Lewis River Fish Passage Program
2017 Annual Report (Final)

FERC Project Nos. 935, 2071, 2111 and 2213

Photo by Al Thomas

PacifiCorp
&
Public Utility District No.1 of Cowlitz County

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ACRONYMS AND ABBREVIATIONS

ACC	Aquatics Coordinating Committee
ADCP	Acoustic Doppler Current Profiler
ATE	Adult Trap Efficiency
AWS	Auxiliary Water Supply
BKD	Bacterial Kidney Disease
CE	Collection Efficiency
CFS	Cubic Feet Per Second
CWT	Coded Wire Tag
EA	Electro-Anesthesia
FCE	Fish Collection Efficiency
FL	Fork Length
FPS	Feet Per Second
FSC	Fish Collection Facility
H&S	Hatchery and Supplemental Plan or Subgroup
HR	Hatchery returns
LWS	Ladder Water Supply
mm	millimeter
NTS	Net Transition Structure
ODS	Overall Downstream Survival
PIT	Passive Integrated Transponder tag
RMIS	Regional Mark Information System
ROV	Remotely Operated Vehicle
SAF	Sorting Area Flow Pumps
UPS	Upstream Passage Survival
ZOI	Zone of Influence

EXECUTIVE SUMMARY

The purpose of this report is to document results of the field assessments associated with implementation of the fish passage program in the existing Lewis River Aquatic Monitoring and Evaluation Plan[1] (M&E Plan) during 2017. The M&E Plan was developed as part of the Settlement Agreement to evaluate performance measures outlined in the new FERC Licenses. These Licenses were issued to PacifiCorp and Cowlitz PUD for operation of the North Fork Lewis Hydroelectric Projects on June 26, 2008. This report summarizes both upstream and downstream fish passage and collection metrics as well as provides an overview of environmental conditions and key procedural changes that occurred in 2017. The following is a brief summary of relevant performance metrics documented in this report:

Description	M&E Obj.	Performance Goal	2017 Data	Summary
Number of Juveniles Passing Eagle Cliff During Screw Trap Operations	Obj. 7 Task 7.1	Monitoring	33,385 coho 2,366 steelhead 6,493 Chinook 1,057 cutthroat	Estimates of the total number of juvenile coho, Chinook, steelhead, and cutthroat were made over a 16-week period using screw trap catch information. The trap was located at the head of Swift Reservoir at Eagle Cliff.
Number of Juveniles Entering Swift Reservoir	Obj. 7 Task 7.2	Monitoring	140,366 coho 17,655 steelhead 57,948 Chinook 10,659 cutthroat	Estimates of the total number of juvenile coho, steelhead, and cutthroat that entered Swift Reservoir during 2017.
Number of Fish Collected at the Swift Floating Surface Collector (FSC)	Obj. 6	Monitoring	28,097 coho 1,816 steelhead 5,801 Chinook 804 cutthroat	A total 39,972 salmonids were captured by the FSC in 2017. Of these fish, 36,972 were transported and released downstream of Merwin Dam.
Juvenile Migration Timing	Obj. 8	Monitoring	Various	Overall, the run timing in 2017 consisted of two pronounced periods. The first followed a normal springtime distribution for rivers west of the Cascades. The peak spring out-migration period generally occurred from the first of April through June. The second was in the fall, which peaked in late-November and early December, and contributed more than 50% of the total annual run numbers for all species.
FSC Collection Efficiency (CE)	Obj. 2	Juvenile Collection Efficiency > 95%	Combined 21.7% Coho 26.7% Chinook 11.3% Steelhead 19.7%	In 2017, CE was evaluated using acoustic telemetry. Of the 520 tagged fish released at the head of Swift Reservoir, 333 were detected in the Zone of Influence and 74 were successfully collected at the FSC for an overall CE estimate of 21.7%.
Swift FSC Injury	Obj. 5	Smolts and Fry < 2%	Fry (0.0%) Smolt (0.2%)	Annual injury rates for all juvenile salmonid species met the required performance standard of 2.0%.

[1] The methods used in this report follow the revised methods for the M&E Plan dated 2016.

Description	M&E Obj.	Performance Goal	2017 Estimate	Summary
Swift FSC Survival	Obj 4.	Fry > 98.0% Smolt > 99.5%	Fry (86.5%) Smolt (98.4%)	The combined survival rate for both salmonid fry (86.5%) and smolts (98.4%) did not meet the performance standards of 98% and 99.5%, respectively. Periods of heavy debris loading largely contributed to this metric not being met.
Overall Downstream Survival (ODS)	Obj. 1	> 80%	Coho 18% Chinook 10% Steelhead 10% Cutthroat 5.4%	During 2017, 398 coho, 269 steelhead, 56 cutthroat, and 494 Chinook were tagged and released for the ODS study. Of these fish, 71 coho, 64 Chinook, 27 steelhead, and 3 cutthroat were recaptured at the FSC and passed downstream.
Number of Adult Fish Collected at the Merwin Fish Collection Facility	Obj. 11	Monitoring	Various	A total 17,551 fish were captured at the Merwin Trap in 2017. Of these fish, a total of 592 blank wire tag winter steelhead, 1,110 spring Chinook, 3,556 early coho, 3,257 late coho, and 54 cutthroat were transported upstream and released above Swift Dam as part of the reintroduction program.
Adult Passage Survival	Obj. 9	99.50%	Coho (S) 99.6% Coho (N) 99.9% Chinook 99.2% Steelhead 99.8% Cutthroat 100%	All cutthroat survived the trapping and transport processes resulting in a UPS of 100 percent. One blank wire tag winter steelhead mortality was observed during the transport process, resulting in a 99.8 percent UPS. Eighteen coho mortalities were observed overall, resulting in a 99.7 percent UPS. Nine spring Chinook were recorded as mortalities at the Merwin Trap, which resulted in a UPS of 99.2 percent in 2017.
Adult Trap Efficiency (ATE)	Obj. 10	> 98%	Coho 63% Chinook NA Steelhead 77%	A third year of evaluation was completed in 2017 for blank wire tag winter steelhead and natural origin coho salmon. The estimated collection efficiency of each species was 77 percent and 63 percent, respectively.

1.0 INTRODUCTION

The North Fork Lewis Hydroelectric Project begins about 10 miles east of Woodland, Washington (Figure 1.0-1), and consists of four impoundments. The sequence of the four Lewis River projects upstream of the confluence of the Lewis and Columbia rivers is: Merwin, Yale, Swift No. 2, and Swift No.1. These four projects are licensed separately by the Federal Energy Regulatory Commission (FERC). Merwin (FERC No. 935), Yale (FERC No. 2071), and Swift No. 1 (FERC No. 2111) are owned and operated by PacifiCorp. Swift No. 2 (FERC NO. 2213) is owned by Public Utility District No. 1 of Cowlitz County (Cowlitz PUD) and is operated by PacifiCorp in coordination with the other projects. Combined, the Lewis River Projects have a generation capacity of 606 megawatts.

On June 26, 2008, PacifiCorp and Cowlitz PUD, FERC issued Orders approving the Settlement Agreement and granting new licenses for the North Fork Lewis River Hydroelectric Projects. Among the conditions contained in each License was a requirement for reintroducing anadromous salmonids and providing fish passage upstream of Merwin Dam and downstream of Swift No. 1 Dam. 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 for reintroduction are spring Chinook salmon (*Oncorhynchus tshawytscha),* early-run (S-type) coho salmon (*O. kisutch),* and winter steelhead (*O. mykiss*).

The Settlement Agreement called for a phased approach for reintroduction that occurs over a seventeen year period following issuance of the new Licenses. The phased approach provides a carefully devised plan to protect the Endangered Species Act (ESA) listed species and to verify the effectiveness of passage facilities as the reintroduction program takes effect. Among the tasks identified for Phase I of the reintroduction plan were establishing a downstream passage facility in the forebay of Swift No.1 Dam and making upgrades to the existing adult fish capture facility at Merwin Dam. Subsequent phases would establish facilities for both upstream and downstream passage at Merwin, Yale, and Swift No.1 Dams, with fish ultimately spawning and rearing naturally throughout the project area. A decision on whether subsequent phases are implemented is anticipated in 2018.

The Lewis River Aquatic Monitoring and Evaluation (M&E) Plan (PacifiCorp and Cowlitz PUD 2016) was developed as part of the Settlement Agreement to evaluate performance measures outlined in the new Licenses. The primary focus of the plan is to provide methods for monitoring and evaluating the fish passage program. In accordance with the Settlement Agreement, the Licensees shall consult with the Aquatic Coordination Committee (ACC) as necessary, but no less often than every five years, to determine if modifications to the M&E Plan are warranted (SA 9.1). Revisions to the original M&E Plan were completed in early 2017 and this report follows the updated methods. The purpose of this report is to document results of the field assessments associated with implementation of the fish passage program in the existing M&E Plan during 2017.

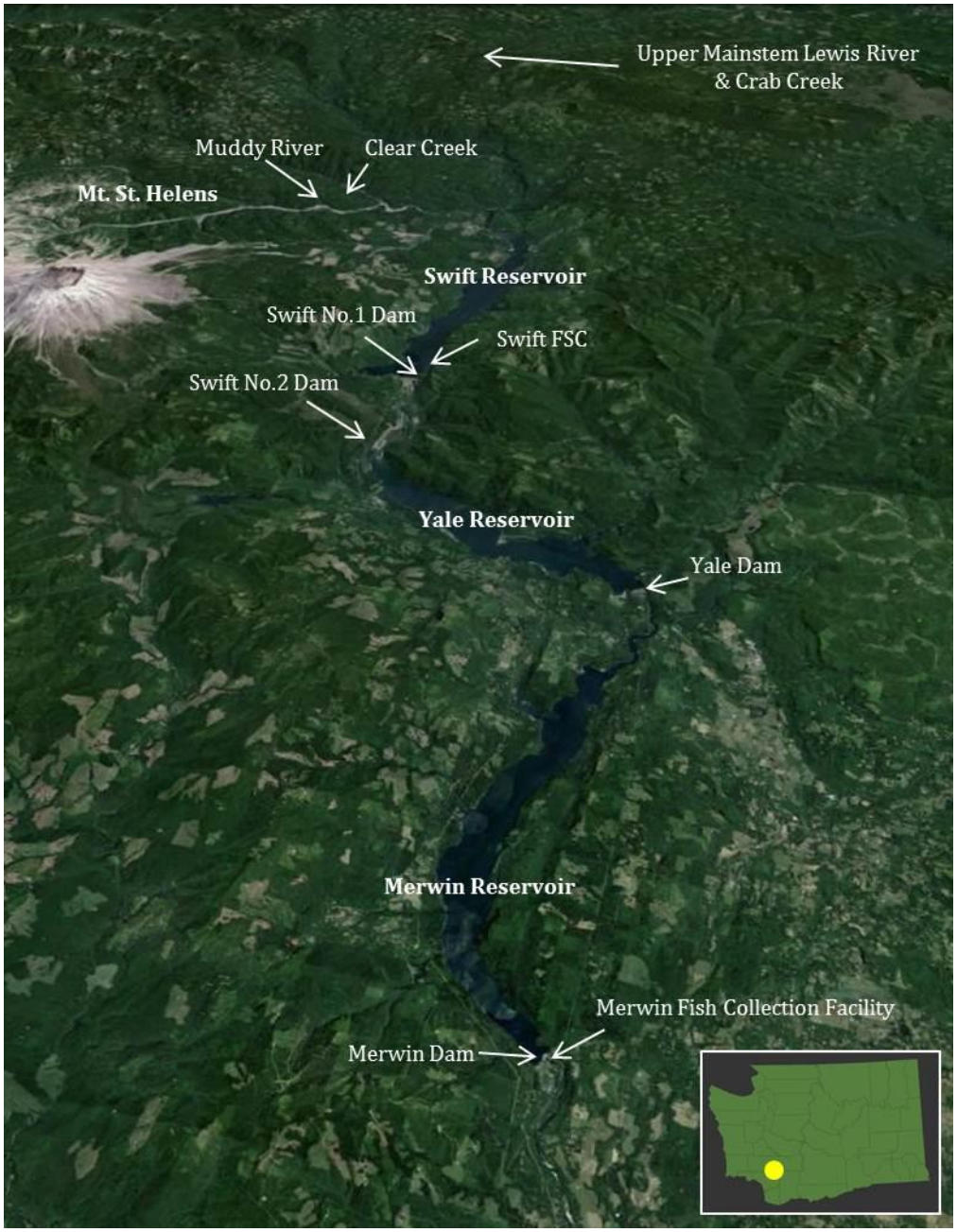


Figure 1.0-1. An overview of key features of the North Fork Lewis River Hydroelectric Project area located in southwest Washington.

Some noteworthy environmental conditions and procedural changes occurred in 2017. These are summarized below:

- *Minimum Flow Requirement Below Merwin Dam:* During calendar year 2017, flows below the Merwin Project were maintained at or above minimum flow levels stipulated in the June 26, 2008 FERC licenses. On average, flows below Merwin Dam were higher than the 10-year average, particularly from January through May, due to higher than average snowpack and subsequent runoff (2016/2017)(Figure 1.0-2).

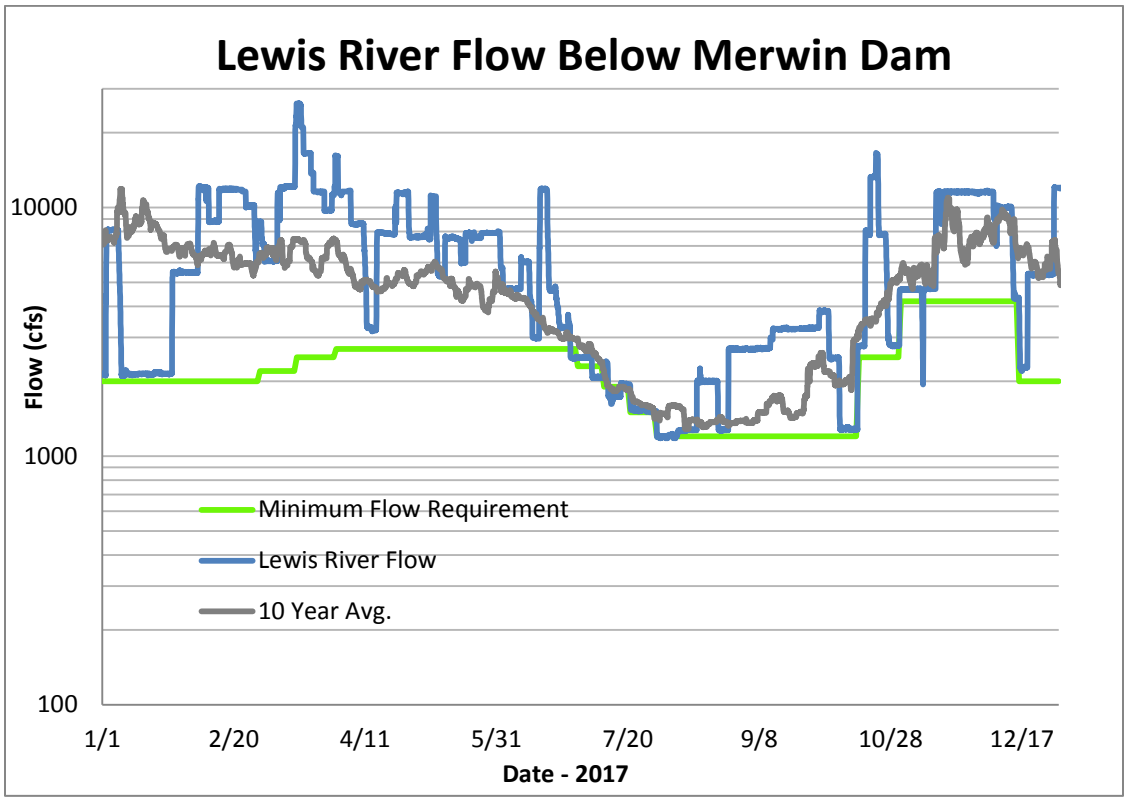


Figure 1.0-2. Lewis River flow below Merwin Dam as recorded by USGS gage (14220500 Ariel WA). Minimum flow requirements for 2017 requirements are also shown. The sharp 'dips' in flow during November are scheduled drawdowns associated with WDFW fall Chinook surveys.

- *FSC Summer Outage and Maintenance Period:* In March 2015, the ACC accepted operational changes that allowed the FSC to be turned off during warm reservoir conditions that occur in the summer (Lewis River Fish Passage Program Annual Report 2015). This was done because data indicated that once reservoir temperatures reach approximately 18 ^{o}C, catch rates of fish declined precipitously. Those fish that were collected also experienced high levels of mortality. Annual maintenance activities are to be performed during this summer outage period. It was also decided that while the FSC was off line, operation of the Merwin Trap would be changed from a seven day per week schedule to a five day per week schedule (Lewis River Fish Passage Program Annual Report 2015). This temporary schedule allows the fish crowder and lift assembly to remain operational seven days per week; however, daily sorting of fish only occurs Monday through Friday. These operational changes were also followed in 2017.

