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Factors Affecting Route Selection and Survival of Steelhead Kelts at Snake River Dams in 2012 and 2013

March 2015

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U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
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Richland, Washington 99352

Abstract

In 2012 and 2013, Pacific Northwest National Laboratory (PNNL) conducted a study that summarized the passage route proportions and route-specific survival rates of steelhead kelts that passed through Federal Columbia River Power System (FCRPS) dams. To accomplish this, a total of 811 steelhead kelts were tagged with Juvenile Salmon Acoustic Telemetry System (JSATS) transmitters. Acoustic receivers, both autonomous and cabled, were deployed throughout the FCRPS to monitor the downstream movements of tagged kelts. Kelts were also tagged with passive integrated transponder tags to monitor passage through juvenile bypass systems (JBS) and detect returning fish. The current study evaluated data collected in 2012 and 2013 to identify environmental, temporal, operational, individual, and behavioral variables that were related to forebay residence time, route of passage, and survival of steelhead kelts at FCRPS dams on the Snake River. Multiple approaches, including 3-D tracking, bivariate and multivariable regression modeling, and decision tree analyses were used to identify the environmental, temporal, operational, individual, and behavioral variables that had the greatest effect on forebay residence time, route of passage, and route-specific and overall dam passage survival probabilities for tagged kelts at Lower Granite (LGR), Little Goose (LGS), and Lower Monumental (LMN) dams. In general, kelt behavior and discharge appeared to work independently to affect forebay residence times. Kelt behavior, primarily approach location, migration depth, and "searching" activities in the forebay, was found to have the greatest influence on their route of passage. The condition of kelts was the single most important factor affecting their survival. The information gathered in this study may be used by dam operators and fisheries managers to identify potential management actions to improve in-river survival of kelts or collection methods for kelt reconditioning programs to aid the recovery of Snake River steelhead populations.

Summary

Steelhead (*Oncorhynchus mykiss*) populations in the Columbia River basin have declined throughout the last century. Snake River steelhead are among the declining populations, and are currently listed as threatened under the Endangered Species Act of 1973. In response to these declines, the 2008 Biological Opinion (BiOp) calls for an increase in Snake River female steelhead abundance through an increase in iteroparity rates, with a focus on B-run fish. Increases in iteroparity rates may be realized through a combination of in-river survival and reconditioning. The goal of this study was to extract additional information from the acoustic telemetry data collected in 2012 and 2013 to improve the understanding of the factors (environmental, temporal, operational, individual, and behavioral) that influenced forebay residence time, route selection, and survival of steelhead kelts. These data may be used to inform managers and dam operators of potential ways to increase the survival of kelts during their seaward migrations. These data may also be helpful in identifying ways to increase the number of kelts collected for the reconditioning program.

Objectives

This report presents the results of several data mining tasks that were designed to help provide a better understanding of the factors that influence the forebay residence time, route selection, and survival of steelhead kelts through Lower Granite (LGR), Little Goose (LGS), and Lower Monumental (LMN) dams. The objectives were as follows:

- Estimate dam passage and route-specific survival probabilities at LGR, LGS, and LMN (pooling data across years).
- Examine the relationship between route of passage and environmental, temporal, operational, individual, and behavioral covariates.
- Examine the relationship between steelhead kelt survival and environmental, temporal, operational, individual, and behavioral covariates.
- Examine the relationship between forebay residence time and environmental, temporal, operational, individual, and behavioral covariates.

Methods

Acoustic telemetry studies were conducted in the lower Snake and Columbia rivers in 2012 and 2013. A total of 811 steelhead kelts were tagged with Juvenile Salmon Acoustic Telemetry System (JSATS) transmitters and passive integrated transponder (PIT) tags to monitor their downstream migration and any upstream migration of returning fish. Fish were captured, tagged, and released in tributaries of the lower Snake River, upstream of LGR, and at the LGR juvenile fish facility. Cabled receiver arrays were deployed on the upstream dam face of LGR, LGS, and LMN to record the three-dimensional (3-D) behavior of the fish in the forebay of the dams and to identify the route of passage. Autonomous receiver arrays were deployed throughout the lower Snake and Columbia rivers and were used to estimate survival using the single-release mark-recapture model.

Likelihood ratio tests were conducted to determine whether or not overall and route-specific dam passage survival estimates differed significantly between years (2012 and 2013) at LGR, LGS, and LMN. If similar, survival data was pooled across years. This was done to increase the precision of the survival estimates and provide a better indication of survival over a range of environmental and operational conditions.

The effect of multiple environmental, temporal, operational, individual, and behavioral factors on forebay residence time, passage route, overall survival, and route-specific survival was evaluated using bivariate and multivariable regression modeling. Environmental factors included forebay and tailrace water temperatures, total dissolved gas (TDG) %, and total discharge. Temporal variables included the ordinal day of dam passage, and the diel period during forebay entrance and dam passage. Operational factors included such variables as the percent of discharge through each turbine unit and spill bay at the time of passage as well as the percent spill. Individual characteristics used in the models included fork length, condition (good or fair), and relative condition factor (weight to length relationship). Behavioral variables were primarily estimated from 3-D tracking of tagged kelts in the forebay of each dam (LGR, LGS, and LMN) that was equipped with cabled receiver arrays. Kelt behaviors included such variables as acclimation depth in the forebay, cross-sectional approach location, near-dam horizontal "searching" activity, forebay horizontal and vertical "searching" activity, and tailrace egress time. Bayesian model-averaging and decision tree analyses were used to identify the factors that best explained forebay residence time, route of passage, overall survival, and route-specific survival of tagged kelts at LGR, LGS, and LMN in 2012 and 2013.

Results

The variability in overall dam passage survival estimates (i.e., all routes combined) was substantial enough that the survival estimates could not be pooled across years at any of the three dams to increase precision. However, survival estimates for the turbine and traditional (deep) spill routes were similar enough to be pooled across 2012 and 2013 at LGR, LGS, and LMN. Additionally, survival estimates for the juvenile bypass system (JBS) were pooled for LGS and LMN, as well as the spillway weir survival estimates at LGS. Pooling estimates across years indicated JBS survival was 0.93 (standard error = 0.04) at LGS and 0.97 (0.03) at LMN; turbine survival was 0.90 (0.09) at LGR, 0.82 (0.07) at LGS, and 0.74 (0.08) at LMN; spillway weir survival was 0.95 (0.01) at LGS; and traditional spill survival was 0.84 (0.05) at LGR and 0.88 (0.03) at both LGS and LMN.

Kelt behavior and discharge worked independently to influence forebay residence times. Kelts that took a more direct path to their passage route and those that passed at higher discharges had lower residence times. Generally, the behavior (approach location, depth, and "searching" behavior) of kelts in the forebay appeared to have the greatest influence on their route of passage. About 67% to 72% of kelts passed the dams over the spillway weirs during the two-year study. The majority of kelts were acclimated to depths shallower than 5 m, which greatly contributed to the high spillway weir passage probabilities observed. Model results indicated shallower-migrating kelts had a higher probability of passing via the spillway weirs and deeper migrating kelts had a higher probability of passing via the powerhouse routes (JBS and turbines). Kelts that displayed a higher level of horizontal "searching" behavior, but lower levels of vertical "searching," had a greater probability of passing via the spillway weirs. The opposite was true of kelts that passed through the powerhouse routes. Kelts that passed through traditional (deep) spill bays generally displayed the lowest levels of "searching" behavior. The side of the river in which kelts approached the dam also affected route of passage. Kelts that passed through the powerhouse were generally first detected approaching the dams in front of the powerhouse and those that passed via traditional spill bays were most commonly first detected approaching in front of the spillway. Kelts that passed over the spillway weirs were drawn to the weir from both sides of the forebay; however, they were most commonly first detected in front of the powerhouse. Dam operations, which are often directly related to discharge levels, also affected the passage routes used by kelts. In particular, higher spill percentages through traditional (deep) spill bays resulted in a higher proportion of kelts passing through those bays at LGR and LMN and higher spill percentages caused a reduction in JBS passage probability at LMN. Individual characteristics, such as fish length, were also found to affect passage routes. Smaller kelts had a higher probability of passing through the JBS at LGR than larger kelts, and a similar, although less pronounced, relationship was observed at LGS and LMN. An evaluation of depth by time and distance prior to passage revealed that most kelts that passed the powerhouse approached the dam faces near the surface where they lingered prior to making their descent to the turbine intakes.

The condition of kelts appeared to be the single most important factor affecting their survival probability during dam passage and tailrace egress. Kelts determined to be in good condition at the time of tagging had a higher probability of survival than fair condition kelts at LGR and LGS and kelts with a higher relative condition factor had a higher probability of survival at LMN than those with a lower relative condition factor. The size of kelts also affected their probability of survival at LGS and LMN where smaller kelts had a higher probability of survival than larger kelts. Relatively few instances were found where dam operations were significantly correlated with survival. The proportion of flow through turbine unit 6 was positively correlated with kelt survival at LGR and kelts that passed LGS when the spillway weir crest was in the low position had a higher survival probability than those that passed the dam at similar discharges when the crest was in the high position. The behavior of kelts in the tailrace of LGR was found to significantly affect their survival probability with those that had lower egress times having higher survival.

Conclusions

The results obtained from this study indicate the behavior of kelts in the forebay of LGR, LGS, and LMN may have the greatest influence on their ultimate route of passage. The migration depth of kelts in the forebay, the side of the forebay in which they approached the dams, and the extent of their horizontal and vertical movements were the primary factors that affected route of passage. The majority of kelts migrated near the surface, which contributed to the high probabilities of spillway weir passage at the three dams. The weirs appeared to draw surface-oriented kelts from the entire width of the forebay. However, those detected in front of the powerhouse had a higher probability of spillway weir passage than those detected in front of the spillway. Kelts that approached the dams in front of the powerhouse displayed a high degree of “searching” behavior, indicating their route selection was more active. The majority of these fish moved or “searched” horizontally, which led to their passage over the spillway weir. Kelts that approached the powerhouse near the surface that did not display a horizontal “searching” behavior eventually undertook a vertical migration to their passage through the powerhouse. Kelts that approached the dams in front of the spillway had a much higher probability of passing through the traditional spill bays than kelts detected approaching in front of the powerhouse. In addition, kelts that passed through traditional spill bays generally displayed less “searching” behavior, indicating their route selection was more passive and occurred farther upstream than was observed for kelts that passed through the other routes. Kelts that were acclimated to deeper depths had a higher probability of passing through one of the powerhouse routes (JBS or turbine).

The dam operations that were identified as being linked to route of passage were generally associated with discharge, and therefore provide relatively little opportunity for operational alterations to intentionally route kelts to specific apertures. However, the current configurations are routing the majority of kelts to the spillway weirs where survival probability is generally highest. Therefore, there is little need to redistribute kelts among the various passage routes unless the goal is to route more kelts to the JBS for reconditioning. Given the surface orientation of the majority of kelts, it may not be possible to route additional fish to the JBS even if desired.

Smaller kelts appear to be more likely to enter the JBS than larger kelts at LGR and perhaps at LGS and LMN as well. This finding has implications for the kelt reconditioning program. In 2012 and 2013, kelts were only collected from the JBS of LGR for reconditioning. If, in fact, the LGR JBS primarily collects smaller kelts, the extent of the reconditioning program as it was implemented during our study may be insufficient to meet the BiOp goal of increasing the abundance of larger B-run Snake River steelhead. In order to collect sufficient numbers of the larger-bodied B-run steelhead kelts for reconditioning, it may be necessary to expand the collection of kelts to the tributary weirs where larger fish may be specifically targeted.

Survival of kelts appeared to be most influenced by their individual characteristics. Specifically, kelts determined to be in good condition at the time of tagging had a higher probability of dam passage survival than those in fair condition. Additionally, smaller kelts had a higher probability of dam passage survival than larger kelts. These results have implications for which kelts should be retained for reconditioning. Although kelts in good condition at the time of capture have a higher probability of surviving the reconditioning process, they also have higher probabilities of in-river survival and repeat spawning, whereas kelts in fair and poor condition have very low probabilities. Reconditioning may be the only hope for fair and poor condition fish to contribute to the population as repeat spawners. Although condition (i.e., good vs. fair) was not a significant predictor of survival at LMN, relative condition factor was positively correlated with survival. These results indicate kelts that had more significant wounds, fungus, or injuries may have been culled in upstream reaches. Those that survived to LMN then had a higher probability of surviving if they had more substantial lipid reserves from which to draw for energy.

Multivariable modeling results did not reveal any strong, direct effects of environmental variables on passage route selection or dam passage survival of kelts. However, discharge indirectly affected route of passage and survival through its interaction with dam operations. Because operations are linked tightly to discharge it was often difficult to discern the true mechanism behind the observed correlations. Discharge, combined with kelt behavior, was found to have a direct correlation with forebay residence times. Kelts that entered the forebays at higher discharges generally had lower forebay residence times. However, the extent of their horizontal and vertical movements, which occurred independent of discharge, also affected forebay residence times with kelts displaying higher levels of this "searching" behavior having longer residence times. It is also expected that kelts passing at higher discharges would have shorter tailrace egress times. As observed at LGR, tailrace egress time can affect survival. Surprisingly, tailrace water temperature was not correlated with survival in any of the models.

The results of this study support the current and proposed plans for managing Snake River steelhead kelts as outlined in the Kelt Management Plan. Due to the low iteroparity rates that have been observed for kelts that migrate in-river, even after the installation of surface routes at FCRPS dams, reconditioning likely presents an option that is necessary to aid in achieving the BiOp goal. As mentioned, the collection of kelts was restricted during the study period to the JBS at LGR, which had the lowest JBS passage probability over the two years. Therefore, our results support the expansion of reconditioning collection efforts to the JBS of LGS and LMN. Additionally, it appeared that smaller kelts were more likely to pass through the JBS at the three dams than larger kelts and larger kelts were less likely to survive dam passage than smaller kelts. Due to the tendency of the JBS to collect smaller kelts and the lower observed survival of larger fish, our results also support the need to expand the collection of kelts for reconditioning to the tributary weirs in order to increase the collection of the larger B-run kelts. Finally, the low survival probabilities observed for fair condition kelts indicate these fish should also be retained for reconditioning as long as space exists at the hatchery reconditioning facilities to provide them with a greater opportunity of survival to repeat spawn. Even with the expansion of collection efforts, the majority of kelts will continue to migrate in-river. The operations used at LGR, LGS, and LMN during the study effectively routed the large majority of kelts to the spillway weirs where dam passage survival was generally the highest.

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Acronyms and Abbreviations

3-D	Three-dimensional
AML	Approximate maximum likelihood
BIC	Bayesian Information Criterion
BMA	Bayesian model-averaging
FCRPS	Federal Columbia River Power System
FL	Fork Length
IHR	Ice Harbor Dam
IQR	Interquartile range
JBS	Juvenile bypass system
JSATS	Juvenile Salmon Acoustic Telemetry System
LGR	Lower Granite Dam
LGS	Little Goose Dam
LMN	Lower Monumental Dam
PIT	Passive integrated transponder
PNNL	Pacific Northwest National Laboratory
PRI	Pulse repetition interval
RSW	Removable spillway weir
SNR	Signal-to-noise ratios
TDG	Total dissolved gas
TMT	Technical Management Team
TSW	Temporary spillway weir
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

This report documents the results of data analyses conducted on two years (2012 and 2013) of a steelhead kelt migration and Federal Columbia River Power System (FCRPS) dam passage study conducted by Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers (USACE), Walla Walla District. The goal of this study was to extract additional information from the acoustic telemetry data collected in 2012 and 2013 to improve the understanding of the factors (environmental, temporal, operational, behavioral, and individual) that influence route selection and survival of steelhead kelts. These data may be used to inform managers and dam operators of potential ways to increase the survival of kelts during their seaward migrations. These data may also be helpful in identifying ways to increase the number of kelts collected in juvenile bypass systems (JBS) for the reconditioning program.

1.1 Background

Steelhead (*Oncorhynchus mykiss*) populations within the Pacific Northwest of the United States have declined over the past several decades. As a result, several stocks, including those from the Snake River basin, have been listed for protection under the Endangered Species Act of 1973 (McClure et al. 2003; NMFS 2004). Reasons for the population declines are numerous and complex, including overharvest, habitat loss and degradation, failed hatchery supplementation practices, predation, and various effects of passage through hydroelectric facilities (Lichatowich 2001; Budy et al. 2002; McClure et al. 2003; Brannon et al. 2004). Reasonable and Prudent Alternative (RPA) 33 of the 2008 Biological Opinion (BiOp) calls for an increase in the abundance of female Snake River steelhead through an increase in iteroparity (repeat spawning) rates. The BiOp recognizes that increases in iteroparity rates can be realized through a combination of reconditioning and in-river survival of kelts (post-spawn steelhead). Understanding the variables important for improving iteroparity rates is critical for helping to manage the population and potentially contribute to population recovery.

Steelhead are unique to other Pacific salmon, as they can exhibit an iteroparous life history strategy. Post-spawn steelhead can migrate downstream to the ocean where they can rebuild their energy stores in an attempt to return to freshwater in future months to spawn again (Busby et al. 1996). A recent study estimated that annual iteroparity rates for Snake River steelhead range from 0.5 to 1.2% (Keefer et al. 2008), which is lower than pre-dam estimates (2%; Long and Griffin 1937). Similarly, Colotelo et al. (2014) reported that 1.2% and 0.2% of the kelts that were tagged in 2012 and 2013, respectively, were detected at the Bonneville Dam adult fish ladder during upstream migrations. Iteroparity is thought to be a crucial step in rebuilding steelhead populations, as fish can have multiple spawning opportunities in their lifetime, which can result in increased lifetime fitness (Fleming and Reynolds 2004). The results of these studies suggest that there is a need to investigate the factors that affect survival, and ultimately iteroparity rates, of Snake River kelts that migrate downstream through the river.

In 2012 and 2013, acoustic telemetry studies were conducted in the lower Snake and Columbia rivers to measure the proportion of steelhead kelts that pass through the available routes at hydroelectric dams (e.g., spillway weir, traditional (deep) spill, JBS, turbines, sluiceway) during their downstream migration through the FCRPS (Colotelo et al. 2013, 2014). These studies also estimated overall dam, route-specific, and reach survivals. The results of these studies showed that most kelts passed via the spillway weirs, if available, and survival was generally higher for kelts that passed these routes. Comparatively, few fish passed through the powerhouse routes (i.e., JBS, turbines), and survival tended to be lower for these fish. The results of these studies are important for understanding how steelhead kelts pass through hydroelectric dams; however, further analysis is needed to understand the variables (i.e., environmental, temporal, operational, behavioral, individual) that influence route selection and survival of kelts in the FCRPS. This information can be used by dam operators and fisheries managers to adaptively manage the configuration and operation of FCRPS dams to maximize kelt survival, and potentially iteroparity rates.

1.2 Research Objectives

The overall goal of this study was to define the relationships between environmental, temporal, operational, individual, and behavioral variables and steelhead kelt route selection and survival through the FCRPS. The specific objectives were as follows:

- Estimate dam passage and route-specific survival probabilities at FCRPS dams (pooling data across years).
- Examine the relationship between route of passage and environmental, temporal, operational, individual, and behavioral covariates.
- Examine the relationships between kelt survival and environmental, termporal, operational, individual, and behavioral covariates.
- Examine the relationship between forebay residence time and environmental, temporal, operational, individual, and behavioral covariates.

1.3 Report Contents

The ensuing sections of this report present the methods (Section 2.0), results (Section 3.0), and discussion and conclusion (Section 4.0). Sources cited in the text may be found in Section 5.0. Appendix A contains the results of bivariate and multivariable logistic regression modeling.

2.0 Methods

The layout of the various dam passage routes, the data sources for environmental, operational, behavioral, and individual fish conditions, and the statistical procedures used to identify the factors that affected route of passage and survival of acoustic-tagged steelhead kelts at LGR, LGS, and LMN in 2012 and 2013 are described below.

2.1 Dam Structure Description

2.1.1 Lower Granite Dam

Normal pool elevation at LGR is 224.9 m, the spillway weir crest elevation is 220.4 m, the spillway crest elevation of traditional spill bays is 207.6 m, the turbine intake ceiling elevation is 205.1 m, the elevation of the bottom end of the turbine intake screens is 187.0 m, and the turbine intake floor elevation is 182.0 m (Figure 2.1). Therefore, at normal pool elevation, the entrance of the spillway weir is positioned 0 m to 4.5 m below the water surface; the entrance of traditional spill bays depends on the position of the spill gate, and extends down to ~17 m below the water surface; the entrance into the turbine intake is positioned ~20 m to ~43 m below the water surface. The turbine intake screens, which extend down from the intake ceiling, are designed to intercept fish at depths of ~20 m to ~38 m below the water surface from entering the turbines, instead routing them to the JBS. Thus, the entrance to the turbines is positioned ~38 m to ~43 m below the water surface.

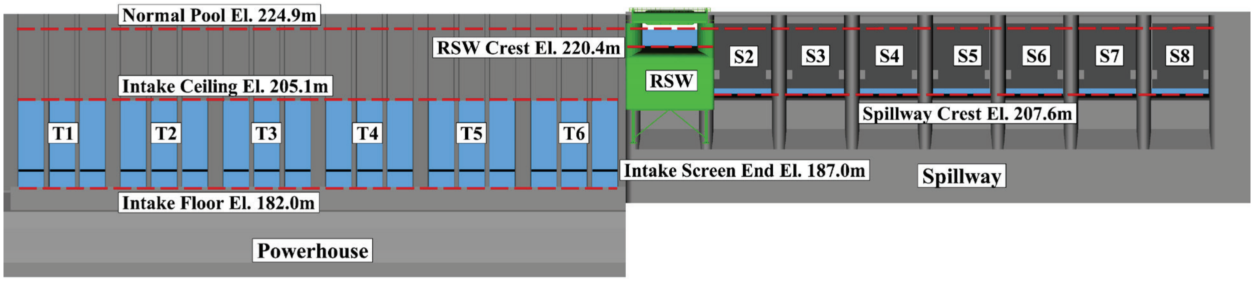

Figure 2.1. View of the upstream face of Lower Granite Dam, displaying normal pool elevation, and the elevations of the removable spillway weir (RSW) crest, traditional spillway crest, turbine intake ceiling, lower end of the turbine intake screens, and turbine intake floor. The numbering scheme of each turbine unit (T) and spill bay (S) and the location of the RSW in spill bay 1 are also displayed.

2.1.2 Little Goose Dam

Normal pool elevation at LGS is 194.5 m, the spillway weir crest elevation is 188.4 m while in "low" position and 189.6 m while in the "high" position, the spillway crest elevation of traditional spill bays is 177.1 m, the turbine intake ceiling elevation is 175.3 m, the elevation of the bottom end of the turbine intake screens is 157.1 m, and the turbine intake floor elevation is 152.2 m (Figure 2.2). Therefore, at normal pool elevation, the entrance of the spillway weir is positioned 0 m to 6.1 m below the water surface while the crest is in the low position, and 0 m to 4.9 m when the crest is in the low position; the entrance of traditional spill bays depends on the position of the spill gate, and extends down to ~17 m below the water surface. The entrance into the turbine intake is positioned ~19 m to ~42 m below the water surface. The turbine intake screens, which extend down from the intake ceiling, are designed to intercept fish at depths of ~19 m to ~37 m below the water surface from entering the turbines, instead routing them to the JBS. Thus, the entrance to the turbines is positioned ~37 m to ~42 m below the water surface.

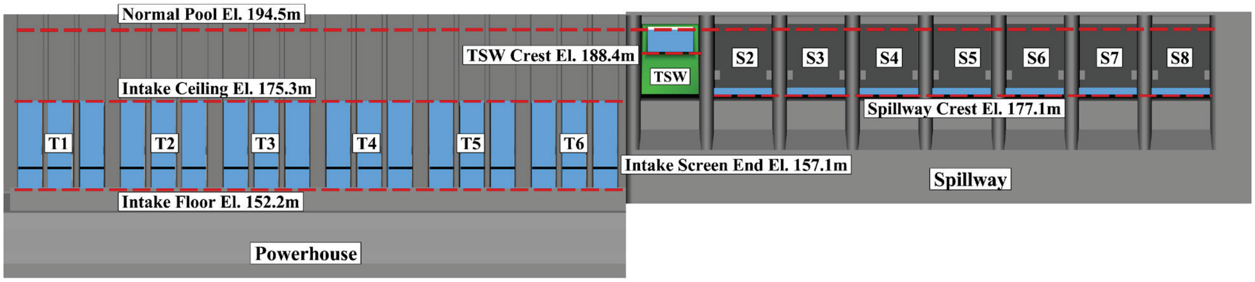

Figure 2.2. View of the upstream face of Little Goose Dam, displaying normal pool elevation, and the elevations of the temporary spillway weir (TSW) crest, traditional spillway crest, turbine intake ceiling, lower end of the turbine intake screens, and turbine intake floor. The numbering scheme of each turbine unit (T) and spill bay (S) and the location of the TSW in spill bay 1 are also displayed.

2.1.3 Lower Monumental Dam

Normal pool elevation at LMN is 164.6 m, the spillway weir crest elevation is 160.0 m, the spillway crest elevation of traditional spill bays is 147.2 m, the turbine intake ceiling elevation is 145.4 m, the elevation of the bottom end of the turbine intake screens is 130.4 m, and the turbine intake floor elevation is 122.3 m (Figure 2.3). Therefore, at normal pool elevation, the entrance of the spillway weir is positioned 0 m to 4.6 m below the water surface, the entrance of traditional spill bays depends on the position of the spill gate and extends down to ~17 m below the water surface, and the entrance into the turbine intake is positioned ~19 m to ~42 m below the water surface. The turbine intake screens, which extend down from the intake ceiling, are designed to intercept fish at depths of ~19 m to ~34 m below the water surface from entering the turbines instead routing them to the JBS. Thus, the entrance to the turbines is positioned ~34 m to ~42 m below the water surface.

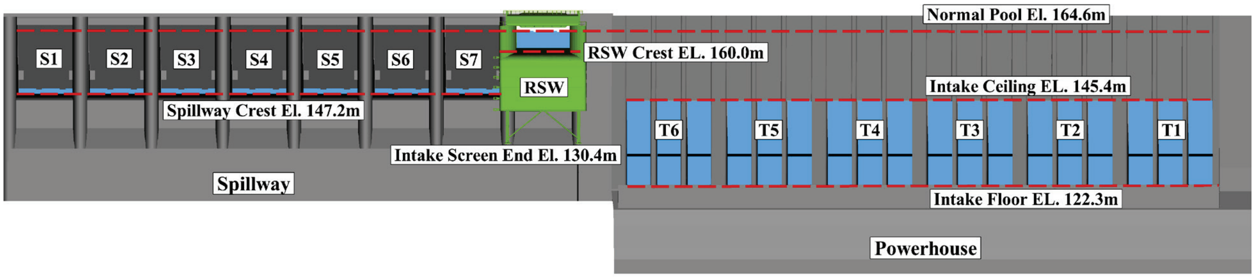

Figure 2.3. View of the upstream face of Lower Monumental Dam, displaying normal pool elevation, and the elevations of the removable spillway weir (RSW) crest, traditional spillway crest, turbine intake ceiling, lower end of the turbine intake screens, and turbine intake floor. The numbering scheme of each turbine unit (T) and spill bay (S) and the location of the RSW in spill bay 8 are also displayed.

2.2 Dam Passage and Route-Specific Survival Probabilities Pooled Across Years

Colotelo et al. (2013, 2014) used a virtual single-release study design to estimate dam passage survival, both overall and route-specific, from the dam faces of LGR, LGS, and LMN to an autonomous receiver array located 27 to 59 km downstream of the dam. Virtual releases are groupings of fish based on detection at a similar location independent of when or where those fish were released and were formed at cabled arrays deployed on each dam face. For route-specific survival estimates, virtual release groups consisted of all fish that passed through the same route at a specific dam (i.e., spillway weir, traditional spillway, juvenile bypass system, turbines). Likelihood ratio tests were conducted to determine whether or not overall and route-specific dam passage survival estimates differed significantly between years (2012 and 2013) at LGR, LGS, and LMN. Estimates determined to be similar among years were pooled to provide more precise estimates of survival.

2.3 Analysis of 3D Acoustic Telemetry Data

Detections on the cabled receiver arrays that were located on LGR, LGS, and LMN in 2012 and 2013 were processed according to the methods outlined in Colotelo et al. (2013, 2014). The output of this process was a data set of events that included accepted tag detections for all times and locations where receivers were operating. Each unique event record included a basic set of fields that indicated the unique identification number of the fish, the first and last detection time for the event, the location of detection, and the number of messages detected within the event.

2.3.1 Three-Dimensional Localization

An approximate maximum likelihood (AML) solver (Li et al. 2014) was used for 3-D tracking of tagged fish as they approached and passed each cabled receiver array. It was expanded from the two-dimensional AML method developed by Chan et al. (2006). The AML solver is different from exact solvers (Spiesberger and Fristrup 1990; Wahlberg et al. 2001; Bucher and Misra 2002) in that it was developed based on the maximum likelihood method and can solve nonlinear localization equations considering the influence from measurement noise. Because accuracy was our priority, maximum likelihood methods were optimum in the sense that its estimation performance can asymptotically attain the highest accuracy, especially when there are more than four hydrophones detecting the same transmission. This robust 3-D AML solver can accurately and efficiently estimate the time sequence of locations of fish tagged with Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic transmitters.

2.3.2 Data Filtering and Interpolation

Because of the uncertainties associated with field environments, the AML tracking results could be affected by many factors, including hydrophone locations, river temperature, temperature gradients, tag transmission signal-to-noise ratios (SNRs), and tag transmission multipath propagation. Occasionally, some tracked points could have large errors and some points could even be physically impossible. Additional quality-control steps were added to filter out potential tracking results with large errors.

Step 1: Track Segmentation. Track segmentation was implemented by first applying a pulse repetition interval (PRI) filter to each tracked location. A tracked location could only pass a PRI filter when there were at least 6 tracked locations within a 12 PRI time window and the time interval between every 2 tracked locations was N times the nominal PRI, where $N = 1,2,3\ldots12$. The PRI of transmitters used in this study was 4.2 sec, so the PRI time window was 50.4 sec (4.2 sec nominal PRI × 12 = 50.4 sec). After applying the PRI filter, sporadic tracked locations that were not continuous in terms of time were removed. A fish track could then be separated into one or more segments based on location continuities. Tracked locations within each segment were continuous in terms of time, and every two consecutive segments were more than eight times the nominal PRI apart. Since the PRI of transmitters used in this study was 4.2 sec, every 2 consecutive segments were more than 33.6 sec apart (i.e., 4.2 sec [PRI] x 8 = 33.6 sec).

Step 2: Swim-Speed Filter. A swimming speed filter was applied to remove erroneous tracked points. The maximum swimming speed was assumed to be nine times the fork length (FL) per second and was specific to each fish (Puckett and Dill 1984). For each tracked point, the swimming speeds to that point from the fish's previous tracked point and to the fish's next tracked point were calculated. If both speeds were faster than the maximum fish speed (9 FL/s), the tracked point was removed.

Step 3: Interpolation. A linear interpolation method was applied to interpolate locations between every two consecutive tracked locations in each segment if there were missing transmissions. Interpolation was performed along the X, Y, and Z directions independently, where X represents the upstream distance of the tag from the dam, Y represents the cross-sectional location of the tag across the width of the river, and Z represents the depth of the tag. After the interpolation, each tracked location represented a time period of the nominal PRI (4.2 sec).

2.3.3 Spatial Distribution and Route-Specific Passage Probability by Forebay Location

The 3-D locations of tracked kelts were used to create contour maps for each dam that described the spatial distribution of kelts in the forebay and route-specific passage probabilities by forebay location.

The data used to create the maps was limited to detections of kelts that occurred within 150 m of the dam. Within this area, the forebay was divided into 5 m × 5 m × 5 m cells. The total number of kelts that were tracked in each cell was enumerated. Each kelt was only counted once in each cell, regardless of how many times the fish was tracked within it. Spatial distributions were displayed as the density of kelts counted in each cell at four different depths. In the contour maps, "Depth = 0" indicates the depth range of 0–2.5 m, "Depth = 5 m" indicates the depth range of 2.5–7.5 m, "Depth = 10 m" indicates the depth range of 7.5–12.5 m, and "Depth = 15 m" indicates the depth range of 12.5–17.5 m.

Route-specific passage probabilities were calculated for each cell by dividing the number of kelts detected in the cell that passed a specific route by the total number of kelts detected in the cell. For example, if 67 kelts were detected in a cell, and 36 of those passed via the spillway weir, 10 through traditional spill bays, and 21 through the powerhouse, the route-specific passage probabilities would be calculated as 36/67 = 0.54 for the spillway weir, 10/67 = 0.15 for traditional spill, and 21/67 = 0.31 for the powerhouse. At least two kelts were required to be detected in a cell to calculate route-specific passage probabilities. If only one kelt was detected in a cell, the cell was displayed as having no data. Both powerhouse routes (JBS and turbines) were combined for this analysis due to the small sample of kelts that passed through these routes.

The depth distribution of kelts at various times and distances to passage were also evaluated by passage route using the tracked locations of kelts in the forebay of each dam. The median depth of each kelt was calculated from all tracked locations that were at a specified distance from the dam (X coordinate only) or time from passage (± a tolerance value). Five distance-to-the-dam values were selected: 0 m (± 0.5 m), 5 m (± 0.5 m), 10 m (± 1 m), 20 m (± 2 m), and 50 m (± 5 m). Five time-to-passage values were selected: 0 min (± 0.2 min), 2 min (± 0.2 min), 5 min (± 0.5 min), 10 min (± 1 min), and 20 min (± 2 min). For example, the median depth of a kelt 10 min prior to passage would be calculated from all tracked locations of that kelt that fell within the range of 9 min to 11 min prior to passage.

2.3.4 Selection Criteria for Acclimation Depth Analysis in Forebay

Although there is a large amount of information on the vertical distributions of fish in lakes and in the marine environment (Mehner 2012), we have not found studies that examined vertical distributions of fish near hydroelectric dams or techniques for defining 3-D telemetry data in terms of the depth distribution of individual fish in the forebay of a dam. With reliable 3-D tracking results and the associated tracking accuracy, the depth where fish could be neutrally buoyant (i.e., acclimated) can be estimated.

Based on results from controlled field testing (Deng et al. 2011) performed in 2012 and 2013, sub-meter tracking accuracy of individual fish locations can be achieved in the forebays of the dams when the horizontal distance-to-the-dam face is within 75 m. Therefore, only 3-D tracking data within 75 m of the dam face in the forebay at the three Snake River dams (LGR, LGS, and LMN) were included in the acclimation depth and depth distribution analyses.

Identification of the depth of acclimation (or neutral buoyancy) prior to dam passage using average depth can be biased by including depth measurements when fish are influenced by the flow velocities near the dam face. The simplest way to exclude the period when fish were influenced by the flow velocities near the dam is to set a horizontal distance limit. To establish this horizontal distance limit, a sensitivity analysis was performed from 0 m to 60 m from the dam face. The results of this analysis demonstrated that a horizontal distance of 20 m was sufficient to eliminate bias in the estimation of the depth of neutral buoyancy. Therefore, tracked points that were within 20 m of the dam face were excluded from the calculations of acclimation depth.

