Responses to Comments Received on Merwin Upstream Passage Adult Trap Efficiency: Winter Steelhead 2017 Annual Report - December 18, 2017

	Date	**Commenter**	**Comment Number**	**Comment**	**Response**
	2/1/2018	Tom Wadsworth, WDFW	1	Kale, Sam and I looked at the report. We found it to be well written and complete, however, at 91 pages it seems a bit long. It would be great if you could find a way to reduce some sections without removing any critical info (e.g., background section? antennae info?).	Comment noted.
	2/1/2018	Tom Wadsworth, WDFW	2	There were some discussion points suggesting the 98% ATE performance metric may not be appropriate for meeting these biological and management goals. As the author stated, we agree that point is beyond the scope of the report - it might be worth a discussion with the ACC at some point if that is truly a concern.	PacifCorp also agrees that the authors comments regarding the preformance metric of 98% ATE to meet the biological and management goals is beyond the scope of this report, although we believe they did have relavance regarding the possiblity of violating the assumptions of the current study design and introducing bias related to: 1) the use trap non-naïve test fish; 2) the use of hatchery origin fish rather than fish from the upper basin; and 3) not accounting for natural starying rates and fish condition.
	2/1/2018	Tom Wadsworth, WDFW	3	Suggestions for the future: Sam had a couple suggestions about reducing the fish that back out of the trap once they enter: (1) add a plate or extend the height of the fyke to cover the gap above it and prevent fish from exiting at high flows, (2) install the fyke so that the opening is not facing the main current flow, should reduce the likelihood of fish following the flow back out once they enter.	Since the report was submitted, PacifiCorp has rectified the hole above the fyke by installing a perferated plate above the fyke to prevent adults from passing back downstream.
	2/1/2018	Tom Wadsworth, WDFW	4	Agree with the suggestion in the report to evaluate trap efficiency for naïve fish as well as the typical evaluation for non-naïve fish in the trap.	The 2018 ATE study will incorporate both trap naïve and non-naïve fish to detect any possible diffences.
	2/1/2018	Tom Wadsworth, WDFW	5	Sounds like we should be expecting a similar report on coho efficiency in the near future?	Yes, the 2017 coho ATE study is on schedule, and the draft report will be submitted to the ACC by March 1, 2018.
	2/1/2018	Tom Wadsworth, WDFW	6	Any plan to do an efficiency study with spring Chinook in 2018? 2018 might be the best spring Chinook return we get for the next few years (due to low recent brood releases) so in some ways it might be a good year to do this but would be good to discuss the pros and cons.	This will need to be discussed by the ACC. PacifiCorp will include this as an agend topic for the March 2018 meeting.
	2/1/2018	Michelle Day, NMFS	7	Need to better define the difference between ATE and PEE and the difference between the two (Ti). Maybe a diagram of the tailrace and ladder/trap showing where the fish enter the study area and where the fish have to cross to be counted in the ATE group versus the PEE group.	Future reports will provide more clarity between the differences in ATE_{TEST} and P_{EE} metrics. The most direct way to think about the difference between the two metrics is that ATE_{TEST} only includes those fish that both physically entered the fish ladder (detected on ENTERANCE receiver) and are actually captured by the elevator and conveyance system, whereas P_{EE} includes all fish that physically enter the ladder regardless of whether they were ultimately captured or not (i.e., eventually exited the ladder back into the tailrace). P_{EE} will always be larger (or equal to) $ATE_{TEST.}$ T_i provides a measure of the difference between the two metrics and provides an index of how efficient the trap is performing. The larger the value of T_i, the less efficient the trap is. P_{EE} additionally provides a conservative measure of "attraction" and whether fish are finding the entrance of the trap. It is conservative because the metric does not include fish that are detected immediately outside the ladder entrance (detected on APPROACH receiver) but do not enter.
	2/1/2018	Michelle Day, NMFS	8	Executive Summary, First paragraph: says the study is to address the requirements of the M&E plan. The study was originally a separate requirement. I can't remember what it was called. It was later incorporated into the M&E plan. Please reference the first document. I'm alright with then saying it was incorporated into the M&E plan.	We believe you are referring to Section 9.2 of the Settlement Agreement which describes the need for developing a Monitoring and Evaluation Plan related to Fish Passage. Among the requirements outlined in this section was the need to assess Adult Trap Efficiency (ATE) at all proposed upstream fish passage facilities including Merwin Dam. The performance standard was later to be defined and presented in the M&E Plan.
	2/1/2018	Michelle Day, NMFS	9	Please remove all parts (except the Lewis River performance standard) about Objective 10 called provide regulatory and biological context behind adult passage standards. It is mentioned in numerous places in the document (in almost every section: executive summary, study objectives, analytical approach, results, discussion, and conclusions). There may be other areas where it appears in the document. The bottom line regardless of what is happening in other areas is that the performance standard identified here must be met. If it is not, then the collection system must be redesigned. It is part of the Settlement Agreement. The SA called for a robust design of the collection facilities at Merwin. Instead of the robust design and construction, it was later agreed that the ATE performance standard would be used to decide when to upgrade.	We believe that the information provided in Objective 10 is informative and should remain. The purpose of the Objective 10 was to provide context to the agreed performance standard of 98% CE as well as provide some background on how the metric is measured and possible factors that may influence it. While the past three years of study on winter steelhead have been informative and have led to facility improvements (e.g., fyke), it is important to understand the limitations of the current study design. Factors related to the use of hatchery origin and trap non-naïve fish, and not accounting for natural straying could be negatively biasing current ATE estimates. PacifiCorp understands its obligation to meet the agreed performance standard, but believes that we need to have the best available information to make informed decisions on the next course of action in pursuing additional trap improvements. We look forward to the 2018 study results which should provide some insight as to the level these factors are playing in the current ATE estimate.
	2/1/2018	Michelle Day, NMFS	10	It is currently inappropriate to make assumptions on what will not work for future changes e.g. a second entrance on the north side. Currently, we do not have enough data to make that type of conclusion. Also, there are other factors that will likely play into future possible facility changes e.g. we are currently working with a majority of hatchery fish that could be attracted to the south side due to the hatchery discharge being there and changes to the water conditions in the north side due to a potential changes in discharge could create better attraction to that area, etc.	Agreed.

MERWIN UPSTREAM PASSAGE ADULT TRAP EFFICIENCY – WINTER STEELHEAD

2017 Final Annual Report

Prepared for:

PacifiCorp
825 NE Multnomah St.
Portland, OR 97232

Prepared by:

Matt Drenner[1], Lucius Caldwell[1], Lindsey Belcher[1], Kai Ross[1], Mark Morasch[1], and Elizabeth Schotman[1]

December 18, 2017

---

[1] Cramer Fish Sciences (CFS); Gresham, OR

EXECUTIVE SUMMARY

This report describes results from the third year of a radio telemetry (RT) study designed to address the requirements of the Lewis River Aquatic Monitoring and Evaluation Plan (M&E Plan; PacifiCorp and Cowlitz PUD 2016). The M&E Plan describes the need for an evaluation of the collection efficiency of the Merwin Dam adult fish trap for upstream migrating steelhead (*Oncorhynchus mykiss*), spring Chinook (*O. tshawytscha*), and coho (*O. kisutch*) salmon. This report focuses on results evaluating collection efficiency of BWT winter steelhead.

The M&E Plan defines a performance standard of 98% collection efficiency, or Adult Trap Efficiency (*ATE)*, for fish that enter the Merwin Dam tailrace. Additional core metrics used to evaluate Merwin Dam trap effectiveness in this report include: trap entrance efficiency (P_{EE}), which quantifies the proportion of fish entering the Merwin Dam tailrace that subsequently entered the trap and indicates the ability of fish to locate and enter the trap from the tailrace; and trap ineffectiveness (T_i), which is the difference between P_{EE} and ATE_{test} and is used to infer an operational or infrastructural weak link in upstream passage at the trapping device—a failure to capture fish once they have entered the trap rather than a failure to attract fish to the trap entrance.

The objectives of the 2017 Merwin *ATE* evaluation were to:

1) Determine ATE_{test} for 2017 and compare this value to the performance standard of 98%.

2) Evaluate directional movement of fish at the trap entrance.

3) Determine if fish in the tailrace spend most of their time near the entrance of the trap or elsewhere.

4) Evaluate the amount of time fish spend in the tailrace and compare to performance standards.

5) Describe the movement and behavior of fish that do not enter the trap, and move back downstream.

6) Evaluate fish condition (i.e., descaling and injury rates).

7) Evaluate key operational or structural changes that could increase *ATE*, and estimate the relative benefits of each option.

8) Evaluate the effectiveness of a fyke in preventing fish from exiting the trap.

9) Compare passage metrics across study years and evaluate whether dam operations influence passage metrics

10) Provide regulatory and biological context behind adult passage standards.

To evaluate Merwin Dam collection efficiency, steelhead were collected from the Merwin Dam fish trap, tagged with radio tags, and released downstream of Merwin Dam. After release, radio telemetry was used to assess collection efficiency and movements of tagged fish at locations in Merwin Dam tailrace, Merwin Dam fish trap ladder, and at sites downstream of Merwin Dam in the Lewis River.

In response to findings described in Caldwell et al. (2016), changes to operations, infrastructure, and other attributes influencing study design were implemented during 2017. The biggest difference in 2017 was installation of a single V-style fyke between ladder pools 1 and 2 within the trap with the goal of preventing fish from exiting the trap and thereby increasing trap efficiency. Additionally, increased frequency of hopper operation was implemented in 2017.

Core passage metrics from 2015-17 are summarized in Table 1, below.

Table 1. 2017 values for P_{EE}, ATE_{test}, and T_i. Sample sizes (*N*) reflect the total number of tagged fish that were released in each study year.

Study Year	**Species**	**N**	**P_{EE} (BCA 95% CI)**	**ATE_{test} (BCA 95% CI)**	**T_i**
2015	Winter steelhead	148	86% (79-90%)	61% (51-67%)	29%
	Spring Chinook	40	90%	38%	58%
	Coho Salmon	35	23%	9%	61%
2016	Winter steelhead	148	93% (87-96%)	73% (65-80%)	21%
	Spring Chinook	*N/A*	*N/A*	*N/A*	*N/A*
	Coho salmon	*N/A*	*N/A*	*N/A*	*N/A*
2017	Winter steelhead	150	83.5% (77-90%)	76.3% (70-84%)	8.6%
	Spring Chinook	*N/A*	*N/A*	*N/A*	*N/A*
	Coho salmon	*N/A*	*N/A*	*N/A*	*N/A*

Key results from the 2017 study pertaining to the core passage metrics for winter steelhead include the following:

- 150 winter steelhead were tagged after being initially captured at the Merwin Dam Adult Fish Collection Facility between February 16th and May 2nd, 2017
- 148 winter steelhead were detected within the study area detection array
- 139 winter steelhead were detected in the tailrace of Merwin Dam (composing the group of fish that were included in estimates of core metrics)
- 116 winter steelhead were detected at the trap entrance, for an overall P_{EE} of 84%
    - 2017 P_{EE} is 11% (approximately 10 percentage points) lower than 2016 P_{EE} estimate for winter steelhead (approximately 93%)
    - 2017 P_{EE} is 4% (approximately 3 percentage points) lower than 2015 P_{EE} estimate for winter steelhead (approximately 86%)
- 106 winter steelhead were successfully recaptured, for an overall ATE_{test} of 77%
    - 2017 ATE_{test} is 4% (approximately 3 percentage points) higher than 2016 ATE_{test} estimate for winter steelhead (approximately 73%)
    - 2017 ATE_{test} is 20% (approximately 15 percentage points) higher than 2015 ATE_{test} estimate for winter steelhead (approximately 61%), a statistically

significant difference ($p<0.05$) as inferred by a bootstrapping randomization exercise

Regarding interannual comparisons among P_{EE} and ATE_{test}, we can say with a high degree of confidence that most differences in metrics across years are not statistically significant (i.e., BCA 95% CIs overlap), with the exception of 2017 ATE_{test} values being greater than 2015 ATE_{test} values (i.e., BCA 95% CIs do not overlap).

We also compared the amount of time that fish were present in the tailrace to *ATE* performance standards: Median residence time was 11.8 hours, which is below the performance standard of 24 hours, but 7% ($n = 10$) of fish exhibited tailrace residence times greater than 168, which is above the maximum 5% performance standard for fish residing within the tailrace for this long.

Consistent with previous years, during the 2017 study year, winter steelhead appeared to locate and enter the trap at a higher rate (P_{EE} of 84%) than the rate at which they were captured (i.e., ATE_{test}). This observation is reflected by a trap ineffectiveness (T_i) of 8.6% for 2017, which was 21 percentage points and 13 percentage points lower than in 2015 (29%) and 2016 (21%), respectively, which is likely a result of the addition of a fyke to the trap. Other evidence that the fyke was effective includes the following observations:

1) In 2016 (before the fyke was added) there were over 700 exit events from Pool 2 to the Entrance site compared only eight exit events in 2017.
2) The network analysis indicated that the Pool 2 site had the highest probability of transitioning forward among all sites in the tailrace and trap; this probability was 50 percentage points higher than in 2016 for the same site.

Although some fish still managed to exit the trap through the fyke in 2017, exit events appeared to be associated with high discharge events (i.e., at tailrace flow > 8,000 cfs), when water levels could have increased to above the height of the fyke, allowing fish to escape through a small gap above the fyke.

Another key finding of the 2017 study emerged from the network analysis, which indicates that fish do not follow clear pathways in the tailrace, which was similar to the 2016 findings. However, in contrast to 2016, fish most commonly first approach the South Shore rather than the North Shore of the tailrace. In addition, milling locations were different in 2017: The most frequent locations of milling in 2017 were at Pool 2 in the trap (formerly the Hopper site in 2016) and at the Approach site outside of the trap entrance. These findings from the network analysis demonstrated fish behave differently from year to year, and the addition of the fyke changed fish behavior in the trap.

Model simulations developed to determine recommendations for future operational or infrastructural scenarios to improve trap efficiency indicated relatively modest gains in ATE_{test}. The addition of a fyke between Pools 3 and 4 only increased simulated ATE_{test} values by four percentage points. The model simulating installation of a new trap on the north shoreline showed no changes to ATE_{test} because there were no credible detections on the receiver on the north shore used in this simulation. We suspect the receiver may not have been functioning properly. To account for this, we replaced 2017 data for the north shore receiver with data from 2016. Even with these changes, the simulation model resulted in only a minor ATE_{test} increase by one percentage point. Overall, all model simulations showed ATE_{test} values remaining below the target *ATE* of 98%.

Cross-year comparisons with data from 2015-2017 were made to understand how operational conditions (e.g., overall discharge from Merwin Dam, discharge from power generating turbines) might influence observed ATE_{test}. Based on these comparisons, there is limited evidence to suggest an effect of discharge from a power generating turbine in front of the trap entrance on trap entrance itself. However, there was some evidence that once overall discharge from Merwin Dam increased above 8,000 cfs, fewer fish reached the area outside the trap entrance or entered the trap. The objective for this report was to explore potential trends related to operations at Merwin Dam, but statistical tests would be required to confirm these trends in an additional report.

Based on an evaluation of passage standards applied across dams in the Columbia River Basin, the 98% passage standard applied at Merwin Dam is consistent with passage standards applied at other facilities in the Columbia Basin, regardless of passage type (i.e., fishway versus trap and haul), species, and dam location. This passage standard is set based on achieved passage at other dams once drop-outs (straying, fisheries capture) were accounted for. Currently, we are unable to account for drop-outs below Merwin Dam with available information, but there is some evidence that rates of straying could be high for steelhead in the system, including the following:

1) Fish spend the most total time at the downstream hatchery, which suggest they are attracted to cues from the Lewis River Hatchery.
2) Fish that are successfully trapped do not appear to follow a single, clear and consistent, directional travel path, based on network analysis of telemetry detections.
3) Many fish appeared to move from the tailrace to downstream locations.
4) Fish tend to visit a large number of sites prior to being captured: 50% of fish that are captured visit 100 or more sites prior to being captured.

All of the above suggest exploratory behavior of BWT steelhead in the Lewis River. Currently, there are no reliable estimates of downstream spawner abundance and straying rates for Lewis River steelhead. Future efforts that enumerate downstream spawning and straying into the hatchery or other tributaries are necessary to resolve the potential effects of straying on observed *ATE* at Merwin Dam, which are likely biased low.

In conclusion, performance standards for collection efficiency at Merwin Dam were not met in 2017, with the exception of the performance standard for median amount of time spent in the tailrace. However, *ATE* estimates in 2017 were improved from previous years. This increase in *ATE* is likely related to managers installing a fyke in the trap ladder system that reduced exit events of fish compared previous years. Estimates of *ATE* may still be negatively biased because there is not currently an ability to account for straying rates of fish and the effects of using trap non-naïve fish to estimate *ATE*.

TABLE OF CONTENTS

Executive Summary ... i
Introduction ... 1
  Study Area ... 1
  Study Background ... 2
  Study Objectives ... 4
Methods ... 5
  Fish Collecting and Tagging ... 5
    Spatial design ... 5
    Antenna types and installation ... 10
    Detection capabilities ... 12
    Metal fyke installation & hopper operation ... 13
  Data Management and Processing ... 15
    Database Construction ... 15
    QA Process ... 15
  Analytical Approach ... 17
    Objective 1: Determine trap effectiveness based on the *ATE* metric defined in the M&E plan for winter steelhead, and compare estimates to the *ATE* performance standard of 98% ... 17
    Objective 2: Determine if winter steelhead show direct movement to the trap entrance and, if some fish do not, document the behavior patterns for those specific fish in the tailrace ... 19
    Objective 3: Determine if winter steelhead in the tailrace spend the majority of their time in the area of the entrance of the trap and, if some fish do not, determine if those fish are holding in another location within the tailrace ... 20
    Objective 4: Determine the total time winter steelhead are present in Merwin Dam tailrace and compare to *ATE* performance standards for safe, timely, and effective passage ... 20
    Objective 5: Describe the movement and behavior of tagged winter steelhead that do not enter or which choose to leave the Merwin Dam tailrace and move back downstream ... 21
    Objective 6: Determine the condition of winter steelhead that are captured by the trap, as a function of rates of descaling and injury ... 21
    Objective 7: Operational Analysis ... 21
    Objective 8: Determine the effectiveness of fyke installation for preventing winter steelhead from leaving trap. ... 22

Objective 9: Summarize trends in $P_{EE,}$ ATE, and T_i metrics between years and describe relationships between capture metrics and Merwin Dam operations 22

Objective 10: Provide policy and biological context for the 98% *ATE* performance standard 23

Results 24

Summary 24

Data Management and Processing 26

Objective 1: Determine trap effectiveness based on the *ATE* metric defined in the M&E plan for each target species, and compare estimates to the *ATE* performance standard of 98% 27

Objective 2: Determine if the fish show direct movement to the trap entrance and, if some fish do not, document the behavior patterns for those specific fish in the tailrace 32

Objective 3: Determine if fish in the tailrace spend the majority of their time in the area of the entrance of the trap and, if some fish do not, determine if those fish are holding in another location within the tailrace 40

Objective 4: Determine the total time fish are present in Merwin Dam tailrace and compare to *ATE* performance standards for safe, timely, and effective passage 45

Objective 5: Describe the movement and behavior of tagged fish that do not enter or which choose to leave the Merwin Dam tailrace and move back downstream 47

Objective 6: Determine the condition of fish that are captured by the trap, as a function of rates of descaling and injury 48

Objective 7: Operational Analysis 49

Objective 8: Determine the effectiveness of fyke installation for preventing winter steelhead from leaving the trap. 51

Objective 9: Summarize trends in *ATE*, P_{EE} and T_i metrics between years and describe relationships between capture metrics and Merwin Dam operations. 53

Objective 10: Provide policy and biological context for the 98% *ATE* performance standard. 58

Discussion 64

Conclusions 69

References 70

Appendix A: Supplementary Figures and Tables 74

List of Figures

Figure 1. Project area map, indicating location of Merwin Dam, Bridge, and Boat Launch (large map), in addition to extent of study area within the Lewis River system (top left), and the project location within the region (top right). 1

Figure 2. Merwin Dam tailrace area with locations of stationed RT antennas and pictures of select antenna orientations. All RT antennas listed in this figure are aerial, except for the Trap. Details of antennas deployed within the trap are shown on the trap schematic in Figure 3. North Shore and South Shore sites comprised two receiver stations each: one each of a short three -element and a long eight-element antenna. These were designed to cover larger areas along the full shorelines from the location where they were deployed (indicated by icon placement) all the way to the bridge. The bridge array (Bridge) comprised four amplified three-element aerial antennas hung equidistantly across the length of the bridge. Receivers North Powerhouse Wall and South Powerhouse Wall comprised one three-element antenna each, pointed towards the powerhouse and angled slightly down. 7

Figure 3. Trap schematic showing the locations of antenna arrays, with arrows showing the progressive movements fish make to reach the hopper and pictures of select antenna orientations. The approach antenna is aerial, and the entrance site comprised two underwater dipole antennas located on the left-hand side within Pool 1-1 at two depths. The hopper site also comprised two-dipole antennas, located outside the path of the ascending and descending hopper. All other trap sites comprised one dipole depth and one dipole location. After moving to the hopper, fish are crowded and then transported toward the Trap antenna at the fish facility (not shown). 8

Figure 4. Locations of detection regions for 8 radio receivers located from the bridge upstream and into the fish passage facilities at Merwin Dam. 9

Figure 5. Reception radiation patterns (tag detection areas) for short-range 3-element (6.0dBd) and long-range 8-element (11.8dBd) Yagi antennas. Numbers around the perimeter of each figure represent directional degrees. 11

Figure 6. Photo of fyke installed at the entrance to Pool 2 within the trap area. Photo was taken looking down into Pool 2 from above during dewatering. Note there is a gap above fyke, where fish could potentially exit through. Photo Credit: L. Caldwell, August 22, 2017 during trap dewatering.......... 13

Figure 7. Photos of the entrance between Pool 1 and 2 within the trap ladder where the fyke was installed. The photos show the entrance during low (< 7,000 cfs; left photo) and high (~ 8,000 cfs; right photo) discharge when the water height was below and above the fyke height, respectively. Photo Credit: Chris Karchesky. 14

Figure 8. Sequence of frequencies of unique fish detected within the Merwin RT array, presented as total number (on left axis) of all tagged fish entering the study area (top panel) See Figure 2 and Figure 3 for receiver locations within the array. Among the 106 fish that were re-captured, five fish shed their radio tags prior to being captured. Fish that shed tags were included as “re-captured” in final estimates of core passage metrics despite having no detections on the trap antenna. 25

Figure 9. Total number of noise detections for trap (red) and tailrace (blue) receivers. 26

Figure 10. The probability of recapture for individual fish plotted as a function of release date. Open circles represent individual fish. The blue line indicates the predicted probability of recapture across release date based on logistic regression. 29

Figure 11. Bootstrap simulated frequencies of *ATE* calculated from one million iterations of randomly resampling (with replacement) the sample of 139 fish that reached the Merwin Dam tailrace. Horizontal bi-directional gray arrow indicates BCA 95% CI (69.7 – 83.8%); vertical gray line indicates target *ATE* of 98%. Note that target *ATE* was reached in zero of one million simulations. Note that a small amount of random noise was added to each bootstrap to create a "smoothed bootstrap". 30

Figure 12. Simulated frequencies of *ATE* calculated from one million iterations of randomly subsampling a set of 139 fish from a simulated "urn" population of 10,000 fish that truly exhibited 98% *ATE*. Vertical gray line indicates observed ATE_{test} of 76.3%. Note that ATE_{test} reported here for 2017 was reached in zero of one million simulated subset samples of 139 fish from the parent population of 10,000. 31

Figure 13. Network diagram of fish movement within study area. Path thickness and color are scaled based on the total number of individual fish traveling the paths (e.g., thicker paths represent a higher number of fish taking the path at least one time across their detection history). Grey paths are scaled to represent the total number of fish that traveled between sites (individuals as the sample unit), and blue paths are scaled to represent the total number of times that a path was used (total number of behaviors, with movements as sample units; *non-independent*). Top figure shows all sites; bottom figure shows only trap sites and includes re-normalized transitional probabilities calculated using detections at trap sites only. 33

Figure 14. Heat map of the transition probabilities of fish moving from an origin site to all potential destination sites, where each row sums to a probability of 1.0. The black reference lines are added between the receivers Approach and Entrance to show the distinction of a fish being located within or outside of the trap. Probabilities in the upper left box represent movements that begin and end in the river or tailrace, while those in the bottom right begin and end in the trap. Probabilities in the upper right box represent paths that begin in the river or tailrace and end in the trap, and the lower left box begin in the trap and end in the river or tailrace (e.g., exiting the trap). E&E represents entrance and exit locations from the study system. For example, fish that are at the Trap always exit the system (e.g., they cannot leave), so there is a probability of 1.0 at the Trap row and E&E column). 35

Figure 15. Number of sites visited before being captured (Trapped) or not captured (Fail). 36

Figure 16. Network diagram of fish movement within the study area at Merwin Dam grouped by fish that ultimately are trapped (blue) or failed to be trapped (red) from 2017. Path thickness and color are scaled based on the total number of transitions which occurred between sites with fish as the sample unit. This figure suggests that there are essentially no significant differences in the spatial patterns between successfully and unsuccessfully passed fish in Merwin tailrace. This graphic depicts the movements of 146 fish; 106 that were successfully passed (i.e., last detected at Trap) and 40 that were unsuccessful (i.e., last detected downriver at Hatchery or Bed and Breakfast). 39

Figure 17. Median residence times by site. The top figure shows the full range of data, including outliers, while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Sample size (n) is displayed in the top of the box plots for each site. Caveat: these data are not scaled based on the detection ranges of each site. 41

Figure 18. Total time spent by all winter steelhead in each site. Caveat: these data are not scaled based on the detection ranges of each site. 42

Figure 19. Median residence times for downriver sites. The top figure shows the full range of data, including outliers, while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Sample size (n) is displayed in the top of the box plot for each site. Caveat: these data are not scaled based on the detection ranges of each site. 43

Figure 20. Total time spent by all winter steelhead in each downriver site. Caveat: these data are not scaled based on the detection ranges of each site. 44

Figure 21. Timing of PL2→ENT transitions (i.e., backwards through the fyke) during varying levels of Lewis River discharge over two study years, 2016 (top panel) and 2017 (bottom panel). Horizontal red bars denote flow less than 7,000 cfs and greater than 8,000 cfs. Red dots indicate PL2→ENT transitions. 52

Figure 22. Unit 1 discharge over time for three years of study. Solid black line indicates discharge. Red and blue dots indicate individual detections at the Approach and Entrance sites, respectively. Data for total river flow was collected from PacifiCorp. See Appendix A, Figures A-1 to A-4 for plots of all operational variables across years. 55