- *Modification of the Supplementation Protocols for Adult Coho Transported Upstream of Swift Dam:* In July 2015, the Hatchery and Supplementation (H&S) subgroup met to discuss the protocol for adult coho supplementation upstream of Swift Dam in fall 2015. As part of this discussion, several important modifications were proposed and were ultimately accepted by the ACC during the August 2015 meeting. These strategies were again implemented for adult coho transported above Swift Dam in fall 2017. A detailed description of these modifications can be found in the Lewis River Fish Passage Program Annual Report 2015 and briefly described below:

- Reduction in the number of coho supplemented from 9,000 to 7,500 adults upstream of Swift Dam;

- The addition of late (Type – N) coho as a supplementation species;

- Extending the upstream transport schedule to include both early (Type – S) and late (Type – N) stocks of adult coho.

- *Releases of Acclimation Fish Changed from Spring Releases to Fall Releases:* During their June 2015 meeting, the ACC agreed that releasing acclimation fish earlier in the fall is a better strategy and more akin to the natural out-migration behavior that has been observed in the upper basin. It was also determined that fish released in the fall would be held a shorter amount of time in the hatchery and thus less susceptible to disease (e.g., Bacterial Kidney Disease [BKD]) that has been observed in previous years. Consequently, it was agreed that fall releases of acclimation fish would be implemented moving forward. In total, approximately 53,400 spring Chinook were released at various locations in the upper basin upstream of Swift Reservoir from mid-July through mid-August. (Table 1.0-1).

- *Outmigration Timing of Directly Released Acclimation Fish:* During the summer of 2017, all spring Chinook acclimation fish were directly released into the Upper Lewis River near Crab Creek, the Muddy River near the HooHoo Creek Bridge, and Clear Creek near the Forest Road 93 bridge (Table 1.0-1). No fish were PIT tagged prior to release. The screw trap located at Eagle Cliff was used to estimate the number of fish entering the reservoir from these releases as well as assess outmigration timing. A detailed description of this evaluation, along with results, is reported in Appendix A.

Table 1.0-1. Summary of acclimation fish released into the Upper Lewis River Basin in 2017. All fish were released at one of three locations: the Muddy River near the Hoo Hoo Creek Bridge, Clear Creek near the Forest Road 93 bridge, or in the Upper Lewis River near Crab Creek.

	2017 Spring Chinook Acclimation Releases			
	Muddy River	**Clear Creek**	**Upper Lewis River**	
	4,135 (Released on 7/18)	**2,016** (Released on 7/19)	**4,160** (Released on 7/20)	
	4,250 (Released on 7/25)	**2,100** (Released on 7/26)	**4,000** (Released on 7/27)	
	4,034 **(**Released on 8/1)	**1,997** **(**Released on 8/2)	**6,042** **(**Released on 8/4)	
	8,370 **(**Released on 8/11)		**8,247** **(**Released on 8/10)	**Total Released**
Total	**20,789**	**10,232**	**22,449**	**53,470**

2.0 PASSAGE FACILITIES

2.1 Swift Reservoir Floating Surface Collector

The Swift Reservoir Floating Surface Collector (FSC) began daily operations on December 26, 2012. The facility is located at the south end of Swift Dam near the turbine intake (Figure 2.1-1), and consists of five primary structures:

- Fish Collection Barge
- Truck Access Trestle
- Mooring Tower
- Barrier and Lead (Guide) Nets
- Net Transition Structure

The Swift Floating Surface Collector is a floating barge that measures 170 feet long, 60 feet wide and 53 feet tall. The purpose of the FSC is to provide attraction flow at the surface of the reservoir where juvenile salmonids are migrating and to capture them. Fish enter the FSC via the Net Transition Structure (NTS), which funnels water and fish into an artificial stream channel created by electric pumps. The stream channel then entrains and guides fish into the collection facility that automatically sorts fish by life-stage (i.e., fry, smolt, and adult) and then routes them to holding tanks for biological sampling and transport downstream[2]. The artificial stream channel is maintained at a capture velocity of approximately 7 feet per second (fps) with 600 cubic feet per second (cfs) attraction flow during normal operations (80% of full flow capacity).

[2] Following transport downstream, smolts are to be transferred into release ponds located near Woodland, WA. Fish are held in these ponds for 24 hours before being allowed to volitionally enter the river. As of December 2017, these ponds were still under construction. It is anticipated that these ponds will be functional by early 2018. Fish transported downstream in 2017 were released directly in the lower river.

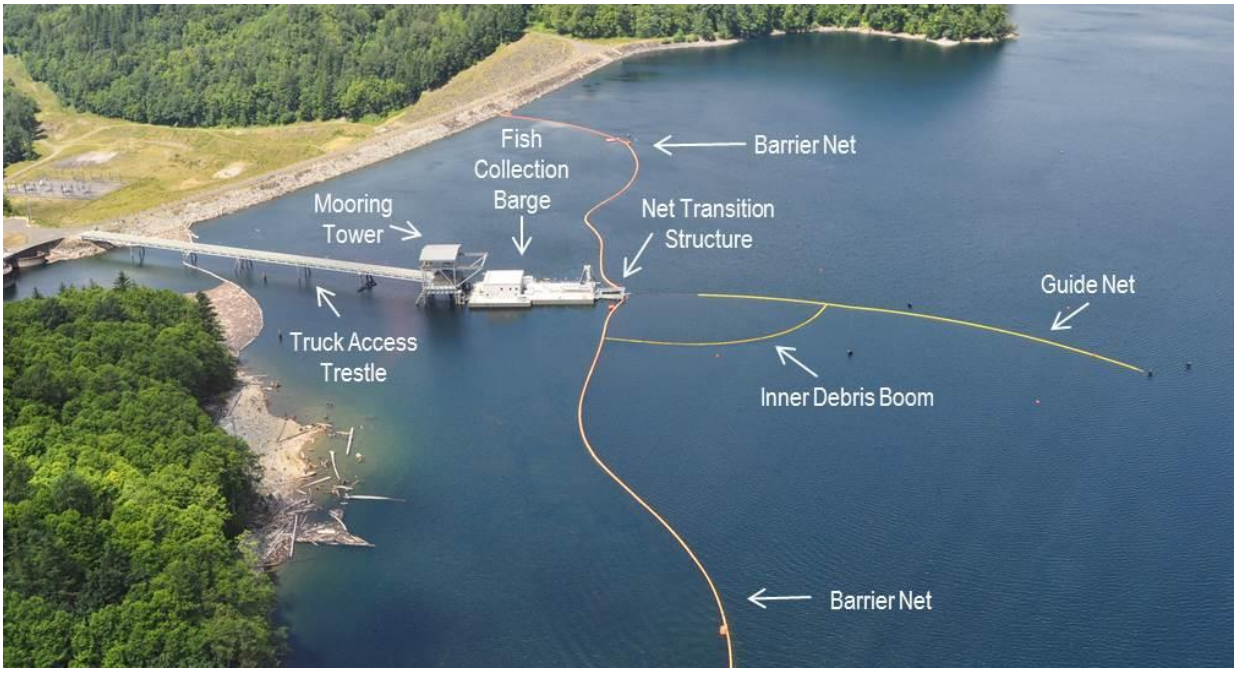


Figure 2.1-1. Aerial photo of the Swift Floating Surface Collector.

The purpose of the 660-foot access trestle is to provide fish transport trucks access to the 280-foot-tall mooring tower. The mooring tower doubles as a hopper-to-truck fish transfer structure, allowing operators to move fish from the FSC to the truck across a broad range of reservoir surface elevations[3].

The portion of the exclusion net located perpendicular to the front of the FSC is approximately 1,700 feet long and consists of three distinct vertical panel materials. The upper section of the net is solid material running 0-15 feet below the surface. The middle net section (15-30 feet) is fine net material (Dyneema™) with 1/8-inch mesh opening. The lower-most section (30 feet and beyond) is also constructed of Dyneema™ with 3/8-inch mesh opening. In addition to the forward-facing exclusion net, there are two side nets that begin at each of the turning points and extend to shore. Each side net is constructed of nylon material. The upper portion (0-15 feet) of the net has a mesh opening of 1/8-inch and the lower portion (15 feet and beyond) has a mesh opening of 3/8-inch.

Soon after the FSC began operation in late December 2012, the exclusion net sustained damage during severe weather conditions. The extent of this damage was evaluated with a number of dive and remotely operated vehicle (ROV) surveys of the net beginning in early February 2013. It was determined that the net separated at both north and south turning points. These tears compromised the effectiveness of the net throughout the 2013 migration season. Efforts to repair the net began in December 2013 and were completed by April 2014. During this repair period, the FSC was turned off. The FSC resumed operation on April 1, 2014.

In March 2016, a lead net was installed at the entrance of the FSC. The purpose of the lead net is to orient out-migrants towards the entrance of the collector and improve collection efficiency. The total length of the lead net is 650 feet and it is oriented nearly perpendicular to the existing FSC barrier net. The top 30 feet of the guide net is constructed from Dyneema© with a 3/32-inch mesh gap and the lower 30 feet is constructed from polyester with a 1/4-inch mesh gap, for a total net depth of 60 feet. The net

[3] The Swift FSC has an operation range of 100 feet in reservoir elevation change.

extends approximately 30 feet inside from the entrance of the existing NTS to prevent fish from easily swimming back out the opposite side of the FSC.

The FSC operated 24-hours a day through 2017 except during periods when it was necessary to shut the facility down due to power outages, facility modification, or scheduled maintenance (Table 2.1-1).

Table 2.1-1. List of FSC outages that occurred in 2017.

Date	Reason For Outage
02/14-02/15	Heavy debris Loading
02/22-02/24	Hydrophone installation
02/24-03/02	Primary screen cleaner drive repair
3/17-3/22	Spill at Swift Dam
7/22-10/20	Summer maintenance period
12/9-12/13	Primary pump installation

2.2 Merwin Upstream Collection Facility

The new upstream collection and transport facility (Figure 2.2-1) at Merwin Dam was considered substantially complete in April 2014. The intent of the modifications made to the existing collection facility was to provide safe, timely and effective passage of adult salmonids being transported upstream.

The new facility is designed to be constructed in phases, offering the ability to incrementally improve fish passage performance (if needed) in the future to meet biological performance goals. Depending on the biological monitoring of the facility's performance (which began spring 2015), there are up to four additional phases that will increase flow into the fishway attraction pools, and add a second fishway with additional attraction flow, if necessary (per the Lewis River Settlement Agreement, Section 4.1.6.).

Phase I represents the initial construction, consisting of four major features (Figure 2.2-1):

- Auxiliary Water Supply Pump Station and Conveyance Pipe
- Fishway Entrance Number 1
- Lift and Conveyance System
- Sorting Facility

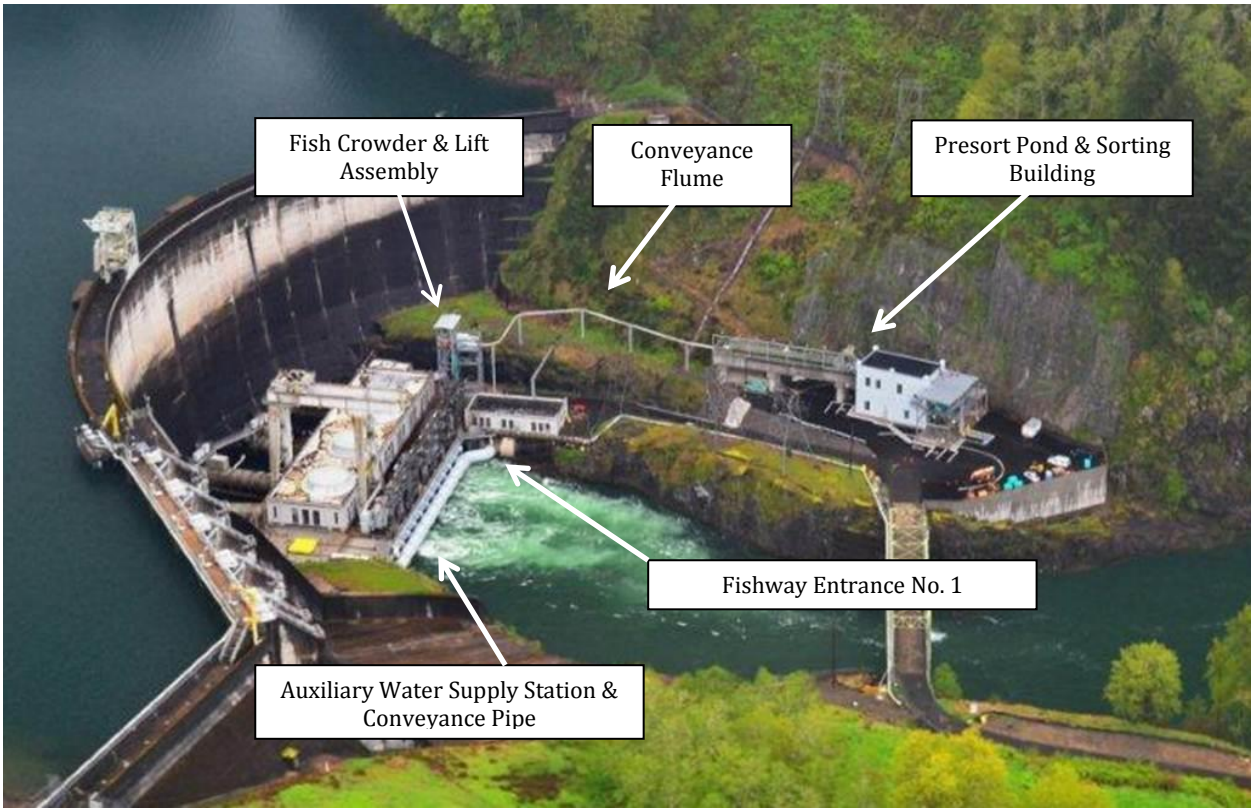


Figure 2.2-1. Merwin Sorting Facility.

The auxiliary water supply (AWS) system provides pumped water from the tailrace to the fishway entrance pools to attract fish from the tailrace. This system uses hydraulic turbines to power attraction water pumps. Tailrace water is used (as opposed to reservoir water) to allow generation with the attraction flow with the high head dam prior to the water's use in the fishway. The AWS system also includes a 108-inch pipeline and conveyance conduits to deliver the water from the tailrace to the lower fishway entrance pools (Pool 1-1). The AWS system has a flow capacity of 400 cfs attraction flow (Phase 1) with the capacity to increase flows to 600 cfs (Phase 2) if needed.

The entrance of Fishway 1 is located in the tailrace of Merwin Dam adjacent to the discharge of Turbine Unit 1 in the south corner of the powerhouse. The entrance pool (Pool 1-1) contains flow diffusers that introduce the AWS attraction water flow along the Pool 1-1 walls. The diffusers are made of construction pickets with 7/8-inch clear spacing, with baffle panels mounted immediately upstream of the diffusers to dissipate energy and provide uniform flow across the diffusers. Upstream of the lower entrance pool (Pool 1-1) are a series of ladder steps. The ladder has two intermediate pools (Pool 1-2 and Pool 1-3) leading to a loading pool (Pool 1-4). The fish ladder is designed to operate at 30 cfs, and is a "vertical slot" style fish ladder. Water is supplied from hatchery return line (HR) (~11 cfs) and the ladder water supply (LWS) system (~19 cfs). The vertical slots allow the pool levels to self-regulate the water surface elevation. Depending on tailwater elevation, the designed water elevation changes between pools ranges from 0.25 to 1.0 foot.

To prevent fish from returning to the tailrace once they have entered the lower fish ladder, a vertical fyke was installed on the upstream side of the Pool 1-2 weir in November 2016. The "V" style fyke was constructed with one inch stainless steel bars with a spacing of two inches on center and has an exit slot width of six inches.

The loading pool (Pool 1-4) is the last in the fishway and contains the fish crowder which automatically loads fish into the hopper of the lift and conveyance system. The lift and conveyance system then transports fish from the fish ladder over to the sorting building. Fish are transported from the top of the elevator shaft to the pre-sort pond by the 16-inch-diameter conveyance flume (Figure 2.2-2). Fish are held in the Pre-sort Pond until they are sorted by biologists on a daily basis.

All fish sorting is performed manually on the sorting table within the sorting building. Fish are moved from the Pre-sort Pond into the sorting building via a false weir and crowder system. An electro-anesthesia (EA) system temporarily anesthetizes the fish to allow easier handling by staff and to reduce the stress of handling on the fish during sorting. Once sorted, fish are routed into holding tanks for transport by truck to their final destination (i.e., transported upstream, to the hatchery, or returned to the lower Lewis River).

The Merwin Fish Collection Facility operated 24-hours a day through 2017 except during periods when it was necessary to shut the facility down due to facility modifications, scheduled maintenance or repairs (Table 2.2-1).