For an individual tagged fish, a representative depth value was needed to describe the depth where fish could be neutrally buoyant (i.e., acclimated). Because of the lack of knowledge regarding acclimation depth distributions (i.e., normal distribution, tailed distribution, or combinations of distributions), the mode depth, which represented the depth each kelt most frequently occupied, was used in this study. The mode depth was calculated for each fish based on all tracked locations that were a horizontal straight-line distance of 20 to 75 m from the dam face.

2.4 Factors Affecting Passage Routes, Survival, and Forebay Residence Time

This section defines the variables and analyses used to identify the factors that influenced route of passage and survival of acoustic-tagged steelhead kelts at LGR, LGS, and LMN in 2012 and 2013. All variables are summarized in Table 2.1.

Table 2.1. Descriptions of environmental, temporal, operational, individual, and behavioral variables used the regression models and the abbreviations used to describe each variable.

Category	Variable	Abbreviation	Units	Description
Environmental				
	Forebay total dissolved gas	FBTDG	%	Total dissolved gas percentage in the forebay of the dam
	Forebay temperature at 1.5 m	SurfTemp	°C	Water temperature at 1.5 m depth in the forebay
	Forebay temperature at 15 m	Temp15	°C	Water temperature at 15 m depth in the forebay
	Forebay temperature at 30 m	Temp30	°C	Water temperature at 30 m depth in the forebay
	Ratio of temperature at 1.5 m and 30 m	TempRatio	-	Ratio of water temperature at 1.5 m depth to 30 m depth
	Tailrace total dissolved gas	TRTDG	%	Total dissolved gas percentage in the tailrace of the dam
	Tailrace temperature	TRtemp	°C	Water temperature in the tailrace of the dam
	Total discharge	Discharge	kcfs	Total discharge through dam
Temporal				
	Day of passage	PassDay	-	Ordinal day (365 day scale used for each year) when each kelt passed the dam
	Diel period of passage	PassDiel	-	Diel period during with the last tracked point occurred at the dam face
Dam Operations				
	Percent discharge through turbine unit 1	T1%Q	%	The percent of total discharge through turbine unti 1
	Percent discharge through turbine unit 2	T2%Q	%	The percent of total discharge through turbine unti 2
	Percent discharge through turbine unit 3	T3%Q	%	The percent of total discharge through turbine unti 3
	Percent discharge through turbine unit 4	T4%Q	%	The percent of total discharge through turbine unti 4
	Percent discharge through turbine unit 5	T5%Q	%	The percent of total discharge through turbine unti 5
	Percent discharge through turbine unit 6	T6%Q	%	The percent of total discharge through turbine unti 6
	Percent discharge through spill bay 1	S1%Q	%	The percent of total discharge through spill bay 1 (spillway weir at LGR and LGS
	Percent discharge through spill bay 2	S2%Q	%	The percent of total discharge through spill bay 2
	Percent discharge through spill bay 3	S3%Q	%	The percent of total discharge through spill bay 3

Category	Variable	Abbreviation	Units	Description
	Percent discharge through spill bay 4	S4%Q	%	The percent of total discharge through spill bay 4
	Percent discharge through spill bay 5	S5%Q	%	The percent of total discharge through spill bay 5
	Percent discharge through spill bay 6	S6%Q	%	The percent of total discharge through spill bay 6
	Percent discharge through spill bay 7	S7%Q	%	The percent of total discharge through spill bay 7
	Percent discharge through spill bay 8	S8%Q	%	The percent of total discharge through spill bay 8 (spillway weir at LMN)
	Spill percentage	%Spill	%	The percent of total discharge that passed through all spill bays
	Crest position at LGS	Crest	-	The position of the weir crest; Low was represented by "1"; High was represented by "2"
Individual Fish				
	Fork length	FL	cm	Fork length of the fish
	Condition	Condition	-	Assessment of overall fish condition; Good condition was represented by "1"; Fair condition was represented by "2"
	Relative condition	RelativeCond	-	Comparison of the actual weight of the fish to a standard
Fish Behavior				
	Acclimation depth	AccDepth	m	Mode depth that each fish was detected at while in the truncated area of the forebay (20 to 75m from the dam face)
	Approach location	FirstY	m	The location on the y-axis (cross-sectional location across the channel width) where each fish was first detected by the cabled receiver array
	Near-dam searching	Search	-	The difference of “hole” (i.e., spill bay or turbine unit) numbers between the “hole” a kelt approached once it was within 10 m of the dam face for the first time and the “hole” the kelt ultimately passed through
	Log-transformed total Y distance traveled	ln(Y dist)	m	Log-transformed sum of the Y distance (back-and-forth across the river channel) traveled by each kelt
	Log-transformed total Z distance traveled	ln(Z dist)	m	Log-transformed sum of the Z distance (vertically in the water column) traveled by each kelt
	Log-transformed tailrace egress time	ln(TR egress)	Hours	Log-transformed time required to travel from the dam face to the downstream boundary of the tailrace

2.4.1 Variables

2.4.1.1 Environmental Variables

Hourly environmental data of water temperatures in the tailrace and at three depths in the forebay (1.5 m, 15 m, and 30 m) as well as total dissolved gas percentages (TDG) in the forebay and tailraces of LGR, LGS, and LMN were downloaded from the USACE Technical Management Team (TMT) website (http://www.nwd.usace.army.mil/Missions/WaterManagement/ColumbiaRiverBasin/WaterQualityProgram.aspx). Dam passage times were rounded to the nearest hour for assignment of temperature and TDG values and to the nearest 5 minutes for assignment of total discharge values to best represent the conditions encountered by each kelt at their time of passage. The final list of environmental variables (and their abbreviations) included in the logistic regression modeling included 1) forebay TDG (FBTDG), 2) forebay temperature at 1.5 m (SurfTemp), 15 m (Temp15), and 30 m (Temp30) depths, 3) the ratio of the temperature at 1.5 m depth to the temperature at 30 m depth (TempRatio), 4) tailrace TDG (TRTDG), 5) tailrace temperature (TRtemp), and 6) total discharge (Discharge).

2.4.1.2 Temporal Variables

Temporal variables included in the models were day and diel period of passage. Day of passage (PassDay) is the ordinal day (365 day scale used for each year) when each kelt passed the dam. This was determined based on the date and time of the last tracked location of each kelt at each dam. Diel period (PassDiel) is based on the diel period during which the last tracked point occurred at each dam face. Separation between day and night was accomplished using civil twilight.

2.4.1.3 Dam Operation Variables

The percent of discharge that passed through each “hole” in the dam (i.e., spill bay or turbine unit), recorded in 5-minute intervals, was calculated from USACE dam operations data for LGR, LGS, and LMN. Again, dam passage times were rounded to the nearest 5 minutes for assignment of the percent discharge through each hole (and total percent spill) at the time of passage for each kelt. Abbreviations used to describe these variables were of the form S1%Q, which, in this example, represents the percent discharge (Q) that passed through spill bay 1 (S1). The percent spill that passed through all spill bays was abbreviated as %Spill. The percent discharge passing through turbine units was represented with a “T” in place of the “S”. The dates that the weir crest changed position at LGS were obtained from either Fish Passage Center reports or from USACE staff. Weir crest position (Crest) was treated as a nominal variable; kelts that passed LGS when the crest was in the “low” position were assigned a “1” and those that passed when the crest was in the “high” position were assigned a “2”.

2.4.1.4 Individual Fish Variables

Data on individual fish were collected at the time of tagging as outlined in Colotelo et al. (2013, 2014). Individual fish variables included in the logistic regression models were fork length in cm (FL) and condition (Condition), assigned as either good or fair. Condition was treated as a nominal factor; kelts in good condition were assigned a “1” and those in fair condition were assigned a “2”. Relative condition factor (Le Cren 1951; Pope and Kruse 2007) was calculated for each kelt that had both a measured length and weight by comparing the actual weight of each fish to a standard predicted by the weight-length regression based on the entire population of kelts tagged during the two years. Relative condition factor (K_n) was calculated as:

$$K_n = (W/W') \times 100$$

where W is individual fish weight and W' is the predicted length-specific weight based on $\log_{10}$ transformed length-weight data.

2.4.1.5 Fish Behavior Variables

Fish behavior variables included acclimation depth, approach location, near-dam searching, total Y distance traveled, total Z distance traveled, and tailrace egress time. These variables are defined as follows:

- **Acclimation depth** (AccDepth) is the mode depth (in m) that each fish was detected at while in the truncated area of the forebay (20 to 75 m from the dam face). Depth was defined by assigning the water surface a value of zero. The deeper a fish was, the more positive its acclimation depth.
- **Approach location** (FirstY) is the location (in m) on the y-axis (cross-sectional location across the channel width) where each fish was first detected by the cabled receiver array. Approach location was defined by assigning a value of zero to the pier nose located between turbine units 1 and 2 at each dam. Values increased from this pier in a northerly direction and decreased from this pier in a southerly direction. Therefore, the approach location for a kelt that was first detected closer to the spillway end of the dam would be a positive value at LGR and LGS and a negative value at LMN. For reference, the FirstY values can be observed on the y-axis of the contour map figures included in the Results section.
- **Near-dam searching** (Search) is the difference of "hole" (i.e., spill bay or turbine unit) numbers between the "hole" a kelt approached once it was within 10 m of the dam face for the first time and the "hole" the kelt ultimately passed through. For example, if a kelt was first detected within 10 m of the dam in front of turbine unit 2 at LGR and passed through spill bay 5, the near-dam searching value would equal 9 because it passed four turbine units and five spill bays.
- **Total Y distance traveled** is the sum of the Y distance (back-and-forth across the river channel) traveled by each kelt (in m). The distance was calculated between each sequential tracked point, and these distances were summed for each fish. Total Y distance traveled data were not normally distributed, being right-skewed; therefore, they were log-transformed and represented by the abbreviation (ln[Y dist]).
- **Total Z distance traveled** is the sum of the Z distance (vertically in the water column) traveled by each kelt (in m). The distance was calculated between each sequential tracked point, and these distances were summed for each fish. Total Z distance traveled data were not normally distributed, being right-skewed; therefore, they were log-transformed and represented by the abbreviation (ln[Z dist]).

- **Tailrace egress time** is defined as the time (in hours) required to travel from the dam face to the downstream boundary of the tailrace. It is calculated as the difference in time between the last detection on the cabled receiver array and the first detection on the tailrace receiver array located 1 to 2 km downstream of the dam. Tailrace egress time data were not normally distributed, being right-skewed; therefore, they were log-transformed and represented by the abbreviation (ln[TR egress]).

2.4.2 Model-Building

Multiple forms of regression modeling were used to assess the factors that affected the route of passage, survival, and forebay residence time of steelhead kelts at LGR, LGS, and LMN in 2012 and 2013. Logistic regression models were created for each route (spillway weir, traditional spill, JBS, turbines) at each dam to examine the relationship between the probability of passing a particular route and environmental, temporal, operational, individual, and behavioral variables. Logistic regression modeling was also used to examine the factors that affected survival of tagged kelts. However, we were only able to evaluate the variables that affected overall passage survival (all routes combined) and spillway weir survival at each dam due to insufficient sample sizes of kelts that passed through traditional spill, JBS, and turbine routes. Survival was defined as the proportion of kelts known to have passed the dam that were detected on any downstream detection array. This approach was possible due to the high detection probabilities of the arrays, which all exceeded 0.95 in 2012 and 0.99 in 2013 (Colotelo et al. 2013, 2014). The first downstream array was located 59 km downstream of LGR, 33 km downstream of LGS, and 27 km downstream of LMN. Therefore, an unknown level of mortality incurred between the tailrace of each dam and the first downstream detection array is included in the survival estimates. General linear modeling was used to evaluate the factors that affected forebay residence times of tagged kelts. Forebay residence time was calculated by subtracting the date and time of first detection on the autonomous detection array located about 1 km upstream of the dam from the date and time of dam passage.

The distribution of each predictor variable was assessed for normality prior to any modeling. Those variables that displayed a highly skewed distribution were log-transformed to achieve normality. Skewed variables were consistent among data sets used to construct each route/dam-specific model, and included tailrace egress time (ln[TR egress]), total Y distance traveled (ln[Y dist]), and total Z distance traveled (ln[Z dist]), which were all highly right-skewed.

The strength and direction of the relationship between each predictor and response variable was first assessed by fitting the values of each predictor variable against the probability of passage through a particular route (versus all other routes) or the probability of survival using bivariate logistic regression models. Variables that were correlated ($\alpha = 0.10$) with the response variable (probability of passage or probability of survival) were retained for inclusion in the multivariable logistic regression modeling procedure. We chose an α level of 0.10 to eliminate some variables from the rather long candidate list, both to reduce the chance of including spurious correlations in the final model and so that the final model was both parsimonious and interpretable. The α level of 0.10 was chosen instead of 0.05 in an attempt to reduce the chances of making a type II error.

Variables found to be significantly correlated with the response variable (probability of passage or survival) were included in the model-building process, which consisted of Bayesian model-averaging (BMA) conducted using the BMA package in R (version 2.14.1; R Core Team 2011). We did not assume to know which variables affected route of passage or passage survival prior to the model-averaging procedure. Therefore, no prior probabilities were assigned to any of the variables.

Advantages of BMA over other multivariable model-building processes, such as step-wise procedures, include the assignment of a level of uncertainty, in the form of posterior probabilities, to each variable and model. Variables included in any of the top five models were assessed for multicollinearity using pairwise comparisons. "Sign-switching," whereby the direction of the relationship between a predictor and response variable changed from the bivariate to multivariable model, was also used as an indication of multicollinearity. Often, the BMA package recognized linear dependencies when a high degree of multicollinearity existed between predictor variables and prevented the model run. When a high level of multicollinearity was encountered, the predictor variable that provided a better fit to the response variable (as judged by P and χ^2 values) in the bivariate models was retained for inclusion in the multivariable model-averaging, the other predictor variable was removed, and the model was re-run. The resultant models were compared using each model's posterior probability ($p[M_k \mid D]$), which is the probability of the model being the correct model, given that one of the models considered is correct. The variables were evaluated using their posterior probability ($p[\Delta \mid D]$), which is the probability that each variable should be included in the model.

Decision tree analyses were also used to identify the variables that affected route selection and survival of acoustic-tagged kelts at each dam in 2012 and 2013. Classification trees, such as those generated by decision tree analyses, are flexible and robust, able to deal with nonlinear relationships and high-order interactions, yet easy to understand and interpret (De'ath and Fabricius 2000). The JMP Partition platform was used to perform the decision tree analyses. Within this platform, the data were partitioned at each split into two mutually exclusive groups, each of which was as homogeneous as possible with regard to response (i.e., passage route probability, survival probability) and predictor (i.e., individual, behavioral, environmental, operational) values. The splitting procedure was then applied to each group separately. Partitioning was done according to a splitting "cut" value for the predictor variable. Splitting was based on maximizing the LogWorth significance value, which is the negative log of the adjusted *P* value, for each split candidate (Sall 2002). We set the adjusted *P* value to 0.05 and the minimum group size to equal 10% of the entire sample. That is, no fewer than 10% of the acoustic-tagged kelts that passed a dam could be split from the data to form a homogeneous group, and the adjusted *P* value that resulted from a split had to be less than 0.05 to be significant. The objective was to partition the response into homogeneous groups while keeping the tree relatively small (De'ath and Fabricius 2000).

General linear modeling was used to identify factors that affected the forebay residence times of tagged kelts at each of the dams. Again, we began by fitting each of a subset of predictor variables against forebay residence times, which were log-transformed to achieve normality. The subset of predictor variables included in the candidate list were several of those described previously that were thought to affect forebay residence time. They included behavioral variables (ln[Z dist], ln[Y dist], Search, FirstY, and FirstZ), an environmental variable (Discharge), operational variables (%Spill, S1%Q at LGR and LGS, and S8%Q at LMN), and an individual variable (FL). The times of first detection on the autonomous detection array located in the forebay (about 1 km upstream of the dam) were rounded to the nearest 5 minutes for assignment of environmental and operational values (obtained from USACE dam operations data) to best represent the conditions encountered by each kelt at the time of their forebay entrance. An additional variable, which represented the diel period (based on civil twilight) at the time of first detection on the forebay array (abbreviated as FBdiel), was also included in the candidate list. Variables that were correlated ($\alpha = 0.10$) with the response variable (ln[FB res]) were retained for inclusion in the multivariable logistic regression modeling procedure, which consisted of Bayesian model-averaging as described previously (using the bicreg function in R instead of the bic.glm function).

2.5 Spill Efficiency Curves

Spillway passage, treated as a nominal variable (spill passage = 1, powerhouse passage = 0), was fit against the percent of total discharge that passed over the spillway to model spill efficiency curves at LGR and LMN. However, LGS is typically operated at 30% spill, regardless of the discharge level. Therefore, the spill efficiency curve for LGS was modeled as the relationship between spill discharge and the probability of spillway passage.

3.0 Results

3.1 Dam Passage and Route-Specific Survival Probabilities Pooled Across Years

Dam passage survival, as measured from the dam face to an autonomous receiver array located 27 to 59 km downstream, differed significantly between years for all Snake River dams (Table 3.1). That is, the variability in overall dam passage survival estimates was substantial enough that the data should not be pooled across years to increase precision of the estimate. However, several of the route-specific survival estimates were similar enough that the data could be pooled across years to improve the precision of those estimates (Table 3.1).

Survival of JBS-passed kelts could be pooled across years for both LGS ($S_{JBS} = 0.93$; SE = 0.04) and LMN ($S_{JBS} = 0.97$; SE = 0.03). Data for turbine-passed kelts could be pooled across years at all three Snake River dams, with pooled survival estimates equaling $S_{Turb} = 0.90$ (SE = 0.09) at LGR, $S_{Turb} = 0.82$ (SE = 0.07) at LGS, and $S_{Turb} = 0.74$ (SE = 0.08) at LMN. Spillway weir survival was similar enough at LGS between years to allow for pooling. The pooled estimate equaled $S_{Weir} = 0.95$ (SE = 0.01). Finally, survival of kelts that passed via traditional spill routes was similar enough at all three dams to pool the two years. Pooled survival through traditional spill routes was $S_{Trad} = 0.84$ (SE = 0.05) at LGR and $S_{Trad} = 0.88$ (SE = 0.03) at LGS and LMN.

Table 3.1. Dam passage survival, as measured from the dam face[1] to an array of autonomous receivers located 27 to 59 km downstream, estimated for acoustic-tagged steelhead kelt at Snake River dams in 2012 and 2013. Results of likelihood ratio tests (χ^2 and *P*) conducted to determine whether overall and route-specific survival differed between years are also shown. Pooled survival estimates (2012 and 2013 combined) are displayed when a significant difference was not observed between years. Standard errors are shown in parentheses. IHR was not fitted with cabled JSATS systems in 2012 or 2013; therefore, route-specific survival estimates are not available. River kilometers are presented as measured from the mouth of the Snake River. NA = not applicable.

Dam	2012	2013	χ^2	*P*	Pooled
LGR (rkm 173) to rkm 114	0.89 (0.03)	0.66 (0.04)	20.07	<0.001*	NA
JBS	0.86 (0.13)	0.33 (0.19)	3.94	0.047*	NA
Turbine	0.88 (0.12)	1.00 (0.00)	0.47	0.492	0.90 (0.09)
Spillway weir	0.90 (0.04)	0.67 (0.05)	12.24	<0.001*	NA
Traditional spill	0.91 (0.05)	0.71 (0.11)	3.14	0.076	0.84 (0.05)
LGS (rkm 113) to rkm 81	0.94 (0.01)	0.89 (0.02)	5.76	0.016*	NA
JBS	0.97 (0.03)	0.88 (0.07)	1.47	0.225	0.93 (0.04)
Turbine	0.78 (0.12)	0.84 (0.08)	0.19	0.660	0.82 (0.07)
Spillway weir	0.97 (0.01)	0.94 (0.02)	1.96	0.162	0.95 (0.01)
Traditional spill	0.94 (0.03)	0.82 (0.05)	3.51	0.061	0.88 (0.03)
LMN (rkm 67) to rkm 40	0.94 (0.01)	0.89 (0.02)	4.30	0.038*	NA
JBS	1.00 (0.00)	0.94 (0.06)	1.54	0.214	0.97 (0.03)
Turbine	0.58 (0.14)	0.84 (0.08)	2.53	0.112	0.74 (0.08)
Spillway weir	0.98 (0.01)	0.93 (0.02)	7.37	0.007*	NA
Traditional spill	0.93 (0.04)	0.83 (0.06)	2.31	0.128	0.88 (0.03)
IHR FB (rkm 17) to rkm 3	0.98 (0.01)	0.94 (0.02)	4.78	0.029*	NA

[1] Dam passage survival, as measured for Ice Harbor Dam (IHR), was estimated from an array of autonomous receivers deployed in the forebay (FB) 1 km upstream from the dam to an array located 13 km downstream of IHR.

3.2 Factors Affecting Route of Passage

A description of the variables correlated with the probability of kelt passage through available routes at LGR, LGS, and LMN from the bivariate and multivariable models are described below. Full details, including the posterior probabilities, the full list of predictor variables tested, and the cumulative posterior probability for each model are outlined in Appendix A.

3.2.1 Lower Granite Dam

3.2.1.1 Spillway Weir

Of the 260 acoustic-tagged kelts that were assigned a route at LGR in 2012 and 2013, 186 (72%) passed via the spillway weir. A total of 15 variables were identified that were significantly correlated with the probability of spillway weir passage for these fish (Table A.1). The two most highly correlated of those variables were AccDepth, which was negatively correlated with spillway weir passage probability ($\chi^2 = 36.5$; $P < 0.001$), and FirstY, which was negatively correlated with spillway weir passage ($\chi^2 = 13.5$; $P < 0.001$). AccDepth ($p[\Delta \mid D] = 1.0$) was the only variable included in each of the top five multivariable models (Table A.2). FirstY was included in three of the top five multivariable models and had a relatively high posterior probability of 0.76. The models indicated spillway weir passage probability was higher for kelts that were acclimated to shallower depths and for those that approached LGR closer to the south (powerhouse) end of the dam. No other variable had a posterior probability of multivariable model inclusion > 0.50.

The decision tree model also included AccDepth and FirstY as the variables that best explained the probability of spillway weir passage for acoustic-tagged kelts at LGR in 2012 and 2013 (Figure 3.1). Kelts that had an acclimation depth shallower than 10 m were grouped together with a spillway weir passage probability of 0.79. Conversely, those that had an acclimation depth that was deeper than 10 m were grouped together with a probability of spillway weir passage of 0.24. Of the 223 kelts that had an acclimation depth that was shallower than 10 m, the 185 that were first detected approaching LGR south of spill bay 3 (i.e., FirstY < 200 m) were grouped together with a 0.86 spillway weir passage probability. Kelts with an acclimation depth shallower than 10 m that were first detected north of this location were grouped together with a spillway weir passage probability of 0.47.

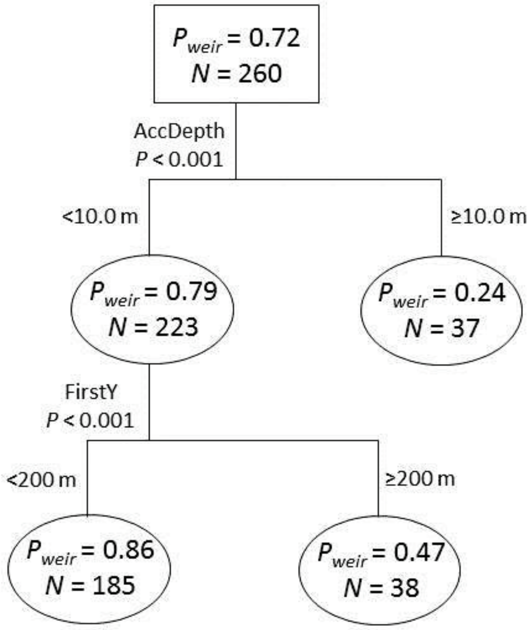

Figure 3.1. Results of a decision tree analysis of spillway weir passage probabilities (P_{weir}) for acoustic-tagged steelhead kelts at Lower Granite Dam (LGR) in 2012 and 2013. The P_{weir} and sample size are shown for the entire sample of kelts that passed LGR in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.22.

Contour maps of spillway weir passage probability by forebay location support the modeling results. The maps indicate kelts detected at depths shallower than 10 m had a high probability of passing via the spillway weir at LGR, even at distances > 50 m from the dam face (Figure 3.2). The maps also display the higher probability of spillway weir passage for kelts migrating on the powerhouse side of the forebay compared to the spillway side. The log boom may have helped to guide kelts to the spillway weir; kelts detected immediately north of the boom at the water surface (0 m depth) had a very high (> 90%) probability of passing via the weir.

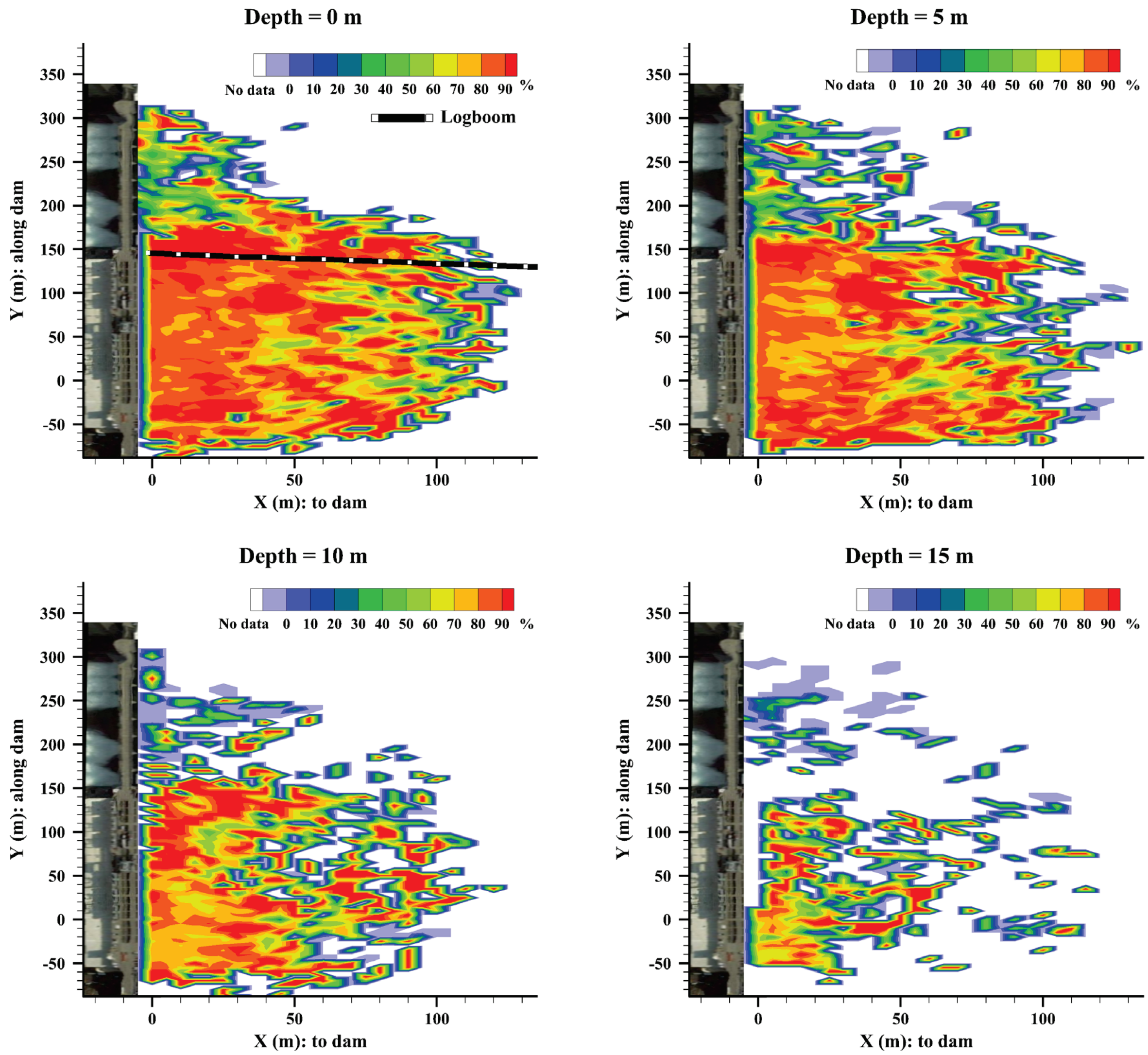

Figure 3.2. Contour maps displaying the probability of spillway weir passage for steelhead kelts at Lower Granite Dam in 2012 and 2013 by their location (at four different depths) in the forebay. The location of the log boom is shown on the 0 m depth map.

The importance of acclimation depth on passage route can also be observed in boxplots of acclimation depth by route of passage (Figure 3.3). Kelts that passed via the spillway weir had a median acclimation depth of 1.2 m (interquartile range (IQR): 0.5–3.1 m), which was several meters shallower than the acclimation depths of kelts that passed through other routes. The majority of kelts were acclimated to depths in the upper 5 m of the water column in the LGR forebay (Figure 3.4), which likely contributed to the high spillway weir passage proportion.

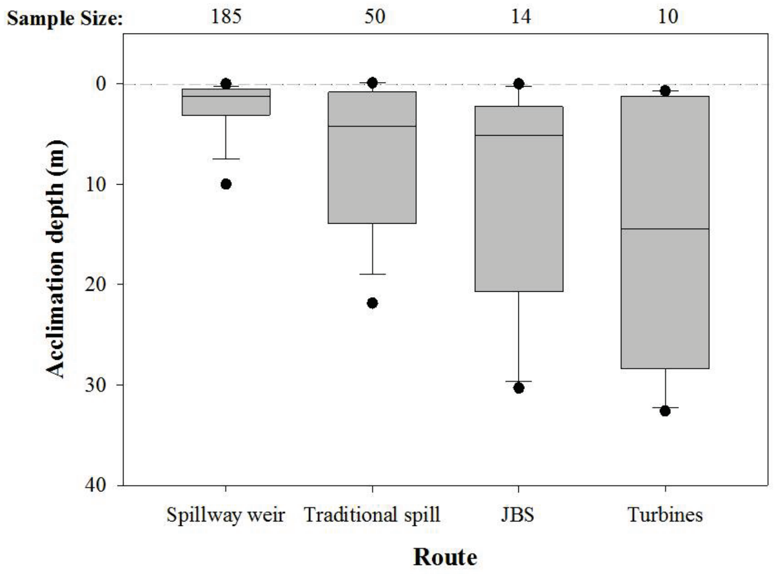

Figure 3.3. Boxplots displaying the distributions of acoustic-tagged steelhead kelt acclimation depths by route of passage at LGR in 2012 and 2013. An acclimation depth value of 0 m represents the water surface. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

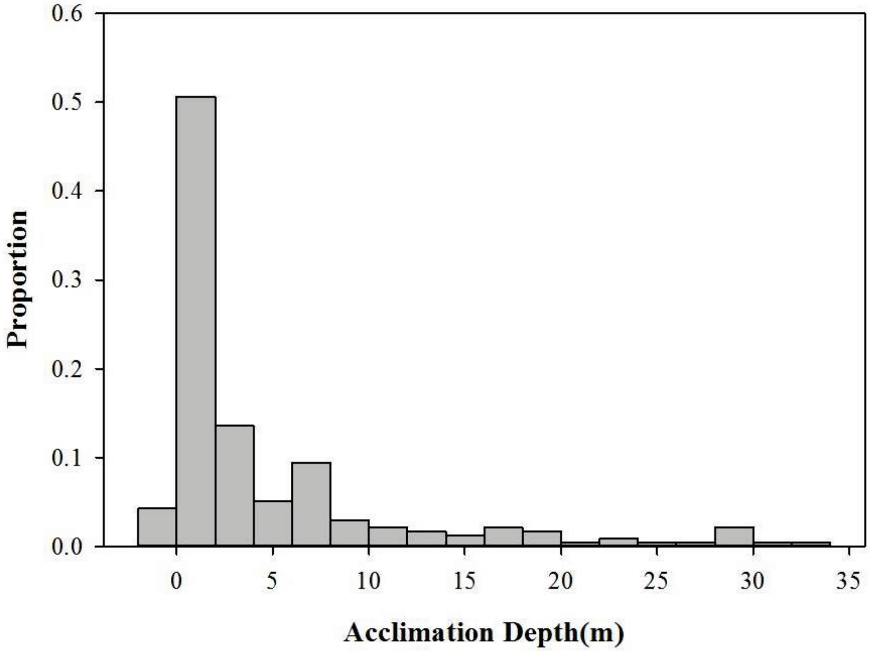

Figure 3.4. Distribution of acclimation depths for acoustic-tagged steelhead kelts in the forebay of Lower Granite Dam (20 to 75 m from the dam face) in 2012 and 2013. An acclimation depth value of 0 m represents the water surface. 3-D fish positions were accurate to 1 m; therefore, some fish had acclimation depths > 0 m.

3.2.1.2 Traditional Spill

Of the 260 acoustic-tagged kelts assigned a route at LGR in 2012 and 2013, 50 (19%) passed via traditional spill bays. Twelve variables were significantly correlated with the probability of traditional spill passage for kelts at LGR in 2012 and 2013 (Table A.3). The most highly correlated of those variables was FirstY, which was positively correlated with traditional spill passage ($\chi^2 = 39.7$; $P < 0.001$), indicating kelts that approached LGR closer to the north (spillway) end of the dam were more likely to pass through traditional spill bays than other routes. FirstY ($p[\Delta \mid D] = 1.0$) was also the only variable included in each of the top five multivariable models constructed to explain the factors that affected traditional spill passage at LGR (Table A.4). S7%Q, which was positively correlated with traditional spill passage probability, appeared in two of the top five models and was the only other variable with a posterior probability > 0.50.

The decision tree model also identified FirstY as the variable that explained the greatest variability in traditional spill passage (Figure 3.5). Kelts that were first detected approaching LGR north of the spillway weir (i.e., spill bay 1; FirstY ≥ 188 m) had a 0.55 probability of traditional spill passage compared to 0.09 for kelts first detected south of this location. Kelts first detected north of spill bay 1 that passed when S3%Q ≥ 3.2% had a traditional spill passage probability of 0.78, which was significantly higher than observed for kelts that passed when S3%Q was < 3.2% ($P_{trad} = 0.35$).