Figure 23. Total river flow over time for three years of study. Solid black line indicates discharge. Red and blue dots indicate individual detections at the Approach and Entrance sites, respectively. Data for total river flow was collected from USGS (USGS 2017). See Appendix A, Figures A-1 to A-4 for plots of all operational variables across years............. 56

Figure A-1. Hourly mean discharge from Merwin Dam power generation Units 1-3 during months of winter steelhead tagging across three years (2015, 2016, 2017). 74

Figure A-2. Hourly mean Lewis River discharge below Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017)... 75

Figure A-3. Hourly mean AWS entrance height (top left), AWS intake head (top right), AWS discharge (bottom left), and trap head drop measured in the trap area at Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017). 76

Figure A-4. Hourly mean discharge from five Spillways at Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017). 77

List of Tables

Table 1. 2017 values for P_{EE}, ATE_{test}, and T_i. Sample sizes (N) reflect the total number of tagged fish that were released in each study year. ii

Table 2. Antenna locations, abbreviations, descriptions and purpose for all 18 radio receiver sites used in the study. 6

Table 3. Core passage metrics for BWT in 2017. 25

Table 4. Summary of passage metrics for tagged fish approaching the tailrace of Merwin Dam during spring 2017. Total number of fish tagged (n), detected in the tailrace (M), detected in the trap (T), and successfully trapped (C), in addition to adult trap entrance efficiency (P_{EE}), collection efficiency (ATE_{test}) and trap ineffectiveness (T_i), for 2017. Fish were considered to have entered the tailrace if they were detected at or upstream of the Bridge receiver. Fish were considered to have entered the trap if they were detected at receivers Entrance, Pool 1-2, Pool 1-4, Hopper, or Trap. 27

Table 5. Passage metrics summarized by release group for 2017. See Table 4 for explanation of notation. 28

Table 6. Probabilities of transitioning further into the system for each site. P_{single} is the probability of a fish transitioning forward to the next most upstream site(s) rather than falling back to the downstream sites. P_{all} is the same probability, across all detections rather than across individual fish. *MI* is a milling index, calculated as the ratio P_{single}:P_{all}. Positive values of *MI* suggest that fish tend not to move forward from that location. Site specific P_{single} or P_{all} <0.5 are shaded blue, and *MI* >0.000 are shaded green. 38

Table 7. Achieved performance standard compliance metrics for safe, timely, and effective passage across three study years for three study species at Merwin Dam. 45

Table 8. Results from simulation models. *ATE* = adult trap efficacy; AVE = average; MED = median. 50

Table 9. Numbers of transitions between sites in 2016 and 2017 across three levels of total river flow: low (< 7,000 cfs); medium (7,000-8,000 cfs); and high (>8,000 cfs). The number of transitions are not relativized by fish (i.e., one fish can be responsible for multiple events). Observations support the hypothesis that fish were able to transition backwards in 2017 when discharge was high; due to water level exceeding fyke height. 51

Table 10. Adult passage metrics (P_{EE}, ATE and T_i) for winter steelhead across three study years. Sample sizes (N) represent the number of tagged fish that were released in each study year. 53

Table 11. Summary statistics for two variables of interest (Unit 1 discharge and total river flow) across 3 study years. 54

Table 12. Total number of detections and number of detection per hour across three study years at two detection sites (Approach and Entrance) under three Unit 1 operational scenarios: low discharge (< 1000 cfs), moderate discharge (1000-2500 cfs), and high discharge (>2500 cfs). 57

Table 13. Total number of detections and number of detection per hour across three study years at two detection sites (Approach and Entrance) under three total river flow scenarios: low discharge (< 7000 cfs), moderate discharge (7000 - 8000 cfs), and high discharge (> 8000 cfs). 57

Table 14. Survival targets for Columbia River salmonids through federally operated hydroelectric projects 59

Table 15. Summary of existing *ATE* target criteria and achieved passage rates for hydroelectric projects along the Columbia River and its major tributaries 60

Table 16. Summary of the number of dams and specific species/runs that achieved an *ATE* of 98% or greater. When multiple species' *ATE* were reported for one dam, the combined average achieved *ATE* was used to determine whether overall a dam achieved a 98% target *ATE*. 61

Table A-1. Radio tag ID, sex, length, and furthest and last locations of detection for fish not recaptured in the Merwin Dam Fish Trap in 2017 study year. 78

INTRODUCTION

Study Area

The Lewis River is a major tributary of the Columbia River, approximately 140 river km (RKM) upstream from the Pacific Ocean. The North Fork Lewis River hydroelectric project begins at Merwin Dam and Powerhouse, located at RKM 31 of the Lewis River, and extends through two other impoundments. This study is focused on the approximately 20 km stretch between the Merwin Dam and the Lewis River Bed & Breakfast in Woodland, Washington, which is the lowermost detection site in the telemetry array employed for the current study (Figure 1). Our analyses for quantifying estimates of core passage metrics focus on fish that were detected within the Merwin Dam tailrace, defined as the area upstream of the access bridge across the North Fork Lewis River, approximately 0.1 km downstream of Merwin Dam.

Figure 1. Project area map, indicating location of Merwin Dam, Bridge, and Boat Launch (large map), in addition to extent of study area within the Lewis River system (top left), and the project location within the region (top right).

Study Background

This report describes the third year (2017) of a radio telemetry study designed to evaluate adult trap efficiency (*ATE*) of upstream migrating salmonids, and to provide insights regarding behaviors of fish approaching the tailrace and trap at Merwin Dam.

In June 2008, the Federal Energy Regulatory Commission (FERC) issued new Licenses for the North Fork Lewis River Hydroelectric Projects to PacifiCorp and Cowlitz Public Utility District (PUD). Within the framework of this licensing process, the collaboratively developed Settlement Agreement (SA) outlined a Monitoring and Evaluation (M&E) Plan (PacifiCorp and Cowlitz PUD 2016) to evaluate a suite of performance measures that would ensure licensing requirements were met. Among the conditions contained in each License are requirements for reintroducing anadromous salmonids, and for providing passage that would support persistence of these reintroduced populations. The overarching goal of this comprehensive reintroduction program is to achieve genetically viable, self-sustaining, naturally reproducing, harvestable populations of anadromous salmonids upstream of Merwin Dam. The target species identified in the Settlement Agreement (SA) for reintroduction are spring Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and winter steelhead *(O. mykiss*).

The SA specifies a phased approach for reintroduction that occurs over a seventeen-year period following issuance of the new Licenses. The phased approach provides for a carefully devised plan to protect listed species and to verify effectiveness of the passage facilities as the reintroduction program proceeds. Among the tasks identified for Phase I of the reintroduction plan was establishing a downstream juvenile passage facility in the forebay of Swift No.1 Dam (completed in December 2012) and making upgrades to the existing adult fish capture facility at Merwin Dam (completed in March 2014). Subsequent phases, pending approval, would establish facilities for both upstream and downstream passage at Merwin, Yale, and Swift No.1 dams, with an ultimate goal being natural spawning and rearing of target fish species throughout the project area.

The primary focus of the M&E Plan is to provide methods for monitoring and evaluating the anadromous fish passage program. Among the objectives outlined in the M&E Plan, "Objective 10" is the evaluation of adult trap collection efficiency (*ATE*) for the new upstream passage facility at Merwin Dam. A performance standard of 98% or greater was agreed upon for *ATE* of target species. The use of radio telemetry was proposed in the M&E Plan to evaluate *ATE* because of the ability to actively monitor fish behavior in the tailrace of Merwin Dam.

A study conducted in 2005 provided initial baseline information on the performance of the historic trap in attracting and capturing four distinct salmonid stocks migrating upstream in the Lewis River: summer steelhead, coho salmon, winter steelhead, and spring Chinook salmon (R2 Resource Consultants 2007). The results of this initial study were used to help reconfigure, and develop the operational guidelines of, the new trap.

The new Merwin Fish Collection Facility is being implemented with a similarly phased approach (separate from the reintroduction program phasing), as follows:

- Phase I includes a new trap constructed in the northeastern (upstream) corner of the tailrace with an attraction flow of 400 cfs.

    - Phase I will also include a biological evaluation of the trap's performance that would help to determine whether the Phase I trap meets the program goals, or if improvements considered for Phase II would be necessary to improve the trap's performance.
- Phase II, if implemented, includes the potential to expand the attraction flow to 600 cfs.
    - Implementation of Phase II and subsequent Phases depends on the outcome of the Phase I biological evaluation.
  - Phase III would add a second trap entrance located at the western corner of the tailrace and opposite the Phase I entrance.
  - Phase IV would add a second penstock tap with 200 cfs pressure reducing valve increasing fishway flow capacity to 800 cfs.
  - If *ATE* standards are not achieved with Phases I through IV improvement, then additional fishway adjustments would be required.

Phase I construction of the Merwin Fish Collection Facility was completed in March 2014.

In 2015, PacifiCorp implemented the first year of a radio telemetry study designed to assess *ATE* and additional core passage metrics (e.g., trap entrance efficiency, tailrace residence time before passage) for the new fish trap at Merwin Dam. All three target species (winter steelhead, spring Chinook salmon, and coho salmon) were evaluated in 2015. Due to low return rates of spring Chinook and coho salmon, samples sizes of these two species were well below the target of approximately 150 fish (Table 1).

In 2016, PacifiCorp implemented a second year of study that focused efforts on resolving fish behaviors in and around the fish crowder and lift assembly, and included an ARIS sonar camera study. Low return numbers of both spring Chinook and coho salmon in 2016 prevented inclusion of these species in the study; consequently, the 2016 *ATE* study focused exclusively on winter steelhead.

Results from both 2015 and 2016 (Table 1; and see Stevens et al. 2016 & Caldwell et al. 2017) indicate a relatively high success rate for tagged fish locating the trap entrance, but lower rates of fish being successfully captured. This indicated fish were exiting the trap before they were collected. Moreover, based on both (1) initial ARIS camera data and (2) operational scenario modeling of network analysis output, it appears that (A) fish passage was constrained at the hopper and that (B) the frequency of fish crowder operation strongly affected rate of successful passage. In general, fish were found to move in and out of the trap entrance and fish crowder at will, in some instances making over 100 trips between the tailrace and the trap without being captured by the fish crowder and lift assembly. One outcome that was informed by these findings was the installation, in November 2016, of a single V-style fyke to prevent fish from returning to the tailrace once they have entered the trap. In addition, increased frequency of hopper operation was implemented to improve *ATE* in 2017.

Study Objectives

This study was designed to address the requirements of the Lewis River Aquatic M&E Plan (PacifiCorp and Cowlitz PUD 2016), which describes the need to evaluate the effectiveness of the Merwin Dam Adult Fish Collection Facility.

The primary goal of this third year (2017) of the Merwin *ATE* study was to continue to evaluate the performance of the Phase I trap location, design, and adequacy of attraction flow using radio telemetry. In particular, this study was designed to: a) assess the effectiveness of a fyke installed to prevent upstream migrants from returning to the tailrace once they have entered the ladder (trap) entrance; and b) to begin to evaluate how dam operations influence regulatory metrics across years. The focus of the 2017 effort was on winter steelhead only because low numbers of spring Chinook returning to the Lewis River in 2017 necessitated all of the adult Chinook captured to be allocated to brood stock collection and/or transported upstream. Additionally, evaluation of coho salmon passage performance and behavior was added as a separate study late in the 2017 season. By request of PacifiCorp, data on coho salmon will be presented in a stand-alone report.

The specific objectives for the 2017 evaluation included the following:

1) Determine *ATE* as defined in the M&E plan for winter steelhead; compare estimates to the performance standard of 98%; and, compare trap attractiveness metric P_{EE} across study years.
2) Determine if winter steelhead show directed movement toward the trap entrance; if some fish do not, document the behavior patterns for those specific fish in the tailrace.
3) Determine if winter steelhead in the tailrace spend the majority of their time in the area of the entrance of the trap and, if some fish do not, determine if those fish are holding or milling in another location within the tailrace.
4) Determine the median and total time winter steelhead are present in Merwin Dam tailrace and compare to *ATE* performance standards for safe, timely, and effective passage.
5) Describe the movement and behavior of tagged winter steelhead that do not enter or which choose to leave the Merwin Dam tailrace and move back downstream.
6) Determine the condition of winter steelhead that are captured by the trap, as a function of rates of descaling and injury.
7) Continue to evaluate whether including a second entrance on the north side of Merwin Dam would improve collection efficiency.
8) Determine the effectiveness of installation of a fyke for preventing winter steelhead from leaving trap area.
9) Summarize capture efficiency trends between years and describe relationships between various capture metrics (i.e. *ATE*, P_{EE}, T_i) and Merwin Dam operations.
10) Provide regulatory and biological context for the 98% *ATE* regulatory requirement.

METHODS

Fish Collecting and Tagging

PacifiCorp staff were responsible for fish collecting and tagging efforts. Late-run winter steelhead were tagged from mid-February through early-May 2017. To maximize the likelihood that these fish were volitionally targeting upstream spawning habitat, fish were captured at the Merwin Dam Adult Fish Collection Facility. Consequently, all fish included in the study had previously navigated and were successfully captured by the trap (i.e., were trap non-naïve). It is worth noting here that one explicit assumption of this study and subsequent analyses is that recapture rates of non-naïve fish accurately and appropriately reflect, and effectively equal, rates of initial capture among naïve fish.

A maximum of 30 fish were tagged and released on any given day, with a total target of 150 individuals. To provide adequate temporal coverage of the run and capture underlying variability in passage rates within the run, captures were temporally protracted over nearly three months. Fish were tagged with Lotek MCFT-3A coded radio transmitter tags (166.660 MHz) that measured 16 mm in diameter and 46 mm in length and had a mass of 16 g, giving them a weight of 157 millinewtons in air but only 66 millinewtons in water. MCFT-3A tags were programmed with a burst rate of 5 s, staggered by 0.5 s intervals within release groups (i.e., each group contained fish implanted with tags bursting at 4.5 s, 5 s, and 5.5 s intervals). When combined with the modest number of fish in each release group, this reduced the frequency of tag collision.

Latex tubing was used to reduce tag regurgitation for the gastric implants. All fish were allowed to recover following the tagging procedure and then released via a transport truck directly into the river approximately 0.6 km downstream from the trap entrance at the Merwin boat launch. Due to the limited number of tag frequencies available for transmitters, transmission frequency was changed each year to reduce the likelihood of picking up similarly numbered transmitters from previous years (e.g., from shed but still active tags or fish morts containing active tags).

Spatial design

During early February 2017, 18 detection antennas (6 underwater; 12 aerial) were deployed in combinations with receivers (19 SRX800D and 1 Lotek SRX800MD; Table 2; Figure 2, Figure 3). Receivers each had the ability to store approximately 1 million records. Site locations in 2017 were identical to those used in 2016 (Table 2), except for moving a receiver previously located in the Gallery behind the powerhouse to Pool 3 of the trap entrance.

Table 2. Antenna locations, abbreviations, descriptions and purpose for all 18 radio receiver sites used in the study.

Site Type	Site Code	Site name	Antenna description/location	Purpose of site	RKM
Trap	TRP	Collection Pool	Underwater antenna located a few feet from the hopper transfer pipe outflow	Detects fish first entering the collection pool	171.3
"	HOP	Hopper	Two combined underwater antennas located on the east and west sides of the collection hopper	Detects fish inside the fish hopper and the last few feet of the crowder section	171.3
"	PL4	Pool 4	Underwater antenna located at the entrance of Pool 4 downstream from the fish crowder	Detects fish before crowder below the collection hopper	171.3
"	PL3	Pool 3	Underwater antenna located on the South Wall of Pool 3 of the Merwin Trap	Added in 2017 to improve detection in the Merwin adult fish trap between PL2 and PL4	171.3
"	PL2	Pool 2	Underwater antenna located 2 feet from the Pool 2 entrance on the northwest wall of Pool 2	Assesses fish passage and residence time near the Fyke weir	171.3
"	ENT	Entrance	Underwater antenna at downstream end (entrance) of Trap.	Determines when fish are inside the Trap	171.3
Tailrace	APR	Approach	3 element antenna pointed vertically at Trap entrance	Monitors fish as they approach the Merwin Trap	171.3
"	NSS, NSL	North Shore Short & Long	Two radio telemetry sites, one long range 8-element antenna (NSL) and one short range 3 element antenna (NSS)	Monitors the North shore of the tailrace	171.3
"	SSS SSL	South Shore Short & Long	Two radio telemetry sites, one long range 8-element antenna (SSL) and one short range 3-element antenna (SSS)	Monitors the south shore of the tailrace to the APR site	171.2
"	PWN	Powerhouse North	3 element antenna pointed north parallel to the front of the tailrace deck	Monitors fish in front of the northern half of the Powerhouse	171.3
"	PWS	Powerhouse South	3-element antenna pointed south along the front of the tailrace deck	Monitors fish in front of the southern half of the Powerhouse	171.3
Gate	BRG	Bridge	Four 3-element antennas located equidistantly along the downstream section of the bridge. The north 2 antennas were amplified producing a uniform detection zone.	Indicates when upstream adult steelhead first enter the tailrace and are attempting to migrate above Merwin Dam.	171.1
Down-stream	BLU	Boat Launch Upstream	6-element antenna downstream the BRG site	Determines direction of fish migration relative to the Merwin Dam boat launch/ fish release site	170.8
"	BLD	Boat Launch Downstream	6-element antenna just upstream of the release site	Determines direction of fish migration relative to the Merwin Dam release site and is the of the first upstream site above the release site	170.3
"	LRH	Lewis River Hatchery	Monitors the Lewis River at the Cedar Creek confluence	Determines direction of fish migration relative to the Merwin Dam release site	165.2
"	BBL	Bed Breakfast Lewis River	Monitors the Lewis River in Woodland, Washington	Confirms fish in study area	152.0

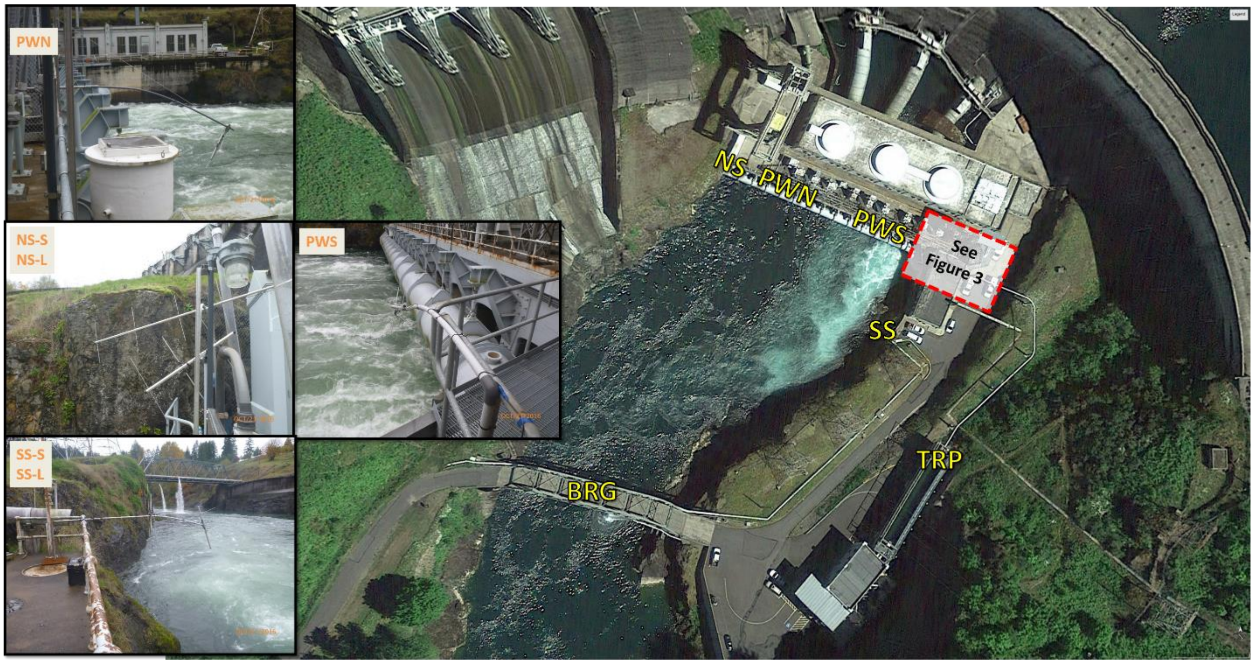


Figure 2. Merwin Dam tailrace area with locations of stationed RT antennas and pictures of select antenna orientations. All RT antennas listed in this figure are aerial, except for the Trap. Details of antennas deployed within the trap are shown on the trap schematic in Figure 3. North Shore and South Shore sites comprised two receiver stations each: one each of a short three -element and a long eight-element antenna. These were designed to cover larger areas along the full shorelines from the location where they were deployed (indicated by icon placement) all the way to the bridge. The bridge array (Bridge) comprised four amplified three-element aerial antennas hung equidistantly across the length of the bridge. Receivers North Powerhouse Wall and South Powerhouse Wall comprised one three-element antenna each, pointed towards the powerhouse and angled slightly down.

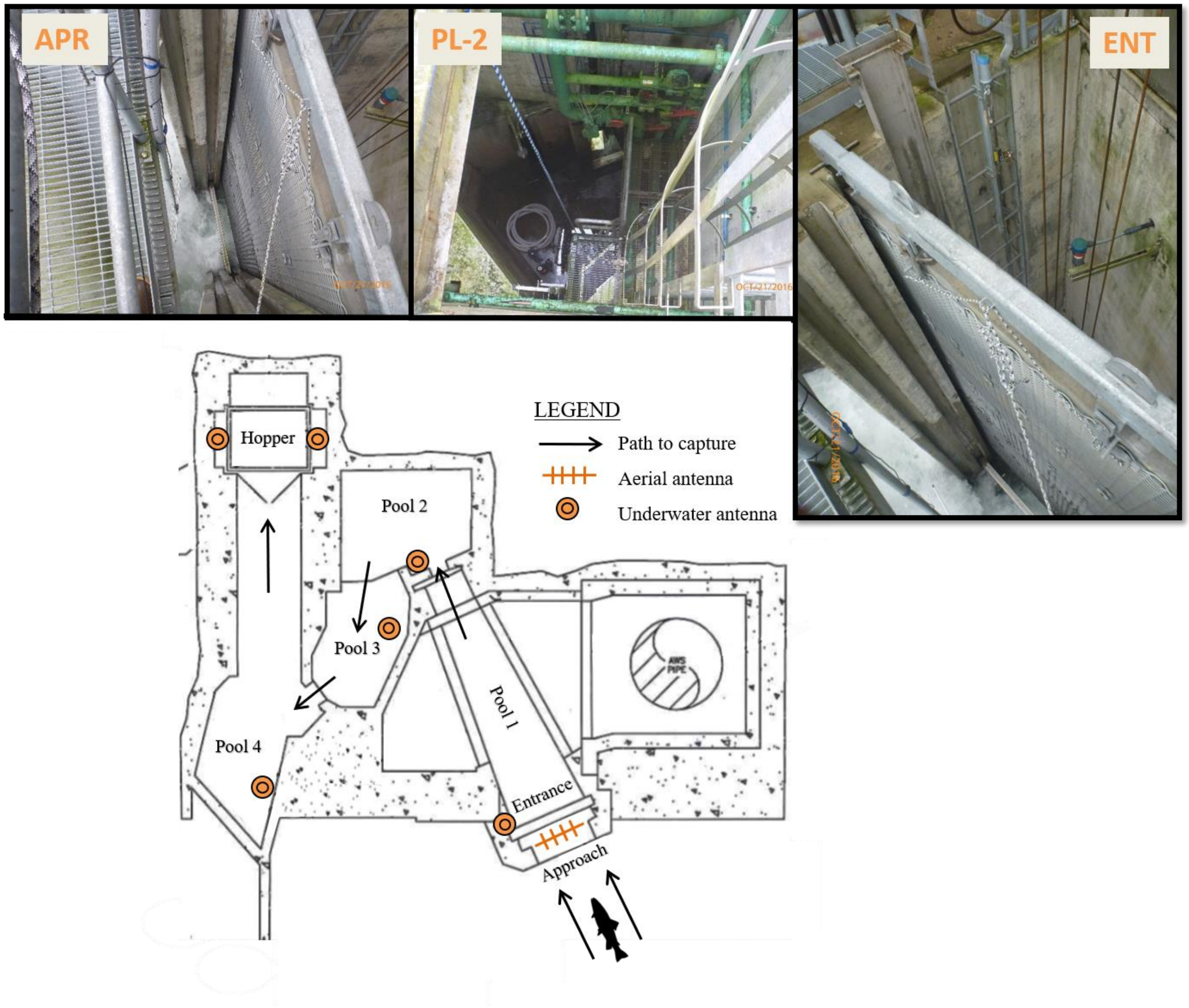


Figure 3. Trap schematic showing the locations of antenna arrays, with arrows showing the progressive movements fish make to reach the hopper and pictures of select antenna orientations. The approach antenna is aerial, and the entrance site comprised two underwater dipole antennas located on the left-hand side within Pool 1-1 at two depths. The hopper site also comprised two-dipole antennas, located outside the path of the ascending and descending hopper. All other trap sites comprised one dipole depth and one dipole location. After moving to the hopper, fish are crowded and then transported toward the Trap antenna at the fish facility (not shown).

The shapes of tag detection regions for each radio receiver were designed for the following endpoints:

(1) To separately and collectively locate tagged fish throughout the study area, as they relate to the approach, entrance, and movements through the Merwin Dam fish passage facilities, and
(2) To identify when fish entered or left the study area (generalized tailrace detection regions presented in Figure 4).

Individual shapes of radio tag detection ranges were designed to provide continuous coverage along both banks of the river, with higher spatial resolution for fish within the passage facilities. Location and orientation of each radio antenna was optimized to maximize detection consistent with site-specific needs and proximate river channel contours, i.e., prioritizing either site sensitivity or specificity. For example, to develop a highly sensitive curtain of detection demarking the tailrace, eight overlapping detection regions were located from the bridge upstream to the dam with either short or long detection ranges, as determined by individual site needs. Additional details concerning the location and purpose of all receiver sites, along with descriptions and locations of all antennas used in the project are provided in Table 2 above.

Figure 4. Locations of detection regions for 8 radio receivers located from the bridge upstream and into the fish passage facilities at Merwin Dam.