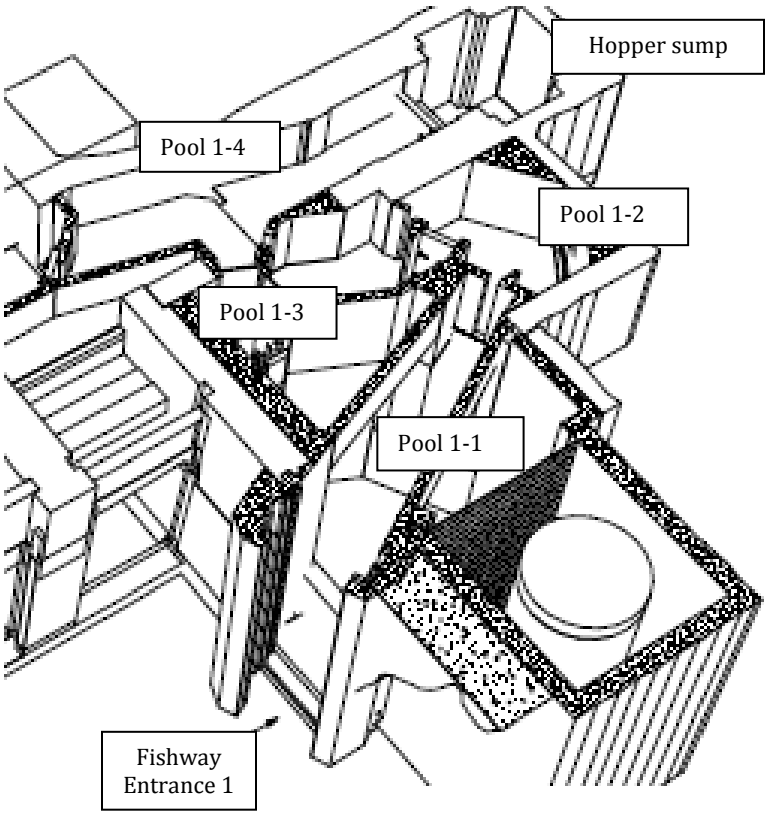


Figure 2.2-2. Merwin Sorting Facility ladder entrance and pool configuration.

Table 2.2-1. List of scheduled outages at the Merwin Fish Sorting Facility in 2017. The fish ladder and fyke remained operational - only the fish lift and crowder assembly was not operated.

Outage Duration	Purpose for Outage
2/8/17-2/13/17	Install RT equip
3/15-3/23	Spill Event
8/16-8/24	Repair bulkhead seal/counterweight cables/seal hole above fyke
9/10-9/15	Sorting table/holding tank modifications

3.0 DOWNSTREAM COLLECTION AND PASSAGE METRICS

3.1 Number of Juveniles Entering Swift Reservoir

3.1.1 Overview

Developing an annual estimate of the total number of juveniles entering Swift Reservoir is required under Section 9.2.1 of the Settlement and is identified as Objective 7 of the M&E Plan. Historically, numbers of juveniles entering Swift Reservoir were estimated through screw trap operations in the mainstem of the North Fork Lewis River near Eagle Cliff during the spring outmigration period from approximately mid-March through the end of June each year. However, historic data from the FSC indicate that a considerable number of anadromous fishes likely migrate into Swift Reservoir when the Eagle Cliff screw trap is not in operation (Fall – late Winter). Additionally, these historical estimates do not include fish that enter Swift Reservoir from reservoir tributaries (e.g., Drift Creek).

The revised M&E Plan addressed this issue by dividing Objective 7 into two separate parts. The first part (Objective 7, Task 7.1) estimates the timing and number of juveniles entering Swift Reservoir from the Upper North Fork Lewis River subbasin through traditional screw trapping operations near Eagle Cliff during the traditional spring migration period (March – June). Because non-sample periods and reservoir tributaries were not accounted for in this analysis, this information was to serve as an annual index that could be compared over the same general time period among years. The second part (Objective 7, Task 7.2) estimates the total number of juveniles entering Swift Reservoir in a given year from annual PIT tag data collected at the Swift Reservoir FSC.

Objective 7 Task 7.1:

Following the M&E Plan, monthly estimates of the total juvenile out-migration by species during the trapping season were to be calculated using the following formula for use of a single partial trap described in Volkhardt et al. (2007), in which the estimated number of unmarked fish migrating during discrete sample period *i* ($\hat{U}$), weekly or monthly, is dependent on actual recapture rates observed:

$$\widehat{U}_i = \frac{u_i(M_i+1)}{m_i+1} \quad \textbf{Equation 3.1-1}$$

Where:

u_i = Number of unmarked fish captured during discrete period *i*
M_i = Number of fish marked and released during period *i*
m_i = Number of marked fish recaptured during period *i*

Discrete sample period variance:

$$V(\hat{U}_i) = \frac{(M_i+1)(u_i+m_i+1)(M_i-m_i)u_i}{(m_i+1)^2(m_i+2)} \quad \textbf{Equation 3.1-2}$$

- Monthly estimates of juvenile migration were to be combined to calculate the total number of juveniles migrating downstream during the monitoring period using the following formula:

$$\hat{U} = \sum_{i=1}^{n} \hat{U}_i \quad \textbf{Equation 3.1-3}$$

Entire monitoring period variance:

$$V(\hat{U}) = \sum_{i=1}^{n} V(\hat{U}_i) \quad \textbf{Equation 3.1-4}$$

95% Confidence Interval:

$$\hat{U} \pm 1.96\sqrt{V(\hat{U})} \quad \textbf{Equation 3.1-5}$$

- In addition, total season variance and confidence intervals will also be estimated using bootstrap methodology for each focal fish species total estimate (Thedinga et al. 1994).

Objective 7 Task 7.2:

Using PIT tag records from the FSC, PIT tagged fish used to estimate the Eagle Cliff screw trap efficiency will also be used to estimate the joint probability of focal fishes that survive passage through Swift Reservoir and are captured by the FSC (Overall Downstream Survival (ODS) Section 3.7). This information can also be used to estimate, using mark-recapture, the total number of juvenile migrants in Swift Reservoir.

Recent hydroacoustic tag re-capture information has shown reservoir hold-over/rearing from one year to the next (Reynolds et.al 2015; Caldwell et.al 2017). Comparing the size class of fish captured at the screw trap to those at the FSC, in addition to assessing long-term mark-recapture data, may be used to parse yearly estimates of total fish (by species) entering the reservoir by size/year class as the long-term mark-recapture data set is developed. For 2017, yearly parsing between fish brood years was not done as more long-term data is needed. Instead, fish captured at the FSC that were too small to receive a PIT tag were not included in the estimate (i.e., they were not included in variable u_i in the description below).

Estimated number of juvenile fish entering Swift Reservoir during the entire migration period were calculated using Equation 3.1-1 above, where:

u_i = Total estimate of unmarked fish captured during the monitoring period at the FSC derived from equation 3.2-1 in Section 3.2;

M_i = Number of fish marked and released during the monitoring period from the screw trap;

m_i = Number of marked fish recaptured during the monitoring period at the FSC.

Discrete sample period variance was calculated using bootstrap methodology (Thedinga et al. 1994). The 95% confidence interval will be calculated using Equation 3.1-5 above.

3.1.2 Results/Discussion

Objective 7 Task 7.1:

Field crews operated the Eagle Cliff 8-foot-diameter rotary screw trap (trap) from April 20 to July 30, 2017, and checked the trap on a daily basis. The trap was turned off (cone raised) due to heavy debris loads for a 48-hour period from May 5 to May 7, 2017; estimates of the number of fish that may have passed the trap during this time period were not made.

The total numbers of fish by species captured during the monitoring period are summarized in Table 3.1-1. Overall, out-migrating salmonids collected at the screw trap ranged in size from less than 60 mm to slightly greater than 400 mm in length (Figure 3.1-1). Juvenile coho were generally smaller, with only about 10% of the captured individuals being larger than 100 mm. In contrast, more than 50% of the cutthroat and rainbow (steelhead) trout collected were greater than 100 mm in length.

A total of 1,206 coho, 676 Chinook, 113 rainbow/steelhead, and 50 cutthroat were marked and released upstream of the trap (as fish were available from trap captures) to estimate trap efficiency via mark-recapture (Table 3.1-2). Fish were marked with a PIT tag, alcian blue tattoo, or upper caudal fin clip. Only fish great than 60 mm fork length (FL) were used for mark-recapture efficiency tests. Sufficient data was collected to produce species/origin-specific trap efficiencies for both coho and hatchery Chinook (Table 3.1-1). Due to low capture rates, an adjusted season average trap efficiency was set for naturally produced Chinook, steelhead and cutthroat (Table 3.1-2).

Capture timing of juvenile salmonids tended to peak during the middle of June and again during the middle of July (Figure 3.1-2). Differing from this were steelhead, having peaks in both mid-May and mid-June. Total estimates of fish passing the trap during the trapping period and 95% confidence intervals were generated using the bootstrap methodology (Thidenga et al. 1994). The sum of discrete interval method for calculating total outmigration described by Volkhardt et al. (2007) for a single partial capture trap was used to make a secondary estimate (Table 3.1-3). . In total 33,385 coho, 20 naturally produced Chinook, 6,473 acclimation (hatchery) Chinook, 2,366 steelhead and 1,057 cutthroat were estimated to pass the trap during trapping operations (Table 3.1-3). These estimates should only be viewed as an index of the total fish that passed the trap during the trapping period and not total species outmigration abundance.

Table 3.1-1. Summary of Eagle Cliff trap total captures.

Species	Total Hatchery Produced ≥60 mm FL	Total Naturally Produced <60 mm FL	Total Naturally Produced ≥60 mm FL	Total Marked & Released Upstream ≥60 mm FL	Total Recaptured	Total Season Trap Efficiency
Coho	0	1,258	1,265	1,206	47	0.039
Chinook	1,200	0	1	676[a]	126	0.186
Rainbow/Steelhead	8	16	116	113	1	0.009
Cutthroat	0	1	52	50	1	0.020
Bull Trout	0	0	6	0	0	NA
All Salmonids Combined				2,045	175	0.086

Species	Total
Sculpin	50
Sucker	76
Dace	9

[a]Only one naturally produced Chinook was captured; this total is all hatchery origin Chinook (acclimation Chinook) plus the single natural origin Chinook marked and released upstream to estimate trap efficiency.

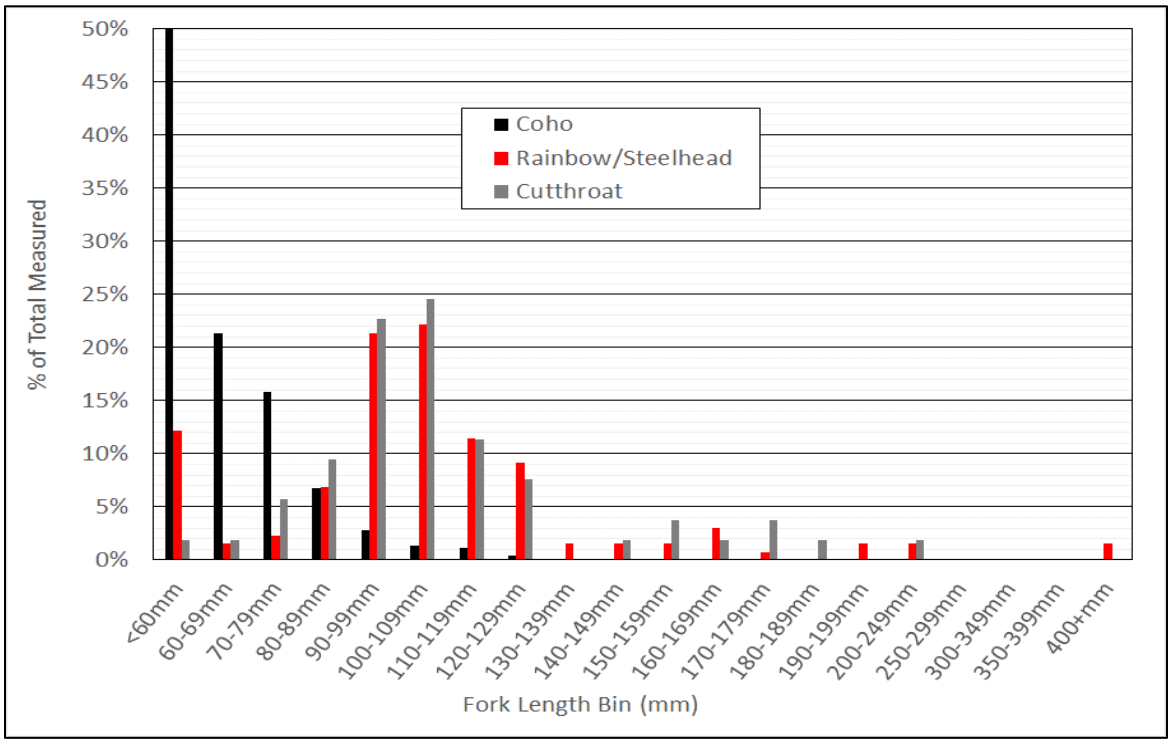


Figure 3.1-1. Length frequency distribution (coho, rainbow/steelhead, cutthroat with adipose fin intact).

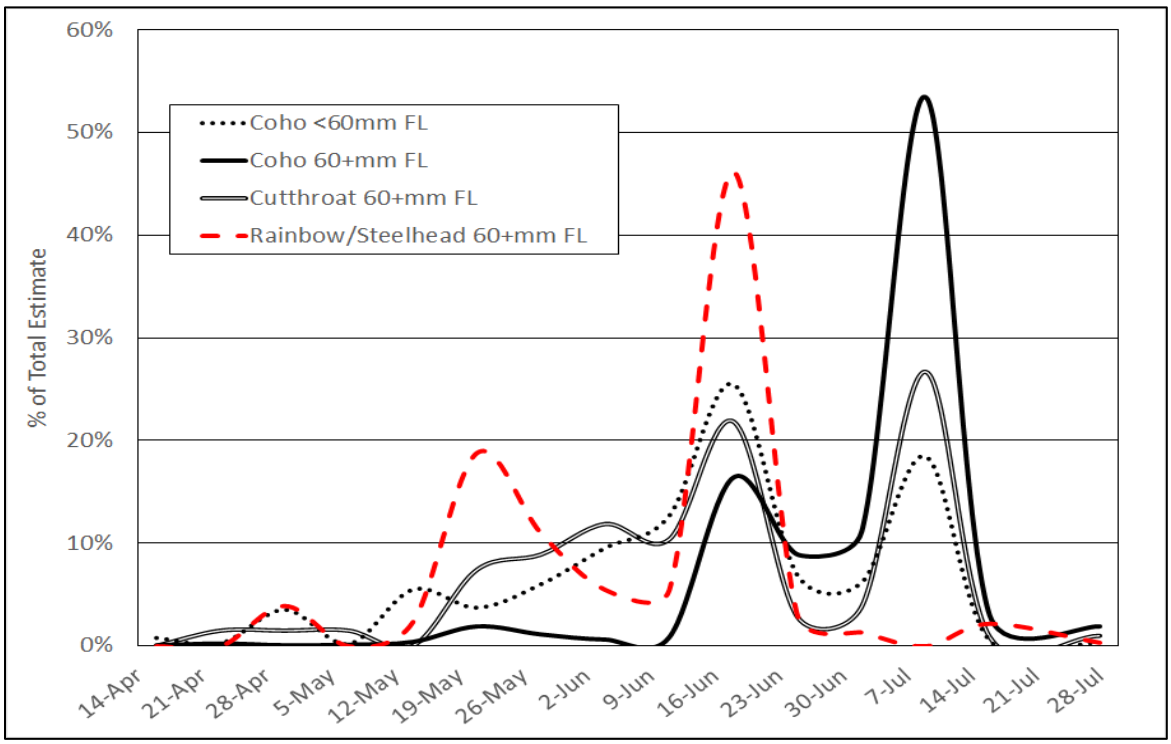


Figure 3.1-2. Species migration timing based on total weekly estimates (adipose fin intact).

Table 3.1-2. Summary of mark-recapture tests of trap efficiency.

Week (first day)	Total Caught ≥60 mm FL	Total Marked & Released Upstream ≥60 mm FL	Total Recaptured	Trap Efficiency	Average Weekly Flow (cfs)[b]	Adjusted Efficiency Based on Flow
16-Apr	1	1	0	NA	2,440	0.036[a]
23-Apr	5	5	0	NA	2,894	0.036[a]
30-Apr	8	7	0	NA	3,111	0.036[a]
7-May	5	3	0	NA	2,670	0.036[a]
14-May	10	10	0	NA	2,334	0.036[a]
21-May	64	63	0	NA	3,206	0.036[a]
28-May	42	38	0	NA	2,904	0.036[a]
4-Jun	27	27	1	0.037	2,334	0.036[a]
11-Jun	29	28	1	0.036	2,116	0.036[a]
18-Jun	226	224	5	0.022	1,943	0.022
25-Jun	264	261	15	0.057	1,300	0.057
2-Jul	239	237	10	0.042	877	0.042
9-Jul	166	163	1	0.006	638	0.006[c]
16-Jul	714	526	68	0.129	514	0.129
23-Jul	848	452	74	0.163	447	0.163
Total	2,648	2,045	175	0.086	-	0.050[d]

[a]Average efficiency measured during weeks of 4-Jun and 11-June with similar average weekly flow.
[b]USGS 14216000 Lewis River Above Muddy River Near Cougar, WA.
[c]Trap was in a poor location with low suspected efficiency, but was moved upstream the following week to increase efficiency.
[d]Average season efficiency.