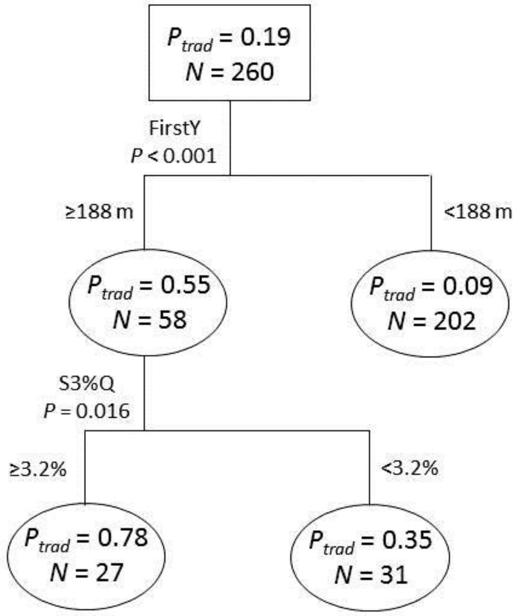

Figure 3.5. Results of a decision tree analysis of traditional spill passage probabilities (P_{trad}) for acoustic-tagged steelhead kelts at Lower Granite Dam (LGR) in 2012 and 2013. The P_{trad} and sample size are shown for the entire sample of kelts that passed LGR in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.25.

The effect of FirstY on the probability of traditional spill passage can be observed in contour maps of passage probability by forebay location (Figure 3.6). Kelts detected in front of the spillway generally had a probability of traditional spill passage > 0.50. In contrast, those detected at locations on the powerhouse side of the forebay generally had traditional spill passage probabilities < 0.30.

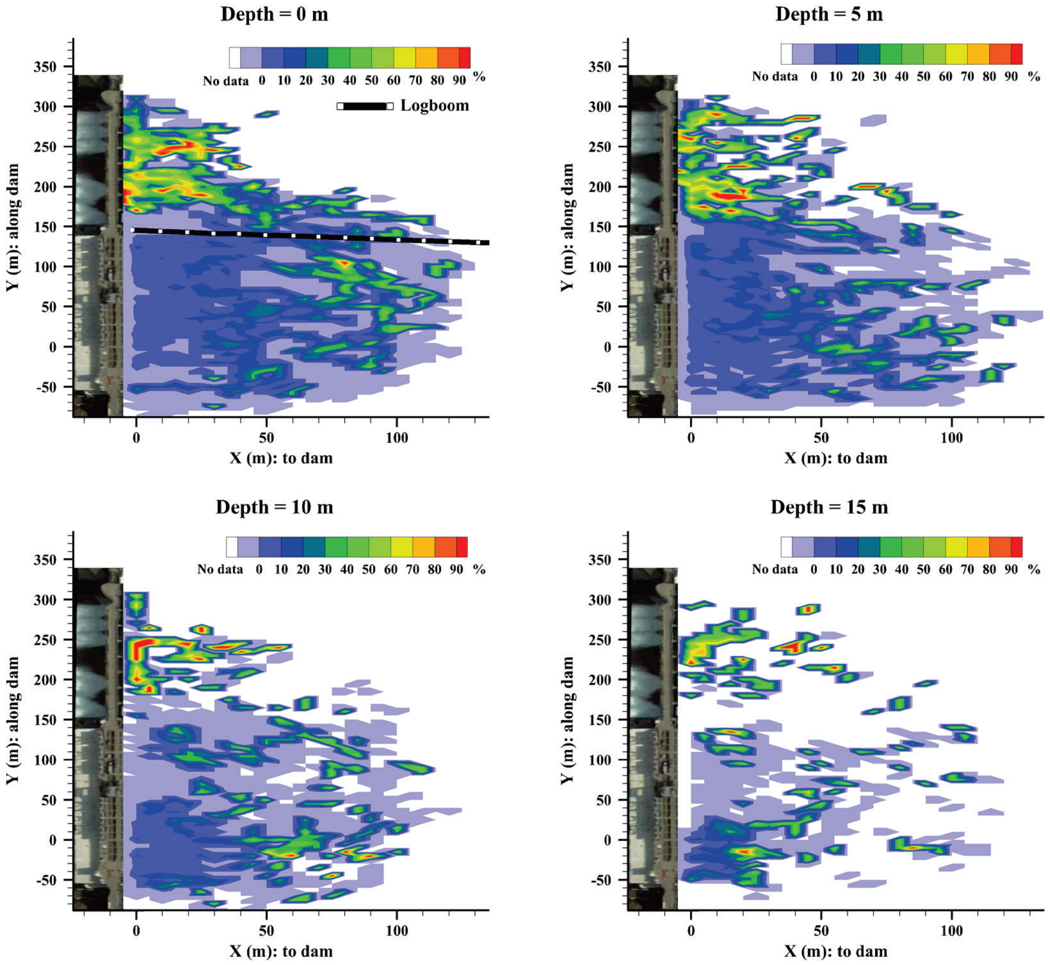

Figure 3.6. Contour maps displaying the probability of deep spill passage for steelhead kelts at Lower Granite Dam in 2012 and 2013 by their location (at four different depths) in the forebay. The location of the log boom is shown on the 0 m depth map.

3.2.1.3 Juvenile Bypass System

Of the 260 acoustic-tagged kelts assigned a route at LGR in 2012 and 2013, 14 (5%) passed through the JBS. Eight variables were identified that were significantly correlated with the probability of JBS passage for acoustic-tagged kelts at LGR in 2012 and 2013 (Table A.5). The four most highly correlated of the variables were FL ($\chi^2 = 11.9$; $P < 0.001$), FirstY ($\chi^2 = 5.9$; $P = 0.015$), and Search ($\chi^2 = 5.7$; $P = 0.017$), which were negatively correlated with the probability of JBS passage, and AccDepth ($\chi^2 = 6.4$; $P = 0.012$), which was positively correlated with JBS passage. The mean FL of kelts that passed through the LGR JBS was 59.9 cm compared to 68.1 cm for kelts that passed through all other routes. The median acclimation depth of kelts that passed LGR through the JBS was 5.1 m, which was deeper than those that passed through the spillway weir or traditional spill bays, but substantially shallower than those that passed through the turbines (Figure 3.3).

Two variables were included in each of the top five multivariable models constructed to identify the variables that affected JBS passage (Table A.6). These included FirstY and Search, both of which had posterior probabilities of model inclusion of 1.0. The variable FL had a posterior probability of 0.84 and was included in four of the top five models. The top model included all three of these variables and indicated kelts that were first detected closer to the south (powerhouse) end of the dam, those that did less near-dam searching, and those kelts that were small in size had the highest probability of passing through the JBS at LGR.

The decision tree analysis also indicated the importance of FL, FirstY, and AccDepth on the probability of JBS passage (Figure 3.7). Kelts that measured < 69 cm FL had a 0.10 probability of JBS passage, which was significantly higher than the probability observed for kelts that were ≥ 69 cm FL (P_{JBS} = 0.01). Of the 134 kelts that measured < 69 cm FL, those that were first detected south of the spillway weir (i.e., spill bay 1) had a JBS passage probability of 0.15 compared to 0.0 for those first detected north of the weir. The highest probability (P_{JBS} = 0.30) of JBS passage at LGR was observed for kelts that measured <69 cm FL, were first detected south of the spillway weir, and were acclimated to depths deeper than 2.6 m.

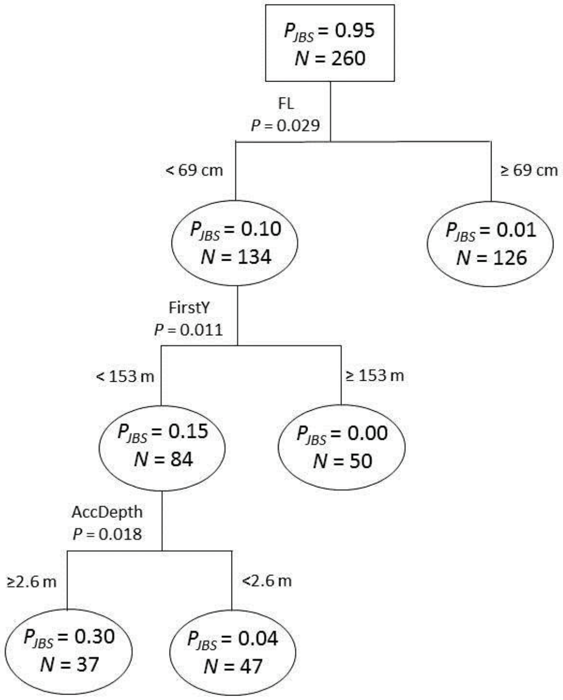

Figure 3.7. Results of a decision tree analysis of juvenile bypass system passage probabilities (P_{JBS}) for acoustic-tagged steelhead kelts at Lower Granite Dam (LGR) in 2012 and 2013. The P_{JBS} and sample size are shown for the entire sample of kelts that passed LGR in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.33.

The effect of depth on powerhouse passage probability was not readily apparent in contour maps of passage probability versus forebay location (Figure 3.8). This phenomenon was likely caused by the small sample size of kelts that passed through the powerhouse at LGR (*n* = 24) and the associated low probability of powerhouse passage regardless of depth. However, the effect of approach location (FirstY) on powerhouse passage probability can be seen in the contour maps. Kelts that were detected in front of the powerhouse had a higher probability of powerhouse passage than those detected in front of the spillway. A distinct separation in powerhouse passage probabilities was observed for kelts at 0 m depth on either side of the log boom, with kelts migrating on the south side of the boom having a higher probability of passing through the powerhouse. No kelts detected north of the boom at 0 m depth passed through the powerhouse.

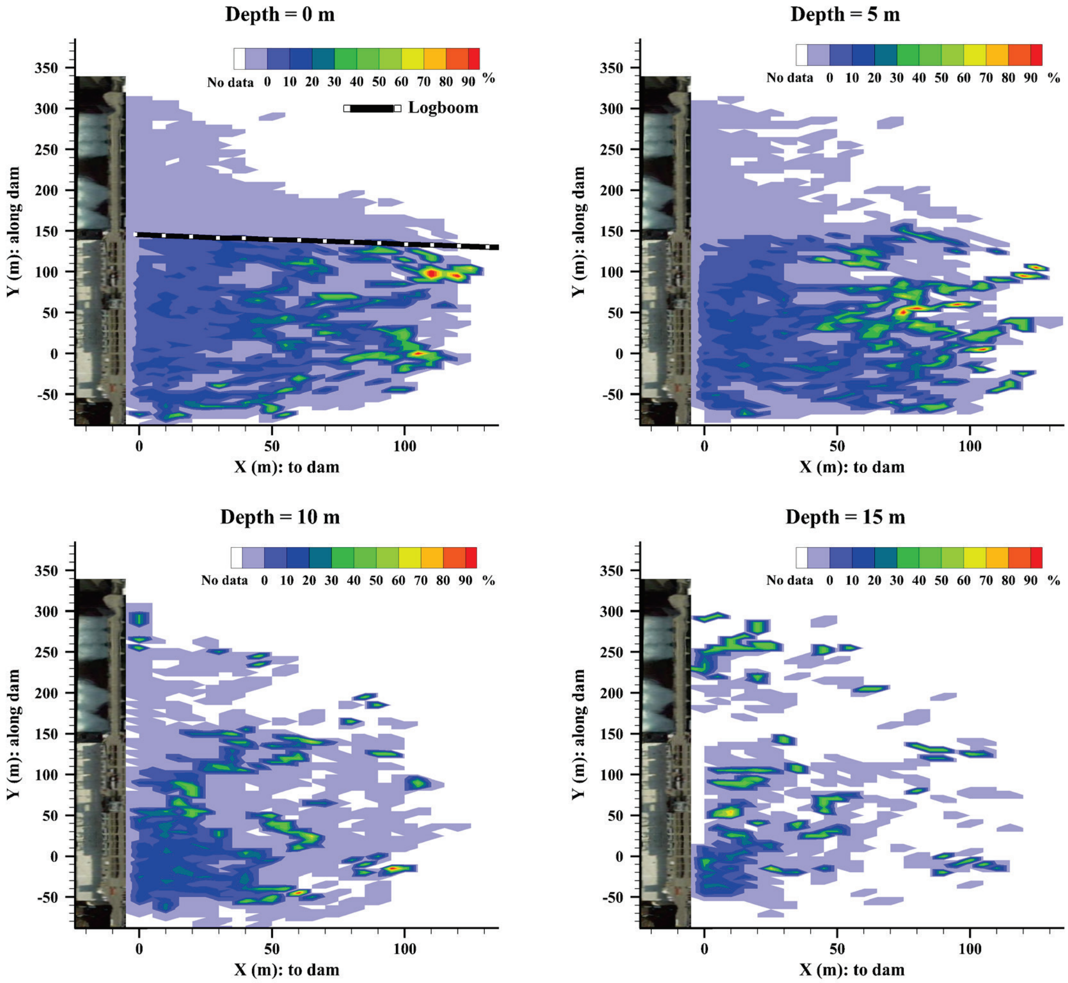

Figure 3.8. Contour maps displaying the probability of powerhouse passage for steelhead kelts at Lower Granite Dam in 2012 and 2013 by their location (at four different depths) in the forebay. The location of the log boom is shown on the 0 m depth map.

3.2.1.4 Turbines

Only 10 of the 260 (4%) acoustic-tagged kelts assigned a route at LGR in 2012 and 2013 passed through the turbines. From the bivariate modeling, 11 variables were identified that were significantly correlated with the probability of turbine passage (Table A.7). The most highly correlated of those variables was AccDepth, which was positively correlated with turbine passage probability ($\chi^2 = 16.2$; $P < 0.001$). The median AccDepth of turbine-passed kelts was 14.5 m, which was substantially deeper than the median AccDepth observed for all other routes (Figure 3.3). AccDepth ($p[\Delta \mid D] = 1.0$) was also the only variable included in each of the top five multivariable models constructed to explain the factors that affected turbine passage probability of acoustic-tagged kelts at LGR in 2012 and 2013 (Table A.8). The variable %Spill was included in three of the top five models, including the top model, with a posterior probability of 0.52; it was negatively correlated with turbine passage probability. The inclusion of these variables in the models indicated turbine passage probability was higher for kelts that were acclimated to deeper depths and for those that passed LGR at lower levels of %Spill.

The decision tree analysis also suggested the importance of AccDepth on the probability of turbine passage at LGR (Figure 3.9). Kelts that were acclimated to depths deeper than 12 m had a 0.21 probability of turbine passage compared to 0.02 for those acclimated to shallower depths. Of the 231 kelts that were acclimated to depths shallower than or equal to 12 m, those that passed when T6%Q was ≥ 13.5% had a 0.09 probability of turbine passage compared to 0.0 for those that passed when T6%Q was < 13.5%.

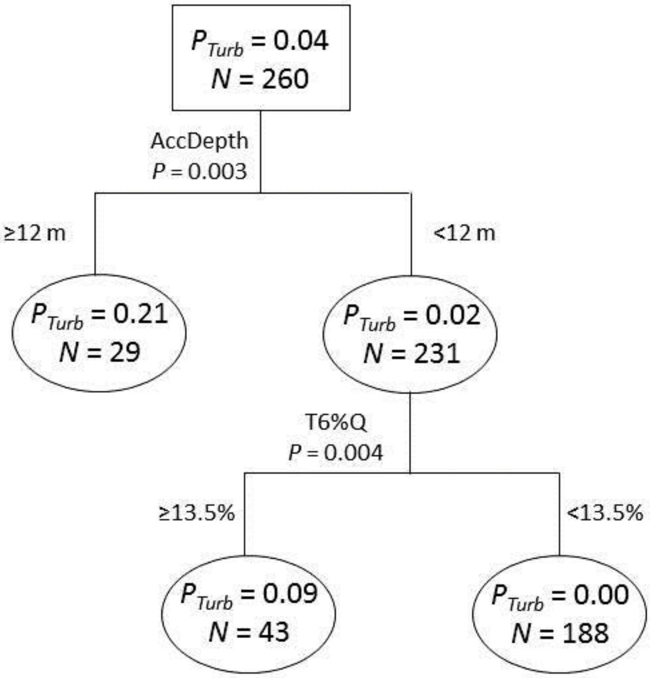

Figure 3.9. Results of a decision tree analysis of turbine passage probabilities (P_{Turb}) for acoustic-tagged steelhead kelts that passed Lower Granite Dam (LGR) in 2012 and 2013. The P_{Turb} and sample size are shown for the entire sample of kelts that passed LGR through the powerhouse in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.38.

The depth distribution of acoustic-tagged kelts that passed LGR through the powerhouse became progressively deeper in advance of their passage, whereas kelts that passed via the spillway either remained relatively shallow (spillway weir) or became progressively more shallow (traditional spill) prior to passage (Figure 3.10). Twenty minutes prior to passage, about half of the kelts that ultimately passed through the powerhouse were located in the upper 5 m of the water column. Kelts began to display a diving behavior between 10 min and 20 min prior to their passage, when they had a median depth of 10 m. Kelts that eventually passed through the powerhouse continued to dive until their median depth was about 25 m below the water surface just prior (0 min) to passage.

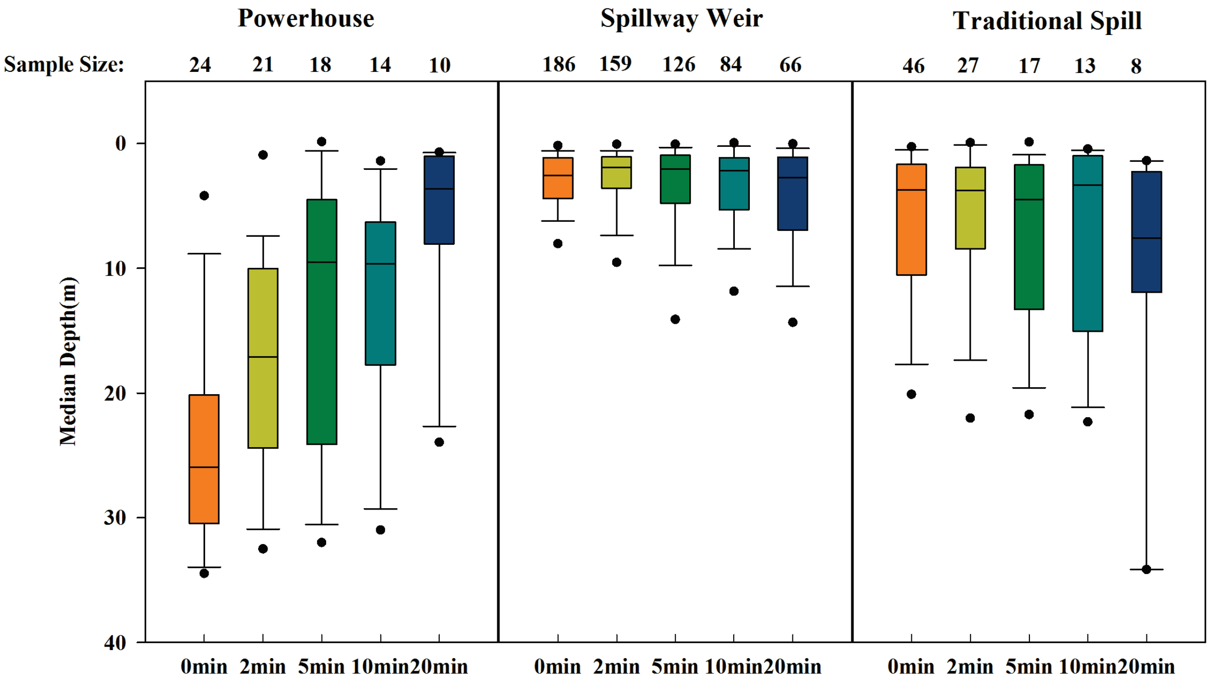

Figure 3.10. Boxplots displaying the depth distribution of acoustic-tagged kelts by passage route 0, 2, 5, 10, and 20 minutes prior to passing Lower Granite Dam in 2012 and 2013. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

Powerhouse-passed kelts were distributed over a wide range of depths throughout their approach to the dam face, with the majority spending most of their time in the upper 15 m of the water column at each distance (0 m, 5 m, 10 m, 20 m, and 50 m) from the dam face (Figure 3.11). These results suggest many of the kelts migrated to the dam face at relatively shallow depths, where they lingered before displaying the diving behavior that ultimately led to their entrance into the turbine intake. This behavior is in contrast to the behavior displayed by kelts that passed LGR via a spillway route. Kelts that passed over the spillway weir appeared to spend most of their time at shallow depths throughout their approach to the dam face. Those that passed through traditional spill bays gradually spent more time at shallower depths as they approached the dam face.

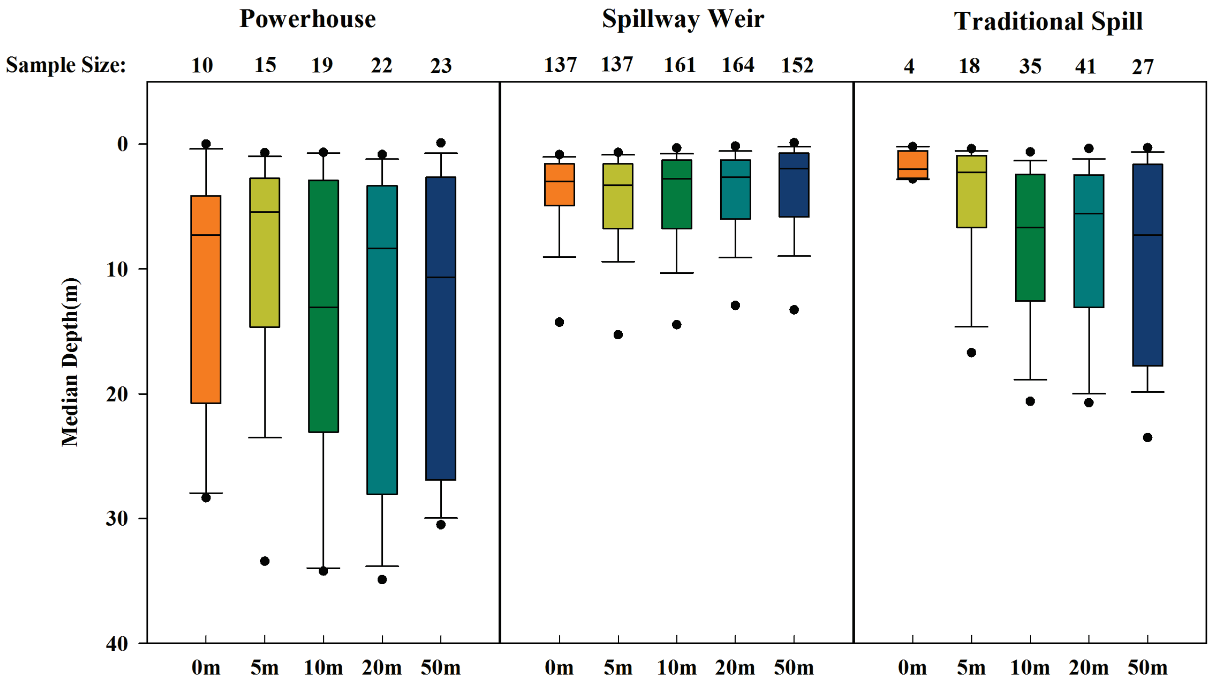

Figure 3.11. Boxplots displaying the depth distribution of acoustic-tagged kelts by passage route 0, 5, 10, 20, and 50 m prior to passing Lower Granite Dam in 2012 and 2013. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, dots represent the 5th and 95th percentiles.

3.2.2 Little Goose Dam

3.2.2.1 Spillway Weir

Of the 661 acoustic-tagged kelts that were assigned a passage route at LGS in 2012 and 2013, 445 (67%) passed via the spillway weir. There were 24 variables significantly correlated with the probability of spillway weir passage from the bivariate models (Table A.9). The three most highly correlated of those included Search ($\chi^2 = 37.1$; $P < 0.001$) and ln(Y dist) ($\chi^2 = 33.1$; $P < 0.001$), which were positively correlated with spillway weir passage probability, and AccDepth ($\chi^2 = 32.1$; $P < 0.001$), which was negatively correlated with spillway weir passage. Three variables (AccDepth, ln[Y dist], ln[Z dist]) were included in each of the top five multivariable models (Table A.10). All three of these variables had high posterior probabilities of model inclusion ($p[\Delta \mid D] > 0.96$), indicating a high level of certainty that they be included in the model. AccDepth and ln(Z dist) were negatively correlated and ln(Y dist) was positively correlated with the probability of spillway weir passage. These relationships indicate kelts that were acclimated to shallower depths, and those that performed more substantial horizontal but limited vertical migrations were more likely to pass over the spillway weir than through other routes.

Results from the decision tree analysis indicated the importance of near-dam searching behavior (Search) and AccDepth on the probability of spillway weir passage at LGS (Figure 3.12). Kelts that displayed a greater level of near-dam searching (i.e., Search ≥3 units/bays) had a significantly higher probability of spillway weir passage ($P_{weir} = 0.82$) than kelts that did less near-dam searching (i.e., Search

<3 units/bays; P_{weir} = 0.54). Regardless of the level of near-dam searching, kelts that were acclimated to shallower depths had a higher probability of spillway weir passage.

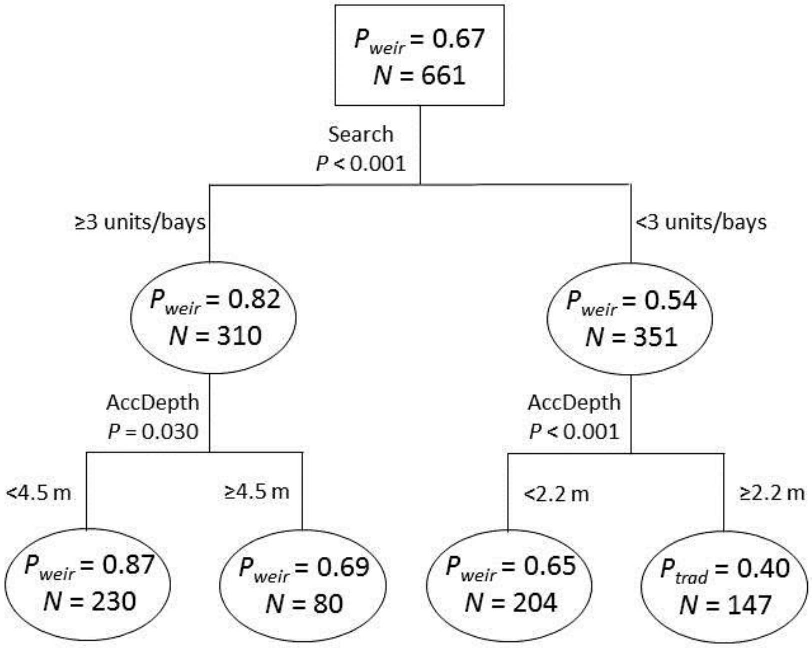

Figure 3.12. Results of a decision tree analysis of spillway weir passage probabilities (P_{weir}) for acoustic-tagged steelhead kelts at Little Goose Dam (LGS) in 2012 and 2013. The P_{weir} and sample size are shown for the entire sample of kelts that passed LGS in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.11.

Model results, particularly the importance of migration depth and horizontal searching behavior on spillway weir passage, can be visualized in contour maps of LGS spillway weir passage probability by forebay location (Figure 3.13). The maps show that kelts migrating near the water surface had a very high probability of spillway weir passage regardless of their forebay location. The probability of spillway weir passage declined for kelts in front of the spillway with increasing depth but remained quite high for kelts in front of the powerhouse down to 15 m depth. The importance of horizontal searching behavior (e.g., ln[Y dist] and Search) can also be observed in the contour maps as the high probability of spillway weir passage at points located a considerable distance from the weir entrance. Kelts detected near the log boom at 0 m depth on either side had a very high probability of passing via the spillway weir, indicating the boom may be guiding surface-acclimated kelts toward the weir.

The effect of migration depth on passage route can also be observed by examining the distribution of acclimation depths by route of passage (Figure 3.14). Kelts that passed LGS over the spillway weir had a median acclimation depth of 1.3 m (IQR: 0.9–3.7 m), which was about 1 to 2.5 m shallower than the median acclimation depth of kelts that passed through other routes. The majority of kelts were acclimated to depths shallower than 5 m in the forebay of LGS (Figure 3.15), which likely played a large role in the high spillway weir passage probability observed in 2012 and 2013.

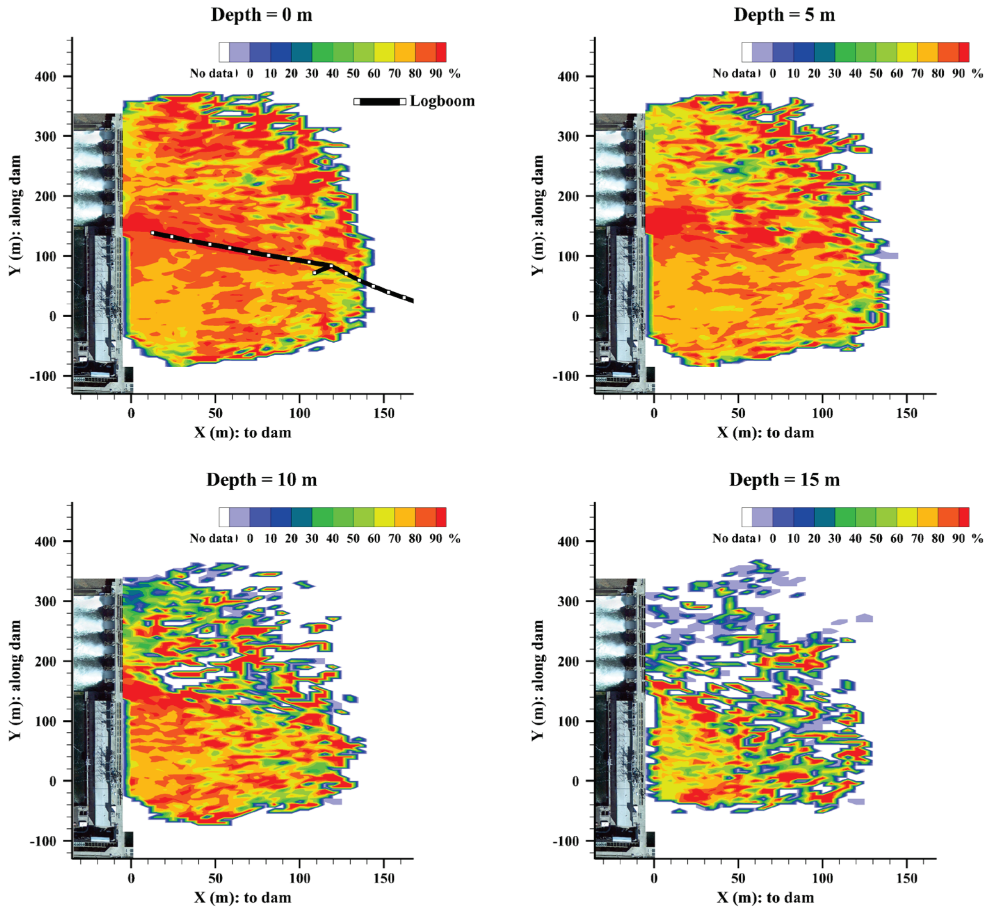

Figure 3.13. Contour maps displaying the probability of spillway weir passage for steelhead kelts at Little Goose Dam in 2012 and 2013 by their location (at four different depths) in the forebay. The location of the log boom is shown on the 0 m depth map.

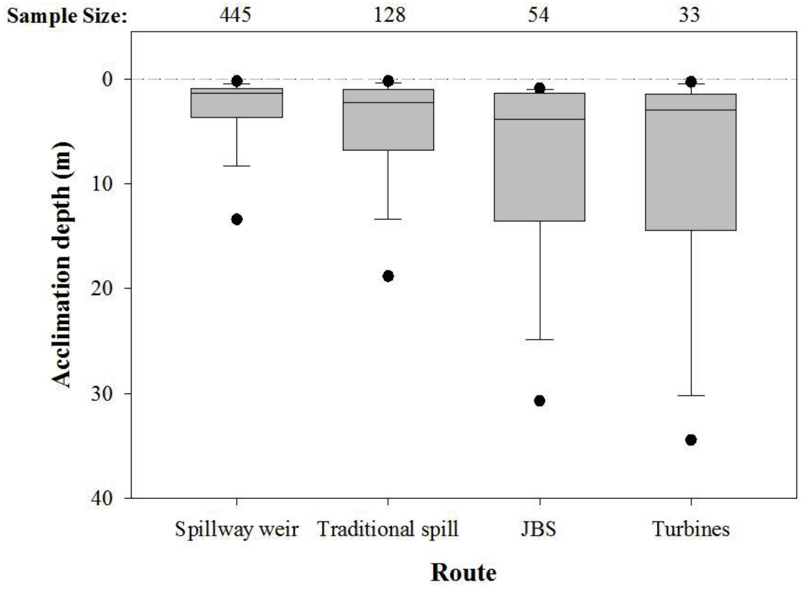

Figure 3.14. Boxplots displaying the distributions of acoustic-tagged steelhead kelt acclimation depths (AccDepth) by route of passage at Little Goose Dam in 2012 and 2013. An acclimation depth value of 0 m represents the water surface. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

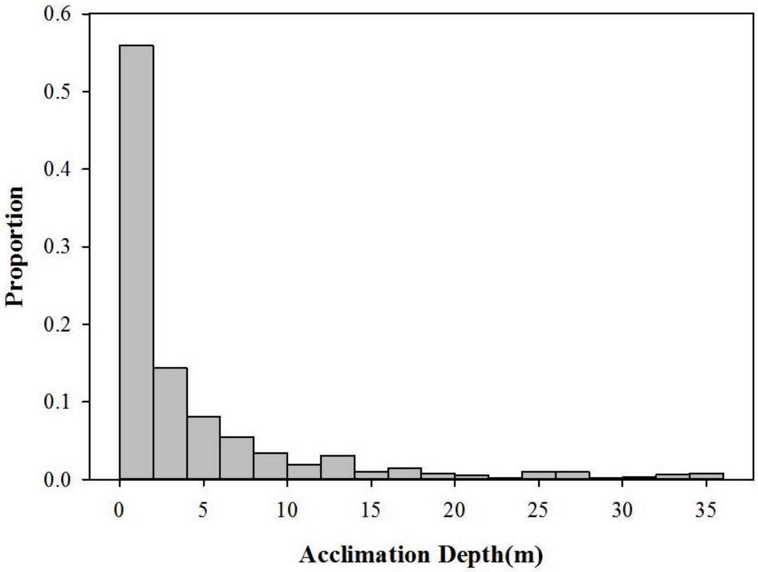

Figure 3.15. Distribution of acclimation depths for acoustic-tagged steelhead kelts in the forebay of Little Goose Dam (20 to 75 m from the dam face) in 2012 and 2013. An acclimation depth value of 0 m represents the water surface.

3.2.2.2 Traditional Spill

Of the 661 acoustic-tagged kelts assigned a route at LGS in 2012 and 2013, 129 (20%) passed via traditional spill bays. A total of 19 variables were significantly correlated with traditional spill passage in bivariate logistic regression models (Table A.11). The three most highly correlated bivariate models included FirstY ($\chi^2 = 92.9$; $P < 0.001$), ln(Y dist) ($\chi^2 = 73.3$; $P < 0.001$), and ln(Z dist) ($\chi^2 = 68.6$; $P < 0.001$). Both FirstY and ln(Y dist) were also included in each of the top five multivariable models with posterior probabilities of 1.0 (Table A.12). Traditional spill passage probability was positively correlated with FirstY and negatively correlated with ln(Y dist), indicating kelts that approached LGS closer to the north (spillway) end of the dam and those with limited horizontal migrations were more likely to pass through traditional spill bays than other routes.