Antenna types and installation

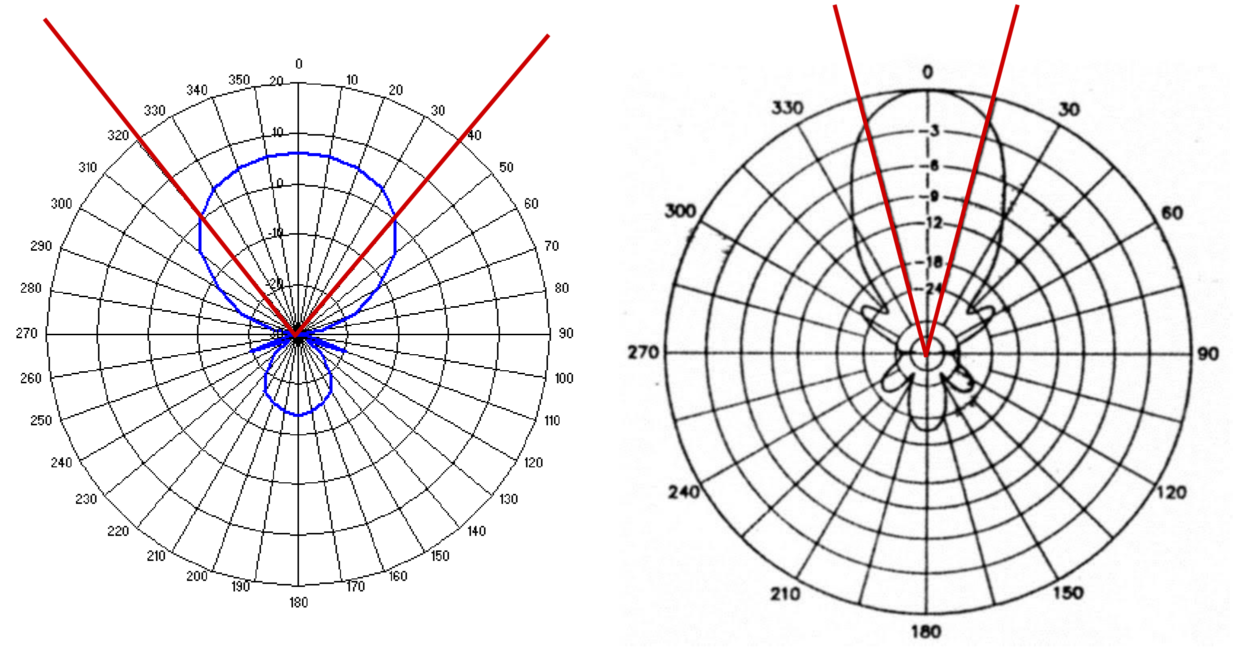
Four types of antennas were used during the 2017 Merwin *ATE* study: 3-, 6-, and 8-element aerial antennas, and underwater antennas. We describe the use and locations of these four antenna types below, with additional details provided in Table 2 above. *Three-element Yagi antennas* – Three-element antennas have a 6 dBd gain increase, the smallest dBd gain of the three Yagi-UDA© (Yagi) antennas used in the Merwin ATE. Three-element Yagi antennas were oriented in two ways, vertically and horizontally relative to the surface of the river. At the BRG site, four vertically mounted 3-element antennas were combined and amplified to detect tagged fish in the tailrace directly beneath the Merwin access bridge. At the APR site, a single vertically mounted 3-element antenna was pointed at the transition area to accurately detect fish between the adult trap and the tailrace. Three-element antennas at the PWN, PWS, SSS, and NSS sites were mounted horizontally to the tailrace.

Six-element Yagi antennas - Six-element antennas have an intermediate (7 dBd) gain increase, and were used for detecting tagged fish in the mainstem of the Lewis River, specifically at the BLU, BLD, LFH and BBL gate sites. Six-element antennas were successfully used for detecting tagged fish across the entire river channel, thus they were used as gate sites.

Eight-element Yagi antennas – Eight-element antennas have an 11.8 dBd gain increase, the largest increase of the Yagi antennas used in the Merwin ATE. These antennas were used at the NSL and SSL sites, and detected tagged fish within a narrower range than the 3- and 6-element antennas.

Underwater antennas - Underwater antennas were used to detect tagged fish in very small areas where high resolution tracking is needed, such as areas within the Merwin Dam fish passage facilities. While detection probability was important at all sites, for these underwater antennas the explicit array design tradeoff was one that valued specificity (confidence in location) over sensitivity (ability to detect every fish). The typical range of these antennas was 10-20 feet in diameter. Receiver gain settings were typically low for these sites due to the proximity of fish to the receivers in confined areas. Underwater antennas were used exclusively in the adult trap and the collection pool sites. At sites PL2, PL3, and PL4, underwater antennas were contained within ¾ inch electrical conduit tubing attached to the fishway with Hilti® concrete bolts. Underwater antenna cables at the ENT, HOP, and TRP sites were weighted down with lead weights.

The type of aerial antenna used at each site was selected based on the strengths and weaknesses of each antenna type. As discussed above, the 3-element antenna has a shorter but very wide (~80°) tag detection area, while the 8-element antenna has a longer but much narrower (~30°) tag detection area (Figure 5), and the 6-element antenna provides detection areas of intermediate distance and width. Collectively, the use of these three different antennas allowed us to optimize fish detection in different parts of the study area.



3-element antenna

8-element antenna

Figure 5. Reception radiation patterns (tag detection areas) for short-range 3-element (6.0dBd) and long-range 8-element (11.8dBd) Yagi antennas. Numbers around the perimeter of each figure represent directional degrees.

Fish detection ranges varied at receiver sites using the three different antennas depending on mounting orientation and gain settings. Individual antenna orientation and gain settings were optimized for either specificity (trap sites) or sensitivity (most other sites) in detecting tagged fish. Gain settings were adjusted based on empirical results of in-river validation of test radio tags at depths of 5 to 10 feet in the study area.

Two main factors can influence tag detections, tag depth and tag-antenna orientation, with tag depth being the most important factor influencing detections. A radio tag signal loses energy as it travels through water. Radio tags that are deeper in the water column require a longer signal path to reach aerial antennas (and shallow underwater antennas). As a result, the signal from these deeper tags is weaker when it reaches the receiver compared to tags that are shallower in the column. In addition to tag depth, the relative radial/axial orientation between tag and the 6-inch antenna influences signal strength.

Detection capabilities

Detection ranges were evaluated indirectly during setup optimization and are reported qualitatively, rather than as detection zones with defined areas. After receivers were constructed and antennas were oriented, detection ranges were evaluated for all receivers within the Merwin Dam tailrace. Range testing followed this general protocol:

- A radio tag attached by zip ties and electrical tape to a rope weighted with a cannonball was lowered into the water column from a boat.
- The boat was driven or drifted along a path or paths selected to evaluate detection range for each receiver in the tailrace.
- Receivers were simultaneously monitored for detection of the tag during deployment from the boat.
- Position of the boat and tag was relayed by handheld radio to the person monitoring receivers.
- The tag was drifted at approximately 7 ft. depth for all antenna sites, and at 7 ft. and 25 ft. depth for the Bridge site.
- If detection ranges did not match expectations associated with array design, adjustments were made to receivers.
- Protocol was repeated until detection ranges were as intended (see Figure 4 for intended detection ranges).

Following initial set-up and range testing, routine inspection of detection data was also made throughout the study to verify detection ranges remained as intended.

Metal fyke installation & hopper operation

In an effort to prevent fish from leaving the fish trap after entrance into the trapping area thereby potentially increasing ATE, during November of 2016, a single V-Style fyke was installed between pools 1 & 2 within the trap system (Figure 6). The single V-Style fyke was constructed of 304 SS 1” bars on 1” spacing with a transitional gap spacing of approximately 6”.

Figure 6. Photo of fyke installed at the entrance to Pool 2 within the trap area. Photo was taken looking down into Pool 2 from above during dewatering. Note there is a gap above fyke, where fish could potentially exit through. Photo Credit: L. Caldwell, August 22, 2017 during trap dewatering.

The fyke installed in the trap was initially designed for placement between Pools 2 and 3, but was later moved to between Pools 1 and 2 so it could be observed during testing. Fyke height is thus not matched to the height of the opening between Pools 1 and 2, and the fyke does not extend to the top of the entrance of Pool 2. As a result, during periods of high discharge (~ >7.000 cfs) within the trap, water levels in the trap system exceeded the fyke height for a portion of the 2017 study (see Figure 7). Fish may have been able to swim over the fyke at high discharge and therefore, the fyke was considered not to be fully operational during these times. (*The potential for the fyke being ineffective during high discharge events is addressed in Objective 8, below*).

Figure 7. Photos of the entrance between Pool 1 and 2 within the trap ladder where the fyke was installed. The photos show the entrance during low (< 7,000 cfs; left photo) and high (~ 8,000 cfs; right photo) discharge when the water height was below and above the fyke height, respectively. Photo Credit: Chris Karchesky.

Another change implemented in 2017 to increase *ATE* was an increase in hopper operation frequency to once every 30 minutes. This interval was chosen based on balancing operational constraints (i.e., increased operation of hopper results in increased maintenance and repairs related to the hopper) with biological benefits from increasing fish ATE.

Data Management and Processing

Database Construction

All weekly data downloads were compiled into a single database in order to calculate various metrics associated with the study objectives and operational recommendations. Each week, every site was visited by one or two technicians who checked the sites for malfunctions or clock drift and downloaded receivers. Although receivers were equipped with GPS time correction capabilities, prior to inclusion into the database each file was double-checked and corrected (if needed) for clock drift away from the synced GMT time.

Raw detection records were processed and compiled into a single MS Access database. During this process, detections determined to be noise or from a tag code not included in our study were filtered out. Although noise detections are inevitable, receivers were calibrated throughout the season to limit the amount of noise logged by receivers while optimizing tag detectability. After downloads were combined, noise codes were counted, visualized, and stored in separate tables to provide a coarse estimate of detection efficiency across the study. It should be noted that receivers may also log anomalous tag codes due to signal collisions from multiple tags pinging on the same site simultaneously (126 such cases occurred during 2016), tags from past tracking efforts that remain within the system (mitigated for by tagging at different frequencies during 2015 and 2016), or environmental noise with a frequency near 167 MHz (e.g., dam operations, power transformers, and motor noise from boats or land vehicles).

QA Process

Detection data were subjected to an automated filtration process, developed in 2015 (Stevens et al. 2015), with following QA goals:

1) Remove consecutive detections at a single site, with the exception of the first and last detection per visit.
2) Calculate the total number of exit events that an individual made from the trap or from the tailrace regions to categorize fish movements in and around the adult trap and bridge.

To achieve these QA goals, an automated data filter was applied, which included the following steps:

- If consecutive detections occurred at the same site and there was a *minimum* of four (4) detections while at that site (i.e., *approximately* 20 s), the first detection was considered the first (“F”) time and the final detection was considered the last (“L”) time at that site. There were three (3) exceptions to this rule, as follows:
    - At the Bridge receiver, only two consecutive detections were needed, as that site had reduced detection sensitivity compared to other sites due to its unique, suspended arrangement.
    - At the pre-sort pond receiver (Trap), only one detection was needed to be considered a fish that had been captured successfully, as this location was physically removed from all other sites and it was not possible for a fish to return to the tailrace.

    - At the trap Entrance receiver, four detections were needed *as well as* a minimum signal strength of 160 (Lotek proprietary units) to consider the fish present. The reasoning for this requirement was because this receiver would often pick up fish at lower signal strength while these fish were in the tailrace; requiring a strong signal, although conservative from the perspective of sensitivity, provides greater confidence that a fish had passed directly adjacent to the antenna (i.e., this approach optimizes specificity of detections at this site).

- When fish moved among sites, we assumed that the time the fish was first detected at the second location was the start time at the new site, and the previous detection was the last time the fish had been at that site.
- If there were two consecutive detections at the same site but there had been more than a 30-minute difference in the time stamps, this was considered a separate event at the same site, resulting in two consecutive start times at the same location, which results in a single loop in the network analysis at the Entrance receiver (see Figure 13).
- Fish were assumed to exit the trap when they moved from any of the trap sites inside the fish ladder (i.e., Entrance, Pool 1-2, Pool 1-4, Hopper) to any of the sites outside the trap (i.e., Approach, Bed and Breakfast, Boat Ramp, Holding Pool, Bridge, Gallery, HRH, North Shore, North Powerhouse Wall, South Powerhouse Wall, South Shore). Exit timing was assumed to occur sometime between the "trap" and "non-trap" detections (e.g., most often the gap between receivers Entrance and Approach), but were coded based on the timing of the first detection outside of the trap.
- If fish were detected moving directly from the inside of the trap entrance to immediately outside the trap entrance receivers (i.e., Entrance→Approach) and the signal strength was stronger at the Approach receiver, then fish were assumed to have left the trap and passed directly under the Approach receiver on their way out of the trap.
    - If, however, the signal strength was weaker at Approach than the previous Entrance detection, we assumed the fish had never entered the trap, but was instead detected outside of the trap with a weak first Entrance detection.

Analytical Approach

Objective 1: Determine trap effectiveness based on the ATE metric defined in the M&E plan for winter steelhead, and compare estimates to the ATE performance standard of 98%

The Lewis River Settlement Agreement defines adult trap efficiency (ATE) for a given species as the percentage of adults actively attempting to migrate above Merwin Dam that are caught in the Merwin fish trap. The Lewis River Settlement Agreement and the Aquatics Monitoring and Evaluation Plan (2016), sets a target (ATE_{target}) of 98% for adult fish migrating upstream towards spawning habitat above Merwin Dam. Estimated observations of ATE are essentially data points that are used to test whether overall ATE for local populations meets ATE_{target}. Consequently, these estimates of ATE are referred to as ATE_{test}, one of two metrics (the other being P_{EE}) that have been developed in order to evaluate trap efficacy. ATE_{test} is an estimate of overall population level ATE, and is calculated as the proportion of fish entering the Merwin Dam tailrace (M) that were ultimately captured at the trap (C).

ATE_{test} is calculated as follows:

$$ATE_{test} = \frac{C}{M}, \qquad (Equation\ 1)$$

where:

M is the number of actively migrating fish that enter the Merwin Dam tailrace, determined by unique detections from the tailrace detection sites at or above the access bridge (0.1 km downstream of Merwin Dam) which is downstream of the entrance of the fish trap, and

C is the number of fish successfully captured (i.e., successfully passing through the fish crowder/conveyance system and entering the presort pond), determined by unique detections from the trap and any manually collected tags from the collection facility or during fish sorting minus dead or mortally wounded fish or those collected after a specified time period.

An additional metric, trap entrance efficiency (P_{EE}), quantifies the proportion of fish entering Merwin Dam tailrace (M) that successfully pass the trap entrance (T), calculated as follows:

$$P_{EE} = \frac{T}{M}, \qquad (Equation\ 2)$$

where:

T is the number of fish that enter the trap, determined by detections at any of the trap entrance, pool, or hopper receivers, and

M is the same as defined for Equation 1, above.

A large relative difference between P_{EE} and ATE_{test} would thus reveal ineffective trapping and suggest an operational or infrastructural “weak link” in upstream passage at the trapping device. Here, we define an additional metric (T_i) to quantify trap ineffectiveness. T_i is calculated as the relative proportion of fish that were attracted to the trap entrance, but were not ultimately trapped:

$$T_i = \frac{T-C}{T}\,. \qquad (\textit{Equation 3})$$

Greater T_i values equate to lower trap effectiveness.

In order to statistically evaluate whether the observed collection efficiency (ATE_{test}) for each species differed from the ATE_{target} of 98%, we undertook two exercises involving randomization and bootstrapping (Manly 2011; Manly 2007). First, using R statistical software (R Core Team 2017) we calculated a 95% confidence interval (95% CI) for the 2017 ATE_{test}, using iterated random subsampling with replacement (bootstrapping). Our method focused on calculation of the bias-corrected and accelerated 95% confidence interval (BCA 95% CI) (Manly 2007), and included resampling with replacement (i.e., bootstrapping) the set of 139 steelhead that entered the Merwin Dam tailrace (M), 106 of which were captured at the trap and were successfully captured (C). Manly (2007) recommends ≥5,000 randomizations for bootstrapping exercises to estimate a CI; we conducted 1,000,000 randomizations. Simulated ATE_{test} values (i.e., ATE_{sim}) were generated for each iteration, and from this set of 1,000,000 simulations, we then calculated BCA 95% CI, and generated a histogram of simulated frequencies. To estimate the likelihood that the sample of tagged fish actually reached the target ATE, we then compared this BCA 95% CI with the target value of 98%, and also calculated the frequency of occurrence of the 98% target among these simulations.

Next, we modeled a population of fish that truly exhibited 98% passage (the “urn”), and randomly subsampled groups of 139 fish from this urn to generate iterative simulations of ATE (ATE_{sim}). For each member of this pool of randomized subsamples, we then calculated the difference between ATE_{sim} and ATE_{target}, and generated a frequency distribution for these simulated differences. From this frequency distribution, we then estimated the likelihood that a group of 139 test fish exhibiting the ATE_{test} observed in 2017 and reported here could have come from a parent population that actually exhibited an ATE of 98%. This urn simulation can be summarized as follows:

1) Construct a simulated dataset such as would be observed under target conditions of comparison (i.e., 98% passage efficiency), for a population of 10,000 fish[2].
2) Randomly subsample 139 test fish (i.e., to match M, the number of tagged fish that entered the Merwin Dam tailrace during the 2017 study) from this overall population of 10,000 fish exhibiting 98% successful passage.
3) Determine passage efficiency (ATE_{sim}) for the subsample iteration.
4) Repeat one million iterations of steps 2 and 3.
5) Calculate the frequency of occurrence for each possible outcome.

---

[2] *NB: drawing from an urn population of 10,000 fish ensures two decimal precision (i.e., 9,800/10,000 = 98.00%) associated with modeled passage success among the simulated urn population; drawing from an urn population of 1,000 fish would generate one decimal precision (i.e., 980/1,000 = 98.0%), and drawing from an urn population of 100 fish would generate zero decimal precision (i.e., 98/100 = 98%).*

6) Determine the frequency of the observed ATE_{test} within the pool of simulated ATE_{sim} values.

Because fish appeared to enter the trap at higher rates than at which they ultimately were captured, we report on the proportion of entry efficiency at the trap (P_{EE}), in addition to ATE_{test}. P_{EE} was calculated as described above (Equation 2).

To determine if *ATE* changes over time, generalized linear models (GLMs) were used to model individual fish passage success with release date. The GLM used logistical regression with a binomial response variable, passage success, being either zero (not collected) or one (collected).

Objective 2: Determine if winter steelhead show direct movement to the trap entrance and, if some fish do not, document the behavior patterns for those specific fish in the tailrace

Network (graph) theory was applied to conceptualize, visualize and analyze fish movements within the tailrace (Wilson 1996). Network theory provides a simple, intuitive method for conceptualizing, visualizing, and analyzing fish movement data—particularly as they relate to fish passage issues. All detections zones were represented as nodes (i.e., vertices) and the movements of individual fish between detection zones were represented as directed connections (i.e., edges) between nodes. After being subjected to the QA process described above (*QA Process*), movement patterns were then analyzed both visually and quantitatively.

The raw transition data were modified in several ways, based on dividing the study area into three distinct zones: downstream, tailrace, and trap. The Bridge receiver separated downstream nodes from tailrace nodes, and the Entrance receiver separated tailrace nodes from trap nodes. Using these logical labels, the transition matrix created from the raw transition data was adjusted in the following ways:

- Downstream transitions were linearized.
    - (Bed and Breakfast→Holding Pool) became (Bed and Breakfast→Hatchery; Hatchery→Boat Ramp; Boat Ramp→Holding Pool).
- Transitions from downstream to tailrace had their downstream section linearized.
    - (Boat Ramp→South Powerhouse Wall) became (Boat Ramp→Holding Pool; Holding Pool→Bridge; Bridge→South Powerhouse Wall), and likewise for the reverse.
- Transitions from the tailrace to the trap were forced to go through receiver Entrance.
    - (North Shore→Pool 1-4) became (North Shore→Entrance; Entrance→Pool 1-4), and likewise for the reverse.
- Transitions from downstream to trap were not altered since it is not possible to infer how the fish went through the trap zone. Linearizing the path to receiver Bridge, and then forcing them to enter the post through receiver Entrance would create multiple false transitions since we do not know what happened in the trap.

Following construction of the transition matrices, network diagrams representing the study area were generated for visual analysis. In general, thickness and color of edges representing fish movements are weighted such that thicker, darker lines indicate a larger weight. However, edges are not weighted the same way in all diagrams, and the specific weighting scheme used in each network diagram is described and reported in each figure caption.

To analyze fish movement behavior, we discuss and compare several metrics including the following:

- overall passage rates (final fate);
- individual (P_{single}) and instantaneous (P_{all}) transition rates (P_{single} is the probability of a fish transitioning forward to the next most upstream site(s) rather than falling back to the downstream sites. P_{all} is the same probability, across all detections rather than across individual fish);
- the difference between individual and instantaneous transition rates, which we define here as the milling index, *MI*

$$MI = P_{all} - P_{single}\ ; \qquad (Equation\ 4)$$

- the most probable paths for fish that were ultimately trapped or not trapped using a heat map; and
- the number of sites visited by each fish before exiting the system.

Objective 3: Determine if winter steelhead in the tailrace spend the majority of their time in the area of the entrance of the trap and, if some fish do not, determine if those fish are holding in another location within the tailrace

The amount of time spent at a site before transitioning to a new site (i.e., residence time) was recorded for each site to determine both the amount of total time spent in the site and the median residence time. We constructed box and whisker plots to both visually and statistically analyze:

1) Median residence times per site; and

2) Total time spent by winter steelhead per site for tailrace and downriver sites.

Precise detection ranges were not available for each receiver, and thus it was not possible to normalize the residence times based on the physical setup of each site. The areas of detection for tailrace sites were tuned to effectively blanket the study area while avoiding excessive noise from the powerhouse and other dam infrastructure and operations. The downstream sites (i.e., below the Bridge receiver) were constructed so that their relative areas of detection are identical. The goal of both sites was to detect against the north and south walls approximately two-thirds of the way from the bridge upstream of the total length of the distance between the powerhouse (and transformer deck) and the bridge.

Objective 4: Determine the total time winter steelhead are present in Merwin Dam tailrace and compare to ATE performance standards for safe, timely, and effective passage

We determined the amount of time that fish are present in the tailrace to assess attraction rates and the potential for fish delay. The median and range of total time spent in the tailrace was summarized for comparison with the *ATE* standard of median tailrace time less than or equal to 24 hours with no more than 5% of fish taking longer than 168 hours to pass. We estimated the total time spent in any tailrace zone to account for fish milling behavior, and to remain comparable with the 2015 and 2016 reports (Stevens et al. 2015; Caldwell et al. 2016).

Objective 5: Describe the movement and behavior of tagged winter steelhead that do not enter or which choose to leave the Merwin Dam tailrace and move back downstream

To describe and compare the movement of fish entering and leaving the trap, we first identified fish that navigated to just inside the entrance of the fish trap (Entrance receiver), but then transitioned back into the tailrace. We then compared the movement and behavior of these fish with the movement and behavior of fish that entered the trap and did not backtrack.

Objective 6: Determine the condition of winter steelhead that are captured by the trap, as a function of rates of descaling and injury

PacifiCorp staff handled trapping and tagging of study fish, and they also conducted fish health assessments prior to tagging. Fish considered in poor condition were disqualified as candidates for tagging. This ensured that the condition of tagged fish did not bias the analyses or their interpretation. A qualitative discussion of fish condition is included in the results for reference.

Objective 7: Operational Analysis

By normalizing the transition rates for each site, we created an Individual Based Model (IBM) to simulate fish passage through the study area. We modeled fish movement as a Markov-Chain (e.g., see Brémaud 2013 and Johnson 2004), meaning each transition was determined solely from the current location (i.e., memoryless transitions; no momentum associated with previous direction and magnitude of vector describing the changes between data states). By releasing fish into the simulation model according to the empirical distributions found from the telemetry data, we created a system that generates results that are literally analogous to (i.e., modeled from) the empirical data, rather than assuming a distribution for those empirical observations and modeling from that. We used this simulation model to investigate how alterations to the system affect the number of fish successfully trapped, and how many sites they visited before being trapped. We tested the following scenarios, each with model runs of 10,000 individuals:

- Control (i.e., model validation): A version of the simulation using the empirical transition rates taken from the data. This model was used to compare against, and to test the Markovian assumption.
- Model 1: Add a transition from North Shore to Entrance, drawing on the transition probabilities of fish passing at the current trap (e.g., “what if a new trap was installed on the north shore that had equivalent efficiency as the trap on the south shore?”).
- Model 2: Reduce transition rates travelling backwards from PL4 by 50% (fyke potential) in the system to model the effect of an additional fyke installation between PL4 and HOP.
- Model 3: Reduce transition rates travelling backwards from PL4 by 90% (fyke potential) in the system to model the effect of an additional fyke installation between PL4 and HOP.

Objective 8: Determine the effectiveness of fyke installation for preventing winter steelhead from leaving trap.

To test the effectiveness of the fyke for reducing the number of exit events from the trap ladder, we contrasted the ability of fish to transition from Pool 2 to Entrance (PL2→ENT) and Pool 2 to Approach (PL2→APR) sites during the following three Merwin Dam discharge (i.e., total river flow) scenarios:

i) fyke considered fully operational (< 7,000 cfs);
ii) uncertain whether fyke was completely operational (7,000-8,000 cfs); and
iii) certain the water level was above fyke height and fyke was not completely operational (>8,000 cfs).

Transitions from Pool 2 to the Approach site were examined to account for missed detections on the Entrance receiver due to the stringent data filtration applied at to detections on the Entrance receiver, which would miss detections of fish exiting quickly. These three flow scenarios for 2017 were further compared to fish transitions from Pool 2 to Entrance and Approach sites in 2016 when the fyke was not installed.

Objective 9: Summarize trends in P_{EE}, ATE, and T_i metrics between years and describe relationships between capture metrics and Merwin Dam operations

P_{EE}, *ATE*, and T_i metrics vary between study years and could be associated with inter-annual differences in physical conditions (temperature, discharge), operations at Merwin Dam (spillway and turbine operations), or the timing of tagging over a distribution of migrating fish (i.e., fish early in a run may behave differently than fish later in a run). Furthermore, regulatory requirements for power generation and dam operations may, at times, conflict with regulatory requirements for passage efficiency. For example, during spillway operations, flow in the tailrace is extremely turbulent, which may impede, if not prevent altogether, a fish's ability to enter the trap. Thus, estimates of passage efficiency metrics outside of instances when other regulatory flow and energy requirements are being met may more accurately describe trap efficiency under conditions managers can control.

First, passage metrics (P_{EE}, *ATE*, T_i) for each study year are contrasted to describe and visualize trends in passage metrics among and within years of study.

Next, Merwin Operational data are summarized across study years to visually inspect for and identify operational variables which may influence metrics between and within study years.