Table 3.1-3. Index estimates of fish (adipose fin intact and ≥60 mm FL) passing the Eagle Cliff trap by species (bootstrap and sum of discrete interval method) from April 20 to July 30, 2017.

Species	Capture Efficiency Applied	Bootstrap Mean Total Estimate	95% CI +/-
Coho	0.039[a]	33,385	10,212
Chinook	0.050[b]	20	38
Hatchery Chinook	0.187[c]	6,473	1,069
Rainbow/Steelhead	0.050[b]	2,366	615
Cutthroat	0.050[b]	1,057	355
Sum of Discrete Interval Method (Volkhardt et al. 2007)			
Species		**Total Estimate**	**95% CI +/-**
Coho		49,891	23,429
Hatchery Chinook		6,940	1,366
Rainbow/Steelhead		3,546	2,285
Cutthroat		1,873	977

[a]Coho specific efficiency.
[b]Average adjusted season efficiency.
[c]Hatchery Chinook specific efficiency.

Objective 7 Task 7.2:

All PIT tags used in the screw trap operations were also used in Task 7.2. In addition to these tags, PacifiCorp PIT tagged coho juveniles captured at the FSC and released them at the head of Swift Reservoir. This was done to bolster sample size. A total of 398 coho, 494 Chinook, 269 steelhead, and 56 cutthroat juveniles were tagged and released at the head of Swift Reservoir for analysis. The bootstrapping methodology was applied to find both the mean and variances of total number fish per species entering Swift Reservoir during 2017. It is estimated that 135,799 coho, 57,948 Chinook, 17,655 steelhead, and 13,110 cutthroat juveniles entered Swift Reservoir during 2017 (Table 3.1-4). These estimates only consider fish parr size and greater because fry cannot be pit tagged. Comparing these estimates to the number of juveniles estimated to pass Eagle Cliff during screw trapping operations in 2017 reveals that the majority of juvenile fish enter Swift Reservoir during times when the screw trap was not in operation and/or from immediate reservoir tributaries.

Table 3.1-4. Estimates of total fish (adipose fin intact and ≥60 mm FL) entering Swift Reservoir during 2017 by species (bootstrap method).

Species	Tags Released	Tags Recaptured at FSC	Capture Efficiency Applied	Total untagged fish captured at FSC	Bootstrap Mean Total Estimate	95% CI +/-
Coho	398	71	0.178	24,505	***140,366***	**30,577**
Chinook	494	64	0.130	5,797	***57,948***	**14,003**
Steelhead	269	27	0.100	1,797	***17,655***	**6,748**
Cutthroat	56	3	0.054	751	***10,659***	**13,110**

3.2 Fish Numbers Collected at the FSC

3.2.1 Overview

Section 9.2.1(j) of the Settlement Agreement requires PacifiCorp to enumerate the number of salmonids collected at FSC (FSC_{COL}) by species and life-stage. This requirement is identified as Objective 6 in the M&E Plan. The M&E Plan originally stated that the number of juvenile fish entering the FSC would be calculated through both subsampling and by automatic fish counters. During development of the M&E Plan, the accuracy of the automatic fish counters was unknown, thus conducting both methods of enumeration was recommended initially. However, during the operating years of 2013 and 2014, many tests and calibrations took place. From this work, it was ultimately determined that the scanners were unreliable, and falsely assigned debris and turbulence as fish. Because the automatic fish counters were shown to be unreliable for long-term daily operation, estimating total number of fish collected at the FSC was achieved through subsampling counts as described in Section 2.6.1 of the M&E Plan; the key assumption inherent in the methodology is that the subsampled fish are representative of the general population.

Subsampling Counts

Diversion gates on the FSC allow smolts to be diverted into either a subsample tank or a general population tank. The diversion gates operate on a time-driven interval within a ten minute time frame (i.e., during a 10 percent sample period the diversion gate would operate one minute out of every ten minute cycle). The intent is that during periods of low migration, the sampling rate is set to 100% and all fish collected are processed. When capture rates increase (i.e., during peak outmigration), only a portion of fish are sampled and the rest are diverted to the general population tanks. As described in the M&E Plan, the daily subsample totals, as well as the associated variance estimators, could then be calculated by:

Total Number of Fish (subsampling period):

$$T = N\bar{y} = \frac{N}{n}\sum_{i=1}^{n} y_i \quad \textbf{Equation 3.2 – 1}$$

With associated variance estimator:

$$\boldsymbol{s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad \textbf{Equation 3.2 – 2}$$

And 95% Confidence Interval:

$$O + T \pm t_{(0.025,n-1)}\sqrt{\frac{N(N-n)s^2}{n}} \quad \textbf{Equation 3.2 – 3}$$

Where,

T = total number of fish during the subsampling period
O = total number of fish during 100% enumeration period
r = subsampling rate
n = number of sampling periods (days sampled)

N = n/r (sampling intensity)
y_i = discrete daily fish count
$\bar{y}$ = average number of fish counted per day
s^2 is the sample variance
t is the t-statistic for n-1 degrees of freedom and α/2

Daily fish collection numbers remained manageable throughout most of 2017, and sample rates were set to 100% for a majority of the year. Subsampling only occurred on 36 days of operation, primarily during the month of June, and again from late-November to late-December, 2017. For this period, the equations described above were used to derive the total number of fish collected on a given day, as well as the associated variance estimator.

3.2.2 Results/Discussion

A total of 39,788 salmonids (95% CI range: 35,492 to 44,084) were captured by the FSC in 2017 (Tables 3.2-1 and 3.2-3). Of these fish, approximately 36,972 were transported and released downstream of Merwin Dam (Table 3.2-2). Juvenile coho accounted for the highest proportion of the overall estimated catch (70.6%), followed by juvenile spring Chinook (14.6%), juvenile steelhead (4.6%) and coastal cutthroat trout (0.7%). A total 2,900 hatchery rainbow trout and 9 bull trout were also collected in 2017and returned to the reservoir. All bull trout were returned to Swift Reservoir; however, an estimated 444 hatchery rainbow trout were passed downstream of Merwin Dam during the subsample collection period (May-June).

Table 3.2-1. Estimated monthly and annual totals of all species collected at the FSC.

Month	Coho				Spring Chinook			Steelhead					Cutthroat			Bull Trout	Rainbow Trout	Total Trapped
	Fry	Parr	Smolt	Adult	Fry	Parr	Smolt	Fry	Parr	Smolt	Adult	Kelt	Fry	< 13 in	> 13 in			
January	47	77	49	44	0	6	49	0	2	3	0	0	1	4	0	2	29	313
February	602	36	115	1	0	1	8	0	0	1	0	0	0	3	1	2	34	804
March	2,000	178	237	0	0	16	82	0	11	16	5	0	4	37	3	0	256	2,845
April	495	155	252	0	0	18	322	0	19	200	8	1	6	40	6	0	1,148	2,670
May	51	56	1,178	0	0	1	184	0	9	831	7	4	2	122	6	2	289	2,742
June	10	86	6,851	0	0	1	43	11	2	454	3	2	0	132	27	2	1,042	8,666
July	0	73	669	0	0	0	7	6	0	9	0	2	0	3	0	0	9	778
August																		0
September																		0
October	39	935	1,678	18	0	7	1,099	0	9	28	0	0	0	40	0	0	0	3,853
November	199	5,473	3,104	72	0	206	1,924	1	17	74	0	0	1	169	2	0	72	11,314
December	154	2,507	791	194	0	22	1,805	1	4	108	0	0	0	194	1	1	21	5,803
Annual Total	**3,597**	**9,576**	**14,924**	**329**	**0**	**278**	**5,523**	**19**	**73**	**1,724**	**23**	**9**	**14**	**744**	**46**	**9**	**2,900**	**39,788**

Table 3.2-2. Estimated annual totals of species transported downstream.

Coho				Spring Chinook				Steelhead					Cutthroat			Bull Trout	Rainbow Trout	Target Species Downstream
Fry	Parr	Smolt	Adult	Fry	Parr	Smolt	Adult	Fry	Parr	Smolt	Adult	Kelt	Fry	<13 in	>13 in	All sizes	All Sizes	
3,598	9,576	14,924	0	0	278	5,523	0	19	73	1,724	0	9	14	744	46	0	444	36,972

Table 3.2-3. Estimated annual totals of species and life stage collected by the FSC.

Species/Lifestage	Estimated Number Collected	Associated Variance	Collection Range at 95% CI
Coho Fry	3,597	26	3,571 - 3,623
Coho Parr	9,576	322	9,254 - 9,898
Coho Smolt	14,924	2,844	12,080 - 17,768
Coho Adult	329	0	329
Chinook Fry	0	0	0
Chinook Parr	278	32	246 - 310
Chinook Smolt	5,523	650	4,873 - 6,173
Steelhead Fry	19	0	19
Steelhead Parr	73	0	73
Steelhead Smolt	1,724	131	1,593 - 1,855
Steelhead Adult	23	0	23
Steelhead Kelt	9	0	9
Cutthroat Fry	14	0	14
Cutthroat <13 in	744	88	656 - 832
Cutthroat >13 in	46	17	29- 63
Bull Trout	9	0	9
Rainbow Trout	2,900	186	2,714 - 3,086
Total	**39,788**	**4296**	**35,492 - 44,084**

3.3 Juvenile Migration Timing

3.3.1 Overview

In accordance with Section 9.2.1(a) of the Settlement Agreement, PacifiCorp is required to determine natural juvenile migration timing by tracking abundance at the FSC each year. This task was identified as Objective 8 in the M&E Plan with the assumption that run-timing is an index that applies to fish arriving at the FSC.

Following the M&E Plan, an index of juvenile migration was developed by tracking the number of fish captured each day at the FSC over time. The number of fish collected each day at the FSC (FSC_{col}) was calculated by equation 3.2.-1, and plotted on a daily basis.

In addition to monitoring migration timing, PacifiCorp also monitored juvenile fork lengths to describe, temporally, the size (or life-stage) of fish entering the FSC. Size distributions for coho, spring Chinook, steelhead and coastal cutthroat were calculated on a seasonal basis for the periods January – March, April – June and October – December. Size distributions were not calculated for the time period between early July through September as the FSC was off for annual summer maintenance.

3.3.2 Results/Discussion

Overall, the run timing in 2017 followed a strong bimodal migration pattern, in which two distinct migration periods developed – one in the spring, which generally peaked around mid-May and the other in the fall, generally peaking in late-November. However, species composition and life-stage varied considerable between each migration period. With the exception of spring Chinook and coho parr, the most out-migration occurred between March 1st and June 30th. Within this time frame, 51.7% of coho smolts, 85.4% of the steelhead and 47.6% of the cutthroat were collected relative to the total annual catch (Figures 3.3-1 through 3.3-12). However, spring Chinook (parr and smolt) and coho parr demonstrated a much later peak migration pattern, which occurred during November and December. During this timeframe, 68.7% of the spring Chinook, and 83.4% of coho parr were collected, relative to the yearly total. Coastal cutthroat demonstrated a more evenly distributed migration pattern, with the approximately half of fish migrating in the spring, and the other half migrating in November and December.

Coho Size Distributions

A bimodal size distribution was observed for juvenile coho collected at the FSC throughout the first quarter of the year. During the months of January-March, coho fry and the much larger, 2-year old smolts (220 – 290 mm) dominated the catch. The bimodal size distribution transitioned into a normal distribution pattern later in the spring (April – June), with size distributions being relatively evenly distributed about the mean (approximately 160 mm). During this timeframe, the majority (>95 %) of coho out-migrants had lengths greater than 121 mm (Figure 3.3-11). Of the coho that were collected in the late fall/early winter (October – December), the majority (83.7%) had lengths of less than 120 mm (Figure 3.3-11).

Spring Chinook Size Distributions

Review of spring Chinook data captured at the FSC in 2017 reveals size class distribution patterns that positively correlate with hatchery smolt releases associated with the acclimation program. This suggests the majority of spring Chinook collected by the FSC in 2017 originated from the acclimation plants that occurred during July and August, with a smaller component of larger acclimation fish that had been released summer 2016. Of the 5,801 spring Chinook that were captured at the FSC in 2017, over 95% had fork lengths >121 mm (Figure 3.3-12). Of the approximately 53,400 spring Chinook that were

released in the upper Lewis River basin during the summer of 2017, we suspect that approximately 8.9% (n=4,824) had been collected at the FSC by the end of December.

Steelhead Size Distributions

The mean fork length for steelhead captured in 2017 was 223 mm with the majority (>94 %) having fork lengths that were >150 mm (Figure 3.3-13). During the peak spring-time migration period (April – June), the mean steelhead fork length was approximately 213 mm (Figure 3.3-13). The majority of steelhead that were captured during the remainder of the year were dramatically smaller (ranging between 91-119 mm) in length (Figure 3.1-13).

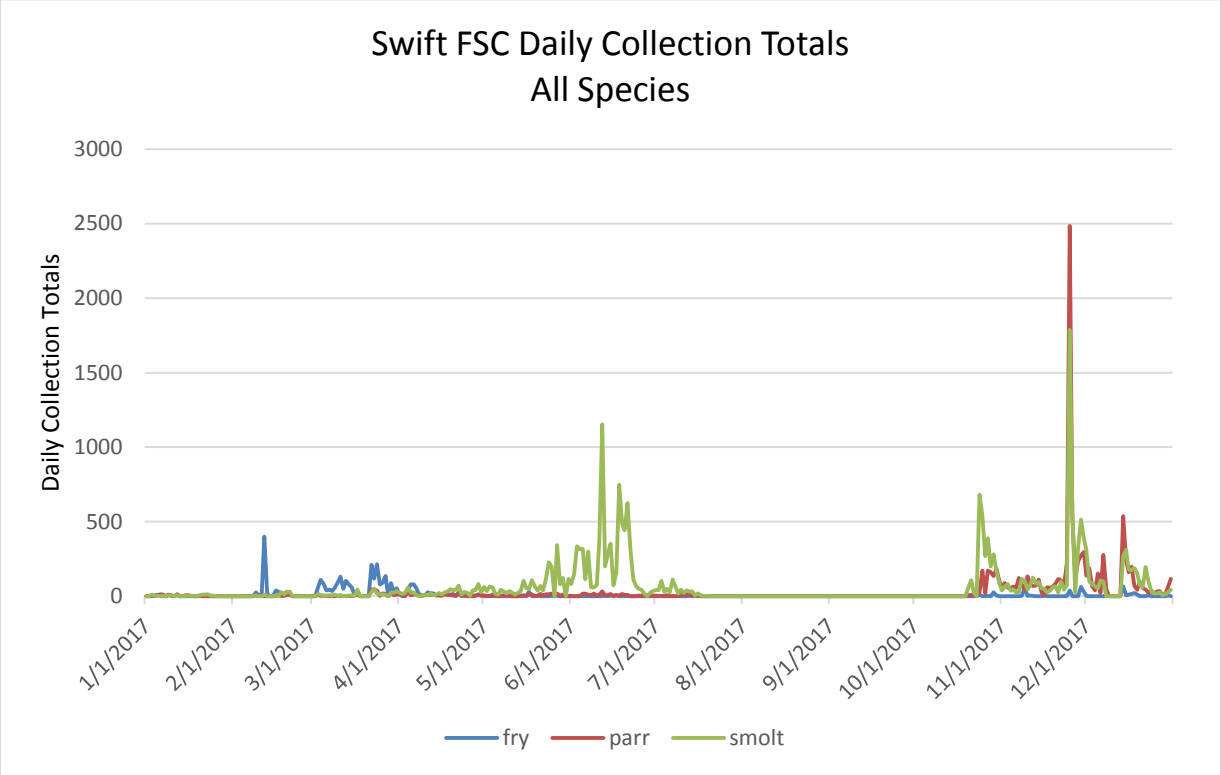


Figure 3.3-1. Estimated daily collection totals for all species at Swift FSC.

