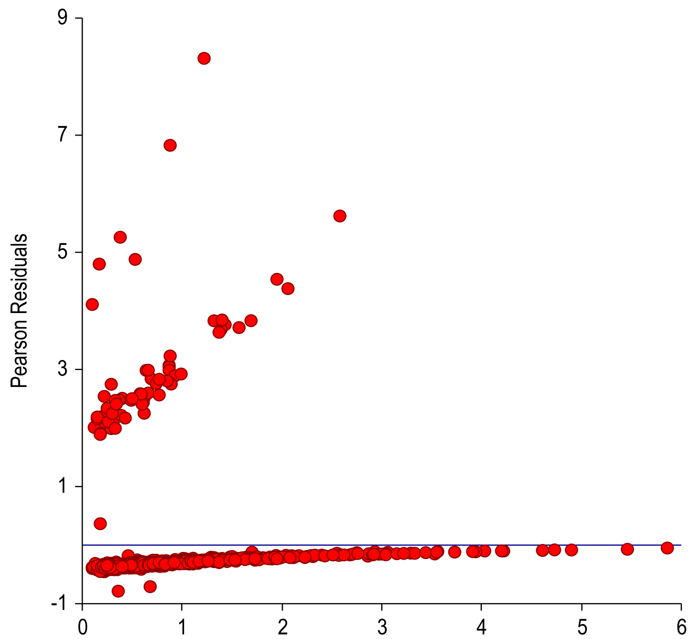


Figure 60. Poisson-model Pearson residuals versus travel time (h) for yearling Chinook salmon that passed through the 14-inch diameter orifice at Lower Granite Dam, spring 2013.