Based on discussions with PacifiCorp (Chris Karchesky), two operational variables were deemed to be of specific interest due to a perceived effect on trap entrance efficiency (P_{EE}): power generation Unit 1 operational status and total river flow (overall Merwin Dam discharge). Unit 1 discharges into the tailrace directly adjacent to the trap entrance, and it is hypothesized that—under high discharge from Unit 1—fish may be less likely to locate and enter the trap from the tailrace. Total river flow is primarily driven by discharge from Merwin Dam; it was hypothesized that elevated discharge, fish are less likely to locate and enter the trap, negatively influencing trap entrance efficiency (and ultimately capture efficiency). To understand the influence of Unit 1 and total river flow on trap entrance efficiency, the number of trap entrance events (i.e., detections at Approach or Entrance receivers) was plotted against discharge and contrasted among three different levels of discharge: (i) low flow (< 1,000 cfs); (ii) moderate flow (1,000 – 2,500 cfs); and (iii) high flow (> 2,500 cfs). For total river flow, the number of entrance events was compared under the following three Lewis River Discharge scenarios:

i) Low flow (<= 3,850 cfs; highest number of trap entrance events predicted under this scenario)
ii) Moderate flow (3,851-7,700 cfs; base flow values)
iii) High flow (7,700-11,500 cfs; at flow higher greater than 11,500 cfs, the elevator is shut down and the conveyance system no longer functions, however the attraction flow (Auxiliary Water Supply (AWS)) and ladder water supply systems continue to operate.)

Objective 10: Provide policy and biological context for the 98% ATE performance standard

A performance standard for adult trap efficiency at Merwin Dam is set at achieving or exceeding 98% *ATE* for fish that enter the tailrace. PacifiCorp has expressed interest in contextualizing this 98% *ATE* regulatory target through comparisons with regulatory targets for fish passage at other dams within the Columbia River basin asking the following questions:

- What is the regulatory or biological basis for a 98% *ATE* target at Merwin Dam?
- Is this target similar among dams within the Columbia River basin?

PacifiCorp personnel also expressed interest in understanding how rates of straying (i.e., fish that attempt to reproduce in a non-natal area) and the use of fish that had been previously trapped (i.e., trapping non-naïve fish) would influence the ability to achieve 98% *ATE* at Merwin Dam. Objective 10 is divided into three sub-objectives addressing the above questions:

- Objective 10a – Policy context for 98% performance standards applied at dams
  - *How are performance standards set in the Columbia Basin?*
- Objective 10b – Summary of reported passage targets and achieved passage rates at dams in the Columbia River Basin
  - *Are passage targets similar across dams and how often are they met?*
- Objective 10c – Summary of straying rates and dam reascension rates for steelhead
  - *How could straying rates and the use of trap non-naïve fish influence achieved ATE at Merwin Dam?*

To address these three objectives, we reviewed available information in reports and peer-reviewed literature. Although this objective is focused on steelhead within the Columbia River Basin, we also include information on other salmon species and from areas outside of the Columbia River Basin to provide further context when data on steelhead in the Columbia River were limited.

RESULTS

Summary

From 16 February – 2 May 2017, 150 adult winter steelhead (73 females; 77 males, FL = 56 – 94 cm) were collected in the Lewis River at the Merwin Dam Adult Fish Collection Facility, located at RKM 31.4 (RM 19.5)[3], implanted with radio tags, and released 0.6 km (0.4 mi) downstream at the Merwin Dam boat launch (Lewis RKM 30.8 (RM 19.1)) to continue their immigrations back to the Merwin Dam trap; consequently, all study fish were considered non-naïve. Of these 150 steelhead, subsequent detections with the telemetry array study area are visualized in Figure 8 and summarized here:

- 148 (99% of total) were detected at least once somewhere within the detection array (two fish were never detected following release, one of which was identified as a mortality at the release site).
- 139 (93% of total) were detected re-entering the Merwin Dam tailrace (*M*). Seven of these 139 fish were only detected at the Bridge site, and never further into the tailrace.
- 128 (85% of total) were detected in the Approach zone immediately outside the trap entrance.
- 116 (77% of total) were detected at the Entrance receiver just inside the trap entrance (*T*).
- 106 (70% of total), comprising 48 females (66% of 73 tagged) and 58 males (75% of 77 tagged) were re-captured (*C*) at the Merwin Dam Adult Fish Collection Facility, transported upstream, and released above Swift Dam.
    - *Post hoc* proportions tests indicated *ATE* estimates differed significantly between sex ($p=0.03$), with tagged male fish having higher recapture rates than females.

From these counts, core metrics of passage were calculated (Table 3).

---

[3] All river distances refer to distance upstream from Lewis River confluence with Columbia River.

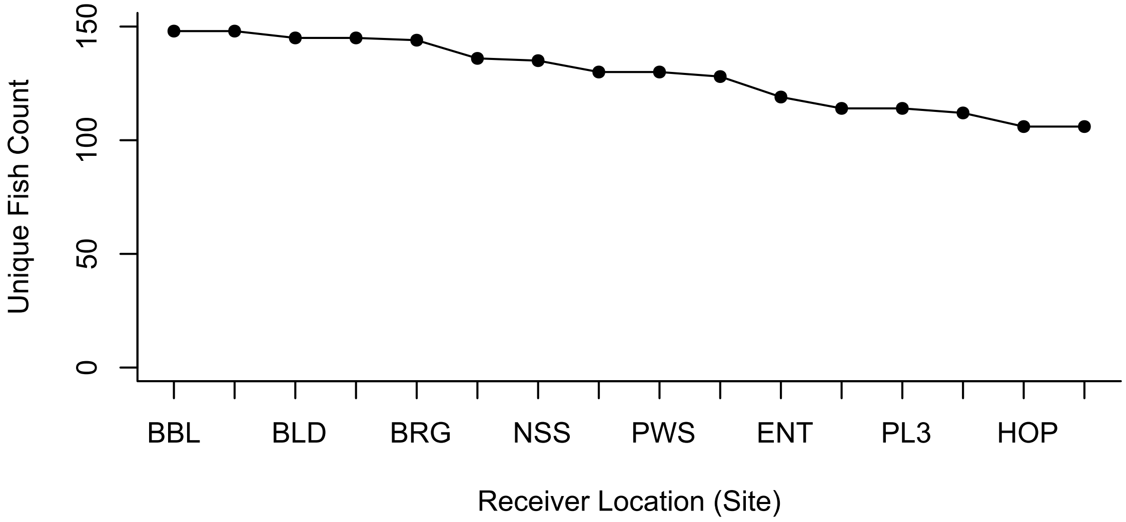


Figure 8. Sequence of frequencies of unique fish detected within the Merwin RT array, presented as total number (on left axis) of all tagged fish entering the study area (top panel) See Figure 2 and Figure 3 for receiver locations within the array. Among the 106 fish that were re-captured, five fish shed their radio tags prior to being captured. Fish that shed tags were included as "re-captured" in final estimates of core passage metrics despite having no detections on the trap antenna.

Table 3. Core passage metrics for BWT in 2017.

Metric	Value
P_{EE}	83.5%
ATE_{test}	76.3%
T_i	8.6%

Data Management and Processing

Database QA

There were 4,206,600 detections in the raw data, and 3,578,868 retained detections after the filter was applied.

Noise detections can block an antenna from detecting an authentic transmitter. In this study, noise accounted for 575,050 of total detections (13.7%), a reasonable value considering the conditions of the study (e.g., a dam tailrace and bridge with occasional car and truck traffic). Noise levels were generally higher for receivers located at the trap than those stationed in the tailrace (Figure 9), but the largest "peak" of noise detections came from the tailrace sites. For reasons that may include more tagged fish in the system, more tagging events, or operational patterns, noise levels peaked around May 1st (Figure 9). The receivers with the most noise hits were: TRP (38.6% of all noise detections), BRG (21.6%), PL4 (8.8%), BLU (7%), and South Powerhouse Wall (6%).

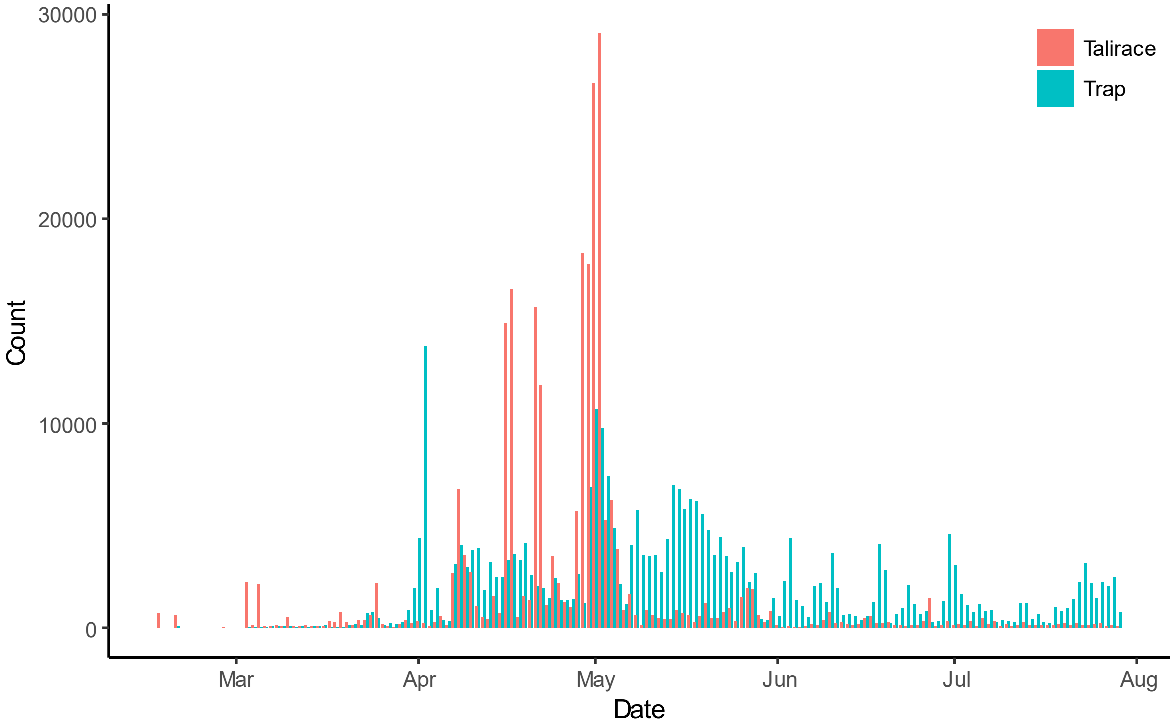


Figure 9. Total number of noise detections for trap (red) and tailrace (blue) receivers.

Objective 1: Determine trap effectiveness based on the *ATE* metric defined in the M&E plan for each target species, and compare estimates to the *ATE* performance standard of 98%

During the 2017 study season, 150 winter steelhead were tagged, of which 148 were detected at least once somewhere within the detection array, 139 were detected within the Merwin Dam tailrace, 116 were detected entering the Merwin Dam trap, and 106 were ultimately captured. These counts provide the basis for calculation of P_{EE} = 83.5% (116/139) and ATE_{test} = 76.3% (106/139; see Table 4, Figure 8).

During 2017, a higher proportion of winter steelhead found and entered the adult trap (P_{EE} = 83.5%) compared to steelhead that were ultimately captured (ATE_{test} = 76.3%). This discrepancy is also reflected by the trap ineffectiveness metric, T_i = 8.6%, indicating that 8.6% (n = 10) of fish that entered the trap in 2017 were not ultimately captured.

Table 4. Summary of passage metrics for tagged fish approaching the tailrace of Merwin Dam during spring 2017. Total number of fish tagged (*n*), detected in the tailrace (*M*), detected in the trap (*T*), and successfully trapped (*C*), in addition to adult trap entrance efficiency (P_{EE}), collection efficiency (ATE_{test}) and trap ineffectiveness (T_i), for 2017. Fish were considered to have entered the tailrace if they were detected at or upstream of the Bridge receiver. Fish were considered to have entered the trap if they were detected at receivers Entrance, Pool 1-2, Pool 1-4, Hopper, or Trap.

Metric	Winter Steelhead	Spring Chinook	Coho
Total Tagged (*n*)	150	N/A	pending
Entered the Merwin tailrace (*M*)	139	N/A	pending
Entered the Trap (*T*)	116	N/A	pending
Captured (*C*)	106	N/A	pending
Trap Entrance Efficiency ($P_{EE} = \frac{T}{M}$)	83.5%	N/A	pending
Collection Efficiency ($ATE_{test} = \frac{C}{M}$)	76.3%	N/A	pending
Trap Ineffectiveness ($T_i = \frac{T-C}{T}$)	8.6%	N/A	pending

Among release groups, ATE_{test} values ranged from 0 – 100% (Table 5). A significant trend between release group and ATE_{test} was detected in previous study years. However, we caution that previous statistical tests using release group as an explanatory variable may have been heavily influenced by small sample sizes of release groups at the beginning and end of the study, and therefore, may have violated model assumptions of equal variance. For this reason, in 2017 we used a different statistical approach (binomial generalized linear model with logistic link) that used individual fish as the sample unit to model the probability of recapture across release date. Using this approach, there was no significant effect (*df* = 148, *p* = 0.6) of release date on recapture probability (Figure 10).

Table 5. Passage metrics summarized by release group for 2017. See Table 4 for explanation of notation.

Release Date	*n*	*M*	*T*	*C*	Group *ATEtest* (%)
02/16/17	1	1	1	0	0%
02/17/17	1	1	1	1	100%
02/20/17	4	4	4	3	75%
02/27/17	4	3	3	3	100%
03/06/17	1	1	0	0	0%
03/07/17	2	2	2	2	100%
03/08/17	2	2	1	1	50%
03/13/17	5	5	1	1	20%
03/15/17	5	4	3	3	75%
03/23/17	10	10	9	9	90%
03/24/17	10	10	9	7	70%
03/27/17	6	5	5	5	100%
03/28/17	10	10	10	10	100%
03/29/17	9	9	8	8	89%
04/03/17	14	13	13	12	92%
04/04/17	9	9	8	7	78%
04/05/17	7	6	5	5	83%
04/10/17	12	10	7	6	60%
04/11/17	13	11	8	7	64%
04/17/17	11	10	7	6	60%
04/18/17	4	4	4	4	100%
04/24/17	5	5	5	4	80%
05/01/17	3	3	1	1	33%
05/02/17	2	1	1	1	100%
Total:	**150**	**139**	**116**	**106**	**See Table 3**

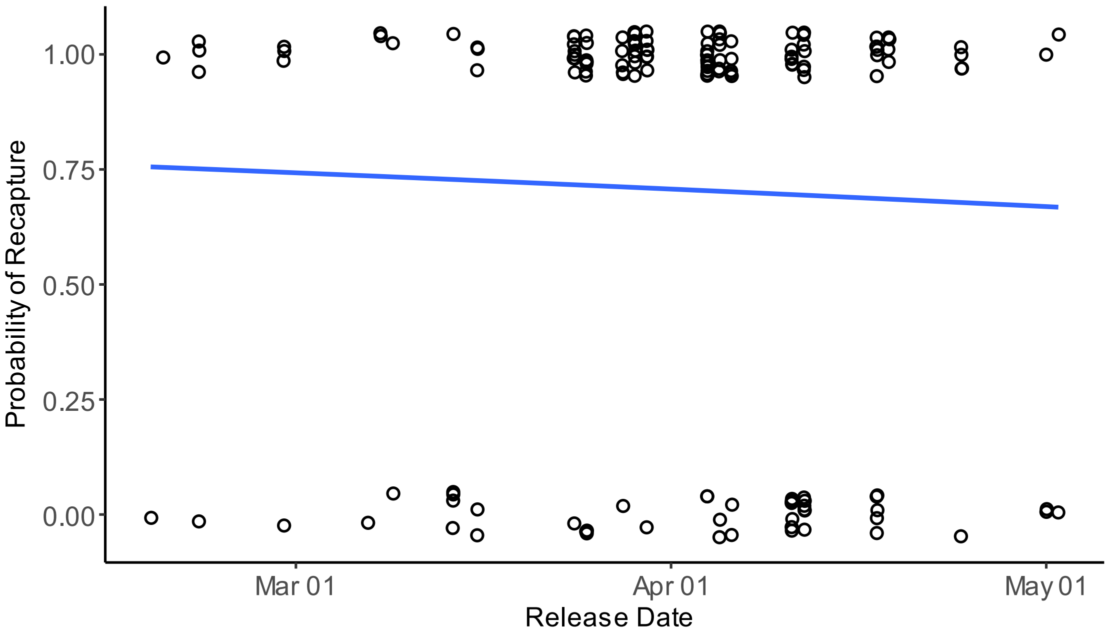


Figure 10. The probability of recapture for individual fish plotted as a function of release date. Open circles represent individual fish. The blue line indicates the predicted probability of recapture across release date based on logistic regression.

Bootstrapping the fish passage dataset generated a BCA 95% CI of 69.7 – 83.8% that converged on stable estimates when the total number of randomized resampling iterations exceeded approximately 1,000 (Figure 11). The calculated ATE_{test} for 2017 can be contextualized appropriately: based on random subsampling of the overall sample of fish observed in the current study: we are 95% confident that, for 2017, $69.7\% < ATE_{test} < 83.8\%$ for Lewis River winter steelhead approaching and attempting to pass Merwin Dam. Note that this inference says nothing about parent population *ATE*. Nonetheless, we can assert a high degree of confidence that ATE_{test} for BWT winter steelhead in 2017 was not truly 98%, because when the sample of fish that reached Merwin Dam tailrace was iteratively subsampled one million times, the target *ATE* of 98% was reached zero times.

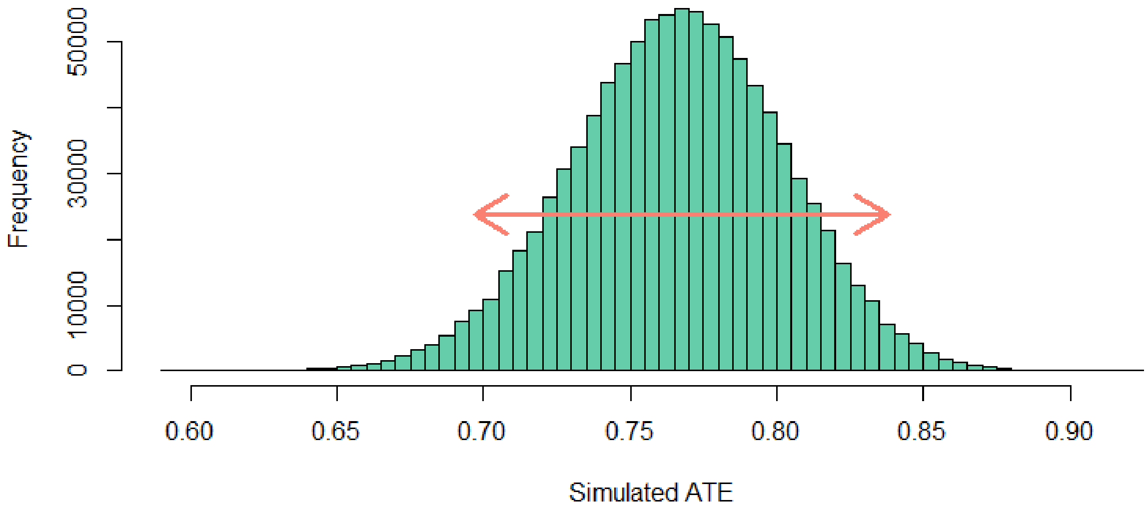


Figure 11. Bootstrap simulated frequencies of *ATE* calculated from one million iterations of randomly resampling (with replacement) the sample of 139 fish that reached the Merwin Dam tailrace. Horizontal bi-directional gray arrow indicates BCA 95% CI (69.7 – 83.8%); vertical gray line indicates target *ATE* of 98%. Note that target *ATE* was reached in zero of one million simulations. Note that a small amount of random noise was added to each bootstrap to create a “smoothed bootstrap”.

Next, in order to quantify the likelihood that the overall population of Lewis River winter steelhead attempting to pass, and spawn in reaches above, Merwin Dam may actually have exhibited *ATE* = 98%, even though ATE_{test} = 76.3% for tagged fish that entered the Merwin Dam tailrace, we conducted an urn simulation. When simulated subsamples of 139 fish were drawn from a parent population that actually exhibited 98% *ATE*, zero out of one million simulated subsamples exhibited ATE_{sim} as low as 76.3% (Figure 12). Among this set of one million ATE_{sim} values, the lowest was 89.2%.

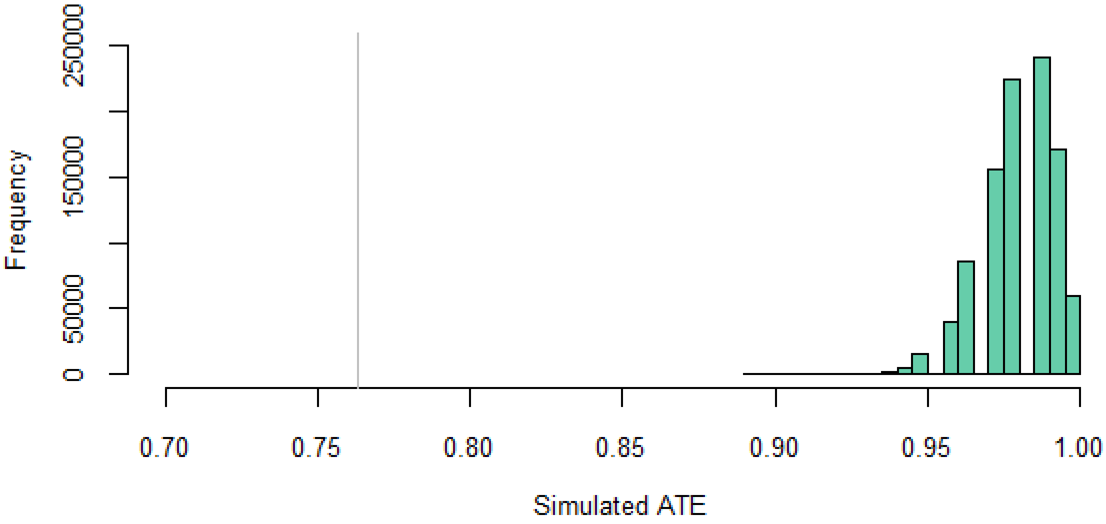


Figure 12. Simulated frequencies of *ATE* calculated from one million iterations of randomly subsampling a set of 139 fish from a simulated “urn” population of 10,000 fish that truly exhibited 98% *ATE*. Vertical gray line indicates observed ATE_{test} of 76.3%. Note that ATE_{test} reported here for 2017 was reached in zero of one million simulated subset samples of 139 fish from the parent population of 10,000.

Objective 2: Determine if the fish show direct movement to the trap entrance and, if some fish do not, document the behavior patterns for those specific fish in the tailrace

A visual analysis of the network diagram for winter steelhead movements throughout the study area illustrates the tendency of fish to move widely within the tailrace (Figure 13). Key findings include:

1) Fish entering the tailrace upstream of the Bridge receiver most commonly headed south to the South Shore, rather than moving along the North Shore (the darkest grey lines leaving Bridge in Figure 13). A smaller proportion of fish first enter the tailrace from Bridge and then head to the North Shore (Figure 13).
2) The most frequent pathway that resulted in a detection at the approach to the trap was from the South Shore (the darkest grey lines pointing towards Approach in Figure 13).
3) Individuals exhibit milling behaviors (blue lines) most commonly on the south side of the tailrace, between receivers Bridge ↔ South Shore, and South Powerhouse Wall ↔ Approach) (Figure 13). There were no milling behaviors that occurred on the north side or the tailrace (Figure 13).
4) Within the trap, the majority of milling occurred between Pool 2 ↔ Pool 3, and to a much lesser extent Pool 2 ↔ Entrance (Figure 13).
5) Milling also occurs immediately downstream of the tailrace between receivers Upper Boat Launch ↔ Bridge (Figure 13).
6) There were no credible movements to or from the North Powerhouse Wall (Figure 13). However, it should be noted that the North Powerhouse Wall receiver may not have been fully functional during the study, and thus may have had limited detection ability at this site.

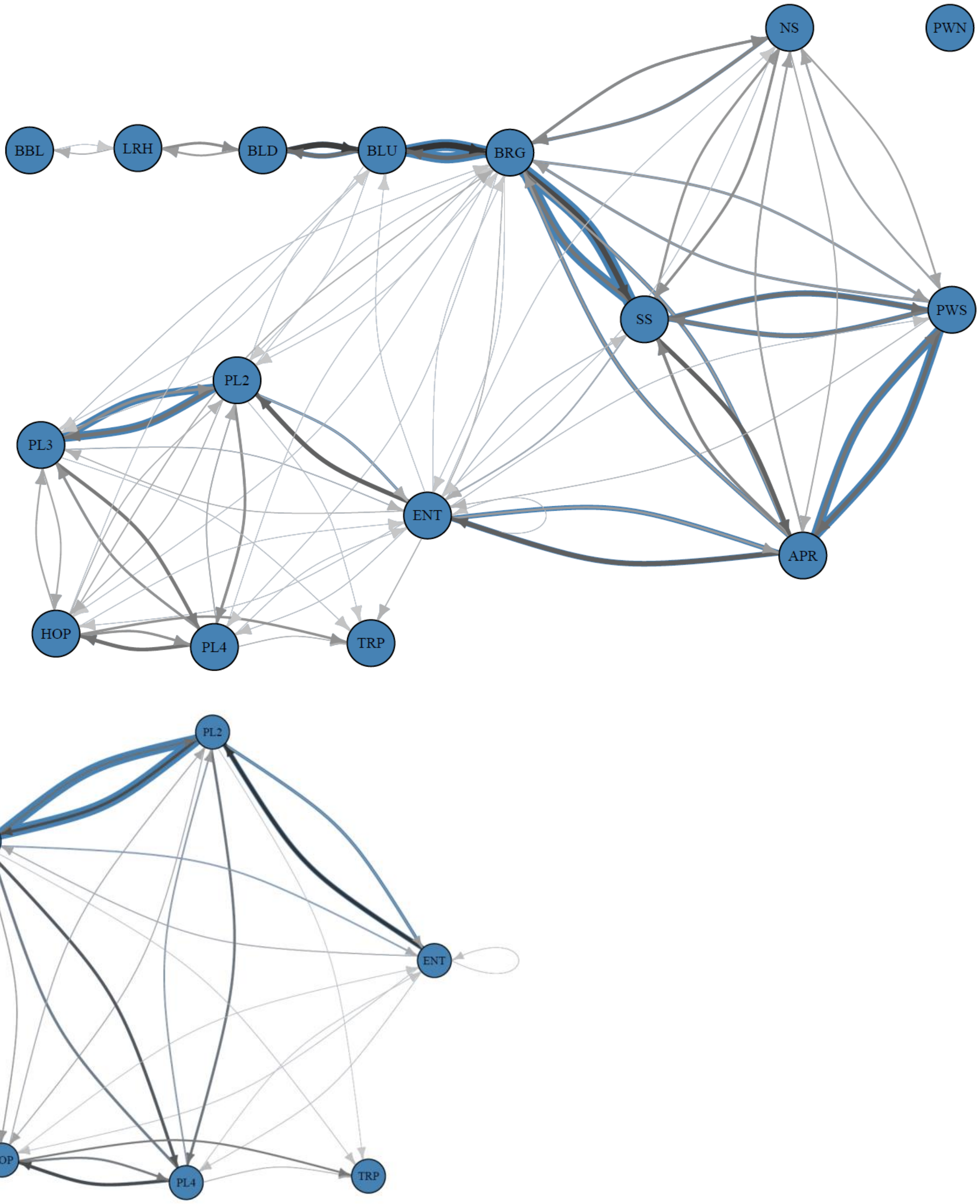


Figure 13. Network diagram of fish movement within study area. Path thickness and color are scaled based on the total number of individual fish traveling the paths (e.g., thicker paths represent a higher number of fish taking the path at least one time across their detection history). Grey paths are scaled to represent the total number of fish that traveled between sites (individuals as the sample unit), and blue paths are scaled to represent the total number of times that a path was used (total number of behaviors, with movements as sample units; *non-independent*). Top figure shows all sites; bottom figure shows only trap sites and includes re-normalized transitional probabilities calculated using detections at trap sites only.