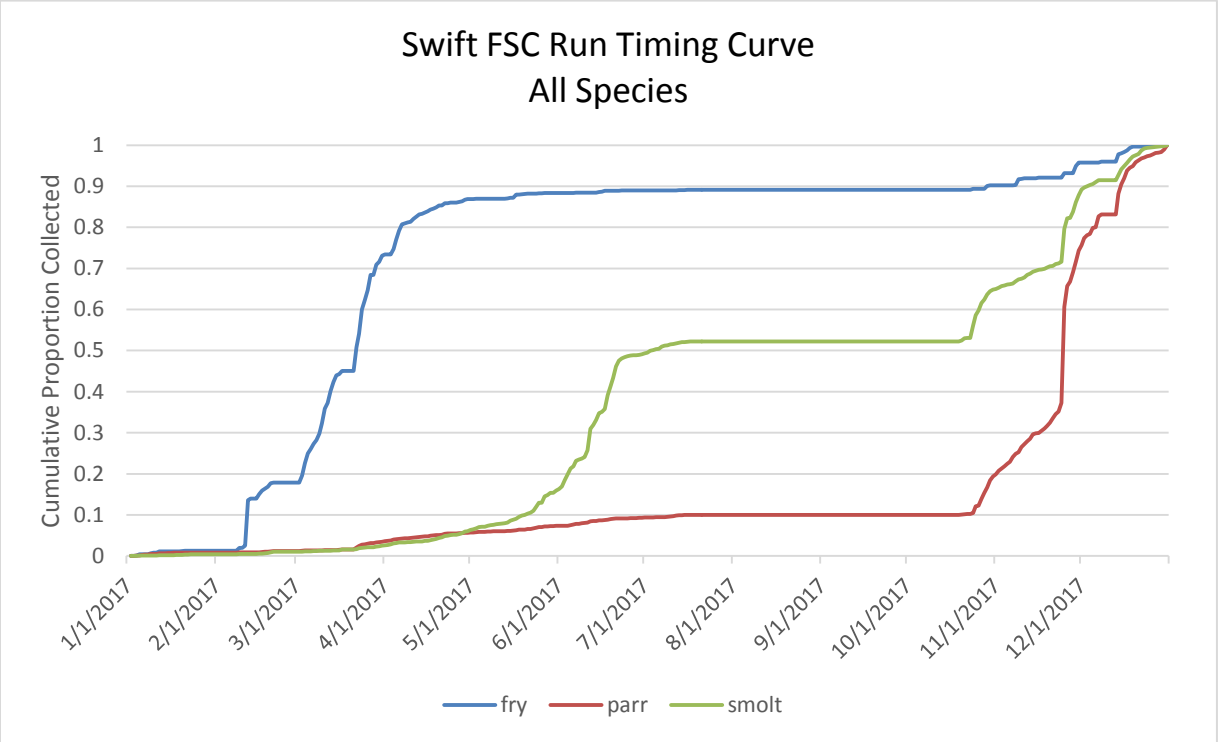


Figure 3.3-2. Cumulative migration timing among all species at Swift FSC.

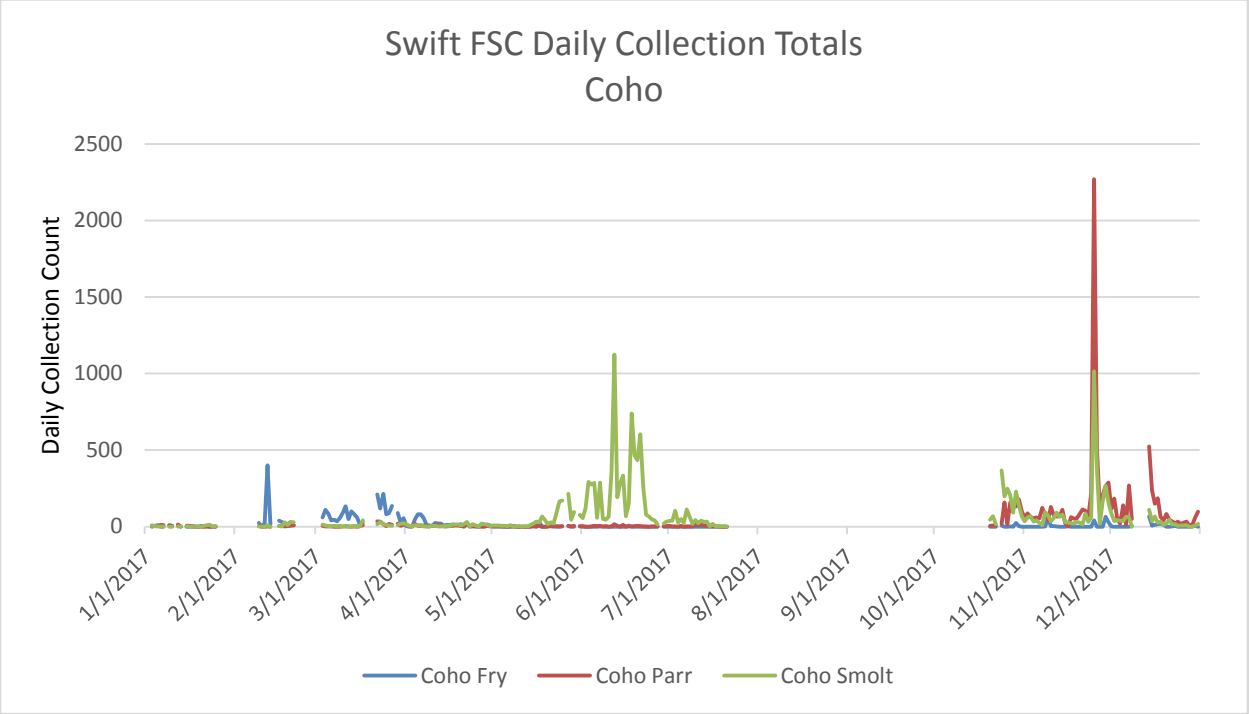


Figure 3.3-3. Estimated daily collection totals of juvenile coho at Swift FSC.

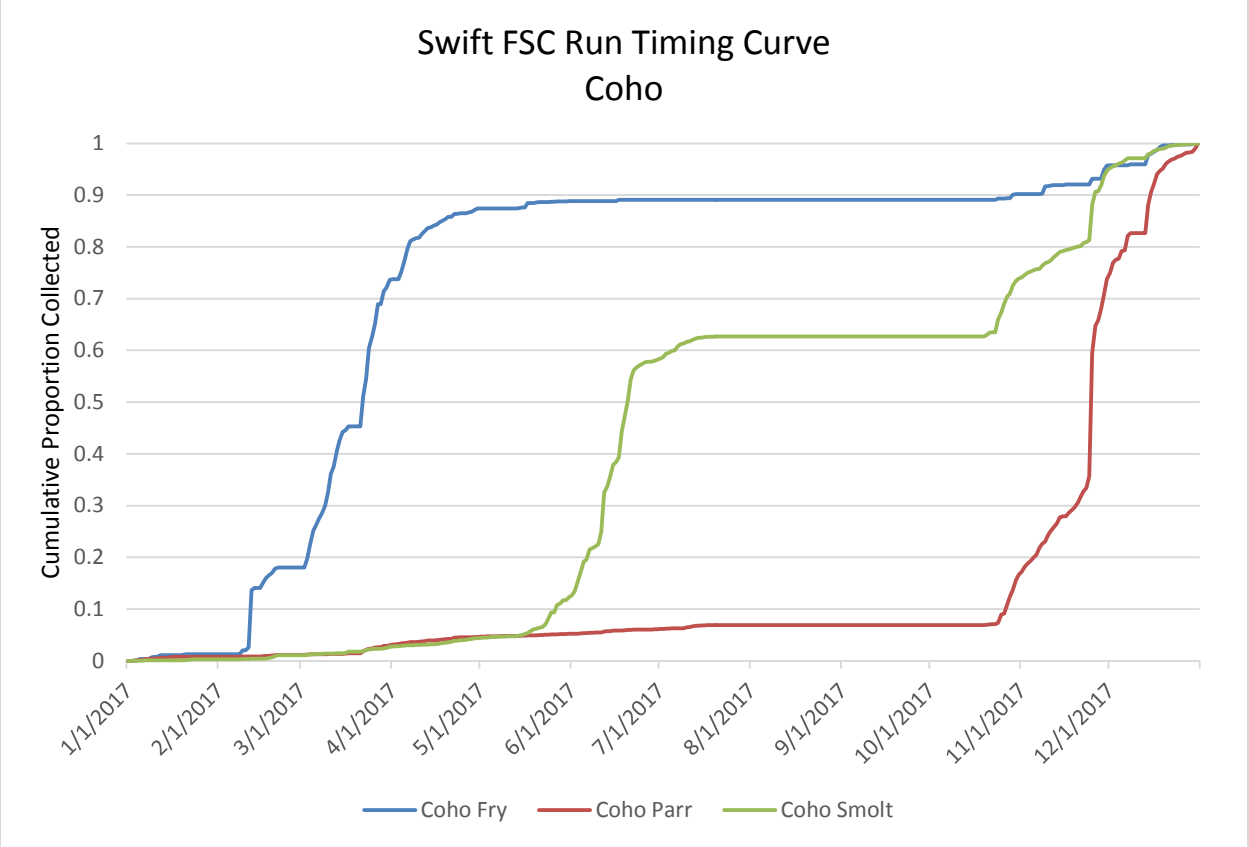


Figure 3.3-4. Cumulative migration timing of juvenile coho at Swift FSC.

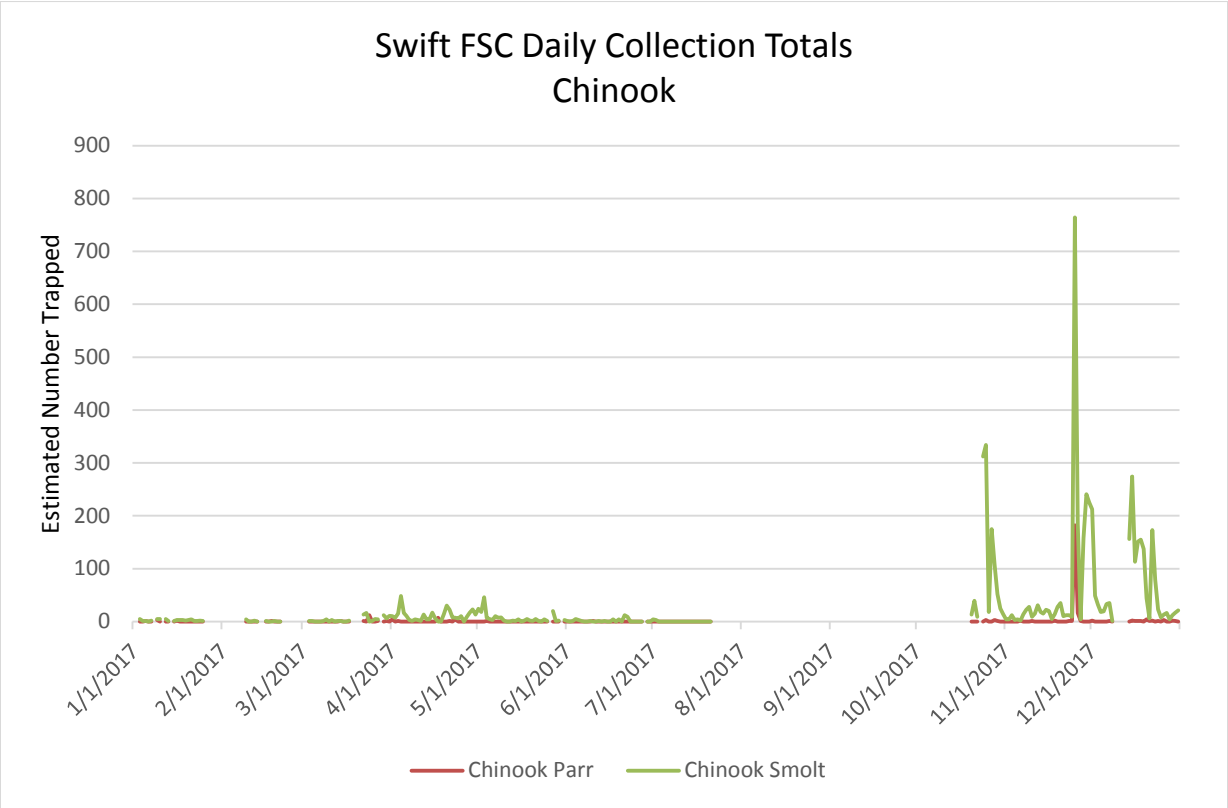


Figure 3.3-5. Estimated daily collection totals of juvenile Chinook at Swift FSC.

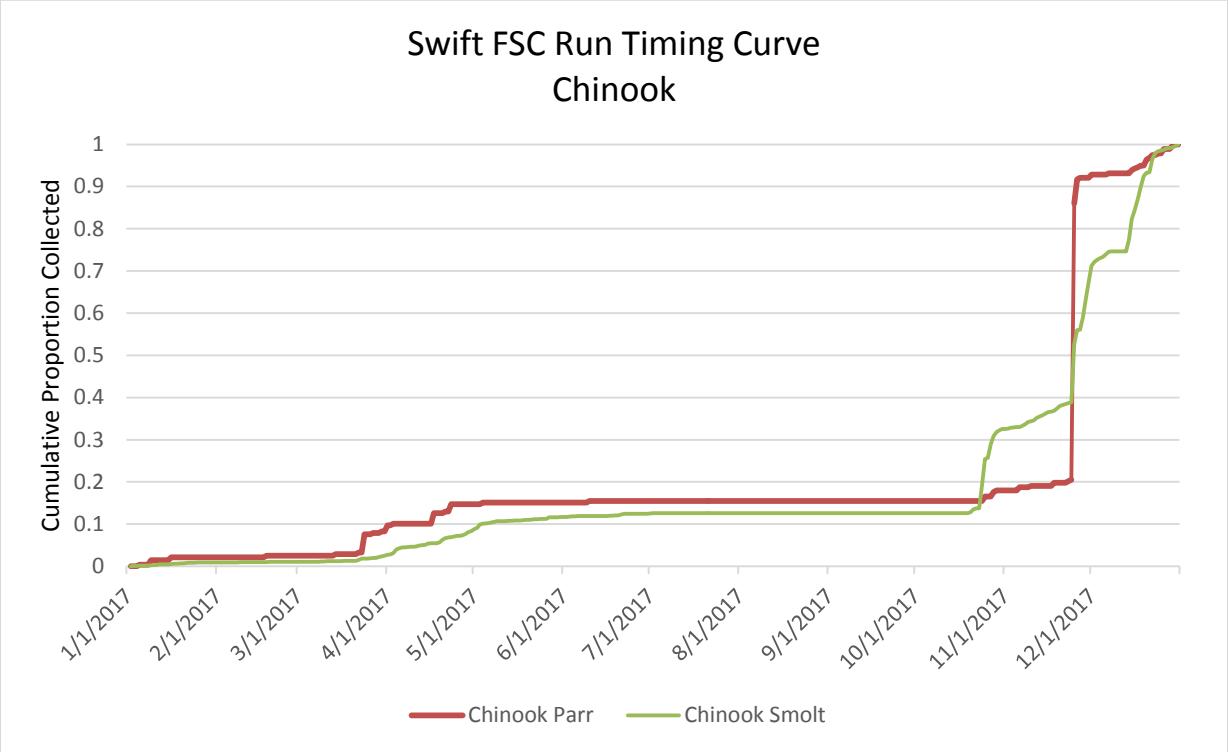


Figure 3.3-6. Cumulative migration timing of juvenile Chinook at Swift FSC.

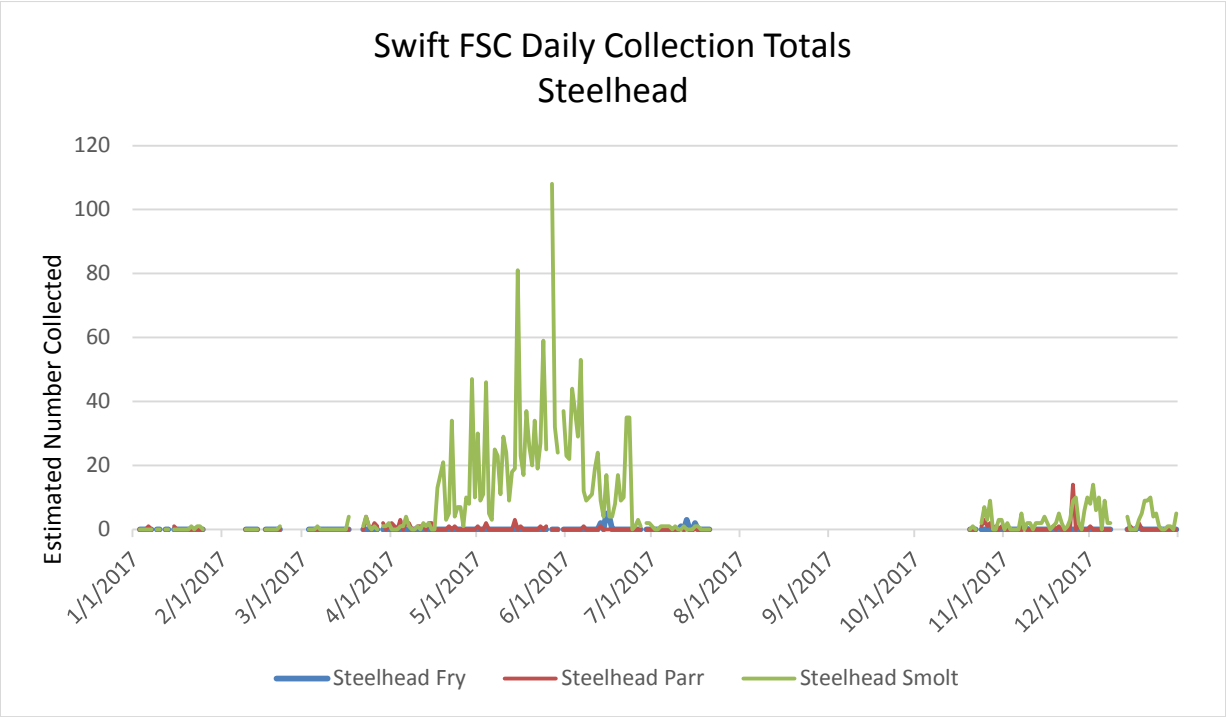


Figure 3.3-7. Estimated daily collection totals of juvenile steelhead at Swift FSC.