Results from the decision tree analysis indicated the importance of approach location (FirstY) on the probability of traditional spill passage at LGS (Figure 3.16). Kelts that were first detected north of the spillway weir (i.e., spill bay 1) (i.e., FirstY ≥ 185 m) had a 0.35 probability of traditional spill passage compared to 0.06 for kelts first detected south of the weir. Of the kelts that were first detected on the spillway (north) side of the spillway weir, those that limited their horizontal migrations to <117 m (i.e., ln[Y dist] < 4.8) had a 0.62 probability of traditional spill passage. Those that had ln(Y dist) values ≥ 4.8 had a traditional pill passage probability of 0.19.

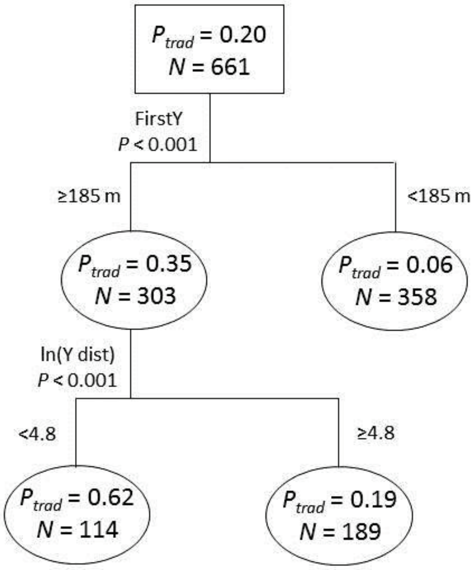

Figure 3.16. Results of a decision tree analysis of traditional spill passage probabilities (P_{trad}) for acoustic-tagged steelhead kelts at Little Goose Dam (LGS) in 2012 and 2013. The P_{trad} and sample size are shown for the entire sample of kelts that passed LGS in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.23.

The results from logistic models developed to explain the factors affecting traditional spill passage can be observed in contour maps of traditional spill passage probability by forebay location (Figure 3.17). The maps clearly indicate kelts detected in front of the spillway had a higher probability of traditional spill passage than those detected on the powerhouse side of the forebay. A distinct separation between spillway and powerhouse passage probability was observed for kelts at 0 m and 5 m depths on either side of the log boom, with kelts migrating on the north side of the boom having a higher probability of passing via the spillway.

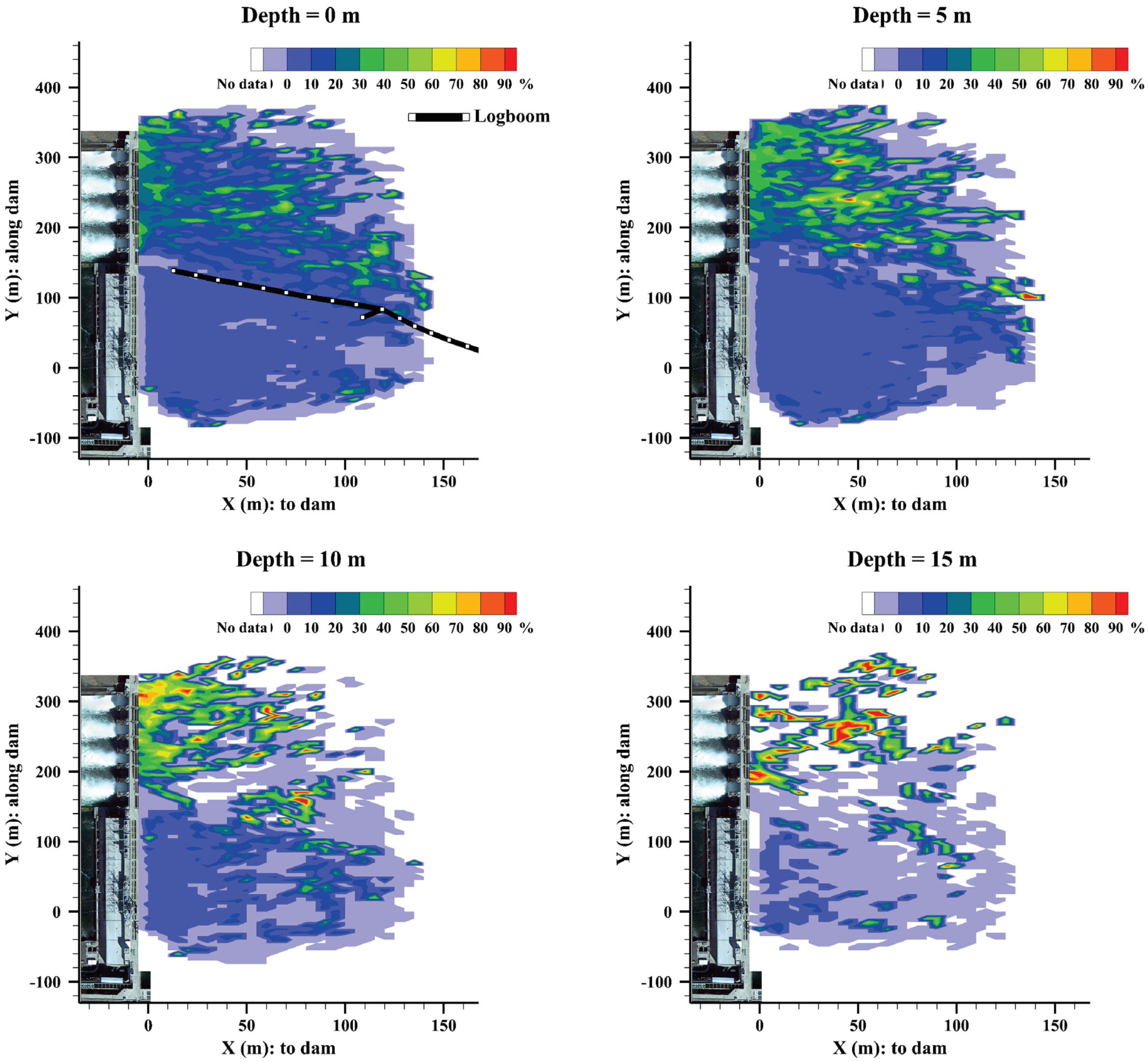

Figure 3.17. Contour maps displaying the probability of traditional spill passage for steelhead kelts at Little Goose Dam in 2012 and 2013 by their location (at four different depths) in the forebay. The location of the log boom is shown on the 0 m depth map.

3.2.2.3 Juvenile Bypass System

Of the 661 acoustic-tagged steelhead kelts assigned a passage route at LGS in 2012 and 2013, 54 (8%) passed through the JBS. A total of 13 variables were significantly correlated with the probability of JBS passage in the bivariate models (Table A.13). The five most highly correlated of these variables included FirstY ($\chi^2 = 46.1$; $P < 0.001$), Search ($\chi^2 = 20.2$; $P < 0.001$), and FL ($\chi^2 = 12.3$; $P < 0.001$), which were negatively correlated with JBS passage probability, and ln(Z dist) ($\chi^2 = 8.1$; $P = 0.005$) and AccDepth ($\chi^2 = 17.0$; $P < 0.001$), which were positively correlated with JBS passage. Four of these variables (FirstY, Search, AccDepth, and ln[Z dist]) were included in each of the top five multivariable models with high posterior probabilities of model inclusion ($p[\Delta \mid D] > 0.90$) (Table A.14). All five of the top models indicated JBS passage probability was higher for kelts that were first detected approaching LGS closer to the south (powerhouse) shoreline, those that did little horizontal near-dam searching, kelts that were acclimated to deeper depths, and for those that undertook more substantial vertical migrations in the forebay.

The effect of migration depth on JBS passage probability can be observed in both the boxplots of acclimation depth by route (Figure 3.14) and the contour maps of powerhouse passage probability by forebay location (Figure 3.18). Kelts that passed through the JBS at LGS had a median acclimation depth of 3.8 m (IQR: 1.4–13.5 m), which was 2.4 m deeper than the median acclimation depth of kelts that passed via the spillway (median = 1.4 m; IQR: 0.9–4.6 m). The contour maps indicate a much higher probability of powerhouse passage for kelts at deeper (≥15 m) depths (Figure 3.18). The contour maps also display the effect of approach location (FirstY) on the probability of powerhouse passage, with kelts located in front of the powerhouse having a higher probability of powerhouse passage than those detected in front of the spillway. Again, a rather distinct difference in powerhouse passage probability can be observed for kelts detected on either side of the log boom at 0 m depth, with those detected south of the boom having a higher powerhouse passage probability than those detected north of the boom.

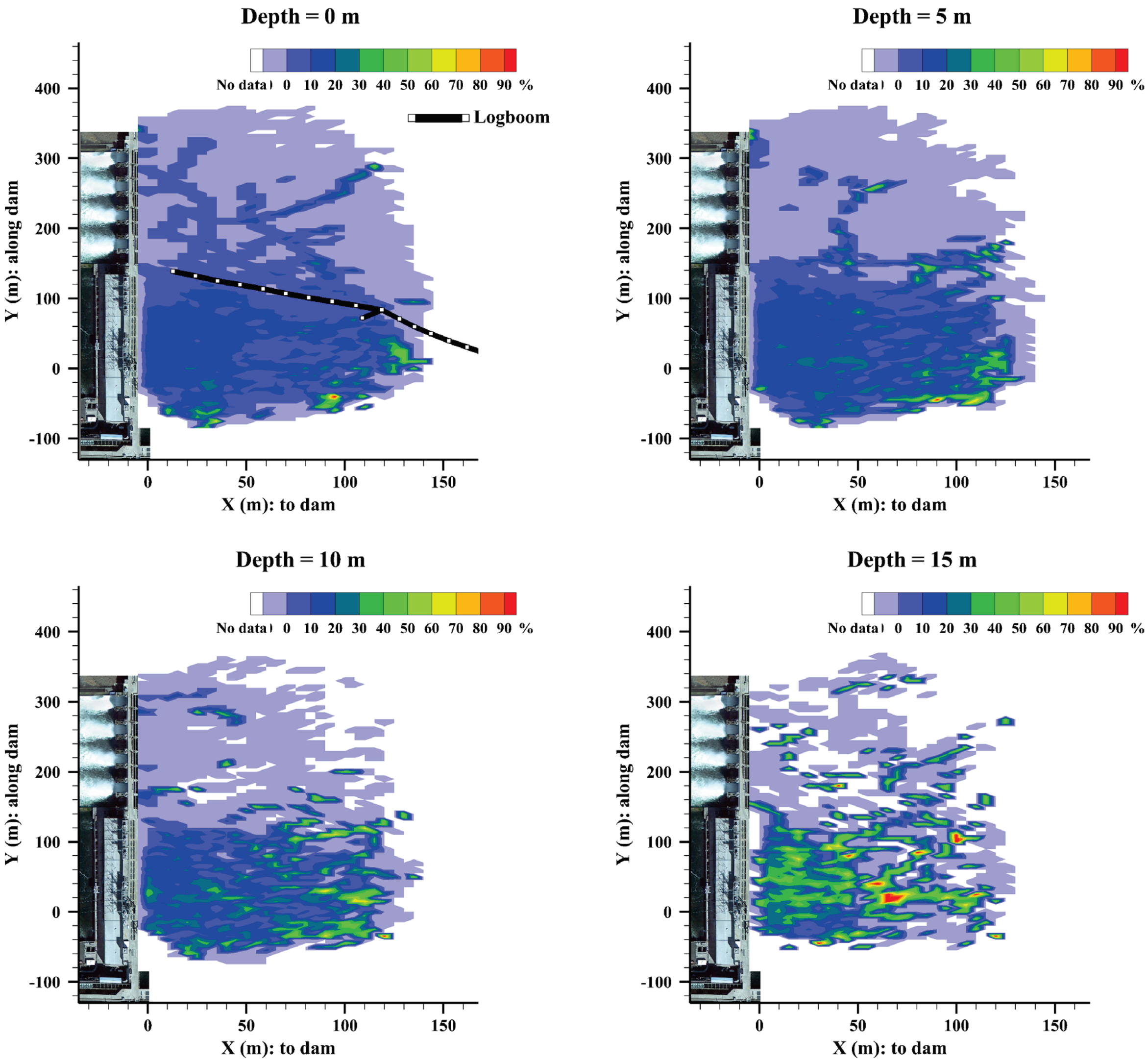

Figure 3.18. Contour maps displaying the probability of powerhouse passage for steelhead kelts at Little Goose Dam in 2012 and 2013 by their location (at four different depths) in the forebay. The location of the log boom is shown on the 0 m depth map.

Only two variables (FirstY and Search) were included in the decision tree model constructed to describe the variables that affected the JBS passage probability of acoustic-tagged kelts at LGS in 2012 and 2013 (Figure 3.19). Kelts that were first detected approaching the dam south of spill bay 4 (i.e., FirstY < 204 m) had a 0.13 probability of JBS passage, which was substantially higher than those first detected north of this point ($P_{JBS} = 0.01$). Of the 389 kelts first detected approaching LGS closer to the powerhouse side, those that did less near-dam searching (Search < 4 units/bays) had a JBS passage probability of 0.20. The highest JBS passage probability ($P_{JBS} = 0.42$) was observed for kelts that did little near-dam searching and approached LGS south of turbine unit 5 (FirstY < 68 m).

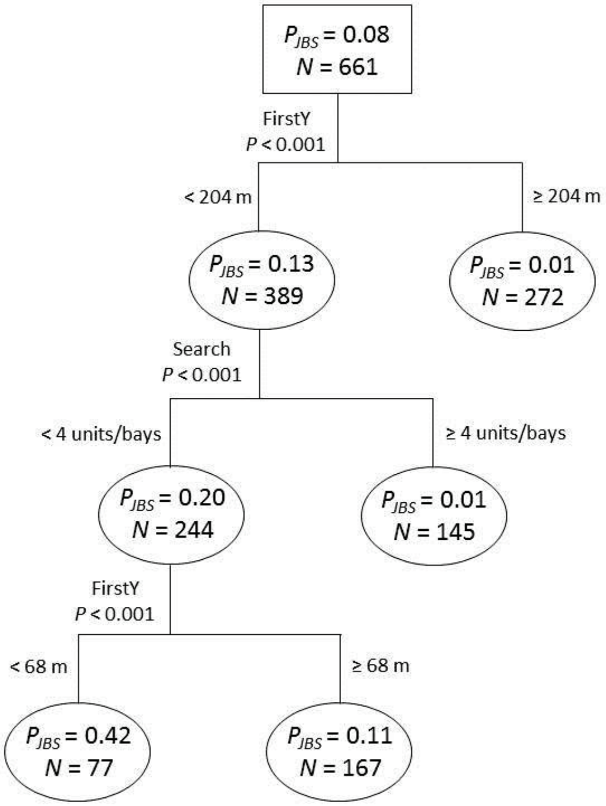

Figure 3.19. Results of a decision tree analysis of JBS passage probabilities (P_{JBS}) for acoustic-tagged steelhead kelts at Little Goose Dam (LGS) in 2012 and 2013. The P_{JBS} and sample size are shown for the entire sample of kelts that passed LGS in the rectangle and for homogeneous groups in the ovals. The adjusted *P* value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.33.

3.2.2.4 Turbines

Of the 661 acoustic-tagged kelts assigned a route at LGS, 33 (5%) passed through the turbines. From the bivariate models, five variables were significantly correlated with turbine passage probability (Table A.15). The four most highly correlated of those variables included FirstY ($\chi^2 = 9.5$; $P = 0.002$) and Search ($\chi^2 = 9.2$; $P = 0.002$), which were negatively correlated with turbine passage probability, and ln(Z dist) ($\chi^2 = 6.8$; $P = 0.009$) and AccDepth ($\chi^2 = 11.0$; $P < 0.001$), which were positively correlated with turbine passage. Both Search and ln(Z dist) were included in each of the top five multivariable models and had very high posterior probabilities of model inclusion ($p[\Delta \mid D] > 0.93$) (Table A.16). AccDepth ($p[\Delta \mid D] = 0.82$) and FirstY ($p[\Delta \mid D] = 0.67$) were included in three of the top five models. All four variables were included in the top model, which indicated turbine passage probability was highest for kelts that did little near-dam searching, undertook substantial vertical migrations, were acclimated to deeper depths, and were first detected approaching LGS closer to the south (powerhouse) end of the dam.

The variables that affected turbine passage probability were generally similar to those found to affect JBS passage probability. The effect of acclimation depth on turbine passage can be observed in both the boxplots of acclimation depth by route (Figure 3.14) and the contour maps of powerhouse passage probability by forebay location (Figure 3.18). The median acclimation depth of kelts that passed through the turbines was 2.9 m (IQR: 1.4–14.4 m), which was deeper than the median acclimation depth observed for kelts that passed via the spillway and similar to that of kelts that passed through the JBS. As previously mentioned, the effect of approach location on powerhouse passage probability is apparent in the contour maps, with kelts detected on the powerhouse side of the forebay having a much higher probability of passing through the powerhouse.

The decision tree model indicated kelts that did little near-dam searching (i.e., Search < 3 units/bays) had a 0.07 probability of turbine passage compared to 0.02 for kelts that did more near-dam searching (i.e., Search ≥ 3 units/bays) (Figure 3.20). Not surprisingly, of the kelts that did less near-dam searching, those that undertook vertical migrations in excess of 29 m (i.e., ln[Z dist] ≥ 3.4) had a much higher probability of turbine passage ($P_{Turb} = 0.14$) than those that did less vertical swimming ($P_{Turb} = 0.01$).

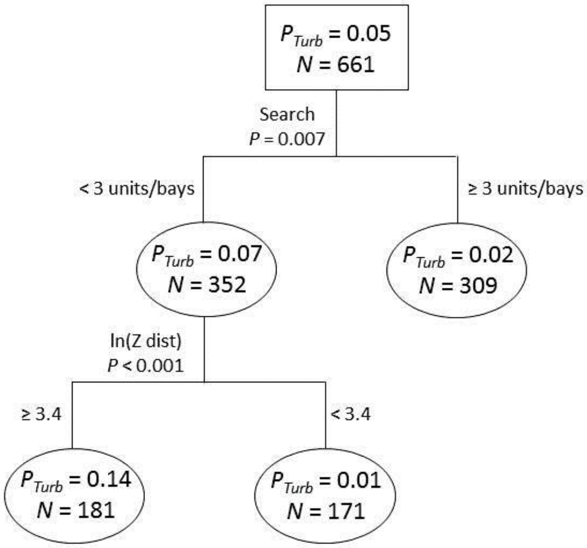

Figure 3.20. Results of a decision tree analysis of turbine passage probabilities (P_{Turb}) for acoustic-tagged steelhead kelts at Little Goose Dam (LGS) in 2012 and 2013. The P_{Turb} and sample size are shown for the entire sample of kelts that passed LGS in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.14.

The timing of vertical migrations displayed by kelts that passed LGS through the powerhouse can be observed in boxplots of the depth distributions by passage route at 0 min, 2 min, 5 min, 10 min, and 20 min prior to passage (Figure 3.21). These figures indicate most kelts that passed through the powerhouse began their descent about 5 to 10 min prior to passage. In contrast, most kelts that passed over the spillway weir remained relatively shallow throughout the 20 min period prior to passage. Most kelts that passed through traditional spill bays became shallower in advance of their passage until 0 min to passage, at which point they descended a few meters to the openings of the traditional spill bays.

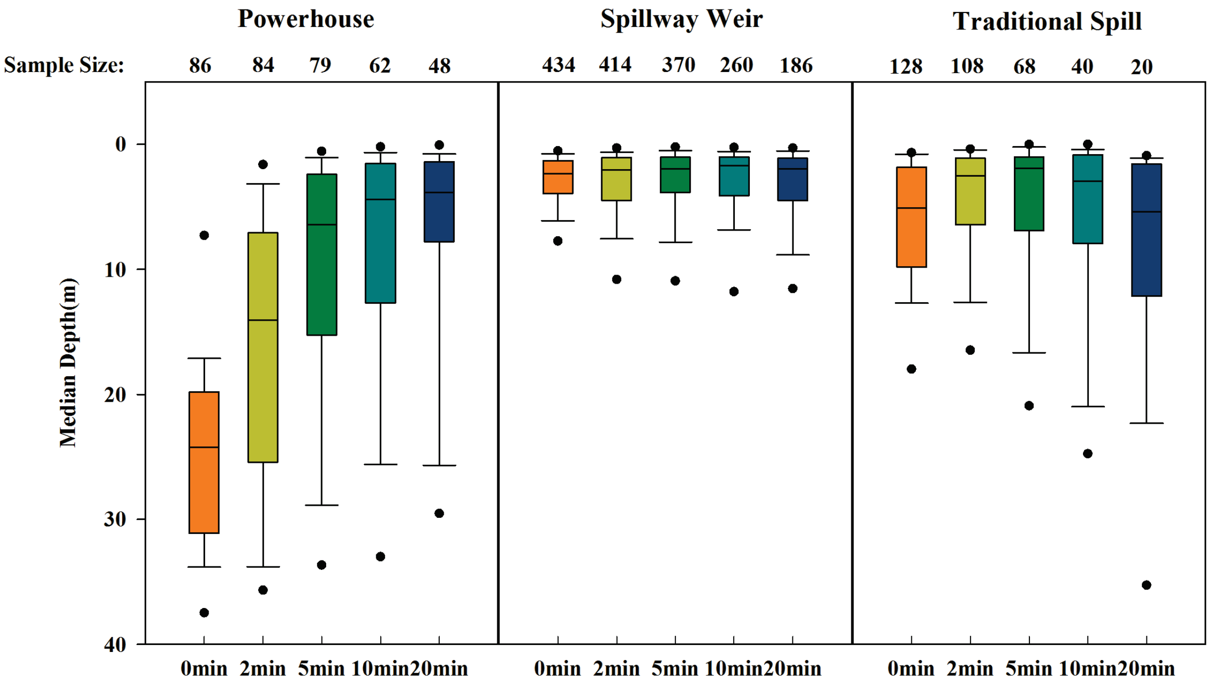

Figure 3.21. Boxplots displaying the depth distribution of acoustic-tagged kelts by passage route 0, 2, 5, 10, and 20 minutes prior to passing Little Goose Dam in 2012 and 2013. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

Although the depth distribution by distance to passage was relatively constant for kelts that passed either spillway route (weir or traditional) throughout their approach to LGS, the distribution varied greatly for powerhouse-passed kelts (Figure 3.22). Kelts that passed LGS through the powerhouse displayed a great deal of variability in depth between 50 m and 5 m in front of the dam. Once at the dam face (0 m), about 90% of the kelts that ultimately passed through the powerhouse had median depths that were in the upper 5 m of the water column. These data, combined with the data presented above of depth distributions by time to passage, indicate powerhouse-passed kelts were very surface-oriented near the dam for prolonged periods before beginning their final descent to the turbine intakes.

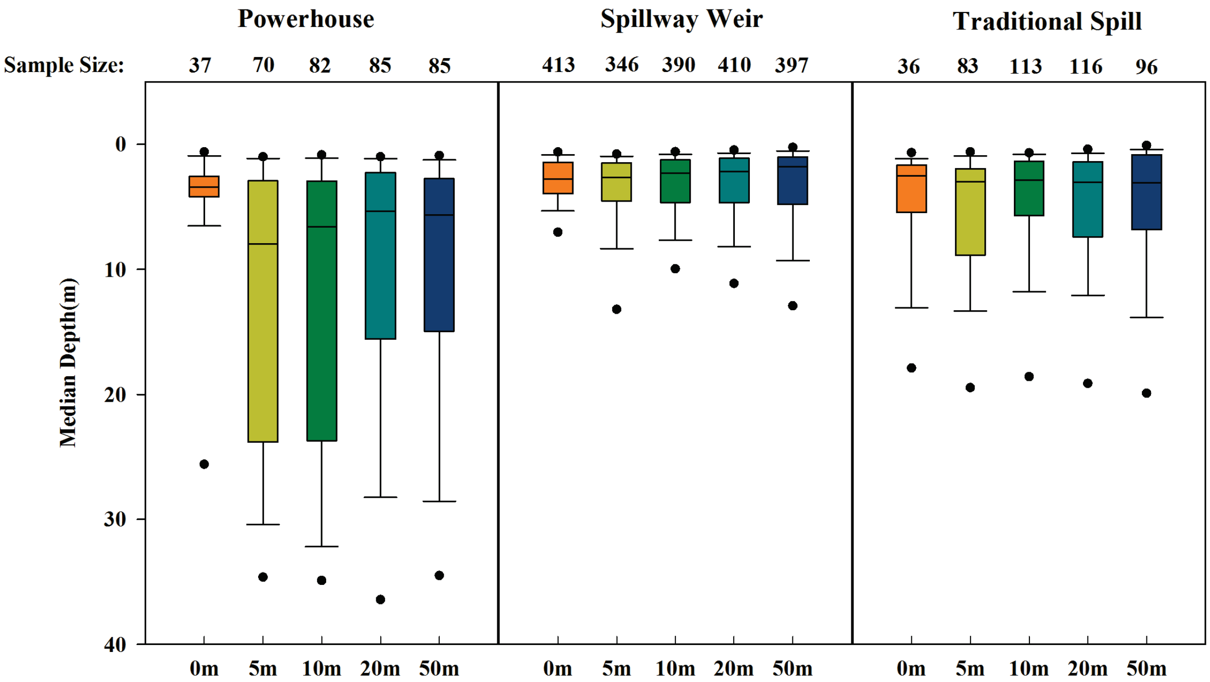

Figure 3.22. Boxplots displaying the depth distribution of acoustic-tagged kelts by passage route 0, 5, 10, 20, and 50 m prior to passing Little Goose Dam in 2012 and 2013. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

3.2.3 Lower Monumental Dam

3.2.3.1 Spillway Weir

Of the 551 acoustic-tagged steelhead kelts that were assigned a passage route at LMN in 2012 and 2013, 385 (70%) passed over the spillway weir. Bivariate modeling revealed 13 variables that were significantly correlated with the probability of spillway weir passage at LMN (Table A.17). The four most highly correlated of those variables included FirstY ($\chi^2 = 31.3$; $P < 0.001$), Search ($\chi^2 = 30.1$; $P < 0.001$), and ln(Y dist) ($\chi^2 = 25.7$; $P < 0.001$), which were all positively correlated with the probability of spillway weir passage, and AccDepth ($\chi^2 = 50.6$; $P < 0.001$), which was negatively correlated with spillway weir passage. Three of these variables, AccDepth, FirstY, and ln(Y dist), were included in each of the top five multivariable models, along with ln(Z dist) (Table A.18). All four of these variables had posterior probabilities of 1.0. The models indicated kelts that were acclimated to shallower depths, approached the dam closer to the north (powerhouse) end of the dam, and displayed more substantial horizontal with limited vertical migrations were more likely to pass via the weir than other routes.

Many of the same variables included in the top bivariate and multivariable logistic models were also included in the decision tree constructed to describe the variables that affected spillway weir passage probability of acoustic-tagged kelts at LMN (Figure 3.23). Kelts that did more near-dam searching (Search ≥ 2 units/bays) had a spillway weir passage probability of 0.83 compared to 0.52 for those that did less near-dam searching. Of those that did less near-dam searching, kelts were more likely to pass over the weir if they were first detected approaching the dam north of spill bay 7 (i.e., on the powerhouse side of the forebay; FirstY ≥ −200 m) ($P_{weir} = 0.62$) compared to those that approached on the spillway side of the forebay ($P_{weir} = 0.22$). The decision tree also indicated kelts that approached on the powerhouse side of the forebay had a higher probability of spillway weir passage if they had limited vertical migrations but more substantial horizontal migrations in the forebay.

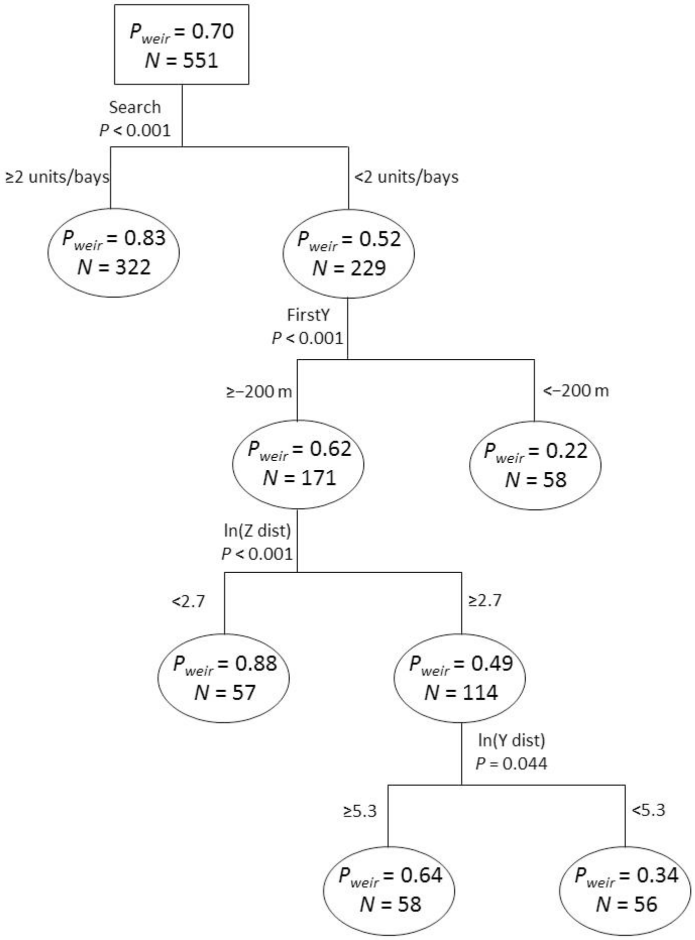

Figure 3.23. Results of a decision tree analysis of spillway weir passage probabilities (P_{weir}) for acoustic-tagged steelhead kelts at Lower Monumental Dam (LMN) in 2012 and 2013. The P_{weir} and sample size are shown for the entire sample of kelts that passed LMN in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.19.

Contour maps of spillway weir passage probability by forebay location indicate the importance of migration depth, horizontal approach (Y) location, and horizontal searching behavior on the probability of weir passage at LMN. Kelts detected on the powerhouse side of the forebay at depths less than 10 m had the highest probability of passing over the weir (Figure 3.24). Relatively high passage probabilities (> 0.50) across the entire width of the forebay also indicate a high degree of horizontal searching behavior by kelts that ultimately passed over the weir. Boxplots of acclimation depth by passage route also suggest the importance of migration depth on the ultimate route of passage. The median acclimation depth was 1.4 m (IQR: 1.0–3.8 m) for kelts that passed LMN via the weir (Figure 3.25) compared to 3.3 m (IQR:

1.0–11.3 m) for kelts that passed all other routes. The majority of kelts were acclimated to depths shallower than 5 m in the LMN forebay (Figure 3.26), which greatly contributed to the high spillway weir passage probability observed in 2012 and 2013.

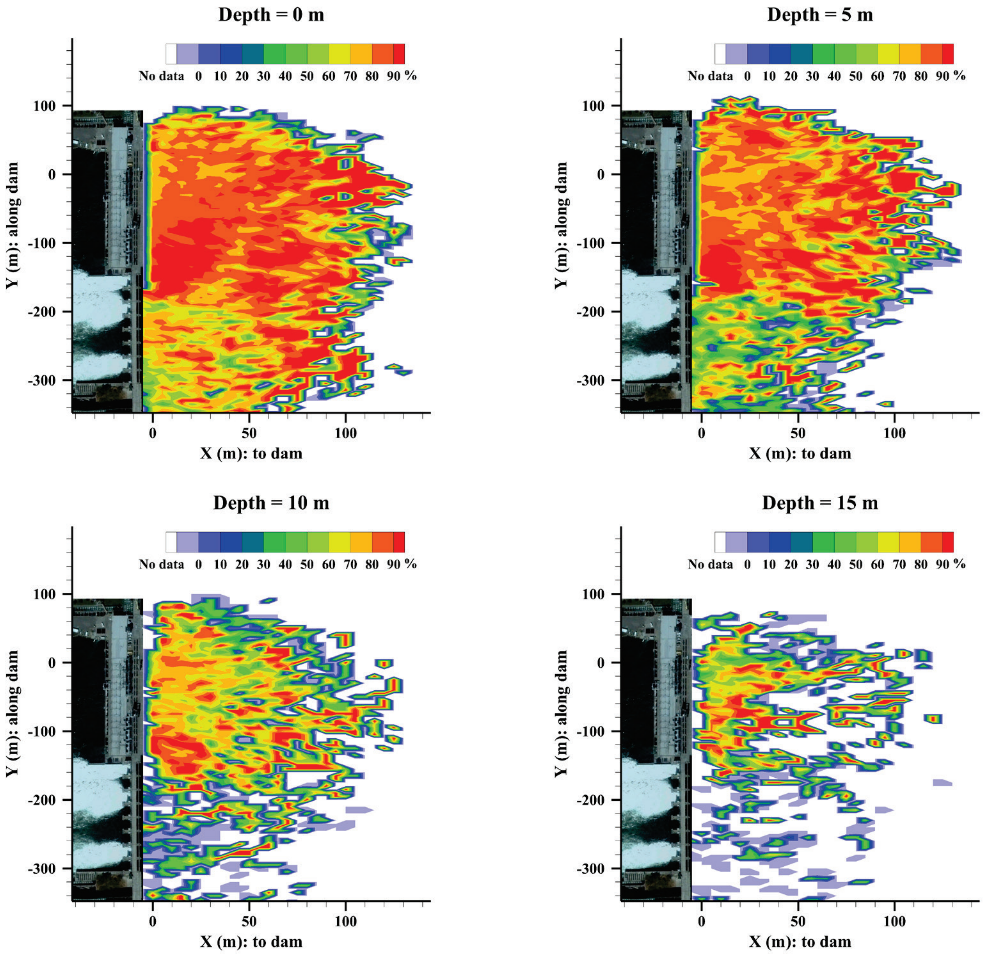

Figure 3.24. Contour maps displaying the probability of spillway weir passage for steelhead kelts at Lower Monumental Dam in 2012 and 2013 by their location (at four different depths) in the forebay.