Next, we generated a heat map in matrix form depicting color-coded probabilities of fish moving from one site to another (Figure 14). Within this figure, a stair-step pattern is apparent from the upper left to the bottom right, suggesting that fish are generally moving sequentially up through the system, but that there is not one clear pathway that ends at the Entrance receiver. Other insights that emerge from the heat map figure include the following:

1) Once a fish has progressed up to the Bridge site, it has a 10 – 60% probability of next being detected at one of four sites within the tailrace, the most likely (with a 60% probability) being the South Shore site.
2) Once a fish has nosed into the trap at the Entrance receiver, there are ten potential sites at which a fish will be detected next, the most likely of which (with a 60% probability) is outside of the trap at Approach.
3) Once inside the trap and detected in Pool 2, there were seven potential sites at which a fish will be detected next, the most likely (with a 70% probability) being further upstream at Pool 3 receiver. Conversely, there was a low probability (30%) of fish moving from inside the trap at Pool 2 to the Entrance receiver, and an even lower probability (10%) of fish moving to other receivers in the tailrace.
4) Once inside of the trap, there are many potential next sites that a fish utilizes, which suggests either (a) that fish are not following a clear directional path once inside, or (b) that antenna detection zones overlap.

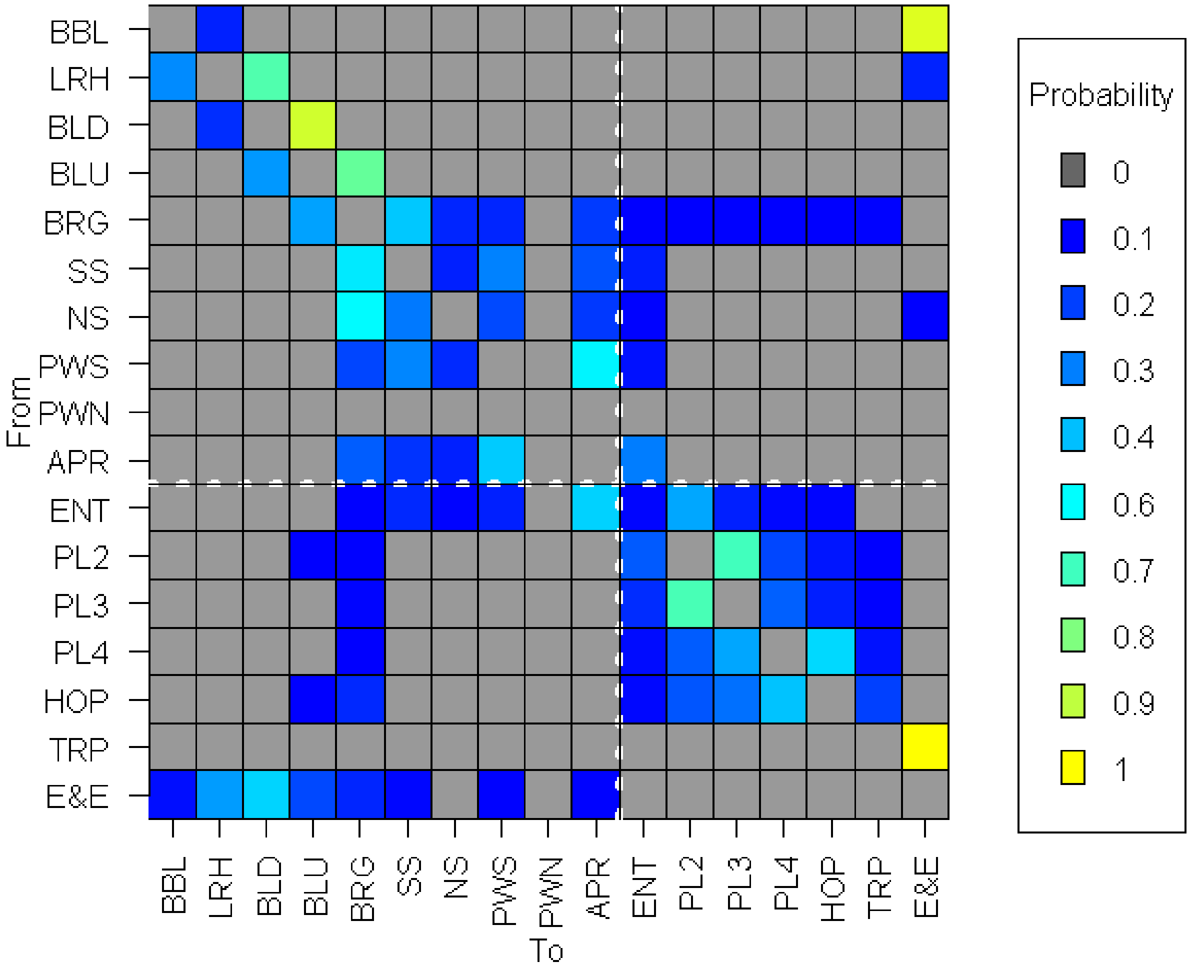


Figure 14. Heat map of the transition probabilities of fish moving from an origin site to all potential destination sites, where each row sums to a probability of 1.0. The black reference lines are added between the receivers Approach and Entrance to show the distinction of a fish being located within or outside of the trap. Probabilities in the upper left box represent movements that begin and end in the river or tailrace, while those in the bottom right begin and end in the trap. Probabilities in the upper right box represent paths that begin in the river or tailrace and end in the trap, and the lower left box begin in the trap and end in the river or tailrace (e.g., exiting the trap). E&E represents entrance and exit locations from the study system. For example, fish that are at the Trap always exit the system (e.g., they cannot leave), so there is a probability of 1.0 at the Trap row and E&E column).

By comparing the number of unique site visits by each fish (Figure 15), it is apparent that fish do not tend to move directly into the trap. More than half of the fish that were eventually trapped had performed 100 or more unique site visits before being trapped.

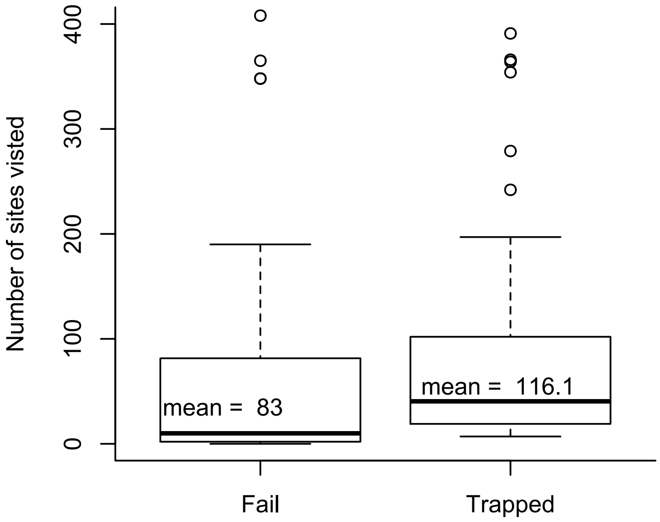


Figure 15. Number of sites visited before being captured (Trapped) or not captured (Fail).

In general, fish tended to move upstream through the telemetry array study area, from the Lewis River Hatchery to the tailrace, with most sites having a forward transition probability greater than 50% ($p \geq 0.50$) (Table 6). Of note, fish at Pool 2 had the greatest chance (82%) of transitioning to receivers upstream, supporting the conclusion that the fyke effectively prevented fish from exiting Pool 2. Fish at receivers South Powerhouse Wall, North Shore, Approach, and Hopper all had higher rates of moving backwards in the system. The two sites with the highest *MI* values (i.e., those where fish milled) were: Pool 3 and Entrance.

Transition probabilities and milling behavior differed between collected and not collected fish (Table 6). Fish that were not collected had much lower probabilities of transitioning forward from the BBL, LRH, and BRG sites compared to collected fish. In addition, not collected fish tended to mill less at the APR and PL2 sites compared to collected fish.

Table 6. Probabilities of transitioning further into the system for each site. P_{single} is the probability of a fish transitioning forward to the next most upstream site(s) rather than falling back to the downstream sites. P_{all} is the same probability, across all detections rather than across individual fish. *MI* is a milling index, calculated as the ratio P_{single}:P_{all}. Positive values of *MI* suggest that fish tend not to move forward from that location. Site specific P_{single} or P_{all} <0.5 are shaded blue, and *MI* >0.000 are shaded green. *P_{single} and P_{all} values are provided for fish not collected (i.e., not recaptured), for fish collected (i.e., recaptured), and for collected and not collected fish combined.*

Receiver	**P_{single} (not collected)**	**P_{all} (not collected)**	***MI***	**P_{single} (collected)**	**P_{all} (collected)**	***MI***	**P_{single} (collected and not collected)**	**P_{all} (collected and not collected)**	***MI***
BBL	0.033	0.033	0.000	1.000	1.000	0.000	0.065	0.065	0.000
LRH	0.320	0.320	0.000	1.000	0.981	0.019	0.618	0.657	-0.039
BLD	0.540	0.864	-0.324	0.881	0.942	-0.061	0.750	0.909	-0.159
BLU	0.500	0.640	-0.140	0.678	0.739	-0.061	0.624	0.700	-0.075
BRG	0.607	0.480	0.127	0.808	0.743	0.065	0.764	0.680	0.085
SS	0.578	0.508	0.071	0.628	0.469	0.159	0.618	0.476	0.142
NS	0.361	0.252	0.109	0.379	0.268	0.112	0.376	0.264	0.111
PWS	0.373	0.557	-0.184	0.423	0.505	-0.083	0.412	0.517	-0.104
PWN	-	-	-	-	-	-	-	-	-
APR	0.146	0.269	-0.124	0.330	0.241	0.088	0.297	0.248	0.049
ENT	0.344	0.296	0.048	0.678	0.454	0.225	0.627	0.418	0.209
PL2	0.607	0.786	-0.179	0.857	0.821	0.036	0.820	0.815	0.005
PL3	0.391	0.175	0.217	0.589	0.274	0.316	0.565	0.258	0.308
PL4	0.333	0.261	0.073	0.567	0.490	0.077	0.544	0.463	0.081
HOP	0.000	0.000	0.000	0.292	0.137	0.156	0.273	0.127	0.146

When evaluating transition probabilities at each site to determine how fish moved through the system, there were no apparent differences between trapped and non-trapped fish (Figure 16).

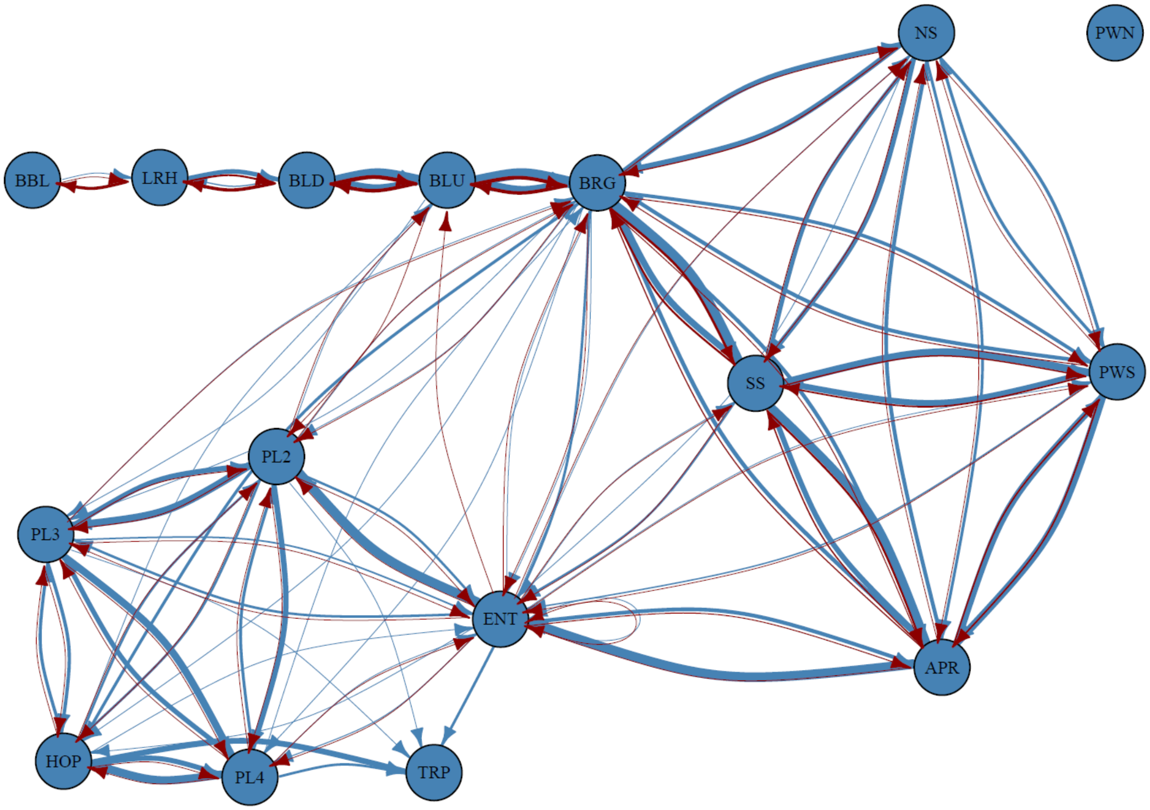


Figure 16. Network diagram of fish movement within the study area at Merwin Dam grouped by fish that ultimately are trapped (blue) or failed to be trapped (red) from 2017. Path thickness and color are scaled based on the total number of transitions which occurred between sites with fish as the sample unit. This figure suggests that there are essentially no significant differences in the spatial patterns between successfully and unsuccessfully passed fish in Merwin tailrace. This graphic depicts the movements of 146 fish; 106 that were successfully passed (i.e., last detected at Trap) and 40 that were unsuccessful (i.e., last detected downriver at Hatchery or Bed and Breakfast).

Objective 3: Determine if fish in the tailrace spend the majority of their time in the area of the entrance of the trap and, if some fish do not, determine if those fish are holding in another location within the tailrace

In general, once in the tailrace, fish tended to spend the majority of their time holding and milling at the south side of the tailrace (South Shore) or just outside of the the entrance of the fish trap (Approach) (Figure 17; Figure 18). Evaluation of winter steelhead behaviors within the tailrace revealed the following observations:

1) Low numbers of visits (n) to the north side of the tailrace (North Shore), but high median residence time at this site suggests that when fish visited this site, they tended to hold for long periods of time.
2) Fish avoided the North Powerhouse Wall zone entirely, but as previoulsy noted, this detection site may not have been functional during the entire study.
3) Fish were detected for the largest total amount of time at the Bridge receiver, while the median residence time at this site was low, suggesting a relativley large detection radius for the Bridge receivers (i.e., the Bridge recievers were detecting fish further in the tailrace). Only 7 fish that "entered the tailrace" were only detected at the Bridge site, and inspection of detection data for thes fish indicates these were true detectoins.
4) Fish spent a lot of time milling and holding on the south side of the tailrace based on large numbers of visits (n) to the South Shore and Approach recievers and the long total amount of time spent at these receivers. This suggests fish may have been attracted to this area adjacent to the trap entrance and held or milled prior to making the decision to enter.
5) Once inside the trap, fish spent the most time holding inside the Hopper (HOP) (and to a lesser extent Pool 4) based on low number of visits (n), but high median residence time and total minutes spent at these sites.
6) Fish spent a lot of time holding and milling in Pool 2 based on high numbers of visits (n) and relativley high residence time and total time spent at this site.
7) Pool 3 was associated with milling behaviour based on high number of visists (n) but low residence time and total time spent at this site.

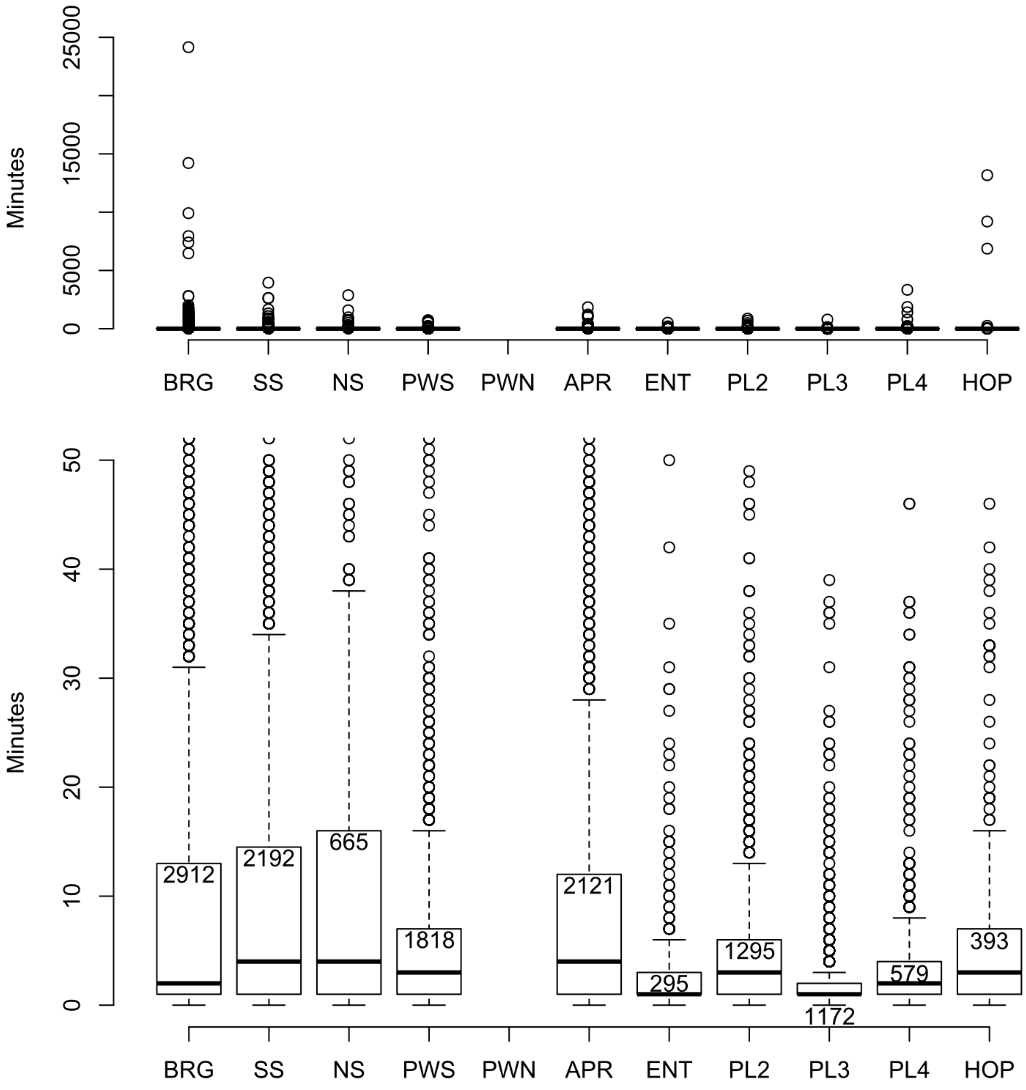


Figure 17. Median residence times by site. The top figure shows the full range of data, including outliers, while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Sample size (n) is displayed in the top of the box plots for each site. Caveat: these data are not scaled based on the detection ranges of each site.

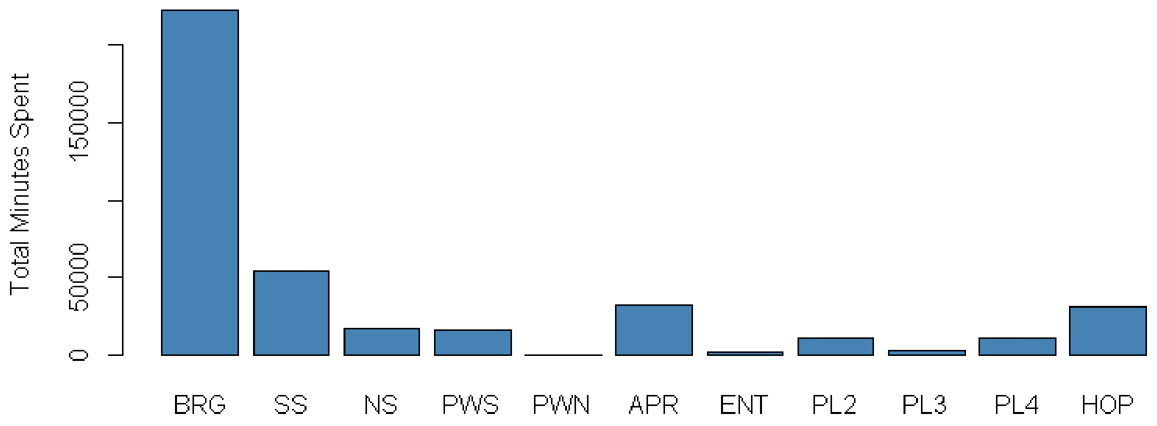


Figure 18. Total time spent by all winter steelhead in each site. Caveat: these data are not scaled based on the detection ranges of each site.

At locations downstream of the tailrace, fish appear to hold near the Lewis River Hatchery, based on a low number of detections, high median residence, and total time spent at this location. Fish also appear to reside at the Bed and Breakfast locations (Figure 19), but the low number of detections combined with the low total amount of time spent at this location (Figure 20) suggest the large amount of residence time was a result of only two behaviors (Figure 19).

Once upstream of the hatchery, individual fish do not spend much time near the Boat Launch sites (Figure 19); however, when aggregated across all winter steelhead included in the 2017 study (i.e., the sum of the total minutes spent at the BLD and BLU sites), a substantial total amount of time (729,494 minutes or ~507 days) is spent in the the Boat Launch area, which could be due to fish recovering after they are released at the Boat Launch (Figure 20).

Interestingly, fish spent a total of 557,137 minutes (~387 days) at the Lewis River Hatchery, which is 1.4 times greater than the amount of time spent in the tailrace (fish spent a total of 403,187 minutes or ~ 280 days in the tailrace).

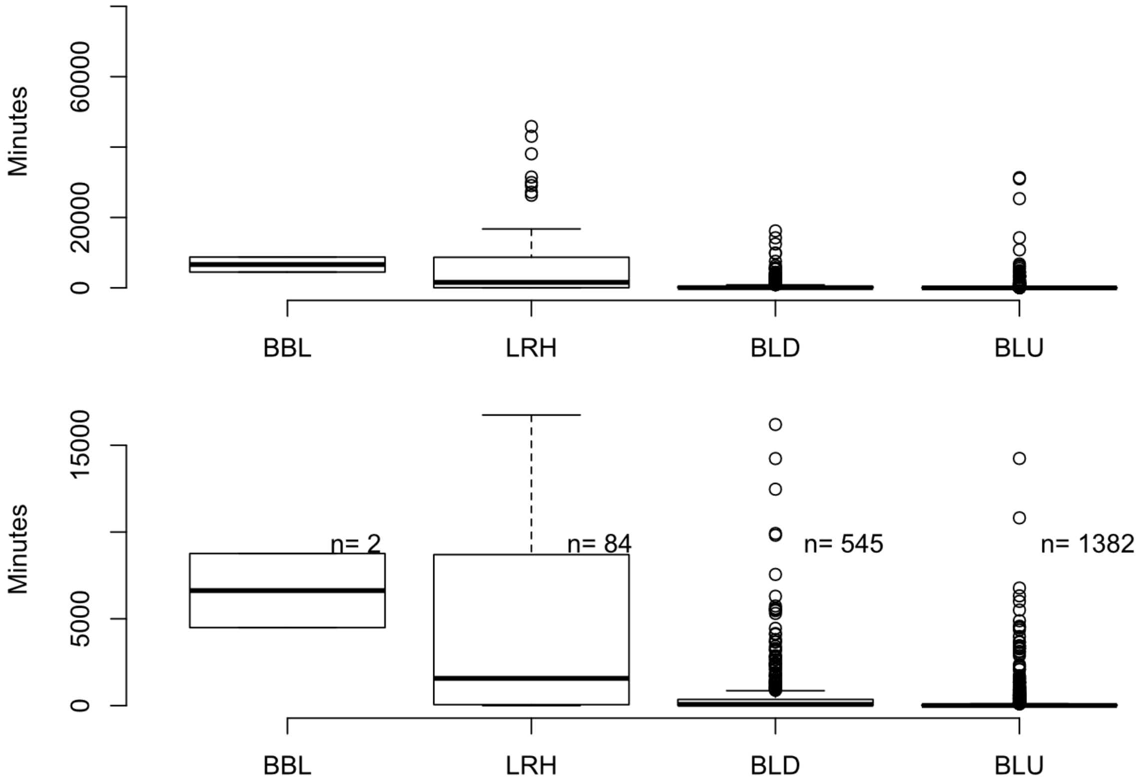


Figure 19. Median residence times for downriver sites. The top figure shows the full range of data, including outliers, while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Sample size (n) is displayed in the top of the box plot for each site. Caveat: these data are not scaled based on the detection ranges of each site.