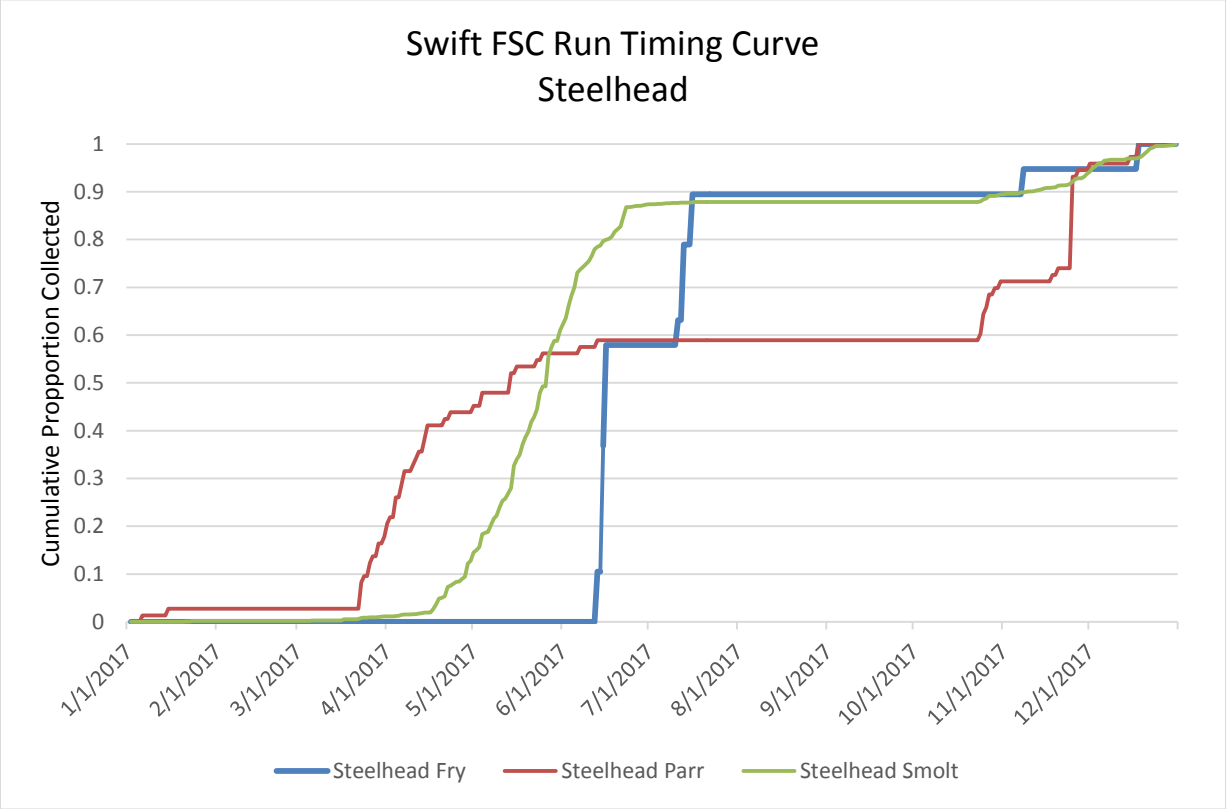


Figure 3.3-8. Cumulative run timing of juvenile steelhead at Swift FSC.

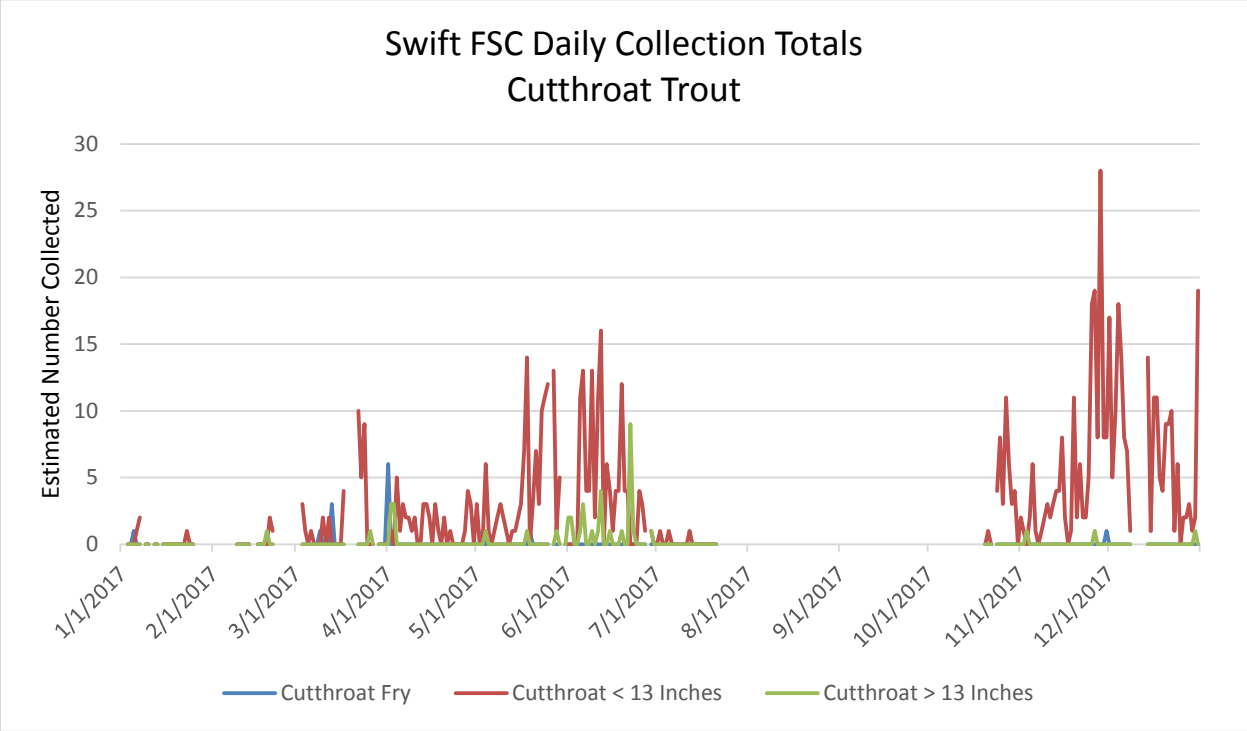


Figure 3.3-9. Estimated daily collection totals of juvenile cutthroat trout at Swift FSC.

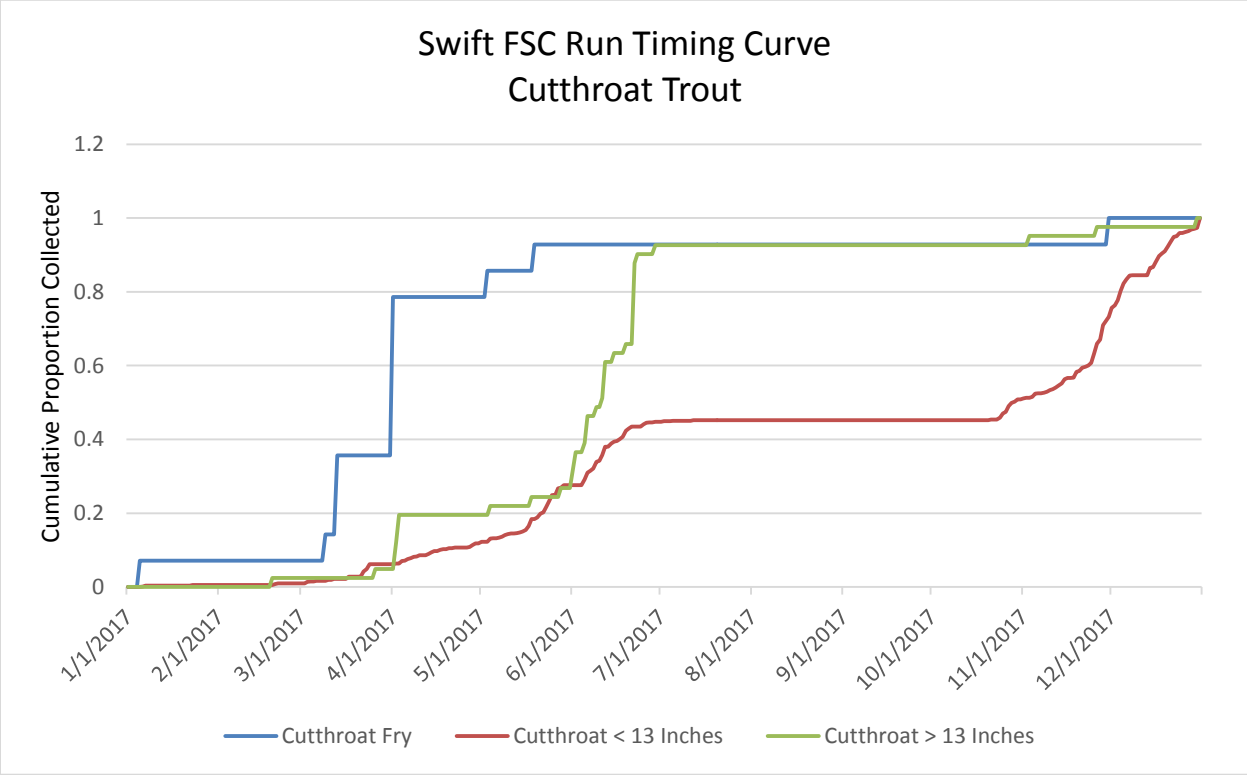
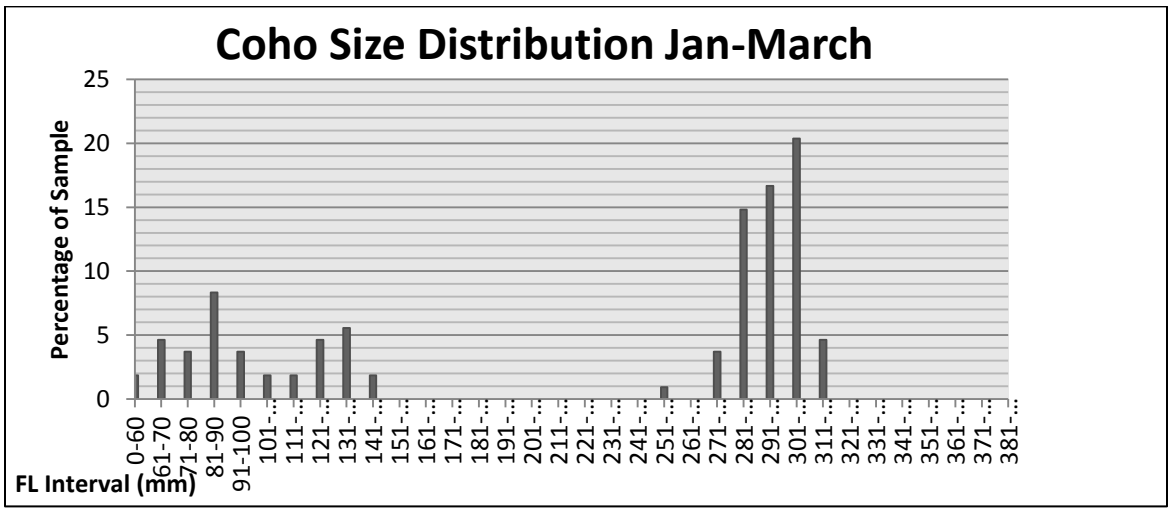
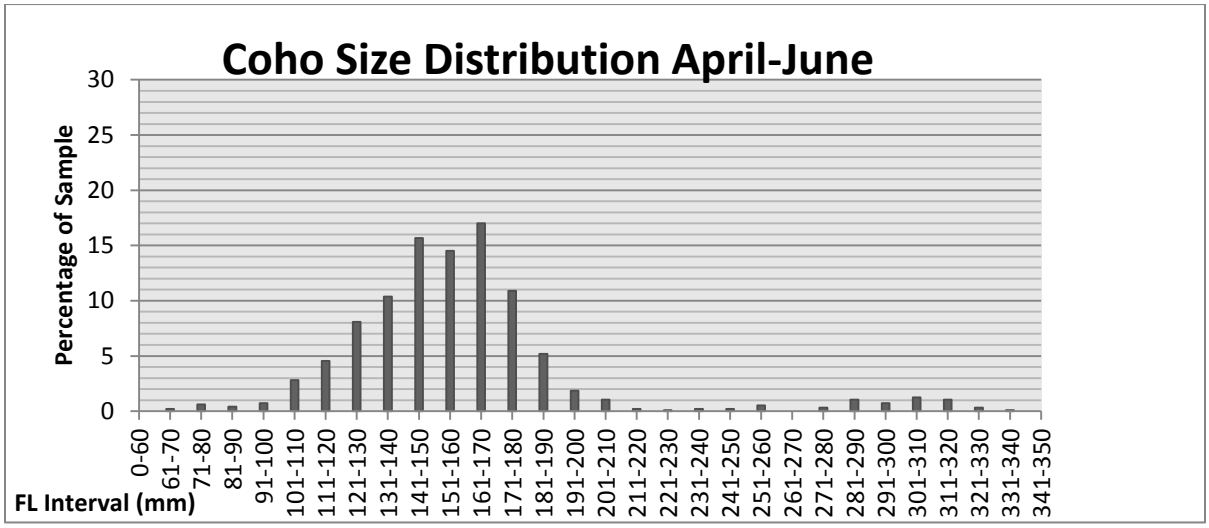


Figure 3.3-10. Cumulative run timing of juvenile cutthroat trout at Swift FSC.