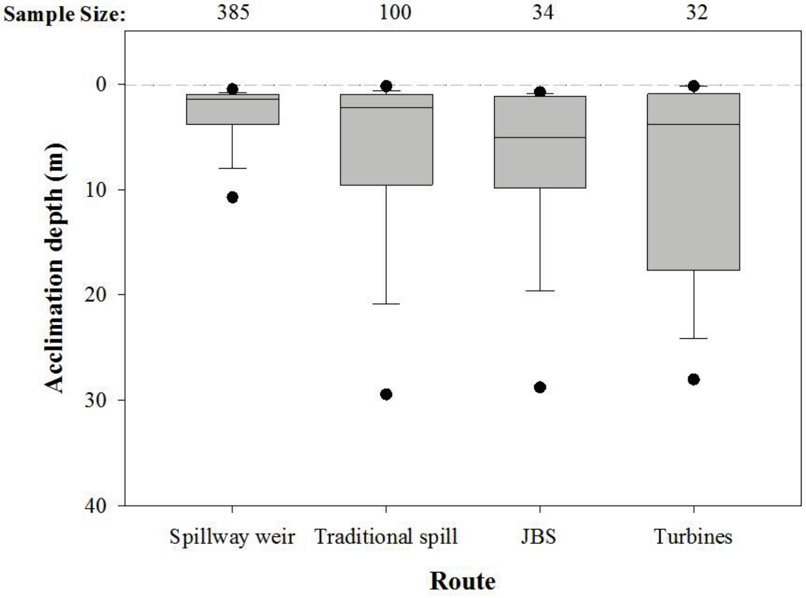

Figure 3.25. Boxplots displaying the distributions of acoustic-tagged steelhead kelt acclimation depths (AccDepth) by route of passage at Lower Monumental Dam in 2012 and 2013. An AccDepth value of 0 m represents the water surface. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

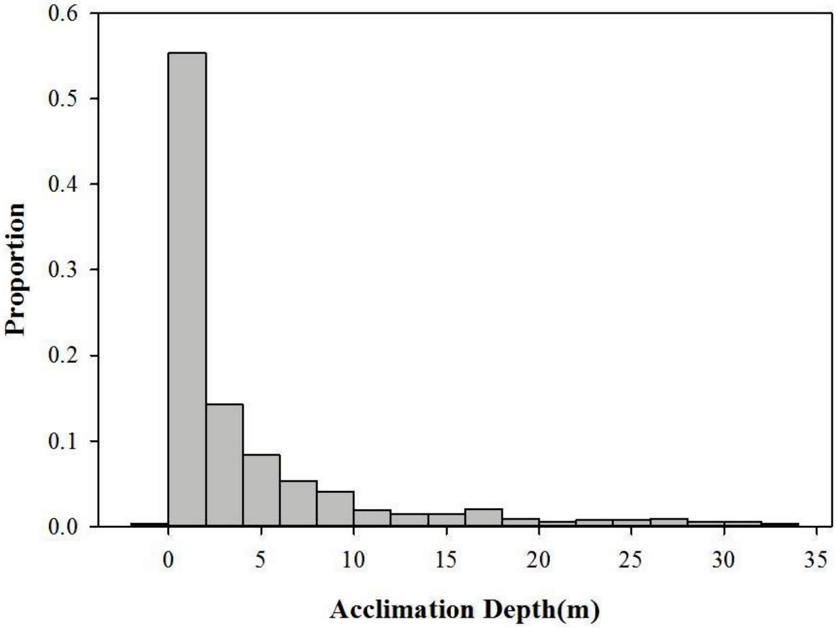

Figure 3.26. Distribution of acclimation depths for acoustic-tagged steelhead kelts in the forebay of Lower Monumental Dam (20 to 75 m from the dam face) in 2012 and 2013. An acclimation depth value of 0 m represents the water surface. 3-D fish positions were accurate to 1 m; therefore, some fish had acclimation depths > 0 m.

3.2.3.2 Traditional Spill

Of the 551 acoustic-tagged kelts assigned a passage route at LMN in 2012 and 2013, 100 (18%) passed via traditional spill bays. Seventeen of the variables were significantly correlated with traditional spill passage probability in bivariate logistic regression models (Table A.19). The most highly correlated of those variables was FirstY ($\chi^2 = 88.1$; $P < 0.001$), which was negatively correlated with traditional spill passage probability. FirstY was also the only variable included in each of the top five multivariable models with a posterior probability of 1.0 (Table A.20). AccDepth ($p[\Delta \mid D] = 0.75$) and S5%Q ($p[\Delta \mid D] = 0.56$) were the only other variables that had posterior probabilities > 0.5. These three variables were included in the top multivariable model, which indicated traditional spill passage probability was higher for kelts that approached LMN closer to the south (spillway) end of the dam, were acclimated to deeper depths, and passed LMN when the percent discharge through spill bay 5 was higher.

FirstY was also identified as the most important variable for explaining traditional spill passage probability in the decision tree model (Figure 3.27). Kelts first detected approaching LMN south of the spillway weir (i.e., spill bay 8; FirstY < −178 m) had a 0.48 probability of traditional spill passage compared to 0.08 for kelts first detected north of the spillway weir (i.e., FirstY ≥ −178 m). Of the 411 kelts that were first detected north of the spillway weir, those that did more near-dam searching (i.e., Search ≥ 5 units/bays) had a higher probability of traditional spill passage than those that did less near-dam searching. The highest traditional spill passage probability was observed for kelts that were first detected on the spillway side of the forebay (i.e., FirstY < −178 m) with limited horizontal migrations in the forebay (ln[Y dist] < 5.1; $P_{trad} = 0.64$).

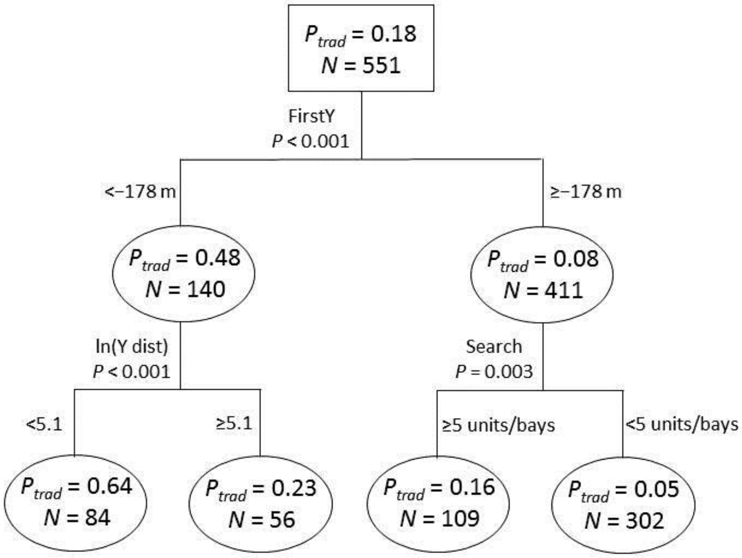

Figure 3.27. Results of a decision tree analysis of traditional spill passage probabilities (P_{trad}) for acoustic-tagged steelhead kelts at Lower Monumental Dam (LMN) in 2012 and 2013. The P_{trad} and sample size are shown for the entire sample of kelts that passed LMN in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.25.

Contour maps of traditional spill passage probability by forebay location also indicate kelts detected on the south (spillway) side of the forebay were much more likely to pass LMN through traditional spill bays than kelts detected on the north (powerhouse) side of the forebay (Figure 3.28). The maps also show a higher probability of traditional spill passage for kelts at depths deeper than 5 m. Although the median acclimation depth for kelts that passed LMN through traditional spill bays was relatively shallow (2.3 m), 25% of the kelts that passed through traditional spill bays had acclimation depths that were deeper than 9.5 m (Figure 3.25).

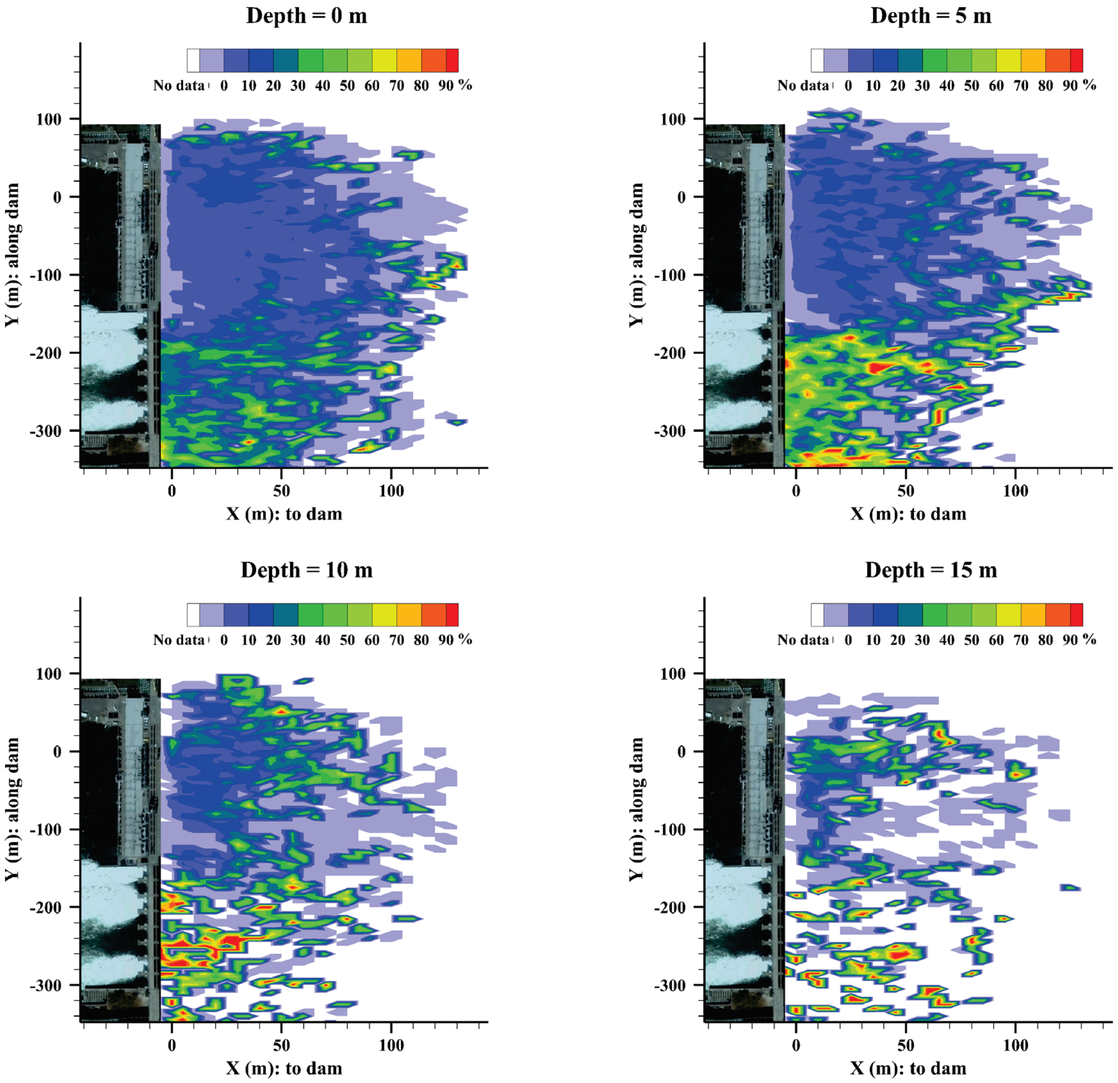

Figure 3.28. Contour maps displaying the probability of traditional spill passage for steelhead kelts at Lower Monumental Dam in 2012 and 2013 by their location (at four different depths) in the forebay.

3.2.3.3 Juvenile Bypass System

Of the 551 acoustic-tagged kelts assigned a passage route at LMN in 2012 and 2013, 34 (6%) were determined to have passed through the JBS. Thirteen variables were significantly correlated with JBS passage probability in bivariate models (Table A.21). The top three of these variables included %Spill (χ^2

= 14.0; $P < 0.001$) and S5%Q ($\chi^2 = 9.7$; $P = 0.002$), which were negatively correlated with JBS passage probability, and AccDepth ($\chi^2 = 8.0$; $P = 0.005$), which was positively correlated with JBS passage. Both %Spill and AccDepth had high posterior probabilities of inclusion ($p[\Delta \mid D] > 0.80$) in the multivariable models (Table A.22). These were also the only two variables included in the top multivariable model, which indicates JBS passage probability was higher for kelts that were acclimated to deeper depths and passed LMN at lower levels of %Spill.

The decision tree constructed to identify variables that influenced JBS passage probability included four splits of the data (Figure 3.29). The first split indicated kelts that were acclimated to depths deeper than 4.1 m had a 0.13 JBS passage probability compared to 0.04 for those acclimated to depths shallower than 4 m. Those that were acclimated to deeper depths had a 0.24 probability of JBS passage if they passed when %Spill was < 25.6% compared to 0.05 for those that passed when %Spill was ≥ 25.6%. For kelts that were acclimated to depths shallower than 4 m, the probability of JBS passage was highest for those that did little near-dam searching (Search < 2 units/bays) and were first detected approaching LMN in front of the powerhouse (i.e., FirstY ≥ −137 m).

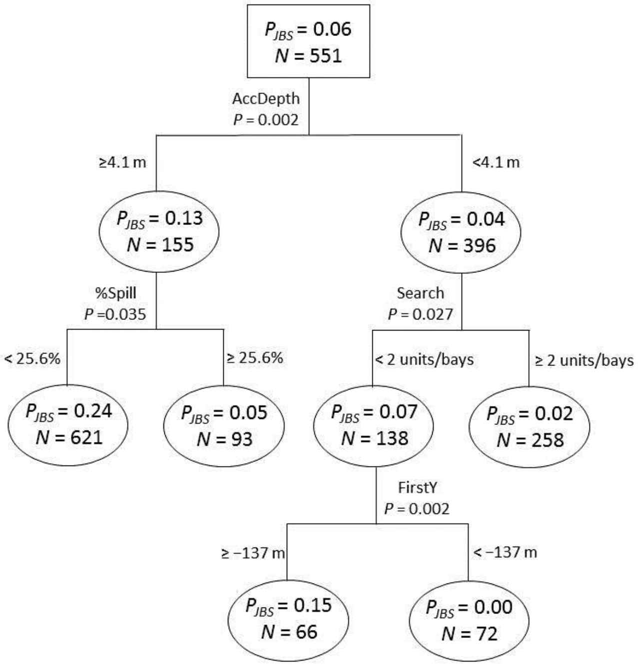

Figure 3.29. Results of a decision tree analysis of juvenile bypass system passage probabilities (P_{JBS}) for acoustic-tagged steelhead kelts at Lower Monumental Dam (LMN) in 2012 and 2013. The P_{JBS} and sample size are shown for the entire sample of kelts that passed LMN in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.20.

Contour maps of powerhouse passage probability by forebay detection location also indicated that deeper migrating kelts and those detected in front of the powerhouse had a higher probability of passing through the powerhouse than shallow migrants and those detected in front of the spillway (Figure 3.30). Boxplots of acclimation depth by passage route also display the relationship between migration depth and route (Figure 3.25). Acoustic-tagged kelts that passed through the JBS had a median depth of 5.1 m (IQR: 1.2–9.9 m), which was substantially deeper than the median depth of kelts that passed LMN via the spillway (median = 1.5 m; IQR: 1.0–4.1 m). Although the median acclimation depth of JBS-passed kelts was deeper than that observed for turbine-passed kelts at LMN, the overall distribution was shallower.

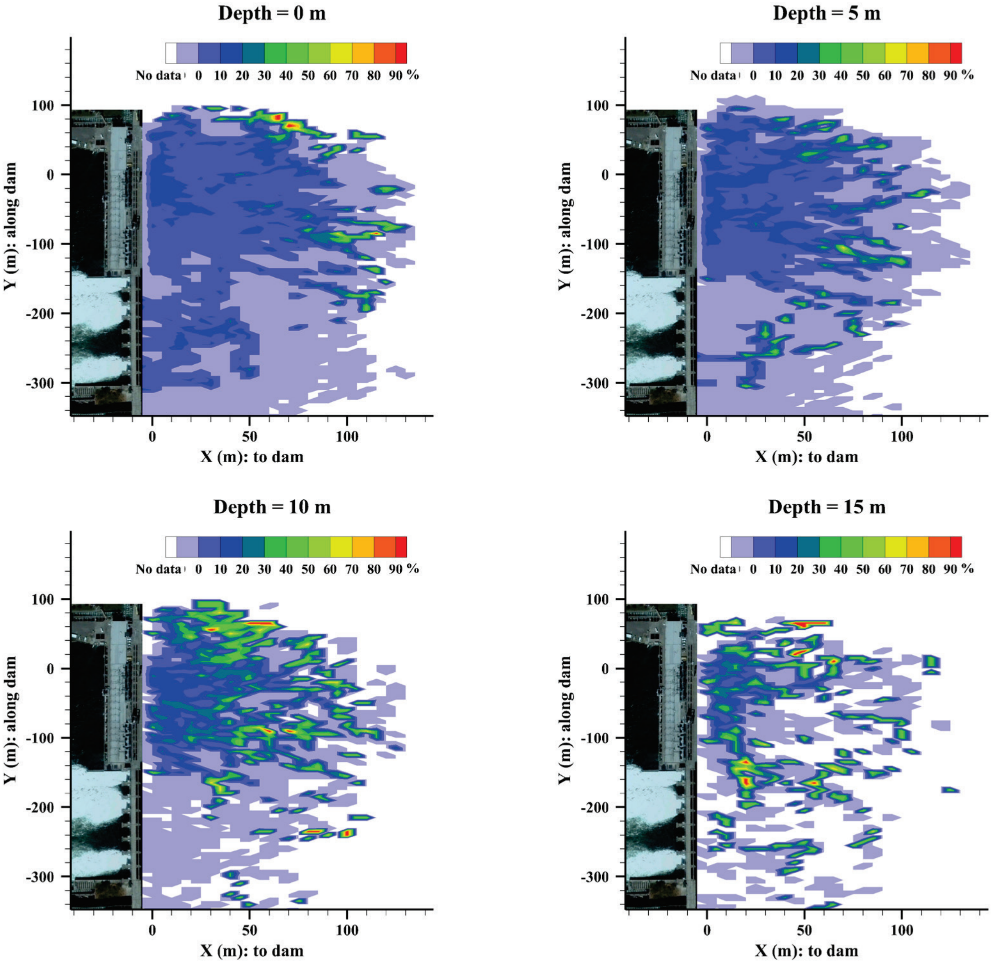

Figure 3.30. Contour maps displaying the probability of powerhouse passage for steelhead kelts at Lower Monumental Dam in 2012 and 2013 by their location (at four different depths) in the forebay.

3.2.3.4 Turbines

Of the 551 acoustic-tagged steelhead kelts that passed LMN in 2012 and 2013, 32 (6%) passed through the turbines. Five variables were found that were significantly correlated with the probability of turbine passage in the bivariate models (Table A.23). The top four of those included Search ($\chi^2 = 23.4$; $P < 0.001$), which was negatively correlated with turbine passage probability, and AccDepth ($\chi^2 = 11.4$; $P < 0.001$), FirstY ($\chi^2 = 7.4$; $P = 0.006$), and ln(Z dist) ($\chi^2 = 4.7$; $P = 0.031$), which were positively correlated with turbine passage. Search, FirstY, and ln(Z dist) were included in each of the top four multivariable models constructed to identify the variables that affected turbine passage of kelts at LMN (Table A.24). All three of these variables had posterior probabilities of model inclusion of 1.0. AccDepth was included in two of the top four models, including the top model with a posterior probability of 0.58. The top model indicated turbine passage probability was higher for kelts that did little near-dam searching, were first detected approaching LMN closer to the north (powerhouse) end of the dam, undertook more substantial vertical migrations, and were acclimated to deeper depths.

As previously described for JBS-passed fish, the effect of migration depth on turbine passage can be observed in the boxplots displaying the acclimation depth distribution by route (Figure 3.25) and in the contour maps that show powerhouse passage probability by forebay location (Figure 3.30). The median acclimation depth of kelts that passed LMN through the turbines was 3.8 m, but the IQR ranged from 0.9 m to 17.7 m.

The decision tree model split the data at three points (Figure 3.31). The first split occurred on the Search variable—kelts that passed fewer than three turbine units and/or spill bays within 10 m of the dam had a 0.10 probability of turbine passage compared to 0.02 for those that did more near-dam searching (i.e., Search ≥ 3 units/bays). Of the kelts that did less near-dam searching, those that undertook more substantial (> 18 m) vertical migrations (i.e., ln[Z dist] ≥ 2.9) had a 0.15 probability of turbine passage compared to 0.0 for those that did not display this behavior. Finally, kelts had the highest probability of turbine passage if they did little near-dam searching, undertook more substantial vertical migrations, and were first detected approaching LMN in front of the powerhouse (i.e., FirstY ≥ −131 m).

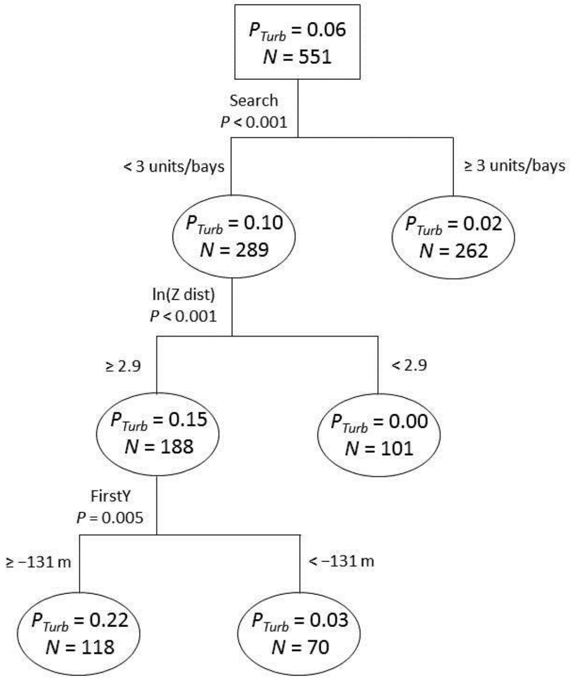

Figure 3.31. Results of a decision tree analysis of turbine passage probabilities (P_{Turb}) for acoustic-tagged steelhead kelts that passed Lower Monumental Dam (LMN) through the powerhouse in 2012 and 2013. The P_{Turb} and sample size are shown for the entire sample of kelts that passed LMN in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.23.

Boxplots of depth distributions by time and distance prior to LMN passage for the various routes showed similar trends to those observed for LGR and LGS. The majority of kelts that passed over the spillway weir at LMN spent most of their time at shallow depths within 50 m of the dam and 20 min to passage (Figure 3.32 and Figure 3.33). Those that passed through traditional spill bays migrated mostly in the upper 5 m of the water column, becoming slightly deeper at the time of passage. Powerhouse-passed kelts displayed great variability in the depths they occupied as they approached the dam, becoming decidedly more surface-oriented once they reached the dam face. Once at the dam face, kelts that would ultimately pass through the powerhouse appeared to linger before beginning their gradual descent to the turbine intakes 10 min prior to passage.

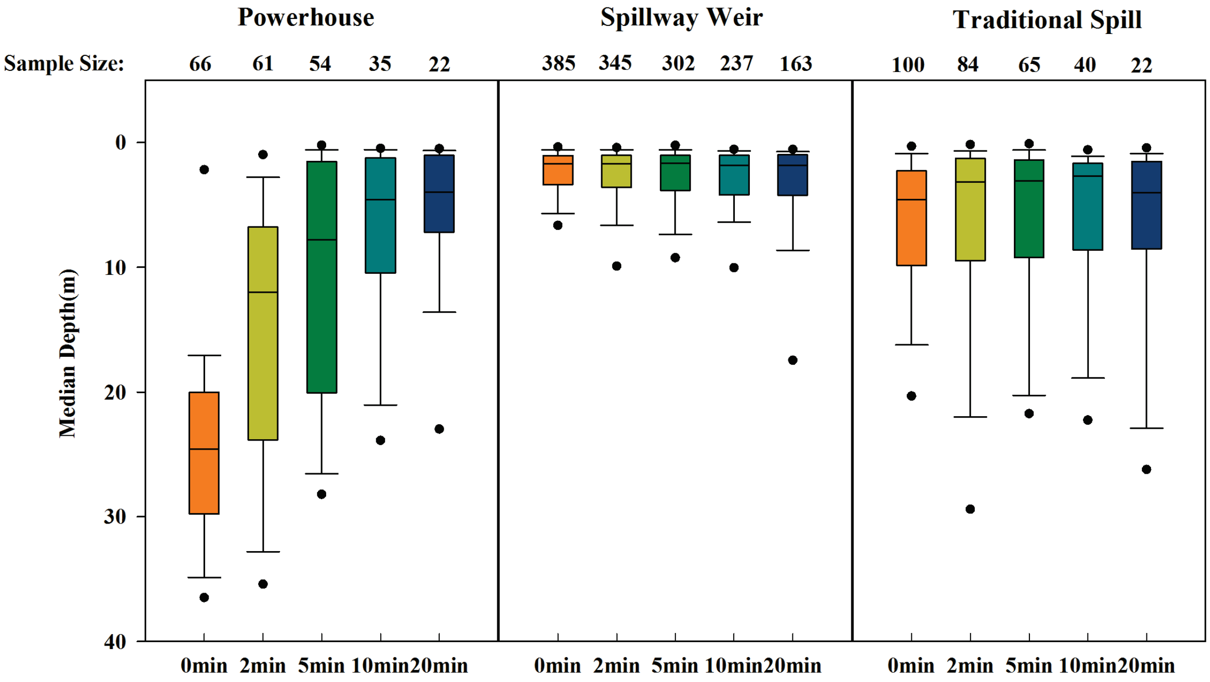

Figure 3.32. Boxplots displaying the depth distribution of acoustic-tagged kelts by passage route 0, 2, 5, 10, and 20 min prior to passing Lower Monumental Dam in 2012 and 2013. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

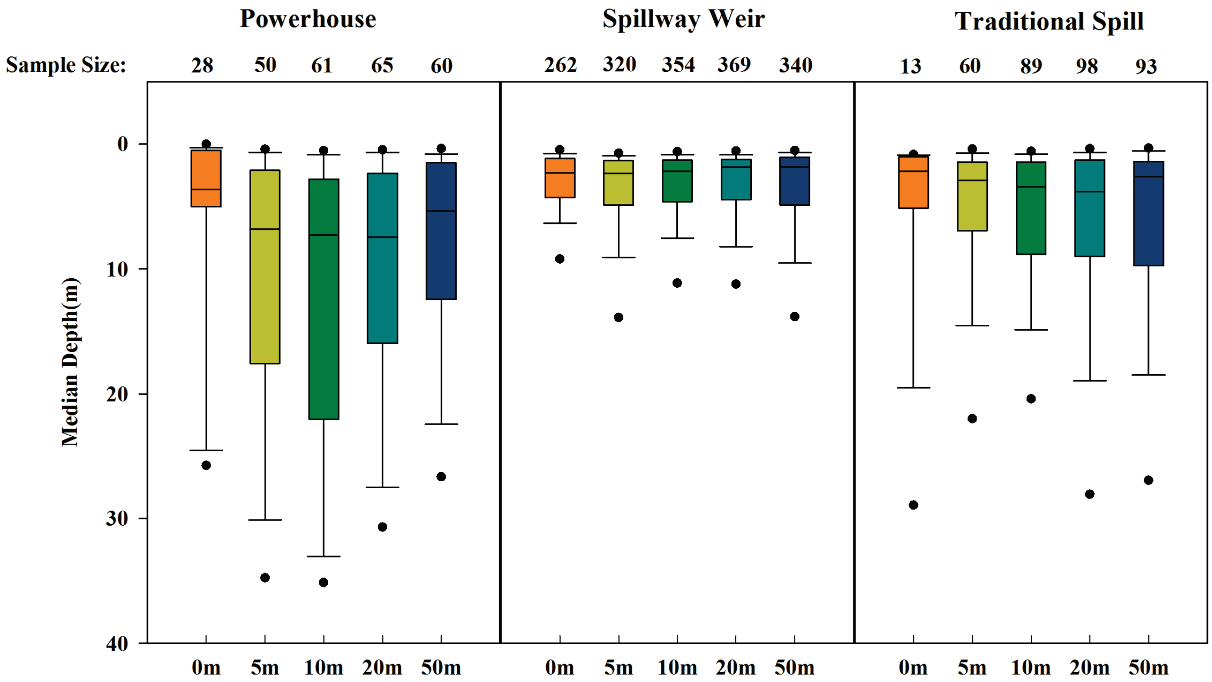

Figure 3.33. Boxplots displaying the depth distribution of acoustic-tagged kelts by passage route 0, 5, 10, 20, and 50 m prior to passing Lower Monumental Dam in 2012 and 2013. Solid lines within the boxes are medians, the box boundaries represent the 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, and dots represent the 5th and 95th percentiles.

3.3 Factors Affecting Survival

A description of the variables correlated with the probability of kelt survival through surface routes and all routes combined at each of LGR, LGS, and LMN from the bivariate and multivariable models are described below. Full details, including the posterior probabilities, the full list of predictor variables tested, and the cumulative posterior probability for each model are outlined in Appendix A.

3.3.1 Lower Granite Dam

3.3.1.1 All Routes

From the bivariate modeling, 11 variables were identified that were significantly correlated with the survival of acoustic-tagged steelhead kelts from LGR to the detection array located 59 km downstream in 2012 and 2013 (Table A.25). The four most highly correlated variables were Condition ($\chi^2 = 32.4$; $P < 0.001$), Discharge ($\chi^2 = 27.3$; $P < 0.001$), S1%Q ($\chi^2 = 24.0$; $P < 0.001$), and T6%Q ($\chi^2 = 23.3$; $P < 0.001$). The observed relationships indicated kelt survival was positively correlated with Discharge and T6%Q, negatively correlated with S1%Q, and higher for good condition kelts. Condition ($p[\Delta \mid D] = 1.00$) was the only variable included in each of the top five multivariable models constructed to identify the factors that affected survival of acoustic-tagged kelts at LGR in 2012 and 2013 (Table A.26). T6%Q had a posterior probability of 0.71 and was included in three of the top five models. The inclusion of these variables in the models suggests that survival was higher for good condition kelts and those that passed LGR when T6%Q was higher.

Turbine unit 6 was only used when Discharge was > 70 kcfs, which indicated the relationship between discharge and T6%Q may have confounded the significant effect of T6%Q on survival. However, a closer look revealed that T6%Q may have affected survival independent of discharge. At discharges between 70 kcfs and 130 kcfs, T6%Q was either 0% or within the range of 10% to 20%. Kelts that passed within this range of discharges when T6%Q equaled 0% had a survival probability of 0.76 compared to 0.93 for those that passed when discharge was between 70 kcfs and 130 kcfs and T6%Q was between 10% and 20%.

The decision tree analysis identified two variables that resulted in significant splits of the data. Kelts that were in good condition had a 0.82 survival probability to the array located 59 km downstream of LGR compared to 0.33 for fair condition kelts (Figure 3.34). Of the 227 good condition kelts, those that had a tailrace egress time < 23 minutes (ln[TR egress] < −4.1) had a joint probability of 0.96 compared to 0.75 for kelts that had egress times ≥ 23 minutes.

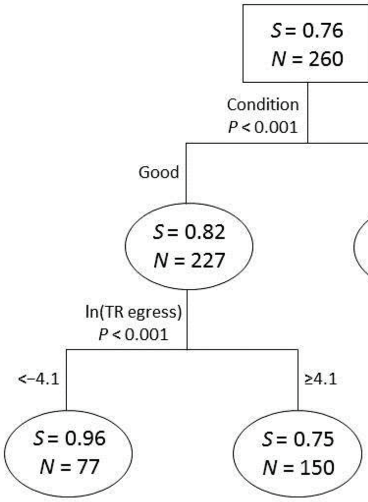

Figure 3.34. Results of a decision tree analysis conducted to identify variables that affected survival (*S*) of acoustic-tagged steelhead kelts from the face of Lower Granite Dam (LGR) to the detection array located 59 km downstream of the dam in 2012 and 2013. The *S* and sample size are shown for the entire sample of kelts that passed LGR in the rectangle and for homogeneous groups in the ovals. The adjusted *P* value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.18.

3.3.1.2 Spillway Weir

The same 11 variables that were correlated with the survival of kelts that passed through all routes at LGR were also found to be correlated with the survival of kelts that passed LGR over the spillway weir in the bivariate models (Table A.27). This result can be attributed to the fact that the majority of kelts (70%) passed LGR via the weir. Therefore, the variables that affected the survival of kelts that passed the weir had great influence on overall passage survival as well. The two most highly correlated of the variables in the bivariate modeling were Condition ($\chi^2 = 27.9$; $P < 0.001$) and T6%Q ($\chi^2 = 22.1$; $P < 0.001$). These two variables were also the only two variables included in each of the top five multivariable models, both with posterior probabilities of 1.0 (Table A.28). The models indicated survival was higher for good condition kelts and for those that passed the weir at LGR when T6%Q was higher.

Similar to the finding described above for kelts passing all routes, T6%Q affected the survival of kelts that passed over the spillway weir. Kelts that passed the weir at LGR when total discharge was between 70 kcfs and 130 kcfs and T6%Q equaled 0% had a survival probability of 0.68 compared to 0.93 for kelts that passed in this range of discharge and T6%Q was between 10% and 20%.

The decision tree analysis incorporated three variables, including Condition, T6%Q, and ln(TR egress) (Figure 3.35). Of the 186 kelts that passed via the spillway weir at LGR, those in good condition had a survival probability of 0.81 to the array located 59 km downstream compared to 0.28 for fair condition kelts. Of the 161 good condition kelts that passed via the weir, the 40 that passed when T6%Q ≥ 12.7% had a 1.00 probability of survival compared to 0.75 for the 121 that passed when T6%Q < 12.7%. Finally, of the 121 good condition kelts that passed when T6%Q < 12.7%, those that had tailrace egress times < 23 minutes had a 0.96 survival probability compared to 0.69 for those with egress times ≥ 23 minutes.

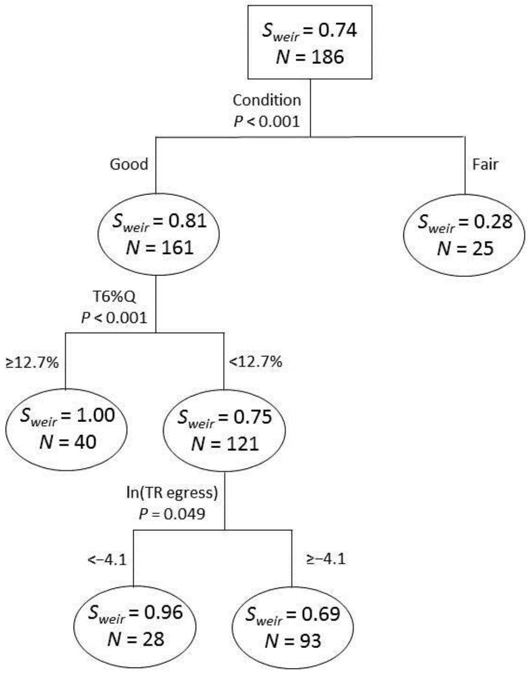

Figure 3.35. Results of a decision tree analysis conducted to identify variables that affected survival (*S*) of acoustic-tagged steelhead kelts that passed Lower Granite Dam (LGR) via the spillway weir to the detection array located 59 km downstream of the dam in 2012 and 2013. The *S* and sample size are shown for the entire sample of kelts that passed LGR in the rectangle and for homogeneous groups in the ovals. The adjusted *P* value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.28.