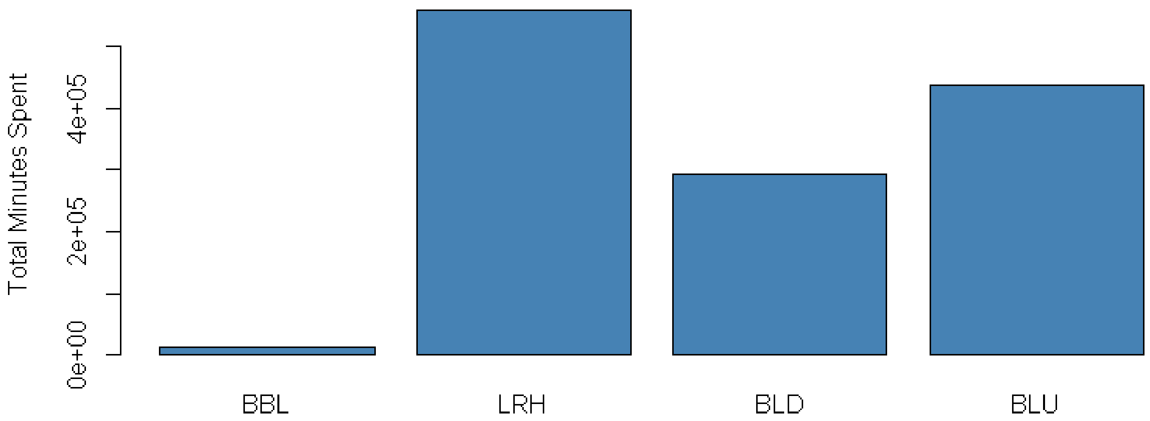


Figure 20. Total time spent by all winter steelhead in each downriver site. Caveat: these data are not scaled based on the detection ranges of each site.

Objective 4: Determine the total time fish are present in Merwin Dam tailrace and compare to *ATE* performance standards for safe, timely, and effective passage

ATE performance standards indicate that safe, timely, and effective passage is associated with median tailrace time of less than or equal to 24 hours, with no more than 5% of fish taking longer than 168 hours to pass. The median tailrace residence time for all winter steelhead in the Merwin Dam tailrace was 11.8 hours (range = <2 minutes – 403 hours). Given fish milling behavior, the upper end of this range may represent total time spent during multiple trips through the tailrace. Only 10 winter steelhead (approximately 7%) had a tailrace residence time greater than 168 hours. Thus, the performance standard compliance metric for median tailrace residence time was met, but the performance standard compliance metric of not more than 5% of fish taking longer than 168 hours was not met. For reference, in 2015 and 2016, neither performance standard compliance metrics were met (Table 7).

Table 7. Achieved performance standard compliance metrics for safe, timely, and effective passage across three study years for three study species at Merwin Dam.

Study Year	Species	*N*	Median Tailrace Residence (range)	Percentage of Fish with Tailrace Residence Time > 168 hrs
2015	Winter steelhead	148	49.4 hrs (0.08-1,077.4 hrs)	13.5%
	Spring Chinook	40	246.5 hrs (0.01-1412.4 hrs)	65%
	Coho Salmon	35	15.3 hrs(0.21-395.7 hrs)	5.7%
2016	Winter steelhead	148	29.2 hrs (0.03-605 hrs)	10%
	Spring Chinook	*N/A*	*N/A*	*N/A*
	Coho salmon	*N/A*	*N/A*	*N/A*
2017	Winter steelhead	150	11.8 hrs (0.03-403 hrs)	7%
	Spring Chinook	*N/A*	*N/A*	*N/A*
	Coho salmon	*N/A*	*N/A*	*N/A*

Additionally, the following insights were apparent from evaluation of the detection data:

- Twenty-three winter steelhead entered the tailrace but never entered the trap.
    - Within this group, fish exhibited a median tailrace residence time of 17.4 hours (range = 0.00 – 403 hours).
    - Two of these fish (~9%) exhibited a tailrace residence time >168 hours.

- Ten winter steelhead entered the trap but were never captured.
    - These fish exhibited a median tailrace residence time of 26.9 hours (range = 0.27 – 235 hours).
    - Within this group, only one fish (10%) exhibited a tailrace residence time >168 hours.
- One hundred six winter steelhead entered the trap and were captured successfully.
    - These fish exhibited a median tailrace residence time of 7.3 hours (range = 0.32 – 401 hours).
    - Within this group, seven fish (~7%) exhibited a tailrace residence time >168 hours.

Objective 5: Describe the movement and behavior of tagged fish that do not enter or which choose to leave the Merwin Dam tailrace and move back downstream

Of the 148 winter steelhead that were detected at least once somewhere within the detection array, 139 were detected in the Merwin Dam tailrace (*M*), 116 entered the trap (*T*), and 106 were captured (*C*) (see Figure 8, Table 4). Of the 116 fish detected at the trap entrance, 93 (80% of *T*) returned to the tailrace after first visiting the trap. Of those 93 fish that moved back downstream after their first post-tagging encounter with the trap, 83 (89%) were eventually captured; the remaining 10 fish were not. This means that 83 out of 106 fish that were ultimately captured had entered and exited the trap entrance at least once after being tagged and released, but prior to being successfully trapped—a greater number compared to the only 19 fish that were successfully trapped during their first post-tagging encounter of the trap. In other words, only 16% (19 of 116) of fish that entered the trap continued through and were captured on their first post-tagging encounter with the trap. Also, of the 139 fish detected in the tailrace, 10 (7%) returned to downriver sites (i.e., below the access bridge); 6 of these 10 (60%) were successfully captured while the remaining 4 fish were not.

Last known detection location for all 44 fish that were not captured is provided in Table A-1. Of the 44 fish note captured, 68% (30/44) and 16% (7/44) were last detected at the B&B and Lewis River Hatchery sites, respectively (Table A-1).

Objective 6: Determine the condition of fish that are captured by the trap, as a function of rates of descaling and injury

Only recaptured radio tagged fish were included in the injury assessment. Including maiden capture, fish would likely be erroneous as, prior to being trapped, fish have traveled long distances and are subject to other sources of injury not associated with trapping operations. Only healthy winter steelhead free of injury were tagged in the study. Once a radio tagged fish was recaptured it was then inspected for injury and any found injuries were assumed to be caused by trapping effects.

Of the 104 radio tagged winter steelhead that were recaptured nine (9) fish were shown to have signs of injury and two (2) fish died during transport. However, two (2) of the nine injured fish had likely been injured due to tangle netting efforts from a separate study in the Lewis River conducted during the same timeframe as this study. They were excluded from the injury assessment. Therefore, it was determined that there was an observed trapping injury rate of 6.7% (7 of 104) for winter steelhead in 2017. Of the seven (7) observed injuries four (4) were due to greater than 10% descaling, and the remaining three (3) were due to small abrasions. Of the mortalities that occurred, one (1) was due to the fish being caught in the flume of the large metal tank truck. The cause of the other mortality is uncertain, as it was found dead at the release location, without any observable trauma.

Of note, three fish were detected consistently under the Hopper for approximately one week in 2017, indicating these fish were trapped under the Hopper. These fish were flushed out by hoisting the hopper for about six hours based on email correspondence dating Apr 19-21. Two of the fish trapped under the hopper were eventually recaptured, and one was last detected at the Boat Launch site.

Objective 7: Operational Analysis

We performed five simulations, including a control of the raw transitional probabilities, in order to evaluate which potential scenario would result in the greatest change in *ATE* rates (Table 8).

Control: The control model returned a higher percentage of captured fish and had a larger median number of sites visited. This is most likely due to aggregating all transitions across all fish. Our model assumes that all fish move equally; in reality, a few outliers contributed disproportionately high numbers of sites visited. We consider this to be relatively unimportant to subsequent utility of this model, because it still provides a useful baseline to make comparisons against as it is representative of the observed behavior

Model 1: To test the effects of installing a trap (or an entrance to a collection channel leading to the current trap) located along the north shore, we increased transition probabilities from the North Shore receiver to the Entrance receiver, to match the probability of transitioning from Approach to Entrance. This had the effect of sending fish from the North Shore to a trap with efficiency identical to that of the south shore trap. The result of the Model 2 simulation shows no increase in the percentage of trapped fish, a result of zero detections on the PWN receiver during the study, which suggests the PWN receiver may not have been fully functional. It should also be noted that this analysis did not account for any changes in flow dynamics associated with installing a second entrance on the north side of tailrace.

Model 2: To test for the effects of an additional moderately effective fyke installed between Pool 3 and Pool 4, we reduced the rate of fish travelling backwards from Pool 4 by 50%. This increased *ATE* by 4% (3 percentage points), to 86%, and reduced the number of sites visited.

Model 3: To test for the effects of an additional highly effective fyke installed between Pool 3 and Pool 4, we reduced the rate of fish travelling backwards from Pool 4 by 90%. Compared to the control model, this increased *ATE* by 5% (4 percentage points), to 87%, and reduced the number of sites visited.

Model 4: Because the PWN receiver may not have been fully functional in 2017, for this simulation we replaced transition rates to the PWN receiver with data from 2016. Only transition rates to the PWN receiver were replaced in this model; all other transition rates in the model are from 2017 data. Using 2016 transition rates to the PWN site increased *ATE* by 1% (one percentage point) and increased the number of sites visited (Table 8). Again, it should also be noted that this analysis did not account for any changes in flow dynamics associated with installing a second entrance on the north side of tailrace.

Table 8. Results from simulation models. *ATE* = adult trap efficacy; AVE = average; MED = median.

Model	**Description**	***ATE***	**Sites Visited (AVE)**	**Sites Visited (MED)**
Raw empirical data	Values from data	76%	106	34
Model Un-modified	Control	83%	118	77
Model 1	Allow North Powerhouse Wall to transfer to Entrance at a similar rate as Approach to Entrance	83%	118	77
Model 2	Reduce rate of travelling backwards from PL4 by 50% (Fyke potential)	86%	103	68
Model 3	Reduce rate of travelling backwards from PL4 by 90% (Fyke potential)	87%	87	60
Model 4	Uses PWN returns from 2016 data	84%	147	95

Objective 8: Determine the effectiveness of fyke installation for preventing winter steelhead from leaving the trap.

To examine fyke effectiveness in preventing fish from exiting Pool 2, we compared the number of transitions from Pool 2 to Entrance or Approach sites (i.e., exit events), between 2016 (before the fyke was installed) and 2017 (after the fyke was installed) (Table 9). We examined transitions from Pool 2 to the Approach site to account for reduced detection ability on the Entrance receiver if fish exited too quickly to register a positive detection. The total number of transitions between Pool 2 and the Entrance and Approach sites was reduced by 98% and 52%, respectively, in 2017 compared to 2016. Other results of note include:

1) Six fish performed only 8 direct PL2→ENT transitions in 2017, whereas 57 fish performed 703 PL2→ENT transitions in 2016 (Table 9).
2) Twenty-three fish performed 119 direct PL2→APR transitions in 2017, whereas 58 fish performed 284 PL2→APR transitions in 2016 (Table 9). The higher number of transitions from PL2→APR compared to PL2→ENT suggests that many fish were not detected on the ENT receiver when they exited the trap, presumably because a more stringent data filtration is applied to detection data on the ENT site, which limits detection efficiency.
3) Total river flow exceeded 8,000 cfs only at the begging of the 2016 study (Figure 21). Therefore, caution should be taken when interpreting results based on differences in discharge in 2016 (i.e., it is difficult to separate the effects of discharge from those of season during in 2016).

Table 9. Numbers of transitions between sites in 2016 and 2017 across three levels of total river flow: low (< 7,000 cfs); medium (7,000-8,000 cfs); and high (>8,000 cfs). The number of transitions are not relativized by fish (i.e., one fish can be responsible for multiple events). Observations support the hypothesis that fish were able to transition backwards in 2017 when discharge was high; due to water level exceeding fyke height.

Site Transition	Year	# Transitions < 7,000 cfs	# Transitions 7,000 - 8,000 cfs	# Transitions > 8,000 cfs	Total # Transitions
PL2→ENT	2016	527	47	129	703
	2017	0	5	3	8
PL2→APR	2016	276	5	3	284
	2017	19	46	54	119

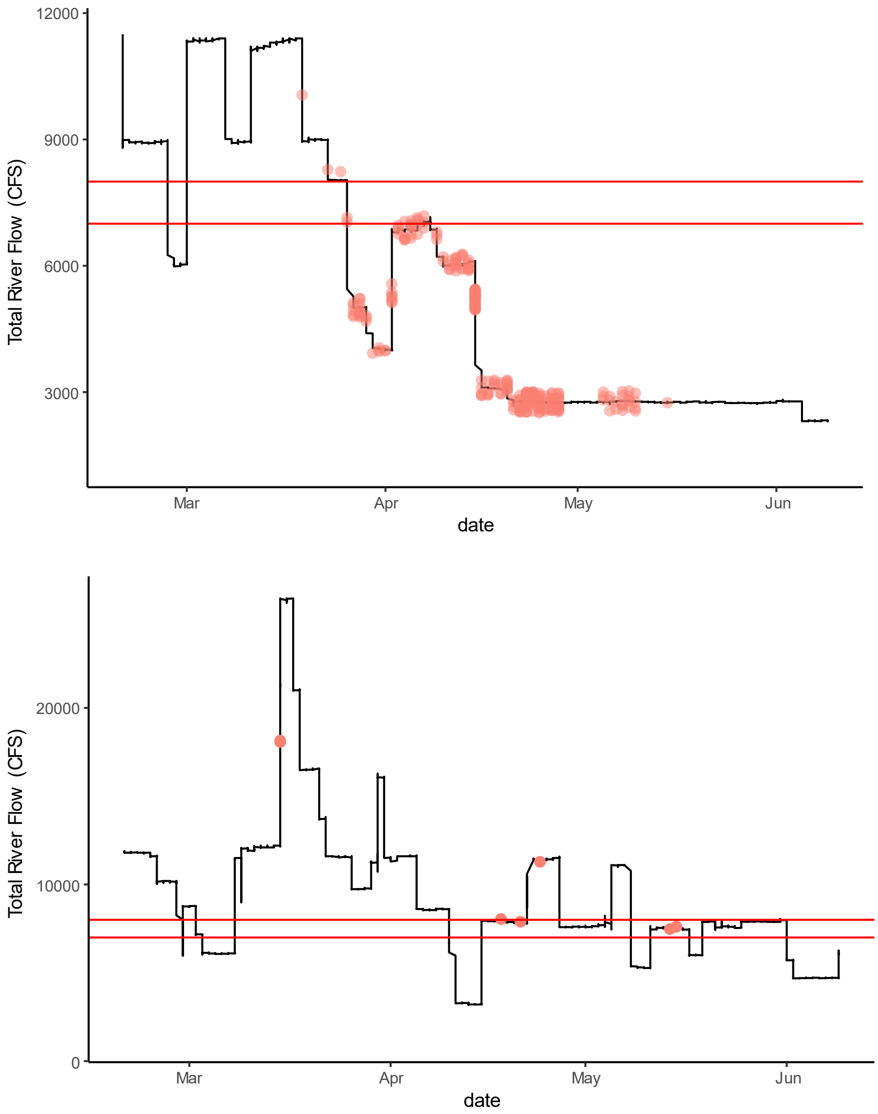


Figure 21. Timing of PL2→ENT transitions (i.e., backwards through the fyke) during varying levels of total river flow over two study years, 2016 (top panel) and 2017 (bottom panel). Horizontal red bars denote flow less than 7,000 cfs and greater than 8,000 cfs. Red dots indicate PL2→ENT transitions.

Objective 9: Summarize trends in *ATE*, P_{EE} and T_i metrics between years and describe relationships between capture metrics and Merwin Dam operations.

Adult passage metrics (P_{EE}, *ATE* and T_i) have been estimated for winter steelhead at Merwin Dam over three years from 2015-2017 (summarized in Table 10). Trap entrance efficiency (P_{EE}) was lowest in 2017 and highest in 2016, a difference of 9 percentage points. Adult trap efficiency (*ATE*) was lowest in 2015 and highest in 2017 when *ATE* was 15 percentage points higher than in 2015, representing a 25% increase.

Based on interannual comparisons of ATE_{test} BCA 95% CI values, we can say with a high degree of confidence that in 2017, ATE_{test} values were greater than 2015 ATE_{test} values (i.e., the BCA 95% CI values do not overlap). ATE_{test} and P_{EE} BCA 95% CI values overlap for all other interannual comparisons. Notably, *ATE* was highest in 2017 despite that year having the lowest proportion of fish entering the trap from the tailrace (i.e., lowest P_{EE}). Trap inefficiency (T_i) in 2017 was approximately one-third of that in previous years, indicating that more fish entering the trap were successfully captured in 2017.

Table 10. Adult passage metrics (P_{EE}, *ATE* and T_i) for winter steelhead across three study years. Sample sizes (N) represent the number of tagged fish that were released in each study year.

Study Year	Species	*N*	P_{EE} (BCA 95% CI)	ATE_{test} (BCA 95% CI)	T_i
2015	Winter steelhead	148	86% (79-90%)	61% (51-67%)	29%
2016	Winter steelhead	148	93% (87-96%)	73% (65-80%)	21%
2017	Winter steelhead	150	84% (77-90%)	76% (70-84%)	8%

Two variables, Unit 1 discharge and total river flow (overall Merwin Dam discharge), were identified of specific interest towards understanding their influence on *ATE* among study years. Mean Unit 1 discharge in 2017 was nearly four and two times higher than in 2015 and 2016, respectively (Table 11). Mean and maximum river flow was highest in 2017, more than double that of 2015 and 1.5 times that of 2016 (Table 11).

Table 11. Summary statistics for two variables of interest (Unit 1 discharge and total river flow) across 3 study years.

Study Year	mean (±sd) Unit 1 discharge (cfs)	range (min-max) Unit 1 discharge (cfs)	mean (±sd) Total River Flow (cfs)	range (min-max) Total River Flow (cfs)
2015	428 (±945)	23-3638	3229 (±1924)	1060-11400
2016	960 (±1479)	23-3767	4905 (±3372)	1260-11600
2017	1921 (±1752)	23-3986	7476 (±4337)	1190-26200

Higher Unit 1 discharge was observed later in the study period for 2017 compared to both 2015 and 2016 (Figure 22).

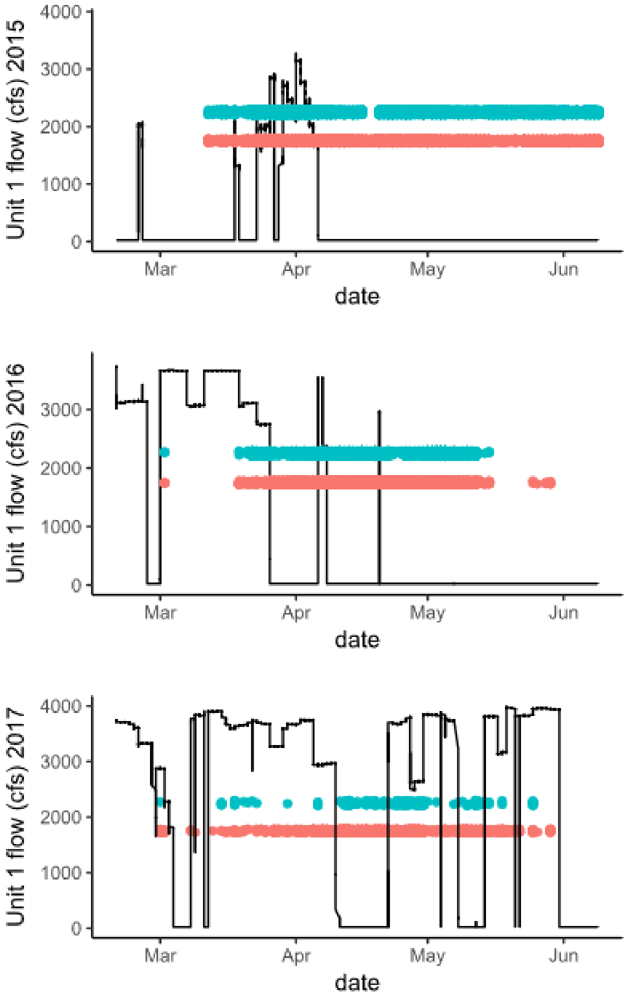


Figure 22. Unit 1 discharge over time for three years of study. Solid black line indicates discharge. Red and blue dots indicate individual detections at the Approach and Entrance sites, respectively. Data for total river flow was collected from PacifiCorp. See Appendix A, Figures A-1 to A-4 for plots of all operational variables across years.

Additionally, in 2017, total river flow spiked in mid-March and was generally higher and more variable than in 2015 and 2016 (Figure 23).

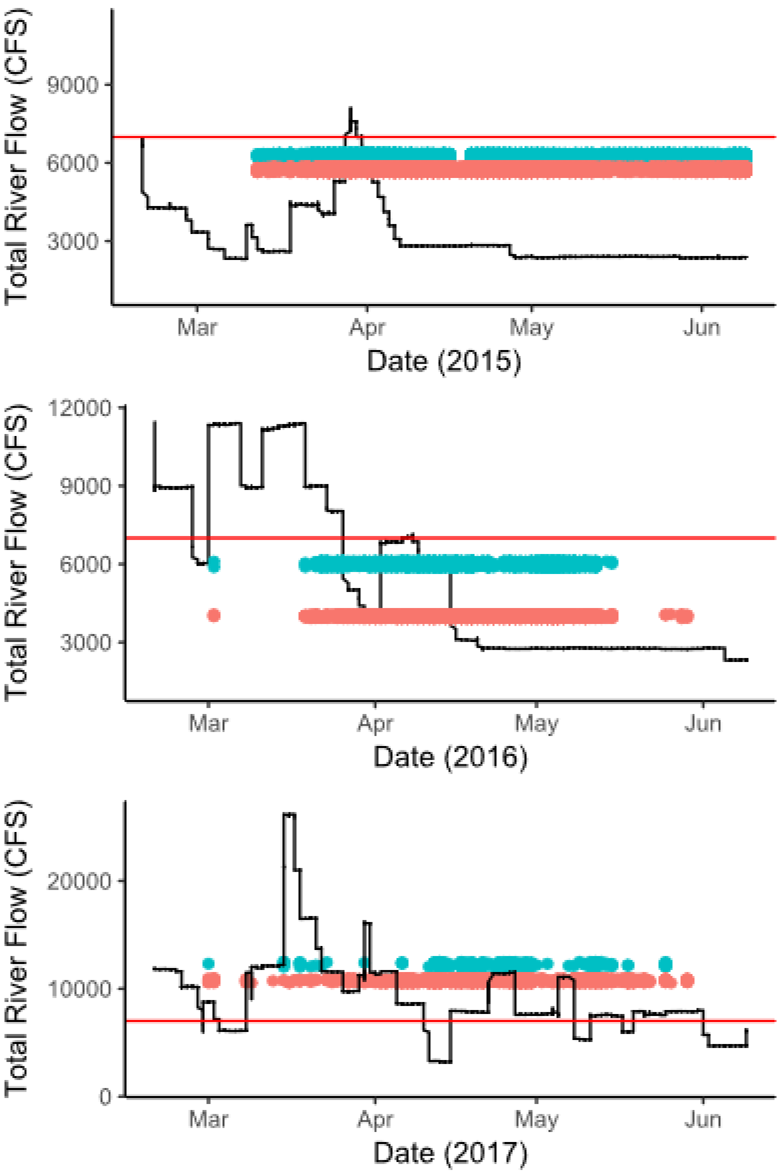


Figure 23. Total river flow over time for three years of study. Solid black line indicates discharge. Red and blue dots indicate individual detections at the Approach and Entrance sites, respectively. Data for total river flow was collected from USGS (USGS 2017). See Appendix A, Figures A-1 to A-4 for plots of all operational variables across years.

It was hypothesized that high discharge from Unit 1 or total river flow controlled from Merwin Dam could impede the ability of fish to locate and enter the trap. The number of detections at the Approach and Entrance site under different discharge conditions was used to examine how discharge influenced trap entrance behavior. The greatest number of detections per hour came at the middle levels of discharge for both Unit 1 (Table 12) and total river flow (Table 13). Of note, the fewest detections per hour occurred mostly during high total river flow (>8000 cfs) suggesting a potential negative influence of high discharge on upstream fish passage. We caution against drawing firm conclusions until appropriate statistical comparisons are conducted. Additional efforts to investigate relationships between operational variables and fish passage metrics are dependent on PacifiCorp's desire to pursue following their evaluation of the exploratory results presented above.

Table 12. Total number of detections and number of detection per hour across three study years at two detection sites (Approach and Entrance) under three Unit 1 operational scenarios: low discharge (< 1000 cfs), moderate discharge (1000-2500 cfs), and high discharge (>2500 cfs).

Site	Year	# Detections < 1000 cfs	# Detections 1000 - 2500 cfs	# Detections > 2500 cfs	# Detections/hour < 1000 cfs	# Detections/hour 1000 - 2500 cfs	# Detections/hour > 2500 cfs
Approach	2015	10384	1454	679	2.9	3.8	2.1
	2016	5143	117	161	1.7	0.9	0.1
	2017	1016	127	980	0.5	0.6	0.4
				Average	**1.7**	**1.8**	**0.9**
Entrance	2015	5157	1735	810	1.4	4.5	2.5
	2016	2141	95	247	0.7	0.8	0.2
	2017	169	1	126	0.1	0.0	0.1
				Average	**0.7**	**1.8**	**0.9**

Table 13. Total number of detections and number of detection per hour across three study years at two detection sites (Approach and Entrance) under three total river flow scenarios: low discharge (< 7000 cfs), moderate discharge (7000 - 8000 cfs), and high discharge (> 8000 cfs).

Site	Year	# Detections < 7000 cfs	# Detections 7000 - 8000 cfs	# Detections > 8000 cfs	# Detections/hour < 7000 cfs	# Detections/hour 7000 - 8000 cfs	# Detections/hour > 8000 cfs
Approach	2015	11860	657	0	2.9	8.4	0.0
	2016	5226	121	74	1.6	1.0	0.1
	2017	643	832	648	0.3	1.0	0.4
				Average	**1.6**	**3.5**	**0.2**
Entrance	2015	6912	790	0	1.7	10.1	0.0
	2016	2196	116	171	0.7	1.0	0.2
	2017	98	121	77	0.1	0.1	0.0
				Average	**0.8**	**3.8**	**0.1**

Objective 10: Provide policy and biological context for the 98% *ATE* performance standard.

Objective 10a: ATE regulatory context

A 98% target for adult trap efficiency (*ATE*; also referred to as adult passage efficiency or *APE*) is applied at Merwin Dam. Similar standards are established in one of two primary ways, depending on the hydroelectric project operator.

Under one scenario, Public Utility Districts (PUD) that operate the Mid-Columbia dams are licensed by the Federal Energy Regulatory Committee (FERC). Each PUD collaborates with the National Marine Fisheries Service (NMFS) to develop a Habitat Conservation Plan (HCP) for each hydroelectric project. The performance standards stipulated by these HCPs are a combined juvenile-adult passage survival of 91%, or 93% juvenile and 98% adult passage survival (NMFS 2008).