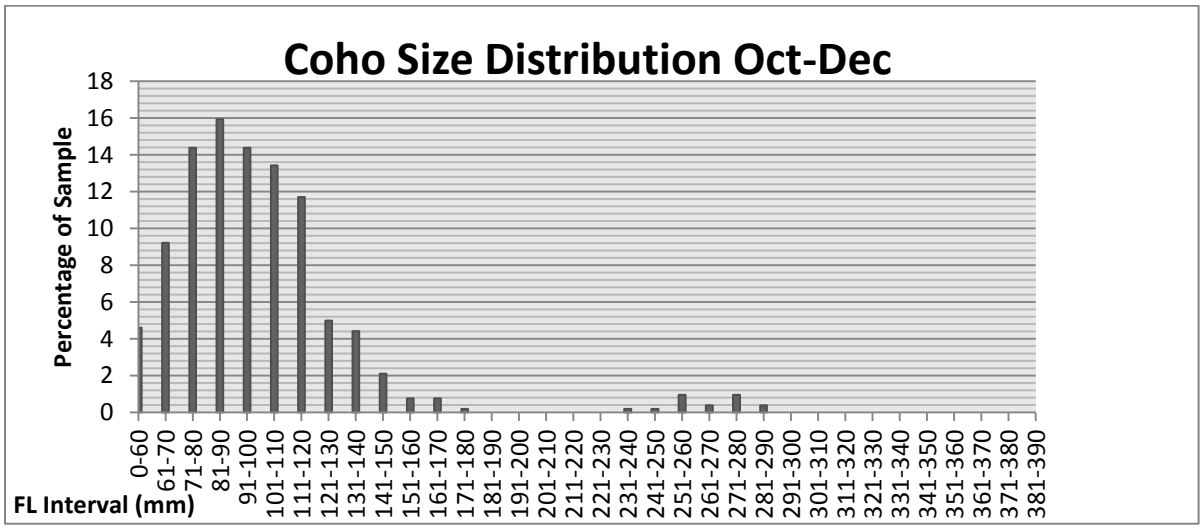
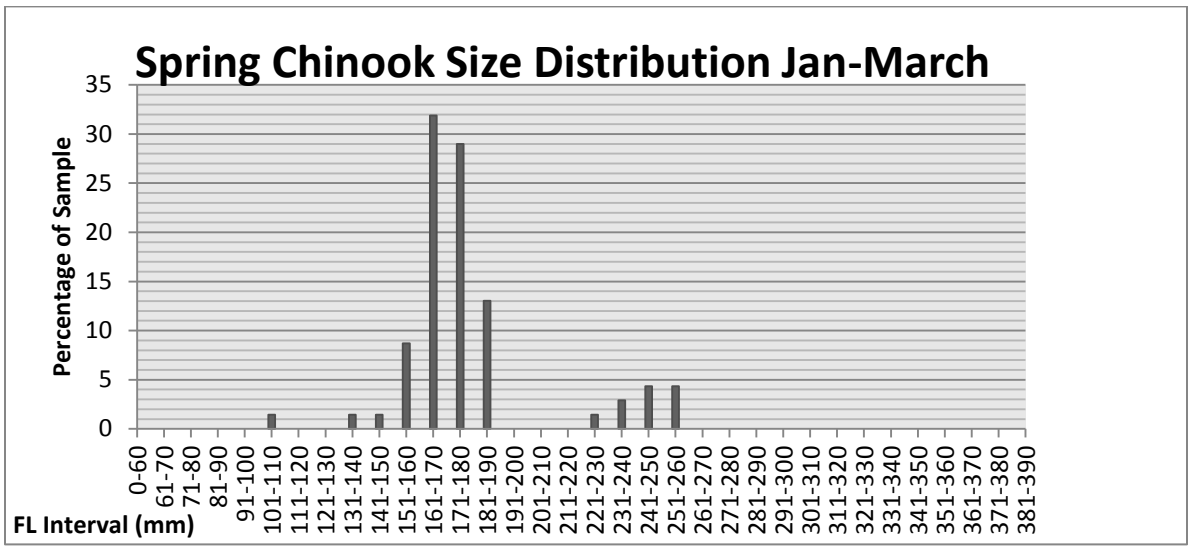
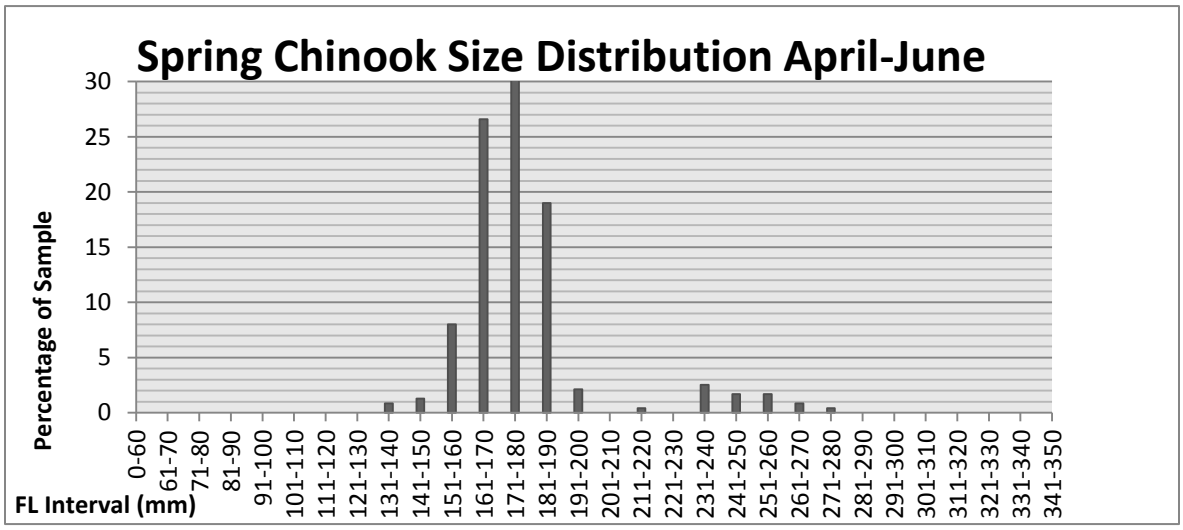


Figure 3.3.11. Size distribution of coho migrants collected at the Swift FSC in 2017.





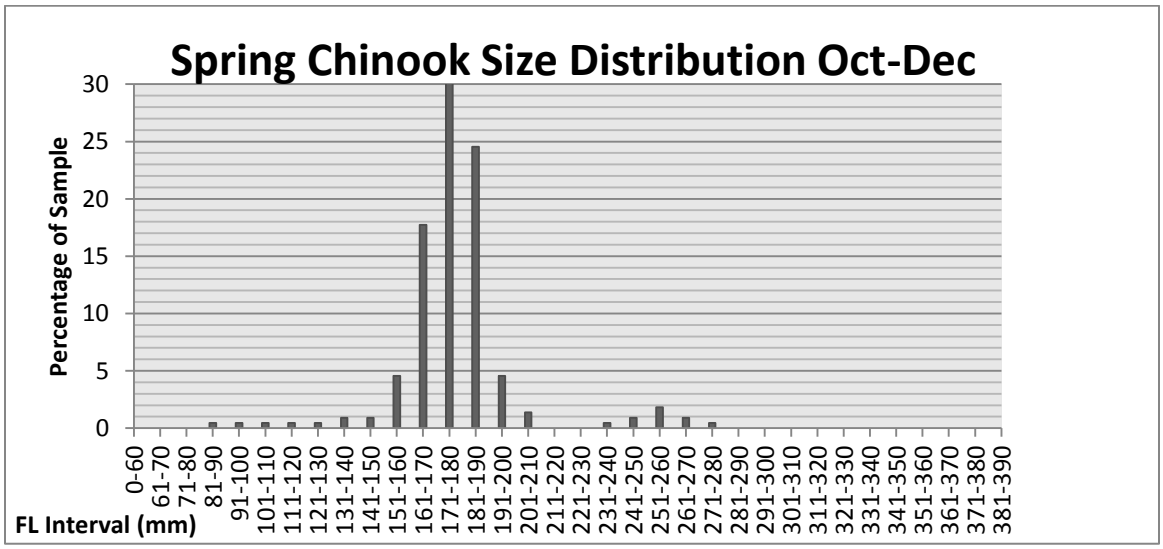
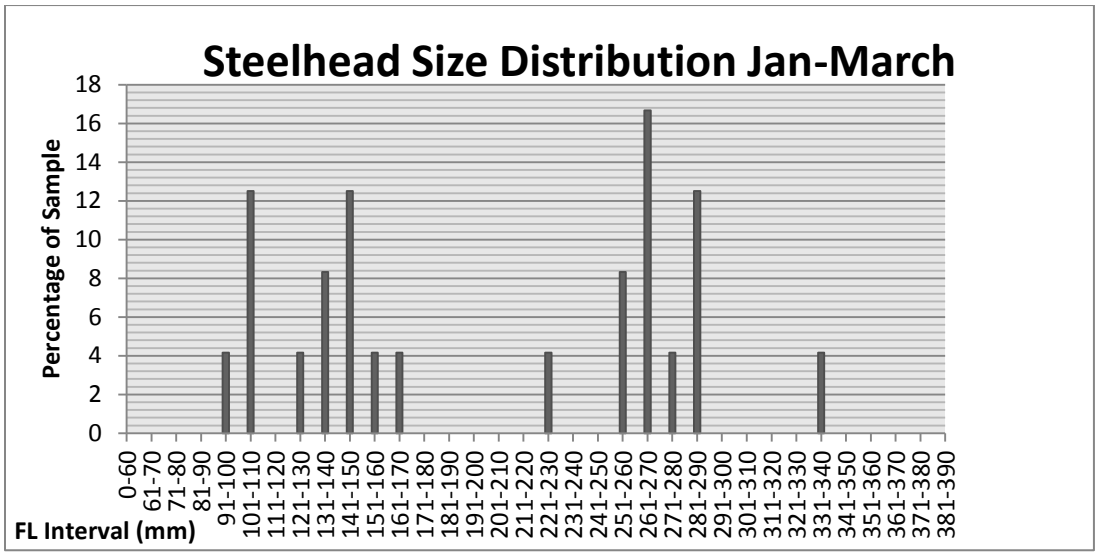
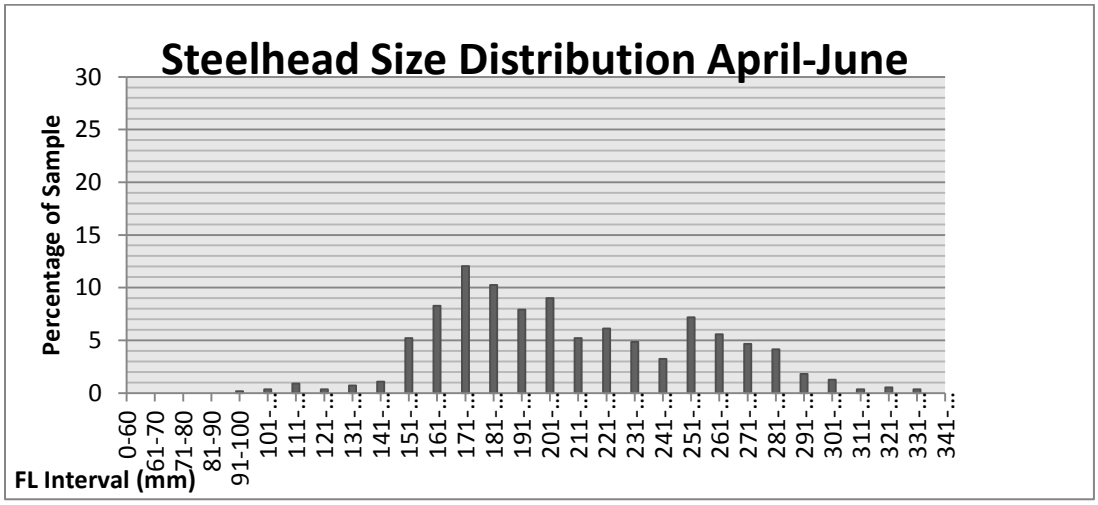


Figure 3.2-12. Size distribution of spring Chinook migrants collected at the Swift FSC in 2017.





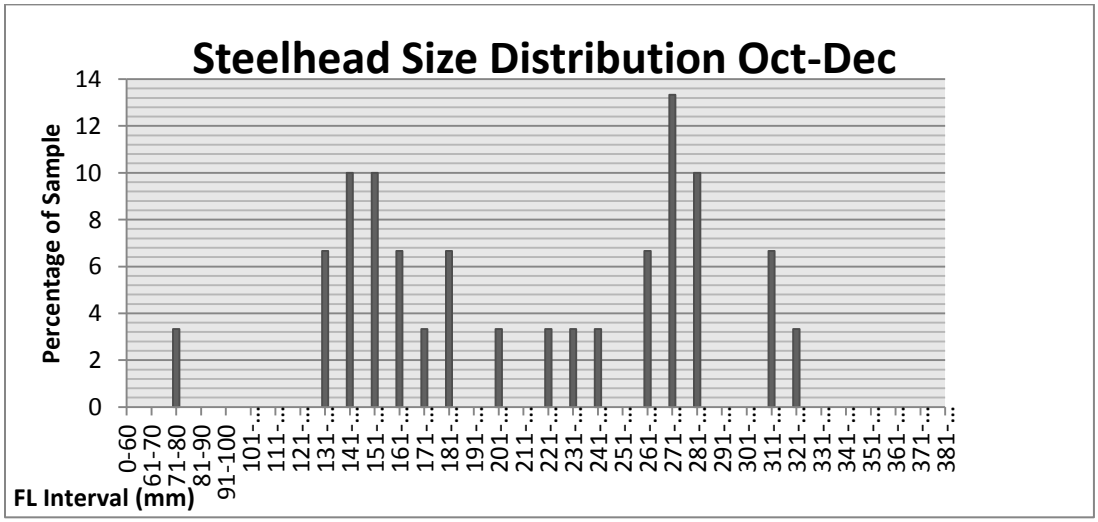


Figure 3.2-13. Size distribution of steelhead migrants collected at the Swift FSC in 2017.

3.4 FSC Collection Efficiency

3.4.1 Overview

The use of biotelemetry to measure collection efficiency (P_{CE}) of juvenile salmonids at the FSC was further evaluated in spring 2017. This evaluation was in accordance with Section 9.2.1(c) of the Settlement Agreement and based on findings and recommendations from the 2013 pilot study (Courter et al. 2013), 2014 evaluation (Stroud et. al 2014), 2015 evaluation (Reynolds et.al 2015) and 2016 evaluation (Caldwell et. al). Objective 2 of the M&E Plan defines P_{CE} as the percentage of juvenile salmonids emigrating from Swift Reservoir that is available for collection and that is actually collected. A juvenile that is available for collection is one that is detected within the zone of influence (ZOI); the area roughly 150 feet in radius immediately outside the NTS that was thought to be influenced by flow entering the FSC. A performance standard of 95% or greater for out-migrating smolts[4] was agreed upon for P_{CE}.

The primary goals of the 2017 Swift Reservoir out-migration study were twofold: 1) determine collection efficiency for juvenile coho, spring Chinook, and steelhead smolts at the FSC; and 2) continue to characterize the behavior of out-migrating smolts once they entered the Swift Reservoir forebay and as they interface with the FSC guide net and NTS. In 2017, acoustic telemetry was used rather than radio telemetry – similar to 2015 and 2016.

The specific study objectives of the 2017 FSC collection efficiency evaluation were to:

1. Estimate the proportion and transit time of downstream migrants released at the head of Swift Reservoir that arrive in the forebay of Swift Dam;

2. Estimate encounter rate (P_{ENC}), the proportion of downstream migrants that enter the FSC forebay and are detected in the FSC flow net attraction area immediately outside the Swift FSC, defined as the zone of influence (ZOI);

3. Estimate entrance efficiency (P_{ENT}), the proportion of downstream migrants that enter the zone of influence and enter the FSC attraction channel;

4. Estimate collection efficiency (P_{CE}), the proportion of downstream migrants that enter the ZOI and successfully pass into the FSC and are captured;

5. Describe the behavior of downstream migrants in the forebay of Swift Reservoir, specifically in the relation to the guide net, ZOI, and entrance of the FSC;

6. Map the 3D flow net of the area of attraction outside the entrance of the FSC with the guide net installed; and

7. Measure underwater sound pressure levels within the hearing range of salmonids that may be generated within the ZOI by various FSC operations.

[4] P_{CE} is only calculated for spring Chinook, coho, and steelhead out-migrating smolts. Cutthroat smolts may be included in future studies if it is determined that anadromous life histories exist.

3.4.2. Results/Discussion

A detailed report describing the methods and results of the 2017 effort can be found in Appendix B. A brief summary of this report is provided below.

In total, 520 smolts were dual tagged with an acoustic transmitter and PIT tag and then released at the head of Swift Reservoir. Of these fish, 333 were detected near the entrance of the FSC at the ZOI and 74 of those fish were successfully collected for an overall seasonal collection efficiency of 21.7%, corrected for receiver detection efficiency (74/[333/.977]; Table 3.4.1).

Behavioral data from this study indicate that most fish are transitioning through Swift Reservoir at a high rate, similar to previous evaluations. Moreover, once fish enter the forebay, they also appear to be finding the entrance of the FSC at a high rate based on observed performance metrics, plots of data, and multiple ZOI encounters. However, fish do not appear to be easily transitioning into the FSC. While the highest density of fish was detected near the entrance, the majority of the fish never actually entered the FSC. Instead, several tagged fish made multiple excursions around the forebay to the Swift Creek Arm and back to Devil's Backbone once spending time at the entrance to the FSC. For all species, the lead net appears to be successfully preventing fish from migrating past the FSC and fish do not appear to be transiting underneath the lead net from either the north or the south side. The density of detected positions for all species indicates that most fish are residing in the area south of the lead net. All tagged fish that entered the FSC did so from the south side; no fish were detected entering the FSC from the north side, although some fish were detected in this vicinity. Though most of the fish spent hundreds of hours in the ZOI, with the highest density near the entrance of the collector, only half of those fish entered the FSC. Based on the telemetry data collected for this study, it appears that out-migrating fish are finding the entrance to the FSC; however, there is something causing them not to enter.

The flow data collected during the acoustic doppler current profiler (ADCP) survey did not show flow patterns with a direct path to the FSC entrance or any significant hydraulic signal for either attraction flow level (i.e., 1,000 cfs or 600 cfs). The velocities overall were low and did not vary much across the survey area for either attraction flow level. The general direction of flow for both flow scenarios was to the southwest towards the dam, which contrasts with the CFD model that indicated flow vectors upstream of the FSC were generally directed toward the FSC in a northwesterly direction. As such, there is no evidence to suggest that a 150-foot ZOI exists. The results of the literature review were also inconclusive as far as identifying a specific hydraulic condition or criterion that could be used to identify specific conditions that would consistently attract fish.

Nearfield factors such as sound and debris and/or debris booms adjacent to the FSC could have disrupted juveniles from finding the FSC entrance. The sound monitoring conducted in 2017 demonstrated that the sorting area flow (SAF) pumps on the FSC were transmitting sound and vibrations to the surrounding aquatic environment. These pumps had been operating during the current and previous study years so the improvements recently made by PacifiCorp to reduce the noise will need to be evaluated during future monitoring efforts. In addition, during the ADCP survey, winds from the north moved the lead net to a more southerly position, which appeared to partially block the FSC entrance. This was also recently rectified by PacifiCorp.

In 2017, like previous studies, most fish were collected before forebay water temperature reached 15°C in late June, which was approximately 2.5 weeks before the end of the fish collection season. This is not surprising given that during earlier studies and in 2017 most fish also arrived near the FSC before temperature reached 15°C.