3.3.2 Little Goose Dam

3.3.2.1 All Routes

Sixteen variables were identified in the bivariate logistic regression models as being significantly correlated with the probability of kelt survival from the face of LGS to the detection array located 33 km downstream (Table A.29). The two most highly correlated of these variables were Discharge (χ^2=19.7; $P < 0.001$), which was positively correlated with survival, and T2%Q (χ^2=19.3; $P < 0.001$), which was negatively correlated with survival. Discharge and T2%Q were also highly correlated with one another ($\rho = -0.76$). However, neither of these variables were included in more than one of the top five multivariable models constructed to identify the factors that had the greatest influence on survival. The two variables that were included in each of the top five multivariable models included Condition and FL, which had posterior probabilities of 0.95 and 0.89, respectively (Table A.30). The inclusion of these variables indicated smaller kelts and those that were in good condition had a higher probability of survival than larger kelts and those in fair condition.

The decision tree analysis included two splits of the data (Figure 3.36). Of the 661 kelts that passed LGS, the 564 kelts in good condition had a 0.94 survival probability compared to 0.81 for the 97 fair condition kelts. Good condition kelts had a higher survival probability (S = 0.96) if they passed when the spillway weir crest was in low position compared to 0.91 for those that passed when the crest was in high position.

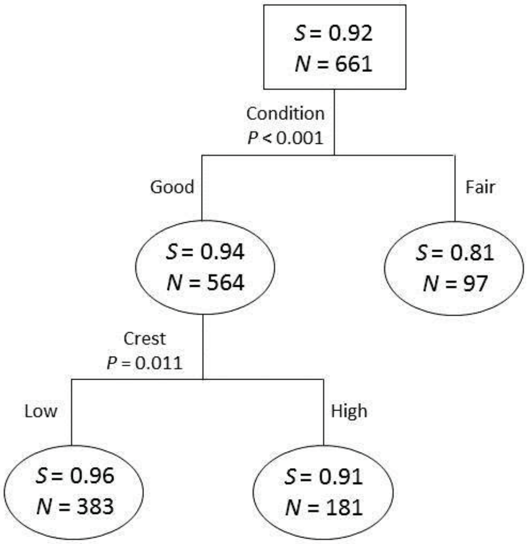

Figure 3.36. Results of a decision tree analysis conducted to identify variables that affected survival (*S*) of acoustic-tagged steelhead kelts from the face of Little Goose Dam (LGS) to the detection array located 33 km downstream of the dam in 2012 and 2013. The *S* and sample size are shown for the entire sample of kelts that passed LGS in the rectangle and for homogeneous groups in the ovals. The adjusted *P* value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.14.

3.3.2.2 Spillway Weir

From the bivariate modeling, 14 variables were significantly correlated with the probability of survival for acoustic-tagged steelhead kelts that passed LGS via the spillway weir in 2012 and 2013 (Table A.31). The three most highly correlated of those variables included T2%Q ($\chi^2 = 17.6$; $P < 0.001$), Crest ($\chi^2 = 15.7$; $P < 0.001$), and Discharge ($\chi^2 = 14.5$; $P < 0.001$). Survival was negatively correlated with T2%Q, positively correlated with Discharge, and higher for kelts that passed when the weir crest was in the low position. T2%Q ($p[\Delta \mid D] = 0.74$) was the only variable included in each of the top five multivariable models constructed to describe the factors that affected survival of spillway weir-passed kelts at LGS in 2012 and 2013 (Table A.32). As mentioned previously, T2%Q was highly negatively correlated with Discharge, making it difficult to discern the true mechanism behind this relationship.

The decision tree model resulted in just a single significant split of the data (Figure 3.37). Of the 445 acoustic-tagged kelts that passed LGS via the spillway weir in 2012 and 2013, the 283 of those that passed when the crest was in low position had a survival probability of 0.98 compared to 0.89 for the 162 kelts that passed when the crest was in the high position. The spillway weir crest was typically in the high position during lower flows (IQR: 60–79 kcfs) and in the low position during higher flows (IQR: 90–121 kcfs), which potentially confounded the relationship between survival and crest position. However, between 64 kcfs and 92 kcfs, nearly equal numbers of kelts passed when the weir was at the low ($n = 85$) and high ($n = 76$) crest position. Those that passed within this range of discharges (64 kcfs to 92 kcfs) at low crest had a survival probability of 0.95 compared to 0.87 for those that passed at high crest. The effect of crest position on survival was marginally significant within the 64 to 92 kcfs range of discharges ($\chi^2 = 3.79$; $P = 0.055$).

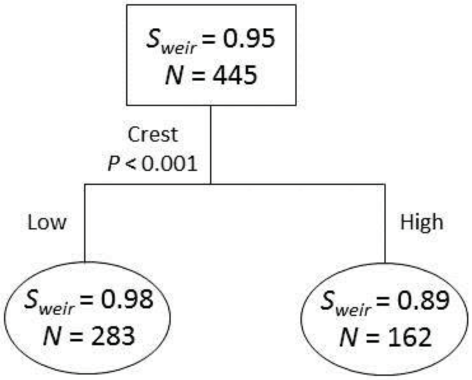

Figure 3.37. Results of a decision tree analysis conducted to identify variables that affected survival (S) of acoustic-tagged steelhead kelts that passed Little Goose Dam (LGS) via the spillway weir to the detection array located 33 km downstream of the dam in 2012 and 2013. The S and sample size are shown for the entire sample of kelts that passed LGR in the rectangle and for homogeneous groups in the ovals. The adjusted P value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.08.

3.3.3 Lower Monumental Dam

3.3.3.1 All Routes

From the bivariate modeling, 10 variables were identified that were significantly correlated with the probability of acoustic-tagged steelhead kelts surviving from the face of LMN to the detection array located 27 km downstream (Table A.33). The most highly correlated of those variables was RelativeCond ($\chi^2 = 10.1$; $P = 0.002$), which was positively correlated with survival. RelativeCond ($p[\Delta \mid D] = 0.98$) and FL ($p[\Delta \mid D] = 1.00$) were the only two variables included in each of the top five multivariable models constructed to describe the variables that affected survival of kelts at LMN (Table A.34). The inclusion of these variables in the models, with high posterior probabilities, indicated survival was negatively correlated with FL and positively correlated with RelativeCond.

Only one significant split of the data resulted from the decision tree model (Figure 3.38). Kelts that measured < 70 cm FL had a survival probability of 0.95 compared to 0.83 for kelts that measured ≥70 cm FL.

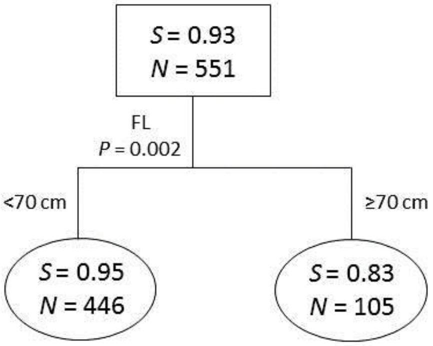

Figure 3.38. Results of a decision tree analysis conducted to identify variables that affected survival (*S*) of acoustic-tagged steelhead kelts from the face of Lower Monumental Dam (LMN) to the detection array located 27 km downstream of the dam in 2012 and 2013. The *S* and sample size are shown for the entire sample of kelts that passed LGR in the rectangle and for homogeneous groups in the ovals. The adjusted *P* value is displayed below the variable on which the split occurred and the value of each variable that separated groups is displayed next to each branch of the split. The decision tree had a coefficient of determination (R^2) of 0.05.

3.3.3.2 Spillway Weir

Eight variables were identified in the bivariate modeling as having a significant correlation with the probability of survival for acoustic-tagged steelhead kelts that passed LMN via the spillway weir in 2012 and 2013 (Table A.35). The top three most highly correlated of those variables included S6%Q, S7%Q, and S8%Q. Survival was negatively correlated with both S6%Q ($\chi^2 = 8.6$; $P = 0.003$) and S8%Q ($\chi^2 = 7.2$; $P = 0.007$) and positively correlated with S7%Q ($\chi^2 = 7.5$; $P = 0.006$). However, S6%Q and S8%Q were both highly negatively correlated with Discharge ($\rho < -0.77$). No variable was included in more than one of the top five multivariable models constructed to explain the factors that affected survival of spillway weir-passed kelts at LMN in 2012 and 2013 (Table A.36). All of the candidate variables of the multivariable model had posterior probabilities of model inclusion < 0.36, indicating a high degree of uncertainty regarding the factors that affected spillway weir passage survival. Additionally, the decision tree analysis did not result in any significant splits of the data.

3.4 Factors Affecting Forebay Residence Time

3.4.1 Lower Granite Dam

Eight of the ten variables assessed were significantly correlated with the forebay residence times of kelts at LGR (Table A.37). The four most highly correlated of those variables included ln(Y dist) ($\chi^2 = 76.8$; $P < 0.001$), ln(Z dist) ($\chi^2 = 76.3$; $P < 0.001$), and S1%Q ($\chi^2 = 27.2$; $P < 0.001$), which were positively correlated with forebay residence time, and Discharge ($\chi^2 = 15.7$; $P < 0.001$), which was negatively correlated with forebay residence time. Because S1%Q and Discharge are directly correlated with one another, S1%Q was omitted from the list of candidate variables to be included in the multivariable modeling. Two variables, ln(Z dist) and Discharge, were the only variables included in each of the top five multivariable models (including the best model) with probabilities of model inclusion of 1.0 (Table A.38). The inclusion of these variables indicated forebay residence time was higher for kelts that undertook greater vertical migrations and for those that entered the forebay during periods of lower discharge.

Although Discharge was significantly negatively correlated with ln(Y dist) ($\chi^2 = 8.1$; $P = 0.004$) and Search ($\chi^2 = 8.8$; $P = 0.003$), indicating kelts did less horizontal swimming back-and-forth across the width of the forebay at higher flows, Discharge was not significantly correlated with ln(Z dist) ($\chi^2 = 1.0$; $P = 0.322$). Thus, it appears kelts displayed vertical migration behaviors independent of discharge; however, both variables affected forebay residence times.

3.4.2 Little Goose Dam

From the bivariate modeling, eight variables were identified that were significantly correlated with forebay residence times of kelts at LGS (Table A.39). The two most highly correlated were ln(Z dist) ($\chi^2 = 542.9$; $P < 0.001$) and ln(Y dist) ($\chi^2 = 517.7$; $P < 0.001$), which were both positively correlated with forebay residence time. Both of these variables were included in each of the top five multivariable models with very high posterior probabilities of model inclusion ($p[\Delta \mid D] > 0.97$) (Table A.40). The variable S1%Q was included in three of the top five models, including the top model, with a posterior probability of model inclusion of 0.78. The models indicated forebay residence time was higher for kelts that displayed greater horizontal and vertical migration behavior and for those that entered the forebay when the percent of total discharge passing over the spillway weir was high (i.e., periods of low discharge).

Discharge was not significantly correlated with either ln(Z dist) ($\chi^2 = 0.3$; $P = 0.588$) or ln(Y dist) ($\chi^2 = 0.6$; $P = 0.432$), suggesting these behaviors occurred independent of discharge. However, similar to the results from LGR, it appears as though kelt behavior and discharge affected forebay residence time.

3.4.3 Lower Monumental Dam

Eight variables were significantly correlated with the forebay residence times of kelts in the LMN bivariate modeling conducted to develop a list of variables to be included in the multivariable modeling procedure (Table A.41). The top four of those included three behavioral variables (ln[Z dist]: $\chi^2 = 289.7$, $P < 0.001$; ln[Y dist]: $\chi^2 = 256.2$, $P < 0.001$; and Search: $\chi^2 = 66.7$, $P < 0.001$), which were positively correlated with forebay residence time, and Discharge ($\chi^2 = 25.4$; $P < 0.001$), which was negatively correlated with forebay residence time. Only two of these variables, ln(Z dist) ($p[\Delta \mid D] = 1.0$) and Discharge ($p[\Delta \mid D] = 0.98$), were included in each of the top five multivariable models (Table A.42). The variable ln(Y dist) was included in three of the top five models, including the top model, with a posterior probability of model inclusion of 0.67. The inclusion of these variables in the top models indicated forebay residence times were higher for kelts that displayed greater horizontal and vertical migration behavior and for those that entered the forebay during periods of low discharge.

Similar to the findings from LGS, these vertical and horizontal migration behaviors appeared to occur independent of flow, as neither was significantly correlated with discharge ($\chi^2 < 1.4$; $P > 0.247$). Therefore, a combination of kelt behavior and discharge affected forebay residence time.

3.5 Spill Efficiency Curves

3.5.1 Lower Granite Dam

Over the range of conditions encountered during the two study years, the relationship between the percent spill (%Spill) at LGR and the probability of acoustic-tagged kelts passing via the spillway (P_{SW}) was modeled using logistic regression as:

$$P_{SW} = \frac{1}{\left(1 + exp\left(-(0.066331 \times \%Spill)\right)\right)}$$

where P_{SW} is the probability of spillway passage expressed as a proportion and *%Spill* is the percent of total discharge passing through the spillway weir and traditional spill bays expressed as a percentage. From this relationship, it is predicted that 79% of kelts will pass via the spillway at 20% spill, 88% spillway passage at 30% spill, 93% spillway passage at 40% spill, and 96% spillway passage at 50% spill (Figure 3.39).

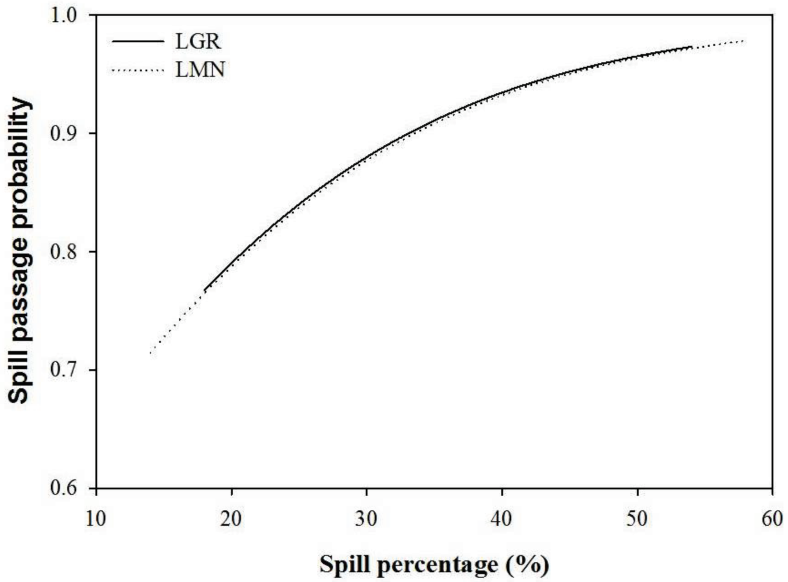

Figure 3.39. Spill efficiency curves for Lower Granite Dam (LGR) and Lower Monumental Dam (LMN) using the modeled logistic regression relationship between spillway passage probability and spill percentage. During the studies conducted in 2012 and 2013, spill percentages ranged from 17.7% to 73.8% at LGR and from 0.0% to 78.3% at LMN.

3.5.2 Little Goose Dam

LGS is typically operated at 30% spill, regardless of the discharge level. Therefore, there was relatively little variability in %Spill during the time of acoustic-tagged kelt passage, with the majority passing when %Spill equaled 30%. No significant effect of %Spill on the probability of spillway passage in 2012 and 2013 was observed ($\chi^2 < 0.1$; $P = 0.847$).

3.5.3 Lower Monumental Dam

Over the range of conditions encountered during the two study years, the relationship between the percent spill (%Spill) at LMN and the probability of acoustic-tagged kelts passing via the spillway (P_{SW}) was modeled using logistic regression as:

$$P_{SW} = \frac{1}{\left(1 + exp\left(-(0.065441 \times \%Spill)\right)\right)}$$

where P_{SW} is the probability of spillway passage expressed as a proportion and *%Spill* is the percent of total discharge passing through the spillway weir and traditional spill bays expressed as a percentage. From this relationship, it is predicted that 79% of kelts will pass via the spillway at 20% spill, 88% spillway passage at 30% spill, 94% spillway passage at 40% spill, and 96% spillway passage at 50% spill (Figure 3.39).

4.0 Discussion

As identified in the 2008 FCRPS BiOp, iteroparity is an important life history strategy of steelhead that may be utilized for increasing population abundance and stability. RPAs proposed in the BiOp focus on a combination of 1) transportation of kelts around the FCRPS, 2) increases to in-river kelt survival through dam passage improvements, and 3) kelt reconditioning to increase iteroparity rates. Given the available data, an analysis included in the 2008 BiOp concluded that a combination of these actions could increase kelt returns enough to increase the number of returning Snake River B-run steelhead spawners to LGR by about 6%.

Previous studies found that reconditioning, whereby kelts are retained in a hatchery setting, fed, and medicated prior to their release, produced much higher iteroparity rates than transportation (Hatch et al. 2013). As a result, the transportation strategy is only used once hatchery capacity is reached. However, the availability of steelhead kelts at collection sites (e.g., JBS of FCRPS dams, tributary weirs) is limited. Therefore, it is important to understand the factors that affect dam passage route selection to identify potential methods that may be used to increase kelt collection. Much of the limitation in collecting kelts is caused by the increase in the proportions of kelts that pass FCRPS dams through non-JBS (i.e., spillway) routes that has occurred since the installation and operation of surface weirs, making them unavailable for collection and reconditioning. Although iteroparity rates have not increased substantially since the installation of surface weirs, it is also important to understand the factors that affect dam passage survival since the majority of kelts migrate in-river.

The results obtained from this study indicate the behavior of kelts in the forebay of LGR, LGS, and LMN may have the greatest influence on their ultimate route of passage. The migration depth of kelts in the forebay, the side of the forebay in which they approached the dams, and the extent of their horizontal and vertical movements were the primary factors that affected route of passage. The majority of kelts migrated near the surface, which contributed to the high probabilities of spillway weir passage at the three dams. The weirs appeared to draw surface-oriented kelts from the entire width of the forebay. However, those detected in front of the powerhouse had a higher probability of spillway weir passage than those detected in front of the spillway. Kelts that approached the dams in front of the powerhouse displayed a high degree of “searching” behavior, indicating their route selection was more active. The majority of these fish moved or “searched” horizontally, which led to their passage over the spillway weir. By the time a kelt was about 20 m to 30 m in front of the spillway weir, they had > 0.90 probability of passing over the weir. Kelts that approached the powerhouse near the surface that did not display a horizontal “searching” behavior eventually undertook a vertical migration about 10 minutes prior to their passage through the powerhouse. Kelts that approached the dams in front of the spillway had a much higher probability of passing through the traditional spill bays than kelts detected approaching in front of the powerhouse. In addition, kelts that passed through traditional spill bays generally displayed less “searching” behavior, indicating their route selection was more passive and occurred farther upstream than was observed for kelts that passed through the other routes. Kelts that were acclimated to deeper depths had a higher probability of passing through one of the powerhouse routes (JBS or turbine).

Because most kelts approached the dams in the upper 5 m of the water column, a surface collector, deployed in front of the powerhouse could be a useful tool for obtaining more kelts for reconditioning. The surface orientation of kelts could also be used to guide kelts to specific passage routes using floating structures such as the log booms at LGR and LGS. Fairly distinct separations between spillway and powerhouse passage probabilities were observed on either side of the log booms for kelts migrating near the surface. It appeared as though some kelts may have swum along the length of the boom until they encountered the dam. In general, kelts detected on the spillway side of the booms had a higher probability of spillway passage than those detected on the powerhouse side and vice versa. Because the majority of kelts migrated near the surface, those that approached the dams in front of the powerhouse were unable to quickly identify a passage route, leading to longer forebay residence times for those fish. A gap in the log boom near the dam face may allow these fish to pass via the spillway weir and reduce their residence time.

The dam operations identified as being linked to route of passage were generally associated with discharge and therefore provide relatively little opportunity for operational alterations to intentionally route kelts to specific apertures. However, the current configurations are routing the majority of kelts to the spillway weirs where survival probability is generally highest. Therefore, there is little need to redistribute kelts among the various passage routes unless the goal is to route more kelts to the JBS for reconditioning. Given the surface orientation of the majority of kelts, it may not be possible to route additional fish to the JBS even if desired.

Smaller kelts appear to be more likely to enter the JBS than larger kelts at LGR and perhaps at LGS and LMN as well. This finding has implications for the kelt reconditioning program. In 2012 and 2013, kelts were only collected from the JBS of LGR for reconditioning. If, in fact, the LGR JBS primarily collects smaller kelts, the extent of the reconditioning program as it was implemented during our study may be insufficient to meet the BiOp goal. In order to maximize collection of the larger-bodied B-run steelhead kelts for reconditioning, it may be necessary to expand the collection of kelts to the tributary weirs where larger fish may be specifically targeted.

Survival of kelts appeared to be most influenced by their individual characteristics. Specifically, kelts determined to be in good condition at the time of tagging had a higher probability of dam passage survival than those in fair condition. Additionally, smaller kelts had a higher probability of dam passage survival than larger kelts. These results are consistent with those from a previous analysis of the data collected during this study that found the in-river survival of kelts was higher for kelts in good condition and negatively correlated with fork length in the Snake and Columbia rivers (Harnish et al. in prep; BPA and ACE 2014). Consequently, good condition kelts would be expected to have higher iteroparity rates than fair condition fish. In fact, Keefer et al. (2008) reported that kelts in good and fair condition were > 25 and > 10 times more likely to return as repeat spawners, respectively, than those in poor condition. They also reported that smaller-bodied kelts were significantly more likely to return as repeat spawners. These results have implications for which kelts should be retained for reconditioning. Although kelts in good condition at the time of capture have a higher probability of surviving the reconditioning process, they also have higher probabilities of in-river survival and repeat spawning, whereas kelts in fair and poor condition have very low probabilities. Reconditioning may be the only hope for fair and poor condition fish to contribute to the population as repeat spawners. Although condition (i.e., good vs. fair) was not a significant predictor of survival at LMN, relative condition factor was positively correlated with survival. These results indicate kelts that had more significant wounds, fungus, or injuries may have been culled in upstream reaches. Those that survived to LMN then had a higher probability of surviving if they had more substantial lipid reserves from which to draw for energy. These results are consistent with those from the previous analysis that indicated in-river survival was positively correlated with condition factor in the Snake and Columbia rivers (Harnish et al. in prep; BPA and ACE 2014).

As mentioned previously, dam operations were rarely correlated with survival. The two instances in which operations were identified that appeared to affect survival included the proportion of flow through turbine unit 6 at LGR, which was positively correlated with kelt survival, and the position of the spillway weir crest at LGS. Turbine unit 6 is located directly adjacent to the spillway weir at LGR and was generally only used at higher discharge (> 75 kcfs) during the study period. At these higher flows, routing more flow through turbine unit 6 may provide kelts that pass through the weir with shorter tailrace egress. As found, shorter tailrace egress times were associated with improved survival of kelts at LGR. At LGS, kelts that passed the dam when the spillway weir crest was in the low position had a higher survival probability than those that passed at similar discharges when the crest was in the high position. Depending on the results from a similar, concurrent study of juvenile salmon dam passage survival, these results may be used to set the position of the spillway weir crest to the low position to optimize survival when flows allow.

Multivariable modeling results did not reveal any strong, direct effects of environmental variables on passage route selection or dam passage survival of kelts. However, discharge indirectly affected route of passage and survival through its interaction with dam operations. Because operations are linked tightly to discharge it was often difficult to discern the true mechanism behind the observed correlations. Discharge, combined with kelt behavior, was found to have a direct correlation with forebay residence times. Kelts that entered the forebays at higher discharges generally had lower forebay residence times. However, the extent of their horizontal and vertical movements, which occurred independent of discharge, also affected forebay residence times with kelts displaying higher levels of this "searching" behavior having longer residence times. It is also expected that kelts passing at higher discharges have shorter tailrace egress times. As observed at LGR, tailrace egress time can affect survival. Surprisingly, tailrace water temperature was not correlated with survival in any of the models.

The information gathered from this study may be used to inform fisheries managers and dam operators of potential ways to increase the iteroparity rates of Snake River steelhead kelts through improvements of in-river survival or increased collection of kelts for the reconditioning program. The pooled survival probabilities presented in this report, combined with the passage route proportions obtained from this study, may be used to update the survival rates and production metrics used in the 2008 BiOp (Bellerud et al. 2007) to better reflect the current configuration of the hydrosystem since the addition of surface passage routes. Another goal of this study was to identify a contingency response plan for kelt management during periods of low flow. Because we identified few dam operations that were correlated with dam passage survival, particularly at low flows, opportunities to improve in-river survival of kelts by adjusting operations appear limited. Additionally, the operations used during the study were successful at routing the large majority of kelts to the spillway weirs where they generally had the highest probability of dam passage survival. Therefore, collecting as many kelts as possible for reconditioning may present the best option during periods of low flow. However, the proportion of kelts that pass through the JBS is likely to be lower during periods of low flow due to the higher proportion passing over the spillway weir (as observed in 2013). Therefore, maximizing the collection of kelts for reconditioning may require expansion of the collection effort to the juvenile bypass systems of LGS and LMN as well as to the tributary weirs. As is the current practice, kelts could be transported around the hydrosystem once hatchery reconditioning facilities reach capacity. Results from a previous analysis of the data collected during this study indicated survival of Snake River kelts was positively correlated with discharge in the Snake River but not in the Columbia River (Harnish et al. in prep; BPA and ACE 2014). Thus, it may be sufficient to transport kelts not held for reconditioning around FCRPS dams of the Snake River, releasing them in McNary pool.

The results of this study support the current and proposed plans for managing Snake River steelhead kelts as outlined in the Kelt Management Plan (BPA and ACE 2014). Due to the low iteroparity rates that have been observed for kelts that migrate in-river, even after the installation of surface routes at FCRPS dams, reconditioning likely presents an option that is necessary to aid in achieving the BiOp goal. As mentioned, the collection of kelts was restricted during the study period to the JBS at LGR, which had the lowest JBS passage probability over the two years. Therefore, our results support the expansion of reconditioning collection efforts to the JBS of LGS and LMN. The 2013 Kelt Management Plan indicates there are plans to collect kelts from the JBS of LGS and potentially LMN in future years (BPA and ACE 2014). Additionally, it appeared that smaller kelts were more likely to pass through the JBS at the three dams than larger kelts and larger kelts were less likely to survive dam passage than smaller kelts. Due to the tendency of the JBS to collect smaller kelts and the lower observed survival of larger fish, our results also support the need to expand the collection of kelts for reconditioning to the tributary weirs in order to increase the collection of the larger B-run kelts. Beginning in 2014, the collection of kelts for reconditioning was expanded to the weir on Fish Creek, a tributary of the Lochsa River (BPA and ACE 2014). Finally, the low survival probabilities observed for fair condition kelts indicate these fish should also be retained for reconditioning, as long as space exists at the hatchery reconditioning facilities, to provide them with a greater opportunity of survival to repeat spawn. Potential structural modifications were identified that could increase the collection of kelts for the reconditioning program, including the use of a surface collector positioned in front of the powerhouse, and log-boom modifications to reduce forebay residence times. Even with the expansion of collection efforts, the majority of kelts will continue to migrate in-river. The operations used at LGR, LGS, and LMN in 2012 and 2013 routed the large majority of kelts to the spillway weirs where dam passage survival was generally the highest.

5.0 References

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Appendix A

Regression Modeling Results

Appendix A

Regression Modeling Results

Table A.1. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of spillway weir passage for acoustic-tagged steelhead kelts that passed Lower Granite Dam in 2012 and 2013. Results ($\chi 2$ and P) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
AccDepth	1.676	0.206	-0.134	0.026	36.481	<0.001*
Discharge	2.069	0.036	-0.013	0.004	13.498	<0.001*
FirstY	1.728	0.272	-0.006	0.002	13.366	<0.001*
S1%Q	-0.251	0.365	0.129	0.039	11.904	<0.001*
T2%Q	-0.181	0.387	0.057	0.020	9.535	0.002*
T1%Q	1.340	0.207	-0.043	0.014	9.041	0.003*
TempRatio	-5.796	2.661	6.279	2.482	7.187	0.007*
Search	0.639	0.195	0.130	0.056	5.676	0.017*
S5%Q	1.532	0.301	-0.156	0.066	5.521	0.019*
T6%Q	1.164	0.181	-0.044	0.020	5.013	0.025*
T5%Q	0.428	0.267	0.028	0.013	4.421	0.036*
S3%Q	1.423	0.281	-0.132	0.063	4.352	0.037*
ln(Y dist)	0.005	0.486	0.193	0.094	4.320	0.038*
FL	-1.242	1.053	0.032	0.016	4.294	0.038*
S7%Q	1.479	0.308	-0.167	0.081	4.287	0.038*
S4%Q	0.257	0.424	0.116	0.071	2.689	0.101
PassDiel	0.873	0.156	-0.226	0.156	2.060	0.151
SurfaceTemp	0.090	0.688	0.079	0.061	1.709	0.191
ln(Z dist)	0.597	0.325	0.106	0.083	1.653	0.199
T4%Q	0.878	0.141	0.046	0.040	1.568	0.211
PassDay	0.041	0.889	0.007	0.007	1.015	0.314
FBTDG	8.032	8.218	-0.069	0.079	0.753	0.386
T3%Q	1.076	0.230	-0.014	0.016	0.734	0.392
Temp15	0.470	0.698	0.047	0.066	0.522	0.470
Temp30	0.491	0.700	0.046	0.067	0.477	0.490
S6%Q	1.127	0.335	-0.057	0.084	0.457	0.499
Condition	1.016	0.216	-0.124	0.216	0.340	0.560
S2%Q	1.083	0.318	-0.048	0.085	0.318	0.573
RelativeCond	0.041	1.830	0.009	0.018	0.286	0.593
S8%Q	1.091	0.407	-0.054	0.122	0.194	0.659
%Spill	0.877	0.486	0.001	0.013	0.009	0.924

Table A.2. Bayesian model-averaging results displaying the top five models for explaining the probability of spillway weir passage for acoustic-tagged steelhead kelts at Lower Granite Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k \mid D]$). The posterior probability of each variable being included in the model ($p[\Delta \mid D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	234
n models selected =	48
Cum. post. prob. =	0.326

Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	1.832	2.103	2.848	1.236	2.222	3.398	3.186
AccDepth	**1.000**	-0.137	0.028	-0.140	-0.136	-0.143	-0.139	-0.133
FirstY	**0.761**	-0.004	0.003	-0.005	-0.005	.	-0.005	-0.005
T1%Q	**0.430**	-0.021	0.028	-0.052	.	-0.051	-0.048	.
S7%Q	**0.259**	-0.053	0.108	.	.	.	-0.175	.
S1%Q	**0.190**	0.021	0.049	.	0.113	.	.	.
Discharge	**0.151**	-0.001	0.004	.	.	.	.	-0.011
T2%Q	**0.101**	0.005	0.017	.	.	.	.	.
S3%Q	**0.086**	-0.012	0.046	.	.	.	.	.
TempRatio	**0.081**	0.450	1.761	.	.	.	.	.
FL	**0.062**	0.002	0.009	.	.	.	.	.
S5%Q	**0.044**	-0.002	0.040	.	.	.	.	.
T5%Q	**0.024**	0.000	0.005	.	.	.	.	.
T6%Q	**0.010**	0.000	0.003	.	.	.	.	.
Search	**0.009**	0.000	0.006	.	.	.	.	.
ln(Y dist)	**0.009**	0.000	0.011	.	.	.	.	.
n variables				3	3	2	4	3
BIC				-1033	-1031	-1031	-1031	-1031
($p[M_k \mid D]$)				0.136	0.049	0.049	0.046	0.045

Table A.3. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of traditional spill passage for acoustic-tagged steelhead kelts that passed Lower Granite Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
FirstY	-3.489	0.458	0.013	0.002	39.683	<0.001*
ln(Z dist)	-0.385	0.370	-0.337	0.107	11.014	<0.001*
S3%Q	-2.326	0.330	0.224	0.068	10.668	0.001*
ln(Y dist)	0.187	0.556	-0.349	0.114	10.011	0.002*
S7%Q	-2.367	0.353	0.271	0.088	9.790	0.002*
S5%Q	-2.335	0.351	0.222	0.073	9.229	0.002*
Discharge	-2.496	0.404	0.012	0.004	9.001	0.003*
S1%Q	-0.390	0.409	-0.116	0.044	7.370	0.007*
T2%Q	-0.406	0.431	-0.054	0.022	6.511	0.011*
AccDepth	-1.895	0.222	0.057	0.022	6.504	0.011*
T5%Q	-0.792	0.291	-0.038	0.015	6.158	0.013*
T1%Q	-1.821	0.241	0.039	0.016	5.626	0.018*
TempRatio	2.858	2.930	-4.018	2.728	2.346	0.126
S2%Q	-1.888	0.367	0.131	0.093	1.929	0.165
S6%Q	-1.903	0.383	0.128	0.093	1.836	0.175
%Spill	-2.089	0.568	0.018	0.015	1.478	0.224
Condition	-1.675	0.279	0.306	0.279	1.355	0.245
S8%Q	-1.908	0.459	0.149	0.134	1.199	0.274
Search	-1.346	0.228	-0.064	0.063	1.087	0.297
T4%Q	-1.396	0.161	-0.043	0.047	0.978	0.323
FBTDG	-10.377	9.417	0.086	0.091	0.907	0.341
T3%Q	-1.630	0.269	0.018	0.019	0.863	0.353
PassDiel	-1.441	0.180	0.168	0.180	0.854	0.355
RelativeCond	0.253	2.094	-0.017	0.020	0.683	0.409
S4%Q	-1.054	0.482	-0.066	0.080	0.678	0.410
T6%Q	-1.531	0.202	0.018	0.023	0.637	0.425
Temp15	-1.880	0.788	0.039	0.072	0.281	0.596
Temp30	-1.858	0.791	0.037	0.074	0.249	0.618
PassDay	-1.792	0.995	0.003	0.007	0.132	0.717
FL	-1.786	1.216	0.005	0.018	0.085	0.770
SurfaceTemp	-1.574	0.765	0.009	0.067	0.019	0.891

Table A.4. Bayesian model-averaging results displaying the top five models for explaining the probability of traditional spill passage for acoustic-tagged steelhead kelts at Lower Granite Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities (p[Mk | D]). The posterior probability of each variable being included in the model (p[Δ | D]) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	234							
n models selected =	23							
Cum. Post. prob. =	0.669							
Variable	**(p[Δ | D])**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-4.959	0.778	-5.007	-4.931	-5.199	-5.123	-4.843
FirstY	**1.000**	0.014	0.003	0.014	0.014	0.013	0.014	0.014
S7%Q	**0.545**	0.202	0.208	0.380	.	0.385	.	.
S3%Q	**0.439**	0.129	0.160	.	0.301	.	0.306	.
AccDepth	**0.195**	0.010	0.023	.	.	0.049	0.051	.
S5%Q	**0.069**	0.009	0.066	.	.	.	.	0.274
T1%Q	**0.056**	0.001	0.007	.	.	.	.	.
S1%Q	**0.043**	-0.002	0.014	.	.	.	.	.
ln(Z dist)	**0.042**	-0.004	0.032	.	.	.	.	.
Discharge	**0.037**	0.000	0.001	.	.	.	.	.
ln(Y dist)	**0.035**	-0.003	0.027	.	.	.	.	.
T5%Q	**0.035**	0.000	0.005	.	.	.	.	.
T2%Q	**0.031**	0.000	0.005	.	.	.	.	.
n variables				2	2	3	3	2
BIC				-1094	-1094	-1092	-1092	-1090
(p[M_k | D])				0.243	0.205	0.092	0.090	0.039