Under a second scenario, fish passage criteria through the Federal Columbia River Power System (FCRPS) are developed by NMFS in compliance with the Endangered Species Act (ESA) and are outlined in a Biological Opinion (BiOp). These performance standards represent the overall survival of a species throughout its run, and are reported in the form of conversion rates (ranging from 80% – 91%), which are calculated using PIT tags detected over multiple, non-adjacent dams (Dauble and Mueller 2000; FRCPS 2016; NMFS 2008). For example, a tagged fish detected at Bonneville must pass through three dams before being detected again at McNary. As such, dam-specific data are not consistently available.

However, a general per-dam survival target can be estimated from the target conversion rate (NMFS 2008). These numbers range from 95% - 99%, and are summarized in Table 14. While these per-dam estimates represent an average and not a mandated target for each specific dam, it should be noted that the Merwin target of 98% *ATE* falls within the range of per-dam survival estimates. However, these survival estimates incorporate additional sources of mortality such as predation, and it is expected that they would be lower than a strict dam passage efficiency target.

Table 14. Survival targets for Columbia River salmonids through federally operated hydroelectric projects

Species & Run	Reach	Number of Dams	*Reach Survival Target (%)	Avg (%)	*Per Dam Survival Target (%)	Avg (%)
Steelhead - Upper Columbia	Bonneville - McNary	3	85 / NA	85	95 / NA	95
Steelhead - Snake River	Bonneville - Lower Granite	7	90 / 83	86.5	99 / 97	98
Spring/Summer Chinook - Upper Columbia	Bonneville - McNary	3	90 / NA	90	97 / NA	97
Spring/Summer Chinook - Snake River	Bonneville - Lower Granite	7	91 / 84	87.5	99 / 98	98.5
Fall Chinook - Snake River	Bonneville - Lower Granite	7	81 / 75	78	97 / 96	96.5
Sockeye - Snake River	Bonneville - Lower Granite	7	81 / NA	81	97 / NA	97

*Migrated in-river / Transported as juveniles

Objective 10b: Regional ATE Targets and Achieved ATE

Below is a summary of passage targets and achieved passage rates of adult salmon and steelhead migrating upstream through the Columbia River and its major tributaries (Table 15). This summary is intended to provide context for the Merwin *ATE* target of 98% to inform whether this target represents a reasonable and achievable goal. The information presented was derived from hydroelectric power project reports and, where possible, published telemetry studies that provided dam- and species-specific passage metrics.

Despite differences in passage type, *ATE* targets are remarkably consistent among passage type and sites, ranging from 95 – 99%, and the *ATE* applied at Merwin Dam is consistent, albeit at the upper end, with upstream salmonid passage performance standards throughout the Columbia River basin.

Table 15. Summary of existing *ATE* target criteria and achieved passage rates for hydroelectric projects along the Columbia River and its major tributaries

Region	Dam	Passage type	Species	Target	Achieved	Notes	Source
WA	Mossyrock	Trap & Haul	~	98%	*Data not found*		(USACE 2015)
	Mayfield	Trap & Haul	~	98%	*Data not found*		
	White River	Trap & Haul	~	98%	*Data not found*		
	Mud Mountain	Trap & Haul	~	98%	*Data not found*		
Mid-Columbia PUD	Wells	Fish Ladder	Spring Chinook	98%	98%	(9-year avg)	(UCRTT 2015)
			Summer Chinook	98%	97%	(4-year avg)	"
			Steelhead	98%	98%	(9-year avg)	"
			Sockeye	98%	99%	(5-year avg)	"
			Coho	98%	*Insufficient Data*		"
	Rocky Reach	Fish Ladder	~	98%	*Data not found*		
	Rock Island	Fish Ladder	~	98%	*Data not found*		
	Wanapum	Fish ladder;	Spring Chinook	98%;	*Data not found;*	Emergency response to 2014 Dam fracture	(Pearsons et al. 2015)
		Emergency Trap & Haul		95% emergency target	100%		
	Priest Rapids	Fish Ladder	~	98%	*Data not found*		
Columbia River Federal Projects	Bonneville	Fish Ladder	Steelhead	*95 - 99% (97%)	*97.7%*	(6-year avg)	(Keefer et al. 2008a)
			Spring-Summer Chinook	*97-99% (98%)	*98.5%*	"	"
			Sockeye	* 97%	*98.8%*	"	"
	The Dalles	Fish Ladder	Spring - Summer Chinook	*97-99% (98%)	96.6%	1 yr avg adult (96.1%) and jack (97.0%) APE	(Frick et al. 2015)
			Sockeye	*97%	98.8%		"

Region	Dam	Passage type	Species	Target	Achieved	Notes	Source
	John Day	Fish Ladder	Spring - Summer Chinook	*97-99% (98%)	98%	2 yr avg adult (97.3%) and jack (98.8) APE	"
			Sockeye	*97%	98%		"
	McNary	Fish Ladder	All spp.	*95 - 99% (97%)	*Data not found*		
	Ice Harbor	Fish Ladder	Steelhead	*97-99% (98%)	*Data not found*		
	Lower Monumental	Fish Ladder	All spp.	*96 - 99% (97.5%)	*Data not found*		
	Little Goose	Fish Ladder	Spring, Summer Chinook	*98 - 99% (98.5%)	97%		(Jepson et al. 2009)
			Steelhead	*97-99% (98%)	85%		"
			Fall Chinook	*96 - 97% (96.5%)	100%		"
	Lower Granite	Fish Ladder	All spp.	*96 - 99% (97.5%)	*Data not found*		

* Range (avg) based off per-dam survival estimates outlined in Table 1 (NMFS 2008).

While *ATE* targets are clearly outlined in the regulatory literature, few sites report an achieved adult passage efficiency. Of the 17 dams investigated, *ATE* data were identified for only six, describing 15 distinct species/runs. A summary of the number of dams and species/runs that achieved ≥ 98% *ATE* can be found in Table 16. Of the dams with sufficient data available (n = 6), 83% (n = 5) demonstrated a combined average *ATE* (or *APE*) of 98% or greater. Of the specific species/runs with sufficient data available (n=15), 67% (n=10) achieved an *ATE* of 98% or greater. Given that only 6 of 17 dams reported ATE, however, the potential for reporting bias cannot be overlooked, as *ATE* at the remaining 11 facilities remains unknown.

Given the limited data available on steelhead, all species were included in Table 16 in order to provide sufficient context. Only three instances of steelhead *ATE* were identified, and only one of those instances achieved a 98% *ATE*.

Table 16. Summary of the number of dams and specific species/runs that achieved an *ATE* of 98% or greater. When multiple species' *ATE* were reported for one dam, the combined average achieved *ATE* was used to determine whether overall a dam achieved a 98% target *ATE*.

Description	Number	Percentage
Dams that achieved *ATE* ≥ 98% (n=6)	5	83%
Species/runs that achieved *ATE* of ≥ 98% (n=15)	10	67%

Objective 10c: Discussion of Straying Rates & Dam Naïveté

Salmonids exhibit remarkable home site fidelity (philopatry), an evolved life history trait that likely increases the chance of locating suitable habitat and mates. However, some proportion of a population may migrate and attempt to reproduce at non-natal spawning sites (straying). Straying is another important evolved life history trait that maintains genetic diversity among populations and allows salmon to colonize new habitats (or recolonize following extirpation). Rates of straying among salmonids vary among species and populations (Quinn et al. 1984). In general, steelhead are thought to have intermediate straying rates when compared to other salmonids (Keefer et al. 2014). Columbia River populations of steelhead typically exhibit straying rates from 3 – 10% (Keefer et al. 2014), but steelhead straying has been reported as high as 55% in the Snake River (Bumgarner and Dedloff 2011). Straying rates are estimated for a population over an entire migration, making it challenging to determine straying rates at one specific location such as a dam. In light of this constraint, the more useful question to ask may be: *"What factors influence steelhead straying rates and how might these apply to steelhead at Merwin Dam?"*

The mechanisms leading to straying have been thoroughly reviewed and discussed by Keefer et al. (2014) and Quinn et al. (1984): straying is thought to be influenced by a variety of factors that occur throughout a fish's life cycle. For example, heightened stress or infection during homing may impair olfactory ability, leading to straying (Morbey et al. 2005). Other mechanisms leading to straying may include incomplete imprinting during rearing, density dependent effects (i.e., attraction to large aggregates of individuals spawning in non-natal areas), genetic effects, hatchery effects, and transportation effects. Density dependent, hatchery effects, and transportation effects may be of specific relevance to straying rates of steelhead at Merwin Dam. Below, we briefly address how each of these may influence straying of steelhead in the lower Lewis River.

BWT steelhead used to estimate *ATE* area of hatchery origin, being reared at Merwin Hatchery. BWT hatchery steelhead are transported downstream as smolts, and released. Transportation distance has been positively correlated with adult stray rates (Keefer et al. 2008b, 2012); potentially a result of weak imprinting on natal cues or the inability to imprint sequentially during downstream migration. Thus, BWT steelhead may be more likely to stray because they were transported as juveniles.

The Lewis River hatchery exists downstream of Merwin Dam, where chemical cues from spawning coho and Chinook salmon are emitted into the lower Lewis River. Chemical cues emitted from congeneric spawning salmon in non-natal waters (or chemical cues associated with the hatchery itself) may attract steelhead (Bett and Hinch 2015). Thus, in the absence of strong natal cues (or weak imprinting on natal cues as juveniles), steelhead might choose to follow odors emitted from congenerics at the Lewis River hatchery, especially when large aggregates of spawning fish occur in high densities, as is the case at a hatchery. Water from the Merwin Hatchery is discharged at the trap entrance with the intention of attracting adult migrants, but the chemical cues in this water could be similar to those emitted downstream at the Lewis River hatchery. Olfactory cues being discharged at two different locations could create competing olfactory cues for migrating salmon and reduce the likelihood of fish choosing to enter the trap. Indeed, in 2017, three BWT steelhead were collected at the Lewis River Hatchery (Chris Karchesky, personal communication), suggesting some straying into the Lewis River Hatchery occurs. A more detailed assessment of numbers of fish that migrate to the hatchery and delay at the hatchery water outlet may help determine and quantify the role and contribution of olfactory cues to passage rates and thus overall *ATE* metrics.

The effects of encountering an obstacle such as a dam on straying rates are poorly understood, especially for fish that previously passed the obstacle. At Merwin Dam, steelhead are collected at the trap for tagging (i.e., tagged fish have already successfully located and entered the trap), which is a common strategy used to monitor dam passage rates of adult salmon during reproductive migrations (e.g., Thorstad et al. 2003, Keefer et al. 2012, Roscoe et al. 2011, Caudill et al. 2007). Evidence that fish have the ability to learn migration routes and thus be more capable of ascending a dam a second time is lacking (Thorstad et al. 2003). However, there is evidence for the opposite, i.e., that salmon have lower rates of successful dam passage after they have already ascended fishways and attempt to reascend a second time (Boggs et al. 2004; Burnett et al. 2014). For example, Burnett et al. (2014) showed that sockeye salmon captured and released from a fish fence below a dam (i.e., dam naïve fish) were 15% more likely to locate and enter the fishway, had 16% greater passage success, and had shorter residence time in the dam tailrace compared to fish that were captured from the top of the fishway and released below the dam (i.e., dam non- naïve fish). Burnett et al. (2014) speculated that the lower passage success of fish attempting to ascend the fishway for the second time was a result of excessive energy expenditure incurred during the first passage attempt (sockeye salmon had to swim anaerobically in order to successfully ascend the fishway based on data acquired from accelerometry tags). However, relatively less energy would be needed to enter the trap at Merwin Dam compared to fish that ascend a fishway.

Indeed, energetic and physiological state of fish may play a key role in the likelihood of a fish reascending or re-entering a trap. An assessment of fish stress and/or energetic state prior to release downstream may provide some insights into its role in behavior after release. Stress can be assessed quickly using reflex impairments (Davis 2007, 2010) or by more in-depth measures of stress hormones (cortisol, lactate) circulating in blood (Raby et al 2012). Energetic state can be easily measured using handheld microwave radio emitters commonly used at fish processing plants (Caldwell et al 2013).

Although different from physically capturing a fish from a dam and releasing downstream, dam "fallback" is not uncommon, and dam reascension by fish that have fallen back is in some ways analogous to dam reascension by dam non-naïve fish. Rates of reascension after fallback have been estimated for steelhead at dams in the Columbia River, with estimates ranging from 46 - 83% (Boggs et al. 2004). Overall, evidence points to the potential for lower passage success of dam non- naïve fish relative to dam naïve fish. Capture and tagging of dam naïve steelhead from the Lewis River below Merwin Dam would provide the ability to compare trap success (and straying rates) of dam- naïve and dam non-naïve steelhead in the Lewis River.

Finally, exploratory behavior is common during homing migrations (Griffith et al. 1999; Keefer et al. 2008c), and fish may routinely make forays into non-natal tributaries or explore upstream areas before reaching final natal spawning sites. Thus, some fish that enter the trap could be simply exploring the area upstream of where they will ultimately spawn.

DISCUSSION

In 2017, 150 winter steelhead were tagged, of which 148 were detected at least once somewhere within the detection array, 139 were detected within the tailrace of Merwin Dam, 116 were detected entering the trap, and 106 were successfully captured. During this year, low return numbers for spring Chinook salmon prevented including this species in the study. Additionally, it was determined that results for coho salmon, a study that was implemented late during steelhead tagging, will be presented as a separate report. As a result, only winter steelhead were evaluated for this report, and ATE_{test} for winter steelhead is the only value contributing to the study-wide ATE_{test} estimate. Furthermore, interannual comparisons of passage metrics presented herein focus on metrics for winter steelhead.

ATE_{test} for the 2017 study was 76% (BCA 95% CI = 69.7 – 83.8), which was significantly below the 98% target ($p<0.05$). Additionally, we found evidence that it is statistically unlikely that the parent population of Lewis River winter steelhead truly exhibited $ATE \geq ATE_{target}$ when the sample of fish that reached the Merwin Dam tailrace exhibited an ATE_{test} of only 76%. Out of one million iterations of randomly drawing samples of 139 fish from an urn-style population modeled to truly exhibit 98% passage, zero exhibited ATE_{sim} as low as the value measured during 2017.

Achieved passage metrics in 2017 were generally better than in previous study years. In 2017, the observed ATE_{test} was 76%, which is 15 percentage points higher than in 2015 (a 25% increase) and 3 percentage points higher than in 2016 (a 4% increase). Similar to in previous years, during the 2017 study year, winter steelhead appeared to locate and enter the trap at a higher rate (P_{EE} of 84%) than the rate at which they were capture (i.e., ATE_{test}). This observation is reflected by a trap ineffectiveness (T_i) of 8% for 2017, which was 21 percentage points lower than in 2015 (a 3.6-fold reduction) and 13 percentage points lower than in 2016 (a 2.6-fold reduction).

The dramatic decrease in T_i for 2017 was likely the result of a fyke that was installed within the trap ladder prior to the 2017 tagging study. Our 2016 study results indicated that winter steelhead frequently exited the trap after they entered, and some of those fish were never recaptured. Thus, to prevent fish from exiting the trap with the overall goal of reducing T_i and increasing ATE_{test}, a fyke was installed between Pool 1 and Pool 2 of the trap's ladder system prior to steelhead tagging in 2017. Lines of evidence suggesting that the fyke was effective in preventing winter steelhead from exiting the trap in 2017 include the following:

1) A 2.6 – 3.6-fold reduction in trap ineffectiveness compared to previous years
2) Only eight exit events (transitions from PL2→ENT) were recorded in 2017 compared to 703 exit events in 2016
3) Network analysis results indicating that, with the exception of movements from the lower to upper Boat Launch site, the site with the highest probability of transitioning forward was Pool 2 with an 82% probability of transitioning forward from this site (this was 50 percentage points greater than in 2016 with no fyke in the trap)
4) Long residence time and total time spent in Pool 2, suggesting fish moved back down to Pool 2, but were unable to exit Pool 2

Some fish were able to exit Pool 2, despite the increased trap effectiveness. Six fish were responsible for transitions backwards from Pool 2 to Entrance, and 23 fish were responsible for transitions backwards from Pool 2 to Approach. Fish may have exited Pool 2 through a gap above the fyke present during periods of high discharge. In 2017, zero transitions from Pool 2 to the Entrance occurred during low discharge (<7,000 cfs); instead, all exit events occurred during medium (7,000 – 8,000 cfs) to high (>8,000 cfs) discharge, when water levels could have been above the fyke height. A similar trend was also observed when examining transitions from Pool 2 to the Approach site in 2017, although the number of transitions was higher for each discharge level compared to the number of transitions between Pool 2 and the Entrance, which indicates the Entrance receiver missed a proportion of fish leaving the trap likely due to more stringent data filtration applied to the Entrance site. Overall, the fyke appears to have increased effectiveness of the trap for retaining fish that entered the trap area, and blocking the gap above the fyke may further increase this effectiveness.

Attraction, rather than retention, appears to be the primary factor limiting fish passage in 2017. Under the hypothetical scenario in which trap ineffectiveness was reduced to zero, the proportion of fish that entered the trap from the tailrace (P_{EE}) would still remain lower than the ATE_{target} of 98% in all study years. Further measures to increase *ATE* are proposed under Phases II-IV of the M&E Plan if *ATE* targets are not met by current operations. One proposed measure is the addition of a second trap entrance at the north side of the tailrace, the effects of which we modeled previously (Caldwell et al 2017) and for the current study, and discuss here.

We operated simulation models to evaluate potential ways to increase *ATE* at the site including a model designed to examine the effects of a second trap entrance on *ATE*. This model showed no difference in *ATE* after addition of a second trap entrance, which can be attributed to zero credible detections at the North Shore Wall receiver in 2017 (the model uses detections at the North Shore Wall to infer transition probabilities at a second trap entrance on the north side of the tailrace). Interestingly, in 2016, there were detections at North Shore Wall, although the total time spent at this site was low. There are two possible explanations for the lack of detections on the North Shore Wall receiver in 2017:

1) steelhead did not enter the detection range of the North Shore Wall receiver; or
2) the North Shore Wall receiver may not have been functional during the study.

The raw detection data at the North Shore Wall show it was detecting the beacon tags (tags set near antennae to act as controls) throughout the study duration and battery power was never low for the receiver, yet there were no detections of tagged fish. It is possible that the cables connecting the antenna to the receiver were worn, which would reduce the detection range of the antenna. However, even if the detection range was reduced, the antenna could still pick up the beacon tag because of its proximity to the antenna. Furthermore, numerous tag detections on other receivers on the north shore of the tailrace (e.g., North Shore receivers) provide evidence that fish were using this side of the tailrace. Prior to initiating the coho study, the cables were replaced on the North Shore Wall receiver, and the detection capability increased with our test tags providing evidence that the receiver cables were not fully functional during the steelhead study. Overall, we are not confident that the North Shore Wall receiver was functioning properly in 2017.

To account for reduced detections on the North Shore Wall in 2017, a fourth simulation model was included that replaced 2017 North Shore Wall transition rate data with data from 2016 to model changes in *ATE* with the addition of a second trap entrance. Even after replacing 2017 data with data from 2016 when we were confident the North Shore Wall receiver was operational, *ATE* only increased by 1% based on the simulation model results.

The second and third simulation models tested the effects of installing an additional fyke at the transition between Pool 3 and Pool 4. Results from these efforts indicated *ATE* values increased to a maximum of 87% (four percentage points higher), and the average number of sites visited reduced by almost 30%. Thus, by reducing the backwards transition rate from the Pool 4, fewer fish exit the Pool 4 and mill between downstream receivers. However, we note that eliminating the gap above the current fyke in Pool 2 may provide similar results as adding a second fyke between Pool 3 and Pool 4.

The network analysis for 2017 indicated that winter steelhead most frequently took a path along the south shore after entering the tailrace and spent large amounts of time milling in the tailrace outside of the trap entrance on the south shore. Interestingly, 92% (n = 128) of fish that entered the tailrace (n = 139) reached the Approach site located directly outside of the trap entrance in the tailrace, yet 10% (n = 12) of those fish never entered the trap area. In contrast, in 2016, winter steelhead frequently took a path along the north shore after entering the tailrace and spent large amounts of time at the north shore of the tailrace. Total river flow in the tailrace was higher in 2017, which could contribute to the observed differences in tailrace pathways between years. Overall, the use of the south shore by fish in 2017 suggests fish were being attracted to the trap entrance.

The network analysis accomplished in this report suggests that there is not a clear pathway that fish are using to navigate to the trap, which is consistent with the 2016 study. However, we do note that fish that were successfully trapped spent 10.1 and 19.6 fewer hours (based on median hours) in the tailrace than fish that were entered the tailrace and were never trapped and fish that entered the trap but were never captured, respectively. This may indicate that fish that were trapped were more motivated to continue migrating upstream, which could be associated with genetic, physiological, or energetic factors. For example, fish that are less reproductively mature and/or have more energy reserves may be more likely to continue migrating rather than selecting to spawn downstream (assuming fish have some innate ability to sense longevity).

It was hypothesized that observed differences in achieved passage success within and among years could be explained by variability in operational and/or physical conditions at Merwin Dam, in particular, discharge from Unit 1 (power generating turbine that discharges adjacent to the trap entrance) and total river flow (overall flow conditions controlled by Merwin Dam). Based on initial examination of data across the three years of study for winter steelhead, there is limited evidence to suggest an effect of Unit 1 discharge on trap entrance, but there was some evidence that once total river flow exceeded 8,000 cfs, fewer fish reached the area outside the trap entrance or entered the trap. In addition, fish tagged in 2017 experienced generally higher river flow than in 2015 or 2016, and fish in 2017 had the lowest probability of entering the trap area from the tailrace (i.e., lowest P_{EE}). We caution that these findings are observational; further statistical testing or future experimental manipulations are needed to confirm the presence of any effects.

ATE targets at Merwin are consistent with passage standards applied at other dams within the Columbia River basin, regardless of species and passage facility type (e.g., fishway versus trap and haul). There are important differences to consider between different types of passage facilities. For example, fish ladders, which made up the majority of reported passage types, require fish to actively ascend a fish ladder, and thus, are energetically costly. In contrast, trap and haul systems reduce the amount of energy expenditure because fish do not have to ascend the dam by swimming, but trap and haul could increase stress levels through confinement and handling. Despite these differences, passage standards are consistent across dams and passage facility type in the Columbia River Basin.

The *ATE* passage standard is set based on an analysis of achieved passage rates observed at other dams in the Columbia River Basin (ACC 2008a, 2008b). Cramer Fish Sciences was unable to acquire the specific analysis, but it was noted that the analysis accounted for drop outs (i.e., strays, fisheries captures). Currently, we are unable to confidently account for drop outs at Merwin Dam, but we note that observed *ATE* at Merwin Dam is likely biased low without accounting for drop outs. Furthermore, there are unique circumstances at Merwin Dam that could influence the number of drop outs in the system including:

1) existence of potentially competing olfactory cues at a downstream hatchery and the trap area;
2) transport and release location effects on juvenile steelhead imprinting;
3) genetic effects;
4) prior trapping of fish used in the study (i.e., the use of trap non-naïve fish); or
5) a combination of the above.

Evidence from this study indicates winter steelhead are attracted to a downstream hatchery, the Lewis River Hatchery. Among of all detection sites, fish spent the most time in the Lewis River outside the hatchery, almost double the total amount of time spent in the tailrace. Fish also appeared to hold in the area of the hatchery based on a relatively high median residence time at the hatchery site. Additionally, during the study, 30 fish were documented exiting the tailrace and moving downstream to the hatchery. Of these 30 fish, 18 fish (60%) were eventually captured. It is important to note that Merwin Hatchery water is used to attract fish to the trap entrance, and similar olfactory cuesin hatchery source water could attract fish to the downstream Lewis River Hatchery. A more detailed assessment of fish returning to the Lewis River Hatchery would increase our understanding of any effects of the downstream hatchery on fish behavior.

Our estimates of *ATE* assume that fish tagged and released as part of the study behave the same as the larger population (i.e., that ATE_{test} is an appropriate surrogate for inferring *ATE* of the parent population). Fish in this study were non-naïve fish to the trap because they had previously navigated to the Merwin Dam tailrace, located the trap entrance, ascended the ladder and were successfully captured. The issue of using trap non-naïve fish continues to be a potential source of bias on observed *ATE*. Our review of reports and scientific literature on fish passage success of non-naïve fish indicates lower passage success of fish that are made to pass an obstacle a second time. However, in many cases, these studies examine dam passage via fishways, which require substantially more effort to pass than passing via the trap at Merwin Dam. Thus, we might expect a reduced effect of non-naïve fish on fish passage estimates at Merwin Dam compared to other fish passage facilities.

A heuristic calculation was applied to current *ATE* estimates to account for negative bias associated with using trap non-naïve fish. Burnett et al. (2014) showed a 16% reduction in passage of fishway non-naïve fish compared to fishway naïve fish. These non-naïve passage estimates represent the lower end of dam reascension rates by non-naïve fish in the literature, but may be most appropriate to apply to *ATE* estimates at Merwin Dam for the reasons described hereafter. Burnett et al. (2014) estimates were not based on fallbacks (fish that descended a fishway after successfully ascending the fishway), rather fish were randomly captured from the top of a fishway and then transported and released downstream, similar to fish used to assess *ATE* at Merwin Dam. We would surmise that fish that fallback in a system may be in poor condition, and therefore, not representative of the overall population of migrants. Therefore, reasension rates of fallbacks may not be comparable to recapture rates of trap non-naïve fish at Merwin Dam. Based on applying a 16% non-naïve correction factor to *ATE* estimates at Merwin Dam, *ATE* estimates for 2017 would increase to 92%. This corrected *ATE* estimate is below the 98% target (104 out of one million urn randomizations as described above returned an ATE of 92% or less, for $p = 0.0001$ that 92% is truly less than the 98% target). However, we note this estimate does not account for straying rates, which also negatively bias *ATE* estimates.

Straying may play a role in observed *ATE* at Merwin Dam due to genetic and life history traits of BWT steelhead, which are complicated due to broodstock used to establish the population (broodstock can be taken from spawning individuals below Merwin Dam) and juvenile life history patterns (juveniles are reared in a hatchery and transported downstream for release). Although straying rates of steelhead are generally thought to be low, our study does include some evidence that BWT steelhead in this study may be more likely to stray. Evidence includes:

1) relatively large amount of time spent at the downstream hatchery suggests fish are attracted to cues from the hatchery;
2) no clear directional path of fish that are successfully trapped based on network analysis;
3) movements of fish from the tailrace downstream; and
4) large overall number of sites visited prior to capture (50% of fish that are captured visit 100 or more sites prior to being captured.

All of the above suggest exploratory behavior of BWT steelhead in the Lewis River. Future efforts that enumerate downstream spawning and straying into the hatchery or other tributaries are necessary to resolve the potential effects of straying on observed *ATE* at Merwin Dam.

Finally, The Lewis River Salmon Program's goals are to create a healthy and sustainable native population of salmon in the upper Lewis River. A larger question, which falls outside the scope of this report, is whether the 98% target is appropriate for meeting these biological and management goals. It is entirely possible that a lower *ATE* could still meet the goals of maintaining genetic diversity and ensuring appropriate recruitment. An analysis of the number of fish required to meet these objectives is possible and could result in a more pragmatic and cost-effective solution to fish passage at Merwin Dam.

CONCLUSIONS

In 2017, estimated adult trap efficiency (*ATE*) for BWT winter steelhead at the Merwin Dam Fish Trap Facility was 76.3%, which is below the performance standard of 98%.

However, the Merwin Dam Fish Trap Facility did achieve the performance standard for median tailrace time of less than or equal to 24 hours (median = 11.8 hours in 2017).

The performance standard of less than or equal to 5% of fish taking longer than 168 hours to pass was also not met (7% of fish took longer than 168 hours to pass in 2017).

Estimated *ATE* in 2017 was the highest among the three study years, which may in part be a result of a fyke installed within the trap ladder prior to the 2017 study.

The fyke proved effective in reducing the number of trap exit events from the previous study year.

Similar to previous study years, *ATE* appears to be limited by the ability of fish to locate and enter the trap from the tailrace.

Preliminary observations suggest elevated overall Merwin Dam discharge may impede fish ability to locate and enter the trap, however, this was only observed at the highest discharge levels.

Models using fish detection data to predict *ATE* in the event a second trap entrance was installed on the north side of the tailrace indicated an increase in *ATE*, but *ATE* levels remained well below the 98% *ATE* target.

A review of *ATE* performance standards showed performance standards for fish passage are consistent across dams within the Columbia River basin, but very few fish passage facilities report their achieved passage efficiencies.

Established performance standards are based on analysis of achieved passage efficiency at other dams within the Columbia River basin.

Importantly, this analysis accounted for dropouts (i.e., straying, fisheries capture), which are currently not accounted for at Merwin Dam.

Factors that could contribute to dropout rates in the Merwin system include straying rates and using trap non-naïve fish (fish used in the study have already been captured once).

Until these factors are accounted for, current *ATE* estimates at Merwin Dam are likely biased low.

We suggest tagging trap naïve fish and enumerating downstream spawning of BWT winter steelhead in future years to understand how using trap non-naïve fish and how straying rates influence *ATE* estimates.

REFERENCES

Aquatic Coordination Committee (ACC). 2008a. Lewis River License Implementation: Final meeting notes. Ariel, WA. June 12, 2008. http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Hydro/Hydro_Licensing/Lewis_River/li/acc/6_12_08_Meeting_Notes.pdf

Aquatic Coordination Committee (ACC). 2008b. Lewis River License Implementation: Final meeting notes. Ariel, WA. February 14, 2008. http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Hydro/Hydro_Licensing/Lewis_River/li/acc/2_14_08_Meeting_Notes.pdf

Bett, N. N., & Hinch, S. G. (2015). Attraction of migrating adult sockeye salmon to conspecifics in the absence of natal chemical cues. *Behavioral Ecology*, *26*(4), 1180-1187.

Blank, S. 2009. Resampling Stats Add-in for Excel User’s Guide. Statistics.com. Arlington, VA.

Boggs, C. T., Keefer, M. L., Peery, C. A., Bjornn, T. C., & Stuehrenberg, L. C. (2004). Fallback, reascension, and adjusted fishway escapement estimates for adult Chinook salmon and steelhead at Columbia and Snake River dams. *Transactions of the American Fisheries Society*, *133*(4), 932-949.

Brémaud, Pierre. 2013. Markov chains: Gibbs fields, Monte Carlo simulation, and queues. Vol. 31. Springer Science & Business Media.

Bumgarner JD, Dedloff JT (2011) Lyons Ferry complex hatchery evaluation: summer steelhead annual report 2008 and 2009 run year. Washington Department of Fish and Wildlife, Olympia

Burnett, N.J., Hinch, S.G., Braun, D.C., Casselman, M.T., Middleton, C.T., Wilson, S.M. and Cooke, S.J., 2014. Burst swimming in areas of high flow: delayed consequences of anaerobiosis in wild adult sockeye salmon. Physiological and Biochemical Zoology, 87(5), pp.587-598.

Caldwell, L. K., A. L. Pierce, and J. J. Nagler. 2013. Metabolic endocrine factors involved in spawning recovery and rematuration of iteroparous female rainbow trout (*Oncorhynchus mykiss*). General and Comparative Endocrinology 194:124-132.

Caldwell, L., D. Stroud, F. Carpenter, L. Belcher, M. Morasch, K. Denton, and K. Ross. 2017. Merwin Upstream Passage Adult Trap Efficiency: 2016 Final Report. *Prepared by*: Cramer Fish Sciences and K. Denton & Associates. *Prepared for*: Pacific Power (A Division of PacifiCorp).

Caudill, C. C., Daigle, W. R., Keefer, M. L., Boggs, C. T., Jepson, M. A., Burke, B. J., ... & Peery, C. A. (2007). Slow dam passage in adult Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality?. *Canadian Journal of Fisheries and Aquatic Sciences*, *64*(7), 979-995.

Dauble, D.D. and Mueller, R.P., 2000. Upstream passage monitoring: difficulties in estimating survival for adult Chinook salmon in the Columbia and Snake Rivers. *Fisheries*, *25*(8), pp.24-34.

Davis, M. W. 2007. Simulated fishing experiments for predicting delayed mortality rates using reflex impairment in restrained fish. ICES Journal of Marine Science: Journal du Conseil 64:1535-1542.

Davis, M. W. 2010. Fish stress and mortality can be predicted using reflex impairment. Fish and Fisheries 11:1-11.

Federal Columbia River Power System (FCRPS), 2017. 2016 Comprehensive Evaluation – Section 1. January 2017.

Frick, K.E., Burke, B.J., Garnett, J., Jepson, M.A., Keefer, M.L. and Caudill, C.C., 2015. Passage evaluation of radio-tagged Chinook and sockeye salmon after modifications at The Dalles and John Day Dams, 2014.

Griffith, J.N., Hendry, A.P. and Quinn, T.P., 1999. Straying of adult sockeye salmon, *Oncorhynchus nerka*, entering a non-natal hatchery. *FISHERY BULLETIN-NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION*, *97*, pp.713-716.

Jepson, M.A., Caudill, C.C., Clabough, T.S., Peery, C.A., Beeman, J.W., Fielding, S. and District, W.W., 2009. *Adult Chinook salmon passage at Little Goose Dam in relation to spill operations - 2008*. Technical Report 2009-6. Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho.

Johnson, Gary E., et al. 2004. A Markov chain analysis of fish movements to determine entrainment zones. Fisheries Research 69.3: 349-358.

Keefer, Matthew & C. Joosten, D & L. Williams, C & M. Nauman, C & A. Jepson, M & Peery, Christopher & C. Bjornn, T & R. Ringe, R & R. Tolotti, K & R. Lee, S & C. Stuehrenberg, L & M. Moser, M., 2008a. Adult Salmon and Steelhead Passage Through Fishways and Transition Pools at Bonneville Dam, 1997-2002.

Keefer, M. L., C. C. Caudill, C. A. Peery, and S. R. Lee. 2008b. Transporting juvenile salmonids around dams impairs adult migration. Ecological Applications 18:1888-1900.

Keefer, M.L., Caudill, C.C., Peery, C.A. and Boggs, C.T., 2008c. Non-direct homing behaviours by adult Chinook salmon in a large, multi-stock river system. *Journal of Fish Biology*, *72*(1), pp.27-44.

Keefer, M. L., & Caudill, C. C. (2012). A review of adult salmon and steelhead straying with an emphasis on the Columbia River basin. *University of Idaho Department of Fish and Wildlife Sciences. Technical Report, 6.*

Keefer, M. L., & Caudill, C. C. (2014). Homing and straying by anadromous salmonids: a review of mechanisms and rates. *Reviews in Fish Biology and Fisheries*, *24*(1), 333-368.

Manly, B.F.J. 2007. Randomization, Bootstrap and Monte Carlo Methods in Biology. Chapman & Hall/CRC (Taylor & Francis Group), Boca Raton, FL.

Manly, B.F. 2011. Bootstrapping with models for count data. Journal of Biopharmaceutical Statatistics 21(6): 1164-1176.

Morbey YE, Brassil CE, Hendry AP (2005) Rapid senescence in Pacific salmon. The American Naturalist 166:556–568.

National Marine Fisheries Service (NMFS), 2008. Recovery Plan Module: Mainstem Columbia River Hydropower Projects. September 24, 2008.

National Marine Fisheries Service (NMFS), 2011. Anadromous Salmonid Passage Facility Design. NMFS, Northwest Region, Portland, Oregon.

PacifiCorp and Cowlitz County PUD No. 1. 2016. Lewis River DRAFT Aquatic Monitoring and Evaluation Plan – First Revision - December 19, 2016. PacifiCorp Energy and Public Utility District No. 1 of Cowlitz County.

Pearsons, T.N., Dresser, T.J., Graf, P.J., Nicholls, M.S., Lowry, S., Clement, M.C. and Dotson, C.L., 2016. Emergency Fish Passage at a Fractured Mainstem Columbia River Dam. *Fisheries*, *41*(11), pp.622-629

Quinn TP (1984) Homing and straying in Pacific salmon. In: McCleave JD, Arnold GP, Dodson JJ, Neill WH (eds.) Mechanisms of migration in fishes. Plenum Press, New York, pp 357–392

R Core Team. 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Raby, G. D., M. R. Donaldson, S. G. Hinch, D. A. Patterson, A. G. Lotto, D. Robichaud, K. K. English, W. G. Willmore, A. P. Farrell, M. W. Davis, and S. J. Cooke. 2012. Validation of reflex indicators for measuring vitality and predicting the delayed mortality of wild coho salmon bycatch released from fishing gears. Journal of Applied Ecology 49:90-98.

Roscoe D.W., S.G. Hinch, S.J. Cooke, and D.A. Patterson. 2011. Fishway passage and post passage mortality of up-river migrating sockeye salmon in the Seton River, British Columbia. River Research and Applications 27:693–705.

Thorstad, E.B., Okland, F., Kroglund, F., and Jepsen, N. 2003. Upstream migration of Atlantic salmon at a power station on the River Nidelva, Southern Norway. Fisheries Management and Ecology 10: 139–146.

Upper Columbia Regional Technical Team (UCRTT), 2015. Final Meeting Notes, 11 February 2015.

U.S. Army Corps of Engineers (USACE), 2015. Final Environmental Assessment for Mud Mountain Dam Upstream Fish Passage, Pierce County, Washington. May, 2015.

U.S. Geological Survey, 2017, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation) at URL [http://waterdata.usgs.gov/nwis/].

APPENDIX A: SUPPLEMENTARY FIGURES AND TABLES

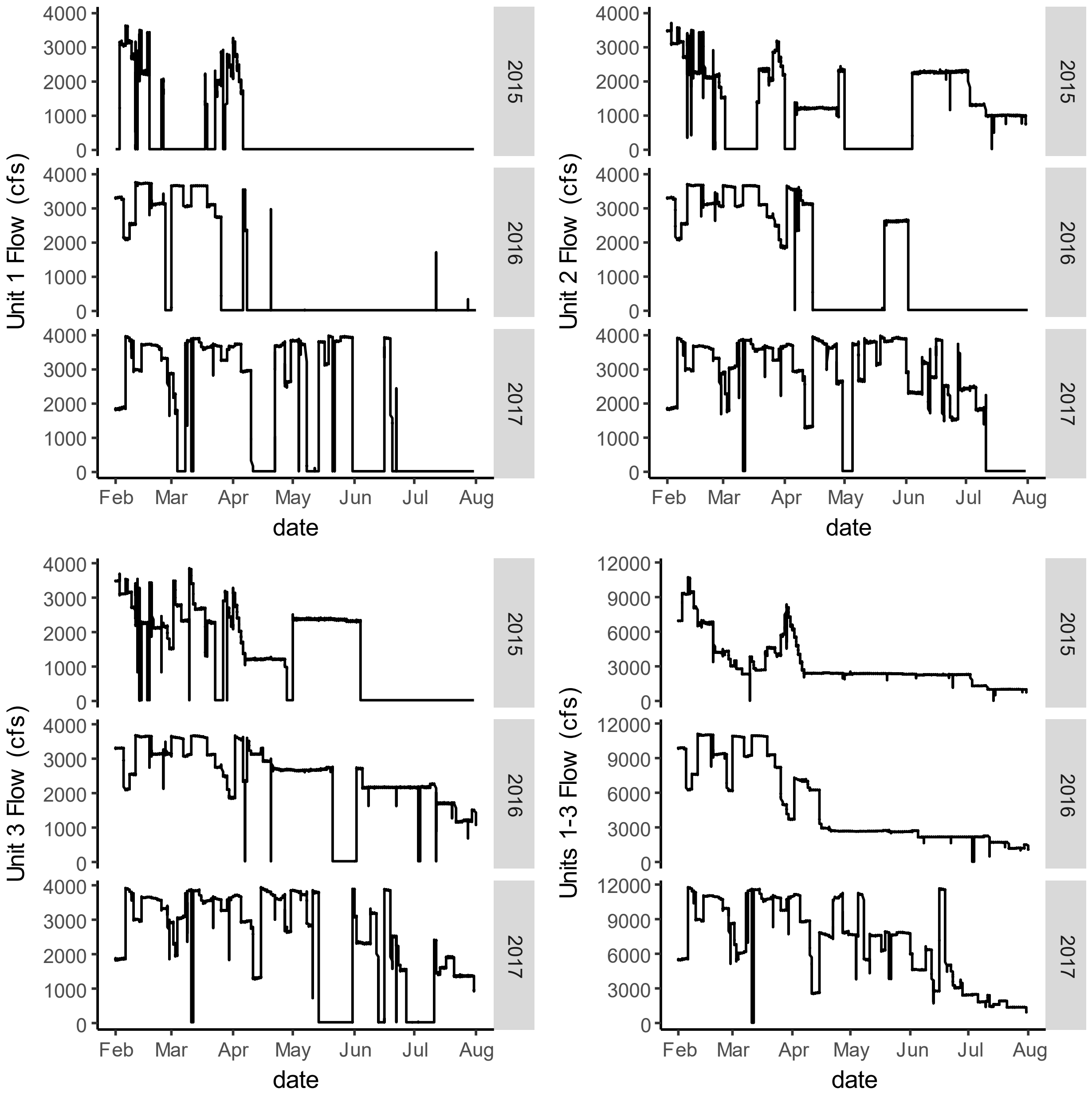


Figure A-1. Hourly mean discharge from Merwin Dam power generation Units 1-3 during months of winter steelhead tagging across three years (2015, 2016, 2017).

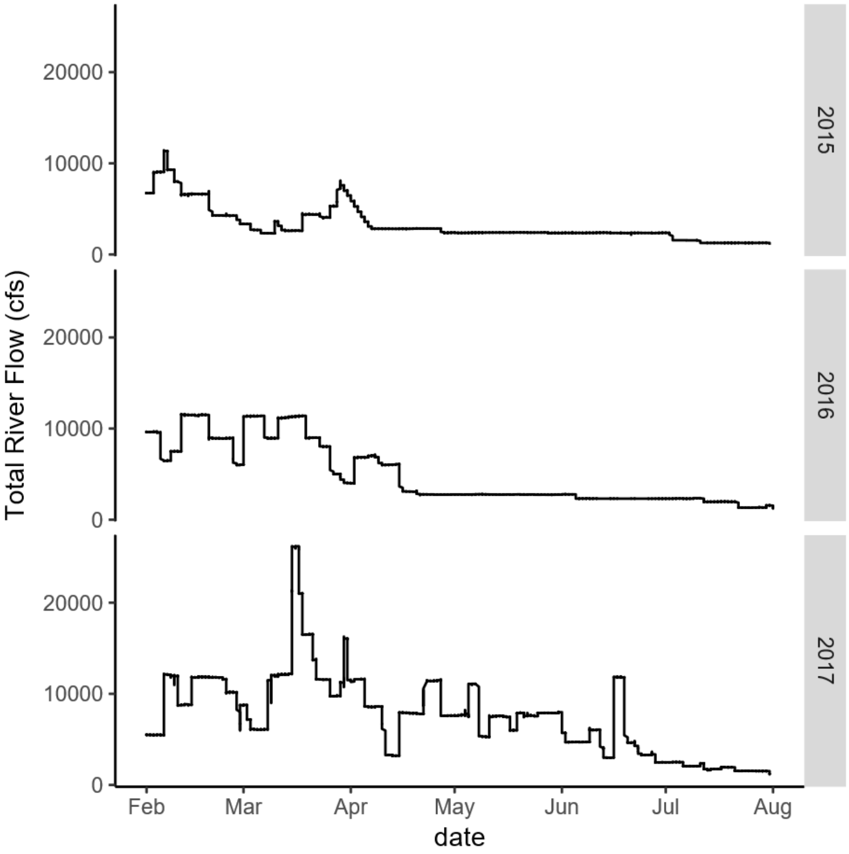


Figure A-2. Hourly mean Lewis River discharge below Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017).

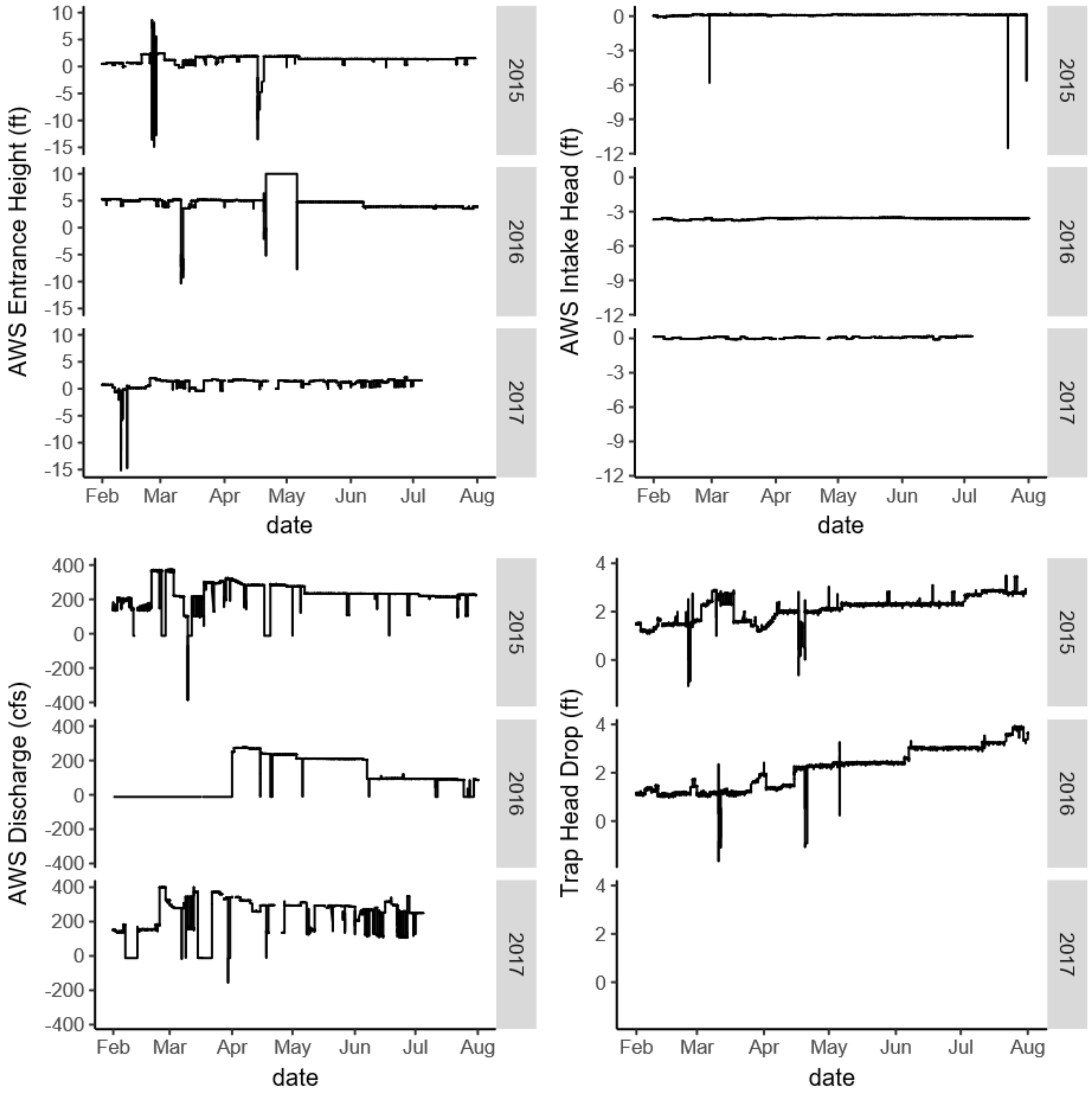


Figure A-3. Hourly mean AWS entrance height (top left), AWS intake head (top right), AWS discharge (bottom left), and trap head drop measured in the trap area at Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017).

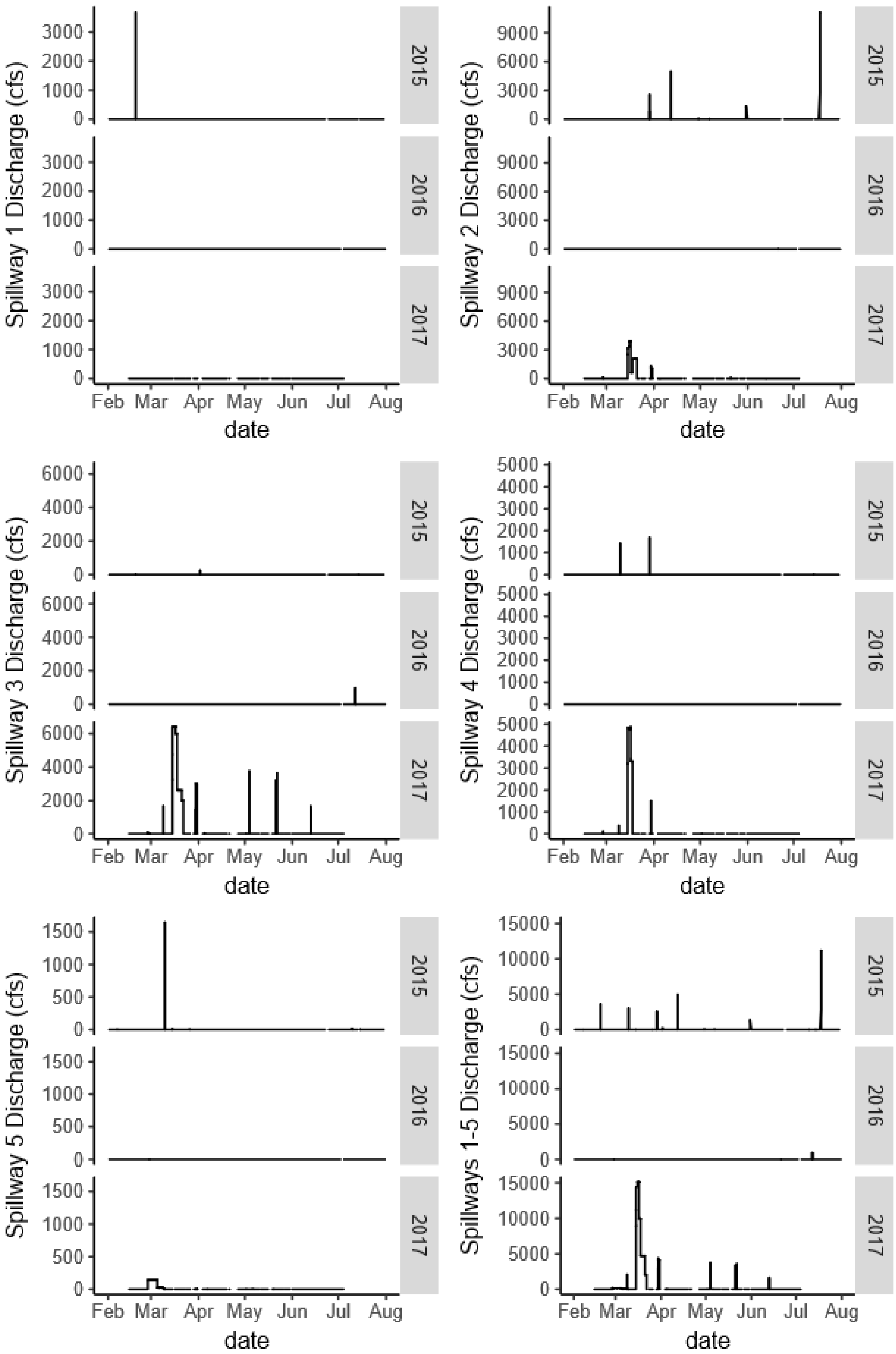


Figure A-4. Hourly mean discharge from five Spillways at Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017).

Table A-1. Radio tag ID, sex, length, and furthest and last locations of detection for fish not recaptured in the Merwin Dam Fish Trap in 2017 study year.

Tag ID	Sex	Length	Furthest Detection	Last Detection
65	F	76	APR	BBL
66	F	73	APR	BRG
114	M	81	APR	BLU
117	F	79	LRH	LRH
119	M	84	BRG	BBL
176	F	87	BRG	BBL
177	F	85	LRH	BBL
187	M	84	BRG	BBL
192	M	72	PL4	BBL
224	F	79	APR	BBL
227	F	82	HOP	BBL
236	F	81	APR	APR
237	M	66	BLD	LRH
238	M	70	BLU	BBL
240	M	65	APR	BBL
241	M	89	APR	LRH
245	F	86	BBL	BBL
252	F	65	BRG	BBL
254	F	64	PL4	BBL
255	F	64	LRH	BBL
259	F	66	APR	LRH
260	F	71	APR	APR
262	F	77	BBL	BBL
263	F	65	PL2	BBL
266	F	78	BRG	BBL
268	F	74	HOP	BBL
271	M	66	BLU	BBL
273	F	78	APR	BBL
274	M	84	BRG	BBL
280	M	77	HOP	BBL
282	F	72	APR	BBL
288	F	78	PWN, PWS	BBL
289	M	75	BLU	BRG
422	F	78	BRG	BBL

Tag ID	Sex	Length	Furthest Detection	Last Detection
424	M	89	PWN, PWS	BBL
432	M	94	LRH	LRH
435	F	71	HOP	BBL
443	F	75	HOP	BBL
449	F	68	PL2	LRH
452	M	63	SS, NS	BBL
454	F	80	HOP	BRG
459	F	79	SS, NS	NS
461	F	81	SS, NS	BBL
463	M	84	LRH	LRH