Table A.5. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of juvenile bypass system passage for acoustic-tagged steelhead kelts that passed Lower Granite Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
FL	4.441	2.220	-0.114	0.036	11.859	<0.001*
AccDepth	-3.270	0.378	0.078	0.028	6.362	0.012*
FirstY	-2.172	0.347	-0.007	0.003	5.894	0.015*
Search	-2.254	0.337	-0.297	0.143	5.694	0.017*
SurfaceTemp	0.364	1.661	-0.305	0.163	4.529	0.033*
TempRatio	8.218	6.333	10.382	6.005	3.851	0.050*
PassDay	0.943	2.171	-0.030	0.018	3.694	0.055*
Temp15	-0.246	1.575	-0.259	0.161	3.116	0.078*
Temp30	-0.487	1.544	-0.238	0.159	2.628	0.105
ln(Z dist)	-3.826	0.701	0.244	0.148	2.605	0.107
PassDiel	2.702	0.280	-0.433	0.280	2.256	0.133
T4%Q	-2.790	0.275	-0.639	6.761	2.067	0.151
Condition	2.640	0.340	0.337	0.340	0.878	0.349
FBTDG	11.245	16.356	-0.137	0.159	0.744	0.388
T5%Q	-3.316	0.632	0.023	0.028	0.721	0.396
T6%Q	-3.005	0.363	0.025	0.039	0.405	0.525
Discharge	-3.223	0.674	0.004	0.007	0.346	0.556
S7%Q	-2.514	0.697	-0.112	0.210	0.326	0.568
ln(Y dist)	-3.370	0.989	0.099	0.178	0.311	0.577
S3%Q	-2.648	0.572	-0.061	0.145	0.190	0.663
T3%Q	-2.723	0.422	-0.014	0.032	0.182	0.670
S1%Q	-2.589	0.715	-0.030	0.072	0.171	0.679
S6%Q	-3.066	0.666	0.055	0.164	0.109	0.741
T1%Q	-2.786	0.363	-0.010	0.029	0.107	0.744
S8%Q	-3.088	0.803	0.070	0.236	0.086	0.770
S5%Q	-2.981	0.583	0.030	0.132	0.050	0.824
%Spill	-2.682	0.967	-0.005	0.026	0.039	0.843
S2%Q	-2.831	0.636	-0.011	0.173	0.004	0.951
RelativeCond	-2.730	3.500	-0.001	0.034	<0.001	0.976
T2%Q	-2.883	0.744	0.001	0.035	<0.001	0.980
S4%Q	-2.871	0.867	0.001	0.141	<0.001	0.996

Table A.6. Bayesian model-averaging results displaying the top five models for explaining the probability of juvenile bypass system passage for acoustic-tagged steelhead kelts at Lower Granite Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities (p[Mk | D]). The posterior probability of each variable being included in the model (p[Δ | D]) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	234
n models selected =	11
Cum. Post. prob. =	0.809

Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	11.231	9.231	7.606	22.790	6.746	0.238	23.370
FirstY	**1.000**	-0.020	0.005	-0.019	-0.021	-0.019	-0.019	-0.021
Search	**1.000**	-0.579	0.177	-0.577	-0.588	-0.529	-0.633	-0.528
FL	**0.839**	-0.098	0.060	-0.117	-0.122	-0.111	.	-0.116
TempRatio	**0.316**	-4.454	7.852	.	-13.850	.	.	-15.250
AccDepth	**0.195**	0.012	0.028	.	.	0.053	.	0.063
SurfaceTemp	**0.038**	-0.007	0.053	.	.	.	.	.
PassDay	**0.031**	0.000	0.004	.	.	.	.	.
Temp15	**0.029**	-0.002	0.037	.	.	.	.	.
n variables				3	4	4	2	5
BIC				-1182	-1180	-1178	-1178	-1178
($p[M_k \mid D]$)				0.405	0.194	0.085	0.067	0.058

Table A.7. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of turbine passage for acoustic-tagged steelhead kelts that passed Lower Granite Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
AccDepth	-4.244	0.546	0.131	0.032	16.169	<0.001*
T6%Q	-4.236	0.624	0.128	0.049	7.730	0.005*
%Spill	-0.210	1.166	0.095	0.040	7.114	0.008*
T1%Q	-4.374	0.708	0.091	0.039	6.612	0.010*
S1%Q	-1.544	0.830	-0.203	0.106	4.487	0.034*
T2%Q	-1.547	0.792	-0.095	0.047	4.460	0.035*
S4%Q	-1.476	0.789	-0.333	0.155	4.458	0.035*
S5%Q	-1.827	0.848	-0.452	0.293	3.677	0.055*
S6%Q	-1.664	0.929	-0.500	0.315	3.460	0.063*
S8%Q	-1.223	1.164	-0.710	0.434	3.388	0.066*
S7%Q	-1.615	1.060	-0.561	0.387	2.919	0.088*
S2%Q	-2.059	0.755	-0.393	0.260	2.679	0.102
Discharge	-4.385	0.834	0.012	0.007	2.646	0.104
FL	0.327	2.390	-0.054	0.037	2.183	0.140
ln(Z dist)	-4.219	0.824	0.252	0.172	2.051	0.152
S5%Q	-2.399	0.720	-0.240	0.207	1.577	0.209
SurfaceTemp	-1.403	1.836	-0.177	0.173	1.212	0.271
FBTDG	-24.246	19.281	0.203	0.185	1.197	0.274
PassDay	-0.942	2.283	-0.018	0.018	1.092	0.296
TempRatio	2.996	6.792	-5.887	6.381	0.983	0.322
Temp30	-1.786	1.806	-0.152	0.181	0.773	0.379
Temp15	-1.805	1.804	-0.148	0.178	0.757	0.384
T5%Q	-2.794	0.582	-0.025	0.031	0.655	0.418
Search	-2.958	0.434	-0.097	0.130	0.592	0.442
ln(Y dist)	-4.047	1.183	0.159	0.207	0.583	0.445
FirstY	-2.939	0.475	-0.002	0.003	0.481	0.488
T3%Q	-3.496	0.582	0.024	0.039	0.379	0.538
RelativeCond	-6.888	5.070	0.030	0.048	0.363	0.547
PassDiel	3.285	0.402	0.149	0.402	0.145	0.703
T4%Q	-3.247	0.338	0.021	0.066	0.093	0.760
Condition	3.326	0.535	-0.139	0.535	0.072	0.788

Table A.8. Bayesian model-averaging results displaying the top five models for explaining the probability of turbine passage for acoustic-tagged steelhead kelts at Lower Granite Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	235
n models selected =	27
Cum. Post. prob. =	0.473

Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-1.234	2.945	0.152	1.485	-2.698	0.889	-5.584
AccDepth	**1.000**	0.169	0.043	0.171	0.179	0.173	0.182	0.139
%Spill	**0.519**	-0.076	0.088	-0.153	-0.123	-0.100	.	.
T2%Q	**0.257**	-0.041	0.079	.	-0.136	.	-0.181	.
T1%Q	**0.251**	0.028	0.055	.	.	0.094	.	.
S6%Q	**0.156**	-0.109	0.317	.	.	.	-0.827	.
T6%Q	**0.131**	0.017	0.050	.	.	.	.	0.159
S5%Q	**0.131**	-0.053	0.201	.	.	.	.	.
S1%Q	**0.084**	-0.025	0.098	.	.	.	.	.
S7%Q	**0.066**	-0.004	0.171	.	.	.	.	.
S4%Q	**0.041**	-0.014	0.109	.	.	.	.	.
S8%Q	**0.036**	0.000	0.176	.	.	.	.	.
n variables				2	3	3	3	2
BIC				-1212	-1210	-1210	-1209	-1209
($p[M_k \mid D]$)				0.214	0.079	0.065	0.064	0.051

Table A.9. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of spillway weir passage for acoustic-tagged steelhead kelts that passed Little Goose Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
Search	0.197	0.124	0.225	0.039	37.083	<0.001*
ln(Y dist)	-1.145	0.341	0.329	0.059	33.144	<0.001*
AccDepth	1.115	0.110	-0.073	0.014	32.144	<0.001*
S5%Q	1.118	0.131	-0.189	0.046	17.392	<0.001*
Discharge	1.761	0.274	-0.011	0.003	16.835	<0.001*
S4%Q	1.739	0.276	-0.299	0.076	16.184	<0.001*
ln(Z dist)	-0.112	0.236	0.201	0.054	14.451	<0.001*
S3%Q	1.233	0.172	-0.185	0.052	12.785	<0.001*
%Spill	2.293	0.457	-0.048	0.014	12.668	<0.001*
S2%Q	1.656	0.289	-0.240	0.070	11.939	<0.001*
S7%Q	1.083	0.141	-0.171	0.052	11.167	<0.001*
S1%Q	-0.321	0.334	0.095	0.030	10.404	0.001*
PassDay	-1.454	0.717	0.016	0.005	9.635	0.002*
T1%Q	0.138	0.209	0.031	0.010	9.068	0.003*
PassDiel[1]	0.601	0.093	-0.271	0.093	8.337	0.004*
S6%Q	1.219	0.198	-0.176	0.062	8.233	0.004*
SurfaceTemp	-0.958	0.621	0.142	0.052	7.909	0.005*
Temp30	-0.978	0.667	0.150	0.058	6.975	0.008*
FirstY	1.038	0.148	-0.002	0.001	6.843	0.009*
Temp15	-0.922	0.661	0.145	0.057	6.671	0.010*
FBTDG	7.049	2.901	-0.057	0.026	4.770	0.029*
Condition[2]	0.572	0.113	0.218	0.113	3.670	0.055*
T2%Q	0.344	0.230	0.022	0.013	3.044	0.081*
T5%Q	0.813	0.102	-0.019	0.011	2.713	0.100*
TempRatio	-1.846	2.044	2.481	1.960	1.676	0.196
Crest	0.754	0.088	-0.099	0.088	1.282	0.258
T4%Q	0.808	0.133	-0.009	0.011	0.756	0.385
T3%Q	0.588	0.175	0.010	0.011	0.703	0.402
RelativeCond	1.496	0.970	-0.008	0.010	0.626	0.429
FL	0.212	0.662	0.001	0.001	0.607	0.436
T6%Q	0.734	0.093	-0.006	0.016	0.139	0.709
S8%Q	0.625	0.288	0.020	0.059	0.114	0.736

[1] Kelts that passed during the day had a higher spillway weir passage probability than those that passed at night

[2] Good condition kelts had a higher spillway weir passage probability than those in fair condition

Table A.10. Bayesian model-averaging results displaying the top five models for explaining the probability of spillway weir passage for tagged steelhead kelts at Little Goose Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	524							
n models selected =	101							
Cum. Post. prob. =	0.264							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-0.959	1.661	-0.664	-0.286	-1.096	-0.460	-0.068
AccDepth	**1.000**	-0.059	0.017	-0.061	-0.055	-0.057	-0.062	-0.055
ln(Y dist)	**0.962**	0.970	0.312	0.891	1.080	1.071	0.872	1.076
ln(Z dist)	**0.962**	-0.771	0.269	-0.748	-0.820	-0.820	-0.744	-0.822
Search	**0.451**	0.060	0.076	0.130	.	.	0.138	.
Discharge	**0.426**	-0.005	0.007	.	-0.014	.	.	-0.015
S5%Q	**0.409**	-0.090	0.117	-0.234	.	-0.238	-0.246	.
Condition	**0.293**	-0.186	0.326	.	.	.	-0.638	-0.607
S1%Q	**0.175**	0.022	0.052	.	.	.	.	.
S4%Q	**0.128**	-0.031	0.090	.	.	.	.	.
SurfaceTemp	**0.080**	0.010	0.038	.	.	.	.	.
Temp30	**0.054**	0.006	0.031	.	.	.	.	.
Temp15	**0.052**	0.006	0.030	.	.	.	.	.
%Spill	**0.047**	-0.001	0.008	.	.	.	.	.
S3%Q	**0.035**	-0.006	0.036	.	.	.	.	.
S2%Q	**0.028**	-0.004	0.030	.	.	.	.	.
PassDiel	**0.023**	0.007	0.057	.	.	.	.	.
FirstY	**0.020**	0.000	0.000	.	.	.	.	.
S7%Q	**0.014**	-0.002	0.020	.	.	.	.	.
PassDay	**0.013**	0.000	0.001	.	.	.	.	.
S6%Q	**0.009**	-0.001	0.014	.	.	.	.	.
T1%Q	**0.007**	0.000	0.002	.	.	.	.	.
T2%Q	**0.004**	0.000	0.002	.	.	.	.	.
T5%Q	**0.003**	0.000	0.001	.	.	.	.	.
FBTDG	**0.000**	0.000	0.000	.	.	.	.	.
n variables				5	4	4	6	5
BIC				-2671	-2671	-2670	-2669	-2669
($p[M_k \mid D]$)				0.068	0.068	0.059	0.037	0.032

Table A.11. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of traditional spill passage for acoustic-tagged steelhead kelts that passed Little Goose Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
FirstY	-3.251	0.271	0.009	0.001	92.915	<0.001*
ln(Y dist)	2.013	0.434	-0.635	0.083	73.298	<0.001*
ln(Z dist)	0.794	0.289	-0.576	0.077	68.601	<0.001*
%Spill	-3.397	0.488	0.060	0.014	17.064	<0.001*
S2%Q	-2.682	0.333	0.318	0.078	16.706	<0.001*
S3%Q	-2.100	0.209	0.237	0.060	15.835	<0.001*
S4%Q	-2.560	0.320	0.330	0.085	15.147	<0.001*
S5%Q	-1.843	0.160	0.194	0.052	13.764	<0.001*
S7%Q	-1.900	0.173	0.219	0.059	13.551	<0.001*
S6%Q	-2.082	0.242	0.229	0.073	10.102	0.002*
S1%Q	-0.211	0.394	-0.111	0.036	9.917	0.002*
Search	-1.199	0.145	-0.110	0.044	6.658	0.010*
Discharge	-2.144	0.316	0.008	0.003	6.102	0.014*
PassDiel[1]	-1.308	0.107	0.265	0.107	5.958	0.015*
PassDay	0.242	0.846	-0.012	0.006	3.993	0.046*
Condition[2]	-1.252	0.127	-0.247	0.127	3.596	0.058*
Temp30	-0.122	0.795	-0.117	0.069	2.979	0.084*
SurfaceTemp	-0.249	0.737	-0.102	0.061	2.854	0.091*
Temp15	-0.167	0.788	-0.113	0.069	2.843	0.092*
S8%Q	-1.937	0.337	0.110	0.067	2.647	0.104
FBTDG	-6.858	3.386	0.049	0.030	2.564	0.109
FL	-2.576	0.769	0.002	0.001	2.302	0.129
RelativeCond	-3.000	1.138	0.015	0.011	1.852	0.174
T1%Q	-1.120	0.244	-0.015	0.012	1.681	0.195
Crest	-1.384	0.101	-0.123	0.101	1.464	0.226
AccDepth	-1.627	0.128	0.018	0.015	1.417	0.234
T3%Q	-1.210	0.202	-0.015	0.013	1.268	0.260
T6%Q	-1.368	0.109	-0.018	0.020	0.870	0.351
T2%Q	-1.180	0.271	-0.137	0.015	0.844	0.358
T5%Q	-1.457	0.120	0.009	0.013	0.418	0.518
TempRatio	-0.307	2.400	-1.113	2.299	0.241	0.624
T4%Q	-1.390	0.154	-0.002	0.013	0.037	0.847

[1] Kelts that passed at night had a higher traditional spill passage probability than those that passed during the day

[2] Kelts in fair condition had a higher traditional spill passage probability than those in good condition

Table A.12. Bayesian model-averaging results displaying the top five models for explaining the probability of traditional spill passage for tagged steelhead kelts at Little Goose Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	544							
n models selected =	32							
Cum. Post. prob. =	0.533							
Variable	**($p[\Delta \| D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-1.548	0.927	-1.598	-1.642	-1.398	-1.739	-2.709
FirstY	**1.000**	0.008	0.001	0.008	0.008	0.008	0.008	0.008
ln(Y dist)	**1.000**	-0.445	0.153	-0.406	-0.415	-0.412	-0.434	-0.438
S7%Q	**0.423**	0.123	0.157	0.305	.	.	.	.
S3%Q	**0.193**	0.053	0.115	.	0.286	.	.	.
S5%Q	**0.119**	0.027	0.081	.	.	0.244	.	.
S6%Q	**0.114**	0.037	0.111	.	.	.	0.346	.
%Spill	**0.100**	0.005	0.017	.	.	.	.	0.061
S1%Q	**0.094**	-0.010	0.036	.	.	.	.	.
ln(Z dist)	**0.086**	0.033	0.125	.	.	.	.	.
S2%Q	**0.075**	0.021	0.081	.	.	.	.	.
Condition	**0.075**	0.042	0.173	.	.	.	.	.
S4%Q	**0.028**	0.007	0.048	.	.	.	.	.
Temp30	**0.025**	-0.002	0.019	.	.	.	.	.
Search	**0.014**	0.001	0.009	.	.	.	.	.
Temp15	**0.014**	-0.001	0.013	.	.	.	.	.
SurfaceTemp	**0.012**	-0.001	0.010	.	.	.	.	.
PassDiel	**0.010**	-0.002	0.033	.	.	.	.	.
Discharge	**0.000**	0.000	0.000	.	.	.	.	.
PassDay	**0.000**	0.000	0.000	.	.	.	.	.
n variables				3	3	3	3	3
BIC				-2999	-2998	-2997	-2997	-2996
($p[M_k \| D]$)				0.206	0.118	0.079	0.077	0.052

Table A.13. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of juvenile bypass system passage for acoustic-tagged steelhead kelts that passed Little Goose Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
FirstY	-1.346	0.187	-0.009	0.002	46.079	<0.001*
Search	-1.755	0.186	-0.313	0.080	20.165	<0.001*
AccDepth	-2.754	0.185	0.069	0.016	17.039	<0.001*
FL	1.962	1.338	-0.007	0.002	12.279	<0.001*
ln(Z dist)	-3.547	0.446	0.249	0.088	8.086	0.005*
Crest[1]	2.634	0.180	-0.462	0.180	7.681	0.006*
T1%Q	-1.627	0.333	-0.043	0.018	6.176	0.013*
Temp30	0.279	1.157	-0.235	0.103	5.568	0.018*
SurfaceTemp	0.030	1.069	-0.204	0.091	5.354	0.021*
Discharge	-3.381	0.457	0.010	0.004	5.146	0.023*
Temp15	0.131	1.149	-0.221	0.102	5.056	0.025*
S8%Q	-1.339	0.529	-0.240	0.118	4.632	0.031*
FBTDG	-11.454	4.764	0.081	0.043	3.515	0.061*
PassDay	-0.475	1.246	-0.014	0.009	2.553	0.110
T4%Q	-2.679	0.249	0.026	0.019	1.915	0.167
T5%Q	-2.559	0.182	0.026	0.019	1.878	0.171
S5%Q	-2.623	0.223	0.096	0.075	1.614	0.204
ln(Y dist)	-2.975	0.572	0.094	0.092	1.035	0.309
S4%Q	-2.822	0.445	0.119	0.121	0.939	0.333
T2%Q	-2.072	0.389	-0.021	0.022	0.885	0.347
RelativeCond	-0.863	1.714	-0.015	0.017	0.825	0.364
S1%Q	-2.001	0.562	-0.038	0.050	0.578	0.447
T3%Q	-2.604	0.322	0.013	0.020	0.445	0.505
TempRatio	-0.919	3.433	-1.397	3.292	0.188	0.665
Condition	2.363	0.191	0.083	0.191	0.180	0.671
S7%Q	-2.489	0.233	0.035	0.087	0.160	0.690
S6%Q	-2.517	0.328	0.035	0.103	0.117	0.732
T6%Q	-2.437	0.160	0.008	0.026	0.082	0.775
PassDiel	2.405	0.162	-0.027	0.162	0.027	0.870
%Spill	-2.343	0.804	0.002	0.024	0.009	0.926
S3%Q	-2.410	0.278	-0.002	0.088	<0.001	0.980
S2%Q	-2.414	0.487	-0.001	0.121	<0.001	0.996

[1] Kelts that passed when the spillway weir crest was in low position had a higher probability of passing through the juvenile bypass system than those that passed when the crest was in the high position.

Table A.14. Bayesian model-averaging results displaying the top five models for explaining the probability of juvenile bypass system passage for tagged steelhead kelts at Little Goose Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k \mid D]$). The posterior probability of each variable being included in the model ($p[\Delta \mid D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	524							
n models selected =	13							
Cum. Post. prob. =	0.701							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-1.337	2.087	-2.259	-3.209	0.336	0.181	0.129
FirstY	**1.000**	-0.013	0.002	-0.013	-0.013	-0.013	-0.013	-0.013
Search	**1.000**	-0.636	0.135	-0.656	-0.652	-0.651	-0.647	-0.650
AccDepth	**1.000**	0.085	0.022	0.085	0.085	0.086	0.088	0.086
ln(Z dist)	**0.904**	0.394	0.187	0.451	0.429	0.418	0.410	0.419
SurfaceTemp	**0.107**	-0.022	0.073	.	.	.	-0.192	.
Temp30	**0.104**	-0.024	0.080	.	.	-0.217	.	.
Discharge	**0.095**	0.001	0.004	.	0.011	.	.	.
Temp15	**0.065**	-0.013	0.058	.	.	.	.	-0.199
T1%Q	**0.057**	-0.002	0.010	.	.	.	.	.
FL	**0.046**	0.000	0.001	.	.	.	.	.
Crest	**0.046**	-0.030	0.170	.	.	.	.	.
S8%Q	**0.034**	-0.006	0.045	.	.	.	.	.
FBTDG	**0.020**	0.001	0.008	.	.	.	.	.
n variables				4	5	5	5	5
BIC				-3022	-3019	-3019	-3019	-3019
($p[M_k \mid D]$)				0.380	0.095	0.081	0.080	0.065

Table A.15. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of turbine passage for acoustic-tagged steelhead kelts that passed Little Goose Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
AccDepth	-3.286	0.234	0.067	0.018	11.037	<0.001*
FirstY	-2.293	0.251	-0.005	0.002	9.471	0.002*
Search	-2.397	0.237	-0.261	0.096	9.218	0.002*
ln(Z dist)	-4.260	0.573	0.286	0.110	6.779	0.009*
T6%Q	-3.150	0.219	0.060	0.029	3.911	0.048*
PassDiel	2.831	0.187	-0.286	0.187	2.212	0.137
TempRatio	4.296	5.479	-6.967	5.298	2.091	0.148
Crest	3.056	0.207	-0.271	0.207	1.852	0.174
Discharge	-3.667	0.570	0.008	0.005	1.842	0.175
ln(Y dist)	-3.851	0.732	0.151	0.115	1.707	0.191
S8%Q	-2.214	0.648	-0.160	0.140	1.396	0.237
PassDay	-1.312	1.554	-0.012	0.012	1.152	0.283
T1%Q	-2.535	0.432	-0.022	0.022	1.008	0.315
T2%Q	-2.523	0.487	-0.025	0.028	0.833	0.362
FBTDG	1.066	6.454	-0.036	0.058	0.394	0.530
T5%Q	-3.021	0.224	0.015	0.024	0.380	0.538
T3%Q	-2.757	0.361	-0.014	0.024	0.326	0.568
S5%Q	-3.051	0.274	0.051	0.095	0.286	0.593
T4%Q	-3.057	0.296	0.011	0.023	0.249	0.617
S3%Q	-3.060	0.354	0.042	0.108	0.150	0.699
Temp30	-3.427	1.357	0.042	0.115	0.131	0.717
RelativeCond	-3.639	2.032	0.007	0.020	0.123	0.725
FL	-2.498	1.435	-0.001	0.002	0.100	0.752
S1%Q	-2.744	0.707	-0.018	0.062	0.084	0.772
Temp15	-3.311	1.346	0.032	0.114	0.077	0.782
S2%Q	-2.803	0.623	-0.037	0.156	0.056	0.814
S4%Q	-3.060	0.561	0.035	0.157	0.048	0.826
%Spill	-2.758	1.036	-0.006	0.031	0.033	0.855
SurfaceTemp	-2.806	1.284	-0.011	0.105	0.011	0.915
S7%Q	-2.924	0.288	-0.009	0.111	0.007	0.934
Condition	2.932	0.249	0.020	0.249	0.006	0.937
S6%Q	-2.922	0.405	-0.008	0.131	0.003	0.954

Table A.16. Bayesian model-averaging results displaying the top five models for explaining the probability of turbine passage for tagged steelhead kelts at Little Goose Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	591							
n models selected =	7							
Cum. Post. prob. =	0.910							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-3.991	1.054	-3.897	-4.891	-4.290	-3.274	-3.983
Search	**1.000**	-0.467	0.137	-0.487	-0.451	-0.483	-0.515	-0.476
ln(Z dist)	**0.934**	0.462	0.190	0.481	0.546	0.510	0.435	0.457
AccDepth	**0.824**	0.056	0.032	0.071	0.062	.	.	0.075
FirstY	**0.666**	-0.004	0.003	-0.006	.	.	-0.005	-0.006
T6%Q	**0.091**	0.005	0.018	.	.	.	.	0.054
n variables				4	3	2	3	5
BIC				-3536	-3535	-3533	-3533	-3532
($p[M_k \mid D]$)				0.448	0.218	0.093	0.083	0.068

Table A.17. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of spillway weir passage for acoustic-tagged steelhead kelts that passed Lower Monumental Dam in 2012 and 2013. Results (χ^2 and P) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	P
AccDepth	1.335	0.126	-0.109	0.017	50.614	<0.001*
FirstY	1.416	0.149	0.005	0.001	31.286	<0.001*
Search	0.193	0.141	0.245	0.048	30.050	<0.001*
ln(Y dist)	-1.090	0.395	0.360	0.073	25.744	<0.001*
PassDiel[1]	0.715	0.103	0.279	0.103	7.253	0.007*
S7%Q	0.959	0.107	-0.110	0.045	6.023	0.014*
S5%Q	1.129	0.160	-0.075	0.033	5.122	0.024*
S3%Q	1.074	0.146	-0.107	0.049	4.710	0.030*
S4%Q	1.064	0.146	-0.089	0.043	4.253	0.039*
FBTDG	7.549	3.375	-0.059	0.029	3.950	0.047*
ln(Z dist)	0.284	0.304	0.144	0.076	3.663	0.056*
Condition[2]	0.665	0.136	0.234	0.136	2.897	0.089*
S1%Q	1.092	0.179	-0.104	0.062	2.857	0.091*
%Spill	1.244	0.270	-0.012	0.008	2.590	0.108
PassDay	-0.457	0.841	0.009	0.006	2.447	0.118
S8%Q	0.515	0.278	0.040	0.033	1.528	0.216
T3%Q	0.558	0.250	0.018	0.015	1.435	0.231
T6%Q	0.753	0.123	0.014	0.013	1.093	0.296
T5%Q	0.750	0.126	0.013	0.012	1.049	0.306
Discharge	1.093	0.299	-0.003	0.003	0.808	0.369
T2%Q	0.643	0.238	0.012	0.013	0.791	0.374
T1%Q	0.920	0.137	-0.009	0.011	0.679	0.410
SurfaceTemp	0.188	0.868	0.046	0.072	0.408	0.523
TempRatio	-1.989	4.886	2.632	4.721	0.319	0.572
Temp30	0.240	0.919	0.043	0.080	0.297	0.586
FL	0.437	0.763	0.001	0.001	0.285	0.593
Temp15	0.264	0.925	0.040	0.079	0.265	0.607
T4%Q	0.884	0.171	-0.004	0.012	0.101	0.750
S6%Q	0.869	0.218	-0.003	0.022	0.024	0.876
RelativeCond	0.756	1.108	0.002	0.011	0.023	0.879
S2%Q	0.852	0.214	-0.003	0.050	0.005	0.945

[1] Kelts that passed during the day had a higher passage probability than those that passed at night

[2] Good condition kelts had a higher passage probability than fair condition kelts

Table A.18. Bayesian model-averaging results displaying the top five models for explaining the probability of spillway weir passage for tagged steelhead kelts at Lower Monumental Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	481							
n models selected =	11							
Cum. post. prob. =	0.788							
Variable	**($p[\Delta \| D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	0.132	1.227	-0.080	-0.076	0.214	0.018	-0.342
AccDepth	**1.000**	-0.082	0.019	-0.082	-0.083	-0.081	-0.084	-0.083
FirstY	**1.000**	0.005	0.001	0.005	0.005	0.005	0.005	0.005
ln(Y dist)	**1.000**	1.114	0.217	1.110	1.160	1.110	1.100	1.090
ln(Z dist)	**1.000**	-1.076	0.236	-1.070	-1.120	-1.080	-1.070	-1.040
Condition	**0.200**	-0.135	0.306	.	-0.682	.	.	.
S5%Q	**0.130**	-0.009	0.028	.	.	-0.072	.	.
PassDiel	**0.049**	0.016	0.087	.	.	.	.	0.326
S7%Q	**0.049**	-0.004	0.020	.	.	.	-0.072	.
S4%Q	**0.045**	-0.003	0.018	.	.	.	.	.
S3%Q	**0.039**	-0.003	0.018	.	.	.	.	.
FBTDG	**0.036**	-0.001	0.010	.	.	.	.	.
Search	**0.034**	0.002	0.015	.	.	.	.	.
S1%Q	**0.028**	-0.002	0.016	.	.	.	.	.
n variables				4	5	5	5	5
BIC				-2430	-2430	-2430	-2420	-2420
($p[M_k \| D]$)				0.420	0.170	0.100	0.049	0.049

Table A.19. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of traditional spill passage for acoustic-tagged steelhead kelts that passed Lower Monumental Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
FirstY	-2.988	0.245	-0.011	0.001	88.055	<0.001*
ln(Y dist)	0.674	0.443	-0.415	0.085	24.980	<0.001*
%Spill	-2.950	0.338	0.042	0.009	22.849	<0.001*
S5%Q	-2.223	0.198	0.173	0.036	22.427	<0.001*
S4%Q	-2.154	0.196	0.233	0.052	21.064	<0.001*
S3%Q	-2.124	0.191	0.257	0.058	20.250	<0.001*
S1%Q	-2.288	0.232	0.302	0.073	17.448	<0.001*
AccDepth	-1.793	0.142	0.061	0.015	15.199	<0.001*
ln(Z dist)	-0.250	0.351	-0.335	0.093	13.596	<0.001*
S7%Q	-1.722	0.131	0.176	0.048	12.652	<0.001*
T6%Q	-1.212	0.136	-0.052	0.017	10.651	0.001*
PassDiel[1]	-1.376	0.118	0.315	0.118	6.826	0.009*
Search	-1.150	0.164	-0.127	0.053	6.116	0.013*
S6%Q	-2.070	0.271	0.061	0.026	5.581	0.018*
Condition[2]	-1.255	0.149	-0.349	0.149	5.107	0.024*
T5%Q	-1.288	0.143	-0.033	0.015	4.910	0.027*
T4%Q	-1.236	0.189	-0.023	0.014	2.810	0.094*
FBTDG	-7.946	3.885	0.056	0.034	2.682	0.102
T3%Q	-1.073	0.289	-0.028	0.018	2.492	0.114
PassDay	-0.461	1.002	-0.008	0.007	1.117	0.291
TempRatio	3.939	6.073	-5.117	5.878	0.817	0.366
SurfaceTemp	-0.478	1.016	-0.074	0.086	0.766	0.381
Temp30	-0.570	1.075	-0.068	0.094	0.545	0.461
Temp15	-0.646	1.079	-0.061	0.093	0.440	0.507
Discharge	-1.283	0.355	-0.002	0.003	0.429	0.512
S2%Q	-1.653	0.256	0.039	0.059	0.422	0.516
S8%Q	-1.702	0.327	0.024	0.037	0.416	0.519
FL	-1.955	0.895	0.001	0.001	0.255	0.614
T1%Q	-1.562	0.163	0.006	0.013	0.240	0.624
RelativeCond	-1.829	1.291	0.003	0.013	0.058	0.810
T2%Q	-1.479	0.283	-0.002	0.016	0.010	0.922

[1] Kelts that passed during the day had a higher traditional spill passage probability than those that passed at night

[2] Good condition kelts had a higher traditional spill passage probability than fair condition kelts

Table A.20. Bayesian model-averaging results displaying the top five models for explaining the probability of traditional spill passage for tagged steelhead kelts at Lower Monumental Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k \mid D]$). The posterior probability of each variable being included in the model ($p[\Delta \mid D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	538
n models selected =	53
Cum. post. prob. =	0.407

Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-3.653	0.996	-4.057	-4.810	-2.810	-3.570	-2.491
FirstY	**1.000**	-0.011	0.001	-0.011	-0.011	-0.010	-0.010	-0.010
AccDepth	**0.748**	0.038	0.027	0.051	0.053	0.046	0.049	.
S5%Q	**0.555**	0.104	0.101	0.196	.	0.195	.	0.199
ln(Y dist)	**0.447**	-0.150	0.232	.	.	-0.222	-0.216	-0.243
%Spill	**0.365**	0.016	0.022	.	0.045	.	0.044	.
ln(Z dist)	**0.131**	0.054	0.194	.	.	.	.	.
Condition	**0.104**	0.069	0.236	.	.	.	.	.
S4%Q	**0.060**	0.012	0.054	.	.	.	.	.
T6%Q	**0.051**	-0.002	0.009	.	.	.	.	.
S7%Q	**0.050**	0.008	0.043	.	.	.	.	.
S3%Q	**0.047**	0.008	0.042	.	.	.	.	.
S6%Q	**0.040**	0.004	0.021	.	.	.	.	.
PassDiel	**0.026**	-0.008	0.068	.	.	.	.	.
S1%Q	**0.024**	0.004	0.034	.	.	.	.	.
T4%Q	**0.015**	0.000	0.003	.	.	.	.	.
T5%Q	**0.000**	0.000	0.000	.	.	.	.	.
n variables				3	3	4	4	3
BIC				-2959	-2959	-2959	-2958	-2958
($p[M_k \mid D]$)				0.120	0.097	0.080	0.059	0.052

Table A.21. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of juvenile bypass system passage for acoustic-tagged steelhead kelts that passed Lower Monumental Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
%Spill	-0.718	0.576	-0.069	0.021	13.953	<0.001*
S5%Q	-1.801	0.348	-0.296	0.113	9.700	0.002*
AccDepth	-3.097	0.235	0.064	0.021	8.035	0.005*
T6%Q	-3.251	0.299	0.067	0.025	7.284	0.007*
FL	1.608	1.743	-0.007	0.003	7.104	0.008*
S1%Q	-2.031	0.299	-0.331	0.133	6.706	0.010*
S8%Q	-1.471	0.556	-0.164	0.074	5.622	0.018*
S4%Q	-2.286	0.241	-0.210	0.095	5.428	0.020*
S2%Q	-1.896	0.398	-0.236	0.111	4.937	0.026*
S6%Q	-1.910	0.397	-0.098	0.047	4.780	0.029*
Search	-2.215	0.242	-0.178	0.088	4.597	0.032*
S3%Q	-2.336	0.247	-0.207	0.109	3.984	0.046*
ln(Y dist)	-1.519	0.681	-0.227	0.128	3.060	0.080*
T4%Q	-3.249	0.393	0.040	0.025	2.856	0.091
FirstY	-2.464	0.225	0.003	0.002	2.645	0.104
Discharge	-3.550	0.575	0.008	0.005	2.396	0.122
PassDiel	2.620	0.187	-0.253	0.187	1.748	0.186
S7%Q	-2.619	0.194	-0.120	0.114	1.316	0.251
T5%Q	-2.903	0.262	0.023	0.023	1.044	0.307
T1%Q	-2.880	0.274	0.017	0.021	0.657	0.418
FBTDG	-7.162	6.158	0.039	0.053	0.503	0.478
T2%Q	-2.467	0.451	-0.015	0.026	0.365	0.546
PassDay	-1.764	1.611	-0.007	0.012	0.363	0.547
SurfaceTemp	-3.447	1.542	0.073	0.126	0.331	0.565
Temp30	-3.469	1.637	0.078	0.139	0.308	0.579
Temp15	-3.405	1.654	0.071	0.138	0.260	0.610
TempRatio	-6.604	7.759	3.892	7.468	0.254	0.615
T3%Q	-2.553	0.471	-0.011	0.028	0.140	0.708
ln(Z dist)	-2.801	0.590	0.020	0.143	0.020	0.888
Condition	2.729	0.275	-0.012	0.275	0.002	0.965
RelativeCond	-2.798	2.201	-0.001	0.022	<0.001	0.979

Table A.22. Bayesian model-averaging results displaying the top five models for explaining the probability of juvenile bypass system passage for tagged steelhead kelts at Lower Monumental Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	488
n models selected =	14
Cum. post. prob. =	0.742

Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-0.273	1.759	-1.016	2.333	-0.695	-2.060	2.790
%Spill	**0.861**	-0.059	0.031	-0.069	-0.066	-0.066	.	-0.062
AccDepth	**0.805**	0.055	0.034	0.069	0.066	.	0.072	.
FL	**0.217**	-0.001	0.003	.	-0.006	.	.	-0.006
S5%Q	**0.139**	-0.044	0.118	.	.	.	-0.318	.
S2%Q	**0.066**	-0.012	0.053	.	.	.	.	.
Search	**0.057**	-0.007	0.038	.	.	.	.	.
ln(Y dist)	**0.025**	-0.003	0.030	.	.	.	.	.
S4%Q	**0.024**	0.003	0.035	.	.	.	.	.
T6%Q	**0.022**	0.000	0.006	.	.	.	.	.
S3%Q	**0.022**	0.002	0.029	.	.	.	.	.
S1%Q	**0.000**	0.000	0.000	.	.	.	.	.
S8%Q	**0.000**	0.000	0.000	.	.	.	.	.
S6%Q	**0.000**	0.000	0.000	.	.	.	.	.
n variables				2	3	1	2	2
BIC				-2782	-2780	-2779	-2779	-2778
($p[M_k \mid D]$)				0.378	0.122	0.115	0.074	0.052

Table A.23. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of turbine passage for acoustic-tagged steelhead kelts that passed Lower Monumental Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
Search	-1.893	0.234	-0.556	0.146	23.429	<0.001*
AccDepth	-3.212	0.244	0.075	0.020	11.409	<0.001*
FirstY	-2.375	0.217	0.005	0.002	7.442	0.006*
ln(Z dist)	-4.118	0.682	0.322	0.151	4.667	0.031*
T4%Q	-3.364	0.412	0.044	0.026	3.145	0.076*
%Spill	-1.990	0.543	-0.025	0.017	2.399	0.121
S6%Q	-2.219	0.412	-0.067	0.046	2.192	0.139
S3%Q	-2.502	0.260	-0.147	0.108	1.985	0.159
S4%Q	-2.519	0.258	-0.119	0.091	1.792	0.181
S5%Q	-2.453	0.325	-0.095	0.083	1.505	0.220
S8%Q	-2.143	0.555	-0.082	0.069	1.491	0.222
S2%Q	-3.239	0.426	0.114	0.092	1.460	0.227
Discharge	-3.441	0.589	0.006	0.005	1.415	0.234
S1%Q	-2.470	0.326	-0.140	0.128	1.238	0.266
T2%Q	-2.364	0.460	-0.026	0.027	0.955	0.328
RelativeCond	-1.246	2.374	-0.017	0.024	0.521	0.471
PassDay	-1.610	1.668	-0.009	0.012	0.513	0.474
FL	-3.761	1.451	0.002	0.002	0.454	0.501
T3%Q	-3.098	0.526	0.020	0.030	0.427	0.513
T5%Q	-2.883	0.261	0.013	0.024	0.307	0.580
Temp15	-1.962	2.076	-0.090	0.180	0.258	0.611
Temp30	-2.002	2.064	-0.088	0.182	0.242	0.623
Condition	2.899	0.311	-0.146	0.311	0.237	0.627
PassDiel	2.841	0.220	0.104	0.220	0.231	0.631
SurfaceTemp	-2.112	1.942	-0.075	0.165	0.216	0.642
T6%Q	-2.859	0.252	0.011	0.025	0.198	0.657
FBTDG	-5.577	6.481	0.024	0.056	0.182	0.669
S7%Q	-2.759	0.204	-0.025	0.097	0.072	0.789
TempRatio	-0.802	11.037	-2.125	10.673	0.041	0.839
ln(Y dist)	-2.931	0.784	0.026	0.138	0.036	0.849
T1%Q	-2.779	0.264	-0.001	0.021	<0.001	0.979

Table A.24. Bayesian model-averaging results displaying the top five models for explaining the probability of turbine passage for tagged steelhead kelts at Lower Monumental Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts = 488

n models selected = 4

Cum. post. prob. = 1.000

Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Intercept	**1.000**	-4.400	1.136	-4.588	-3.753	-5.629	-4.313
Search	**1.000**	-1.003	0.201	-0.979	-1.033	-0.988	-1.034
FirstY	**1.000**	0.011	0.003	0.011	0.010	0.011	0.010
ln(Z dist)	**1.000**	0.908	0.221	0.942	0.859	0.961	0.841
AccDepth	**0.577**	0.040	0.039	0.066	.	0.077	.
T4%Q	**0.181**	0.011	0.027	.	.	0.064	0.046
n variables				4	3	5	4
BIC				-2841	-2841	-2838	-2836
($p[M_k \mid D]$)				0.445	0.374	0.132	0.049

Table A.25. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of survival for acoustic-tagged steelhead kelts from the face of Lower Granite Dam to the detection array located 59 km downstream of the dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
Condition[1]	0.425	0.204	1.118	0.204	32.244	<0.001*
Discharge	-0.771	0.422	0.025	0.006	27.288	<0.001*
S1%Q	3.107	0.47	-0.19	0.041	23.954	<0.001*
T6%Q	0.713	0.166	0.127	0.031	23.26	<0.001*
T1%Q	0.641	0.18	0.073	0.018	18.97	<0.001*
T5%Q	2.511	0.391	-0.068	0.017	18.954	<0.001*
T2%Q	2.816	0.456	-0.078	0.02	17.807	<0.001*
ln(TR egress)	-0.176	0.479	-0.44	0.136	10.406	0.001*
TRTDG	-12.573	4.958	0.121	0.044	9.918	0.002*
S4%Q	2.516	0.525	-0.224	0.081	8.261	0.004*
T3%Q	0.746	0.219	0.042	0.017	5.739	0.017*
TRtemp	0.013	0.728	0.109	0.069	2.645	0.104
%Spill	1.96	0.529	-0.022	0.014	2.56	0.11
RelativeCond	-1.678	1.837	0.025	0.018	2.047	0.153
PassDay	-0.018	0.952	0.009	0.007	1.598	0.206
S5%Q	0.806	0.317	0.096	0.078	1.595	0.207
S3%Q	0.843	0.304	0.089	0.077	1.437	0.231
S6%Q	0.885	0.359	0.079	0.095	0.708	0.4
T4%Q	1.13	0.15	0.031	0.04	0.682	0.409
S2%Q	1.075	0.337	0.026	0.092	0.08	0.777
S7%Q	1.08	0.333	0.025	0.093	0.074	0.785
PassDiel	1.155	0.17	0.029	0.17	0.029	0.866
S8%Q	1.125	0.435	-0.012	0.132	0.008	0.93
FL	1.145	1.118	0	0.016	<0.001	0.988

[1] Good condition kelts had a higher probability of survival than fair condition kelts

Table A.26. Bayesian model-averaging results displaying the top five models for explaining the probability of survival from dam passage (all routes combined) to the detection array located 59 km downstream for acoustic-tagged steelhead kelts at Lower Granite Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	248							
n models selected =	23							
Cum. Post. prob. =	0.545							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	0.764	2.692	1.309	2.168	0.204	0.127	3.018
Condition	**1.000**	-1.996	0.449	-2.109	-1.973	-2.053	-1.904	-2.036
T6%Q	**0.709**	0.075	0.059	0.120	0.094	0.115	.	.
ln(TR egress)	**0.304**	-0.100	0.174	.	.	-0.329	.	.
T5%Q	**0.296**	-0.014	0.025	.	-0.039	.	.	-0.065
Discharge	**0.154**	0.002	0.007	.	.	.	0.020	.
T1%Q	**0.133**	0.006	0.019	.	.	.	.	.
TRTDG	**0.052**	0.004	0.021	.	.	.	.	.
S1%Q	**0.039**	-0.004	0.024	.	.	.	.	.
T2%Q	**0.027**	-0.001	0.006	.	.	.	.	.
S4%Q	**0.012**	0.000	0.011	.	.	.	.	.
T3%Q	**0.012**	0.000	0.002	.	.	.	.	.
n variables				2	3	3	2	2
BIC				-1144	-1142	-1142	-1141	-1141
($p[M_k \mid D]$)				0.194	0.115	0.108	0.069	0.059

Table A.27. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of survival for acoustic-tagged steelhead kelts that passed Lower Granite Dam via the spillway weir from the face of the dam to the detection array located 59 km downstream of the dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
Condition[1]	0.265	0.245	1.209	0.245	27.934	<0.001*
T6%Q	0.617	0.185	0.161	0.045	22.149	<0.001*
Discharge	-0.711	0.493	0.024	0.007	16.499	<0.001*
T1%Q	0.610	0.200	0.073	0.022	13.353	<0.001*
S1%Q	2.799	0.551	-0.165	0.047	13.260	<0.001*
T5%Q	2.370	0.458	-0.064	0.019	12.950	<0.001*
T2%Q	2.469	0.511	-0.065	0.021	10.049	0.002*
S4%Q	2.304	0.586	-0.203	0.088	5.627	0.018*
ln(TR egress)	-0.698	0.786	-0.505	0.214	5.574	0.018*
TRTDG	-10.931	6.215	0.106	0.055	4.537	0.033*
T3%Q	0.718	0.245	0.035	0.019	3.226	0.073*
%Spill	1.973	0.612	-0.025	0.016	2.534	0.111
TRtemp	0.167	0.793	0.084	0.074	1.330	0.249
PassDay	-0.128	1.063	0.009	0.008	1.288	0.257
RelativeCond	-1.501	2.137	0.022	0.021	1.206	0.272
S5%Q	0.775	0.387	0.079	0.100	0.645	0.422
T4%Q	1.027	0.173	0.024	0.041	0.391	0.532
S3%Q	0.874	0.364	0.052	0.094	0.318	0.573
S8%Q	1.307	0.516	-0.080	0.156	0.263	0.608
PassDiel	1.007	0.196	-0.091	0.196	0.213	0.644
S2%Q	1.144	0.383	-0.027	0.103	0.066	0.798
FL	1.223	1.292	-0.002	0.019	0.017	0.896
S6%Q	1.012	0.411	0.013	0.107	0.014	0.906
S7%Q	1.090	0.460	-0.011	0.137	0.006	0.937

[1] Good condition kelts had a higher probability of survival than fair condition kelts

Table A.28. Bayesian model-averaging results displaying the top five models for explaining the probability of survival from dam passage to the detection array located 59 km downstream for tagged steelhead kelts that passed Lower Granite Dam via the spillway weir in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	181							
n models selected =	10							
Cum. Post. prob. =	0.790							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	0.840	2.113	1.070	1.638	0.508	0.421	0.994
Condition	**1.000**	-2.080	0.522	-2.087	-2.014	-2.115	-2.113	-2.027
T6%Q	**1.000**	0.231	0.084	0.232	0.213	0.247	0.222	0.219
T5%Q	**0.095**	-0.002	0.010	.	-0.026	.	.	.
S4%Q	**0.054**	0.005	0.032	.	.	0.085	.	.
ln(TR egress)	**0.053**	-0.010	0.071	.	.	.	-0.189	.
T1%Q	**0.049**	0.001	0.007	.	.	.	.	0.016
TRTDG	**0.047**	0.002	0.018	.	.	.	.	.
Discharge	**0.041**	0.000	0.002	.	.	.	.	.
S1%Q	**0.041**	0.001	0.014	.	.	.	.	.
T2%Q	**0.040**	0.000	0.005	.	.	.	.	.
T3%Q	**0.040**	0.000	0.004	.	.	.	.	.
n variables				2	3	3	3	3
BIC				-773	-770	-768	-768	-768
($p[M_k \mid D]$)				0.539	0.095	0.054	0.053	0.049

Table A.29. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of survival for acoustic-tagged steelhead kelts from the face of Little Goose Dam to the detection array located 33 km downstream of the dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
Discharge	0.378	0.503	0.025	0.006	19.669	<0.001*
T2%Q	4.195	0.44	-0.09	0.02	19.307	<0.001*
T4%Q	1.911	0.187	0.078	0.02	16.483	<0.001*
TRTDG	-27.589	8.513	0.265	0.075	16.427	<0.001*
Condition[1]	-2.145	0.159	-0.666	0.159	15.439	<0.001*
FL	6.602	1.151	-0.006	0.002	13.368	<0.001*
S5%Q	1.986	0.193	0.319	0.099	12.159	<0.001*
Crest[2]	-2.455	0.15	-0.514	0.15	11.972	<0.001*
T1%Q	3.758	0.422	-0.059	0.017	11.865	<0.001*
S8%Q	4.06	0.507	-0.314	0.092	10.972	<0.001*
S6%Q	1.776	0.297	0.281	0.109	6.672	0.010*
S1%Q	3.932	0.609	-0.124	0.049	6.271	0.012*
ln(TR egress)	1.314	0.559	-0.378	0.155	5.338	0.021*
S3%Q	1.977	0.269	0.209	0.098	4.766	0.029*
S7%Q	2.118	0.221	0.208	0.1	4.572	0.033*
T5%Q	2.325	0.166	0.043	0.024	3.753	0.053*
T6%Q	2.391	0.158	0.052	0.034	2.635	0.105
S2%Q	1.785	0.547	0.19	0.144	1.918	0.166
%Spill	1.38	1.032	0.035	0.032	1.405	0.236
TRtemp	1.52	1.017	0.086	0.088	0.965	0.326
PassDiel	2.586	0.183	0.155	0.183	0.755	0.385
S4%Q	2.135	0.462	0.111	0.135	0.684	0.408
PassDay	1.961	1.238	0.004	0.009	0.196	0.658
RelativeCond	2.638	1.771	-0.001	0.018	0.002	0.967
T3%Q	2.508	0.316	-0.001	0.02	0.001	0.977

[1] Good condition kelts had a higher survival probability than those in fair condition

[2] Kelts that passed at low crest had a higher survival probability than those that passed at high crest

Table A.30. Bayesian model-averaging results displaying the top five models for explaining the probability of survival from dam passage (all routes combined) to the detection array located 33 km downstream for tagged steelhead kelts at Little Goose Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	633							
n models selected =	21							
Cum. Post. prob. =	0.677							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	1.000	4.383	7.427	8.610	4.984	6.594	0.747	-18.240
Condition	0.948	-1.205	0.454	-1.253	-1.273	-1.368	-1.197	-1.315
FL	0.889	-0.006	0.003	-0.006	-0.006	-0.006	.	-0.007
T2%Q	0.444	-0.035	0.043	-0.080	.	.	.	.
Discharge	0.384	0.009	0.013	.	0.023	.	0.027	.
T4%Q	0.122	0.006	0.020	.	.	0.065	.	.
TRTDG	0.098	0.018	0.063	.	.	.	.	0.225
ln(TR egress)	0.032	-0.006	0.046	.	.	.	.	.
S7%Q	0.030	-0.004	0.029	.	.	.	.	.
S8%Q	0.022	-0.006	0.043	.	.	.	.	.
S3%Q	0.016	-0.002	0.021	.	.	.	.	.
T1%Q	0.013	0.000	0.004	.	.	.	.	.
S5%Q	0.000	0.000	0.000	.	.	.	.	.
Crest	0.000	0.000	0.000	.	.	.	.	.
S6%Q	0.000	0.000	0.000	.	.	.	.	.
S1%Q	0.000	0.000	0.000	.	.	.	.	.
T5%Q	0.000	0.000	0.000	.	.	.	.	.
n variables				3	3	3	2	3
BIC				-3792	-3792	-3790	-3789	-3789
($p[M_k \mid D]$)				0.261	0.226	0.071	0.063	0.055

Table A.31. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of survival for acoustic-tagged steelhead kelts that passed Little Goose Dam via the spillway weir to the detection array located 33 km downstream of the dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
T2%Q	5.281	0.681	-0.121	0.029	17.636	<0.001*
Crest[1]	-2.956	0.241	-0.876	0.241	15.705	<0.001*
Discharge	0.079	0.762	0.035	0.01	14.454	<0.001*
TRTDG	-43.348	14.341	0.408	0.127	13.018	<0.001*
T4%Q	2.239	0.251	0.091	0.03	10.762	0.001*
S8%Q	4.866	0.73	-0.394	0.127	9.063	0.003*
FL	7.787	1.716	-0.008	0.003	8.987	0.003*
T1%Q	4.381	0.64	-0.069	0.025	7.467	0.006*
Condition[2]	-2.479	0.229	-0.667	0.229	7.244	0.007*
T5%Q	2.59	0.222	0.097	0.047	6.371	0.012*
S5%Q	2.394	0.269	0.325	0.151	5.343	0.021*
S6%Q	1.933	0.406	0.383	0.161	5.224	0.019*
S3%Q	2.188	0.369	0.294	0.15	3.984	0.046*
PassDiel	3.275	0.374	0.576	0.374	3.199	0.074*
ln(TR egress)	1.161	1.06	-0.465	0.28	2.556	0.11
T6%Q	2.732	0.221	0.069	0.054	2.071	0.15
S1%Q	3.885	0.895	-0.088	0.073	1.438	0.231
PassDay	4.734	1.696	-0.013	0.012	1.229	0.268
S7%Q	2.629	0.322	0.129	0.147	0.802	0.37
%Spill	1.559	1.761	0.041	0.056	0.682	0.409
TRtemp	3.874	1.349	-0.085	0.111	0.573	0.449
S2%Q	2.478	0.779	0.103	0.206	0.265	0.607
RelativeCond	3.983	2.554	-0.01	0.025	0.167	0.682
S4%Q	2.604	0.678	0.08	0.205	0.156	0.693
T3%Q	2.929	0.45	-0.005	0.028	0.031	0.86

[1] Kelts that passed at low crest had a higher survival probability than those that passed at high crest

[2] Good condition kelts had a higher survival probability than those in fair condition

Table A.32. Bayesian model-averaging results displaying the top five models for explaining the probability of survival from dam passage to the detection array located 33 km downstream for tagged steelhead kelts that passed Little Goose Dam via the spillway weir in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k \mid D]$). The posterior probability of each variable being included in the model ($p[\Delta \mid D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	443							
n models selected =	66							
Cum. Post. prob. =	0.349							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	1.000	4.365	10.504	9.512	5.281	10.010	5.364	5.090
T2%Q	0.743	-0.096	0.079	-0.116	-0.121	-0.108	-0.114	-0.079
FL	0.465	-0.003	0.004	-0.007	.	-0.007	.	.
Condition	0.442	-0.552	0.703	.	.	-1.266	-1.142	.
Crest	0.329	-0.469	0.754	.	.	.	.	-1.172
S8%Q	0.123	0.084	0.264	.	.	.	.	.
PassDiel	0.082	-0.091	0.375	.	.	.	.	.
Discharge	0.078	0.002	0.009	.	.	.	.	.
TRTDG	0.073	0.021	0.086	.	.	.	.	.
S6%Q	0.035	-0.008	0.065	.	.	.	.	.
S3%Q	0.031	-0.007	0.048	.	.	.	.	.
T4%Q	0.026	0.001	0.010	.	.	.	.	.
T1%Q	0.017	0.000	0.005	.	.	.	.	.
T5%Q	0.016	0.001	0.010	.	.	.	.	.
S5%Q	0.014	-0.001	0.023	.	.	.	.	.
n variables				2	1	3	2	2
BIC				-2518	-2518	-2518	-2517	-2517
($p[M_k \mid D]$)				0.089	0.088	0.081	0.051	0.040

Table A.33. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of survival of acoustic-tagged steelhead kelts from the face of Lower Monumental Dam to the detection array located 27 km downstream of the dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
RelativeCond	-4.273	2.224	0.070	0.023	10.113	0.002*
Discharge	1.019	0.543	0.017	0.006	8.601	0.003*
S7%Q	2.327	0.174	0.359	0.164	7.864	0.005*
T2%Q	3.576	0.425	-0.057	0.020	7.367	0.007*
FL	5.976	1.280	-0.005	0.002	7.314	0.007*
S8%Q	3.726	0.487	-0.136	0.050	7.030	0.008*
S6%Q	3.349	0.416	-0.083	0.037	4.957	0.026*
T1%Q	2.222	0.212	0.042	0.020	4.443	0.035*
TRTDG	-11.118	7.370	0.117	0.063	3.533	0.060*
T4%Q	2.143	0.260	0.036	0.020	3.237	0.072*
PassDiel	2.446	0.174	-0.249	0.174	1.963	0.161
%Spill	3.049	0.473	-0.015	0.013	1.309	0.253
Condition	2.373	0.219	0.242	0.219	1.113	0.291
S5%Q	2.757	0.278	-0.054	0.054	0.909	0.340
S3%Q	2.377	0.241	0.083	0.093	0.834	0.361
T3%Q	2.861	0.473	-0.020	0.027	0.530	0.467
TRtemp	3.439	1.261	-0.071	0.103	0.464	0.496
T5%Q	2.473	0.219	0.010	0.022	0.234	0.629
T6%Q	2.484	0.215	0.010	0.023	0.184	0.668
S1%Q	2.582	0.310	-0.015	0.109	0.020	0.889
PassDay	2.702	1.452	-0.001	0.011	0.011	0.915
ln(TR egress)	2.742	0.322	0.010	0.102	0.009	0.925
S4%Q	2.533	0.249	0.005	0.077	0.005	0.946
S2%Q	2.527	0.378	0.005	0.090	0.003	0.958

Table A.34. Bayesian model-averaging results displaying the top five models for explaining the probability of survival from dam passage (all routes combined) to the detection array located 27 km downstream for tagged steelhead kelts at Lower Monumental Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k \mid D]$). The posterior probability of each variable being included in the model ($p[\Delta \mid D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	488							
n models selected =	11							
Cum. Post. prob. =	0.750							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-0.977	6.587	0.649	-0.843	1.121	0.976	-14.670
FL	**1.000**	-0.009	0.002	-0.009	-0.008	-0.008	-0.009	-0.009
RelativeCond	**0.979**	0.076	0.026	0.079	0.077	0.078	0.073	0.080
TRTDG	**0.101**	0.014	0.049	.	.	.	.	0.129
Discharge	**0.096**	0.001	0.004	.	0.012	.	.	.
T2%Q	**0.091**	-0.004	0.014	.	.	-0.043	.	.
S7%Q	**0.086**	0.022	0.087	.	.	.	0.257	.
S8%Q	**0.066**	-0.006	0.029	.	.	.	.	.
T1%Q	**0.066**	0.003	0.012	.	.	.	.	.
T4%Q	**0.065**	0.002	0.011	.	.	.	.	.
S6%Q	**0.033**	-0.002	0.012	.	.	.	.	.
n variables				2	3	3	3	3
BIC				-2796	-2794	-2794	-2793	-2793
($p[M_k \mid D]$)				0.398	0.096	0.091	0.086	0.080

Table A.35. Bivariate logistic regression modeling results displaying the relationships between each candidate variable and the probability of survival for acoustic-tagged steelhead kelts that passed Lower Monumental Dam via the spillway weir to the detection array located 27 km downstream of the dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
S6%Q	4.621	0.670	-0.155	0.053	8.647	0.003*
S7%Q	2.718	0.248	0.864	0.522	7.535	0.006*
S8%Q	4.750	0.721	-0.192	0.068	7.212	0.007*
T1%Q	2.521	0.285	0.076	0.034	5.887	0.015*
Discharge	1.246	0.798	0.020	0.009	5.195	0.023*
T2%Q	4.086	0.601	-0.048	0.027	3.986	0.046*
SW%Q	4.380	0.757	-0.040	0.019	3.950	0.047*
T4%Q	2.469	0.357	0.052	0.029	3.096	0.079*
TRtemp	5.906	1.805	-0.226	0.141	2.472	0.116
RelativeCond	-1.537	3.144	0.046	0.032	2.247	0.134
FL	5.232	1.915	-0.003	0.003	1.346	0.246
S5%Q	3.386	0.419	-0.096	0.081	1.237	0.266
S1%Q	3.375	0.488	-0.148	0.164	0.797	0.372
ln(TR egress)	3.484	0.583	0.143	0.166	0.765	0.382
Condition	2.800	0.328	0.288	0.329	0.688	0.407
PassDay	4.695	2.042	-0.012	0.014	0.680	0.410
TRTDG	-4.535	11.198	0.065	0.096	0.471	0.492
S2%Q	3.348	0.555	-0.085	0.123	0.461	0.497
T6%Q	2.874	0.308	0.023	0.034	0.445	0.505
PassDiel	2.934	0.271	-0.161	0.271	0.338	0.561
T3%Q	3.378	0.714	-0.022	0.040	0.312	0.576
S3%Q	2.886	0.362	0.065	0.145	0.205	0.651
T5%Q	2.918	0.322	0.013	0.032	0.177	0.674
S4%Q	3.041	0.374	-0.012	0.120	0.010	0.919

Table A.36. Bayesian model-averaging results displaying the top five models for explaining the probability of survival from dam passage to the detection array located 27 km downstream for tagged steelhead kelts that passed Lower Monumental Dam via the spillway weir in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	384
n models selected =	23
Cum. Post. prob. =	0.596

Variable	**($p[\Delta \| D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	3.714	1.245	4.621	2.718	4.750	3.012	2.521
S6%Q	**0.355**	-0.054	0.083	-0.155	.	.	.	.
S7%Q	**0.321**	0.248	0.465	.	0.864	.	.	.
S8%Q	**0.168**	-0.028	0.073	.	.	-0.192	.	.
T1%Q	**0.139**	0.009	0.026	.	.	.	.	0.076
%Spill	**0.089**	-0.003	0.013	.	.	.	.	.
T4%Q	**0.068**	0.003	0.013	.	.	.	.	.
Discharge	**0.055**	0.001	0.005	.	.	.	.	.
T2%Q	**0.048**	-0.002	0.012	.	.	.	.	.
n variables				1	1	1	0	1
BIC				-2136	-2135	-2135	-2134	-2134
($p[M_k \| D]$)				0.232	0.133	0.113	0.060	0.058

Table A.37. Bivariate general linear regression modeling results displaying the relationships between each candidate variable and the forebay residence times for acoustic-tagged steelhead kelts at Lower Granite Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
ln(Y dist)	-0.715	0.219	0.385	0.041	76.831	<0.001*
ln(Z dist)	0.025	0.146	0.339	0.036	76.260	<0.001*
S1%Q	0.380	0.178	0.093	0.017	27.175	<0.001*
Discharge	1.873	0.167	-0.007	0.002	15.707	<0.001*
Search	0.977	0.103	0.104	0.030	11.910	<0.001*
%Spill	0.771	0.255	0.014	0.007	4.011	0.045*
FL	2.334	0.546	-0.002	<0.001	3.899	0.048*
FirstZ	1.159	0.091	0.021	0.011	3.628	0.057*
FirstY	1.352	0.119	-0.001	<0.001	0.844	0.358
FBdiel	1.319	0.091	0.081	0.091	0.793	0.373

Table A.38. Bayesian model-averaging results displaying the top five models for explaining the forebay residence time for tagged steelhead kelts at Lower Granite Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k \mid D]$). The posterior probability of each variable being included in the model ($p[\Delta \mid D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	234							
n models selected =	7							
Cum. Post. prob. =	0.920							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	0.628	0.467	0.615	0.163	1.412	0.985	0.590
ln(Z dist)	**1.000**	0.324	0.040	0.325	0.328	0.319	0.322	0.320
Discharge	**1.000**	-0.006	0.002	-0.006	-0.006	-0.007	-0.006	-0.006
%Spill	**0.248**	0.003	0.006	.	0.011	.	0.012	.
FL	**0.160**	0.000	0.001	.	.	-0.001	-0.001	.
FirstZ	**0.049**	0.000	0.003	.	.	.	.	0.008
Search	**0.045**	-0.001	0.008	.	.	.	.	.
ln(Y dist)	**0.035**	0.001	0.022	.	.	.	.	.
n variables				2	3	3	4	3
BIC				-75	-73	-72	-70	-70
($p[M_k \mid D]$)				0.512	0.199	0.110	0.049	0.049

Table A.39. Bivariate general linear regression modeling results displaying the relationships between each candidate variable and the forebay residence times for acoustic-tagged steelhead kelts at Little Goose Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	**Intercept**	**SE**	**Estimate**	**SE**	χ^2	***P***
ln(Z dist)	-1.137	0.083	0.526	0.018	542.855	<0.001*
ln(Y dist)	-2.081	0.117	0.548	0.019	517.693	<0.001*
Search	0.660	0.062	0.155	0.017	81.801	<0.001*
FirstY	1.560	0.072	-0.003	<0.001	54.793	<0.001*
FirstZ	1.032	0.054	0.018	0.007	7.473	0.006*
Discharge	1.486	0.149	-0.004	0.002	5.302	0.021*
S1%Q	0.786	0.176	0.033	0.015	4.840	0.028*
FL	0.506	0.377	0.001	<0.001	2.995	0.084*
%Spill	1.362	0.255	-0.006	0.008	0.656	0.418
FBdiel	1.170	0.053	0.009	0.053	0.026	0.871

Table A.40. Bayesian model-averaging results displaying the top five models for explaining the forebay residence time for tagged steelhead kelts at Little Goose Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k \mid D]$). The posterior probability of each variable being included in the model ($p[\Delta \mid D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	587							
n models selected =	7							
Cum. Post. prob. =	0.937							
Variable	**($p[\Delta \mid D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-1.798	0.307	-1.947	-1.327	-1.884	-1.571	-1.753
ln(Z dist)	**1.000**	0.363	0.063	0.352	0.371	0.368	0.375	0.356
ln(Y dist)	**0.969**	0.191	0.067	0.203	0.184	0.174	0.180	0.199
S1%Q	**0.777**	0.023	0.015	0.031	.	0.030	.	0.023
Discharge	**0.221**	-0.001	0.001	.	-0.003	.	.	-0.001
Search	**0.068**	0.001	0.005	.	.	0.017	.	.
FL	**0.032**	0.000	0.000	.	.	.	.	.
FirstY	**0.000**	0.000	0.000	.	.	.	.	.
n variables				3	3	4	2	4
BIC				-582	-580	-578	-577	-577
($p[M_k \mid D]$)				0.610	0.185	0.068	0.037	0.036

Table A.41. Bivariate general linear regression modeling results displaying the relationships between each candidate variable and the forebay residence times for acoustic-tagged steelhead kelts at Lower Monumental Dam in 2012 and 2013. Results (χ^2 and *P*) of likelihood ratio tests are also shown. * indicates a significant correlation at $\alpha = 0.10$.

Parameter	Intercept	SE	Estimate	SE	χ^2	*P*
ln(Z dist)	-1.168	0.113	0.538	0.028	289.689	<0.001*
ln(Y dist)	-1.679	0.149	0.478	0.026	256.181	<0.001*
Search	0.471	0.065	0.156	0.018	66.705	<0.001*
Discharge	1.625	0.142	-0.007	0.001	25.361	<0.001*
FirstY	1.111	0.061	0.002	<0.001	17.86	<0.001*
S1%Q	0.497	0.124	0.055	0.014	14.599	<0.001*
FL	0.023	0.372	0.001	<0.001	6.158	0.013*
FBdiel	0.982	0.052	0.094	0.052	3.248	0.072*
%Spill	0.804	0.13	0.004	0.004	1.278	0.258
FirstZ	0.939	0.055	-0.002	0.007	0.072	0.789

Table A.42. Bayesian model-averaging results displaying the top five models for explaining the forebay residence time for tagged steelhead kelts at Lower Monumental Dam in 2012 and 2013. Top models were selected and ranked by their Bayesian Information Criterion (BIC) and posterior probabilities ($p[M_k | D]$). The posterior probability of each variable being included in the model ($p[\Delta | D]$) is also shown, along with the mean parameter value and standard deviation, and the parameter value of each variable in the top five models. Also displayed are the number of kelts that were included in the model construction, the number of models created from which the top five were selected, the cumulative posterior probability of the top five models, and the number of variables included in each of the top five models.

n kelts =	485							
n models selected =	11							
Cum. Post. prob. =	0.839							
Variable	**($p[\Delta \| D]$)**	**Mean**	**SD**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Intercept	**1.000**	-0.878	0.324	-0.930	-0.636	-0.813	-1.323	-0.517
ln(Z dist)	**1.000**	0.430	0.098	0.380	0.546	0.362	0.382	0.544
Discharge	**0.979**	-0.006	0.001	-0.006	-0.006	-0.006	-0.006	-0.006
ln(Y dist)	**0.674**	0.116	0.096	0.169	.	0.185	0.164	.
FBdiel	**0.217**	-0.034	0.074	.	.	-0.162	.	-0.133
FL	**0.103**	0.000	0.000	.	.	.	0.001	.
Search	**0.063**	0.001	0.007	.	.	.	.	.
S1%Q	**0.043**	0.001	0.009	.	.	.	.	.
n variables				3	2	4	4	3
BIC				-303	-302	-301	-299	-299
($p[M_k \| D]$)				0.384	0.213	0.153	0.048	0.041

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