Table 3.4-1. Summary of seasonal corrected passage metrics for tagged fish released at the head of Swift Reservior by species.

Metric	Coho Salmon	Spring Chinook	Steelhead	Total
Total tagged (n)	232	108	180	520
Detected in the Forebay	184	75	117	376
P_{RES}[1]	81.0%	69.4%	66.7%	73.6%
Detected at ZOI	164	62	107	333
P_{ENC}[1]	91.6%	82.7%	89.2%	89.0%
Entered NTS	96	29	51	176
P_{ENT}[1]	65.1%	46.8%	48.6%	56.6%
Retained in NTS	46	7	21	74
P_{RET}[1]	41.1%	24.1%	40.4%	38.3%
Captured at FSC	46	7	21	74
Collection Efficiency (P_{CE})[1]	26.7%	11.3%	19.7%	21.7%

Note: [1] P_{RES}, P_{ENC}, P_{ENT}, P_{RET}, and P_{CE} have been corrected to account for array detection efficiencies.

3.5 Swift FSC Injury and Survival

3.5.1 Overview

Injury and survival of captured juvenile out-migrants, and adult cutthroat, bull trout, and steelhead (kelts) were monitored daily on the FSC during 2017 in accordance with Objectives 4 and 5 of the M&E Plan and Section 9.2.1(d) of the Settlement Agreement.

As outlined in the M&E Plan, smolt injury and survival was evaluated based on fish collected in the subsample tanks. The methods outlined in the M&E Plan assume that rates of fish injury and mortality found in subsampled fish would be representative of the general population. PacifiCorp is required to achieve 99.5% survival and less than (or equal) to 2.0% injury (Table 3.5-1).

Each day the FSC was operational, biologists anesthetized juvenile out-migrants collected in the subsample tanks, enumerated fish by species, and inspected them for injury or mortality. Classifications for injury types were grouped into three categories: 1) recordable injuries or injuries caused by collection practices that may substantially decrease the chance of surviving; 2) non-recordable injuries or injuries caused by collection purposes that likely will not decrease the chance of survival; and 3) non-trap related injuries or injuries from natural occurrences prior to fish entering the FSC (Table 3.5-2).

Table 3.5-1. Specified injury and survival standards.

Species and Life Stage	Recordable Injury Rate	Survival Rate
Chinook, Coho, Steelhead, Cutthroat Smolts	2.0%	99.5%
Chinook, Coho, Steelhead, Cutthroat Fry	2.0%	98.0%
Bull Trout	2.0%	99.5%

Table 3.5-2. Categories used for documenting visible injury at the FSC.

Recordable Injury		Non-Recordable Injury
Hemorrhaging	Open Wound (No Fungus)	Open Wound (Fungus)
Gill Damage	Bruising > 0.5 cm diameter	Bruising ≤ 0.5 cm diameter
Loss Of Equilibrium	Descaling > 20%	Descaling < or = 20%

Any mortality observed in the subsample tank was also recorded. Mortality was classified into two categories: 1) trap related mortality; or 2) non-trap related mortality. Biologists used various signifiers to determine whether or not mortality was caused by collection practices. Signifiers included presence of fungus, gill coloration, inspection for cause of death (i.e., descaling, brain trauma, predation, hook and line injury), and *rigor mortis*.

As specified in the current M&E Plan, injury and survival rates were calculated daily and are shown in Equation 3.5-1 and Equation 3.5-2, respectively.

$$R_{Inj} = \frac{SS_{Inj}}{SS_{Total}} \qquad \textbf{Equation 3.5-1}$$

Where:

R_{Inj} = Observed daily injury rate per species;
SS_{inj} = Number of injured fish per species in subsample, mortalities are not included;
SS_{Total} = Total number of fish per species in subsample, mortalities are not included.

$$CS = \frac{M_{SS}}{SS_{Total}} \qquad \textbf{Equation 3.5-2}$$

Where:

CS = Observed collection survival rate per species;
M_{SS} = Number of mortalities of a particular species and age class in the subsample;
SS_{Total} = Total number of fish of a particular species and age class in the subsample.

3.5.2 Results/Discussion

Injury Rate

Combined annual injury rates for each target species ranged from 0 to 0.37 percent (Table 3.5-3). Juvenile Chinook (parr and smolt) had the highest overall injury rate (0.37%), followed by juvenile coho (0.18%), steelhead (0.06%) and cutthroat (0%). Descaling accounted for the greatest proportion of the injuries observed (greater than 90%) in all species, followed by open wounds and fin damage (each 3.5%) and hemorrhaging (1.8%) (Figure 3.5-1). No injuries were observed among coho fry (n=3,589), steelhead fry (n=19), or cutthroat fry (n=14). Similarly, injuries were not observed on any of the adult steelhead or bull trout collected.

Overall, annual injury rates for all juvenile salmonid species (smolt and parr) and adult fish met the required performance standard maximum of 2.0%. Only juvenile Chinook were found to have an injury

rate greater than 0.3%. However, these fish were almost exclusively comprised of fish from the acclimation program and were susceptible to descaling due to the prevalence of BKD.

PacifiCorp will continue to address the causes of injury in the future. Debris loading on the fry and smolt separator bars continues to be the major source for fish injury. As a temporary solution to this problem, PacifiCorp staffed the FSC around the clock to clear debris from the separator bars during peak migration periods. PacifiCorp is in the process of modifying the fry dewatering tank to better accommodate debris. This tank modification, along with various forms of debris conveyance, will likely reduce injuries and mortalities associated with debris.

Table 3.5-3. Annual injury rates for target species collected at the FSC are shown with the associated 95% confidence interval.

	No. Injured[a]	No. Sampled[b]	Injury Rate (%)
Coho (Fry)	0	3,589	0.0
Chinook (Fry)	0	0	0.0
Steelhead (Fry)	0	19	0.0
Cutthroat (Fry)	0	14	0.0
Combined (Fry)	**0**	**3,622**	**0.0**
Coho (Parr & Smolt)	37	20,026	0.18 ± 0.05
Chinook (Parr & Smolt)	18	4,830	0.37 ± 0.01
Steelhead (Parr & Smolt)	1	1,580	0.06 ± 0.12
Cutthroat (Parr & Smolt)	0	641	0
Combined (Parr & Smolt)	**56**	**27,077**	**0.21 ± 0.05**
Steelhead Adults	0	23	0.0
Steelhead Kelts	0	9	0.0
Bull Trout	0	9	0.0

[a] Mortalities with injuries are not assigned as injured fish; they are assigned to mortality totals.
[b] The number sampled for injury rate calculations does not include mortalities.

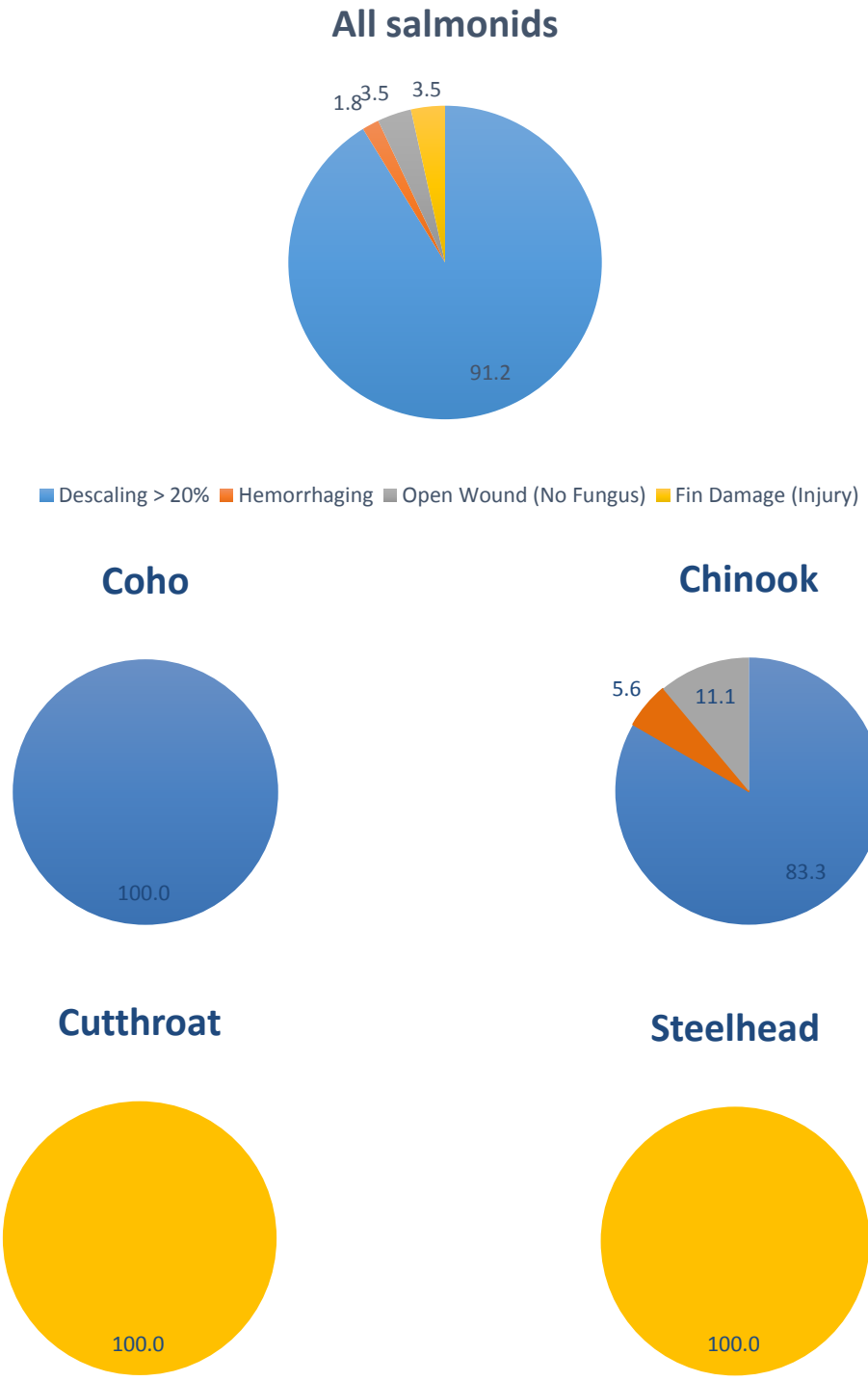


Figure 3.5-2. Composition of injury type occurrences by species. Percentages reflect parr and smolts numbers collected that are referenced in Table 3.5-3.

Survival Rate

In the absence of juvenile Release Ponds, annual survival rates were based solely on collection survival (S_{COL}) because the Release Ponds were not constructed in 2017. Transported fish were directly released into the Lewis River below Merwin Dam (Pekins Ferry Boat Launch near rivermile three) and consequently, a true estimate of transport survival (S_{TRAN}) was not possible.

Annual survival rates among all target species and life-stages passing through the FSC ranged from 82.6 to 100 percent (Table 3.5-4). Bull trout had the highest overall survival rate (100%) followed by cutthroat (99.0%), steelhead (97.6%), spring Chinook (98.4%), coho (98.3%), and adult steelhead (85.7). Coho fry accounted for all mortality among salmonid fry (survival of 86.4%). No mortality was observed among any other species of fry.

Nearly all mortality observed was associated with high debris loading and accumulation on the fish sorting bars and in the holding tanks. This is a particular problem during high run-off periods in the winter and early-spring when sub-yearling out-migrants (parr) are prevalent. Modifications to the sorting areas and tanks are currently being engineered to help manage debris accumulation and further reduce mortality.

Table 3.5-4. Annual survival rates for juvenile salmonids (parr and smolt), cutthroat, bull trout, and adult steelhead.

Species	No. of Mortalities	No. Sampled	Survival% (CS)	Combined Survival% (CS) with 95%CI
Coho Parr	229	9,258	97.5	98.3± 0.81
Coho Smolts	128	10,768	98.8	
Chinook Parr	4	266	98.5	98.4 ± 0.35
Chinook Smolts	73	4,564	98.4	
Steelhead Parr	2	73	97.2	99.4 ± 0.38
Steelhead Smolts	8	1,507	99.5	
Cutthroat(> 13 inches)	7	592	98.8	99.0 ± 0.81
Cutthroat (< 13 inches)	0	38	99.2	
Total	451	27,066	**Overall:**	98.4± 0.15
Steelhead Adults	4	23	82.6	85.7
Steelhead Kelts	1	9	88.9	
Bull Trout	0	9	100	100

Table 3.5-5. Annual survival rates for salmonid fry.

Species	No. of Mortalities	No. Sampled	Survival% (CS)
Coho Fry	491	3,589	86.4±1.12
Chinook Fry	0	0	100
Steelhead Fry	0	19	100
Cutthroat Fry	0	14	100
		Overall:	**86.5±1.11**

3.6 Swift Powerhouse Entrainment Evaluation

Assessing the proportion of fish entering the intake of the Swift No.1 Powerhouse is required under Section 9.2.1(f) of the Settlement Agreement and identified as Objective 3 of the M&E Plan. However, this M&E Objective will not be quantified until downstream passage facilities are installed at Yale and Merwin dams.

3.7 Overall Downstream Survival (ODS)

3.7.1 Overview

The Settlement Agreement requires that the Utilities achieve an overall downstream survival (ODS) rate of greater than or equal to 80%[5]. ODS is defined in Section 4.1.4 of the Settlement Agreement as:

> *The percentage of juvenile anadromous fish of each of the species designated in Section 4.1.7 that enter the reservoirs from natal streams and survive to enter the Lewis River below Merwin Dam by collection, transport and release via the juvenile fish passage system, passage via turbines, or some combination thereof, calculated as provided in Schedule 4.1.4.*

In other words, ODS is the percentage of fish entering the Lewis River reservoirs that are successfully captured and released alive below the Project (e.g., Merwin Dam). It should be noted that Schedule 4.1.4 of the Settlement Agreement contains a caveat that the methodology described in the schedule needs to be ground-truthed and may not be the best method to use.

Initially, ODS was to be measured from the head of Swift Reservoir to the exit of the Release Ponds located downstream of Merwin Dam (Figure 2.1-1). Estimates of ODS are to be developed for coho, spring Chinook, steelhead and sea-run cutthroat trout. ODS estimates for sea-run cutthroat trout will be delayed until data indicate that this cutthroat life-history is present in the upper Lewis River basin and that the number of juveniles produced is sufficient, as determined by the USFWS, for experimental purposes.

PIT tags compatible with those used throughout the Columbia Basin for salmonid evaluations and direct enumeration of fish collected and transported from the FSC are used to develop estimates of ODS. All PIT tags used will be entered into the Pacific Northwest Region PIT tag database (PTAGIS).

Consistent with the Settlement Agreement, juveniles passing Swift Dam either through the turbines or spill will not be counted toward meeting the ODS standard because they are unlikely to survive passage through multiple dams and reservoirs not equipped with passage facilities.

3.7.1 Methods

The methods for developing estimates of ODS are as follows:

[5] An ODS of greater than or equal to 80% is required until such time as the Yale Downstream Facility is built or the Yale in Lieu Fund becomes available to the Services, after which ODS shall be greater than or equal to 75%. The parties to the Settlement Agreement acknowledge that ODS rates of 80% or 75% are aggressive standards and will take some time to achieve.

- Test fish will be obtained from a screw trap operated at the head of Swift Reservoir or at the FSC. Fish collected at the FSC will only be used if enough fish cannot be collected at the screw trap. Preference will be to use fish collected at the screw trap as these fish would have not been exposed to the reservoir environment; an exposure that may alter fish behavior, and thus interpretation of study results.

- Fish captured at the traps will be identified to species, measured for length and a subsample tagged with PIT -tags. Only fish greater than, or equal to, 60 mm in length will be tagged. On an annual basis, the ACC will evaluate the appropriate size limits for tagging.

- Fish will be released at the head of Swift Reservoir weekly throughout the major part of the migration season (April-June). A total of 996 fish of each species will be released weekly in the spring in proportion to the run-timing of each species. PIT tag releases will continue into summer or fall as long as a persistent juvenile migration exists

- Sample size for the release was based on a reservoir survival rate of 80 percent, tag detection probability of 95 percent and a precision of 0.025. The test fish will be held for 24 hours prior to release to quantify handling mortality.

- PIT-tag detectors will be located on the FSC and at the exit of the release ponds and will generate the tag detection histories necessary to estimate ODS.

- The FSC, transport trucks and release ponds (when completed) will be examined daily by biologists to determine the number of fish killed during the handling and transport processes. All dead fish will be examined for the presence of a PIT tag. Dead tagged fish found in the FSC and release ponds would be assigned to collection loss (S_{COL}) and transport loss (S_{TRAN}), respectively.

- Once CE exceeds 60 percent, 50 dead PIT-tagged fish will be released into the FSC over the course of the season as a check on the ability of the biologists to detect and recover dead fish. If tag recoveries are less than 100 percent, estimates of ODS will be adjusted based on the calculated error rate.

The seasonal ODS estimate will be based on pooling release–recapture data over the season. Because some proportion of tagged fish are likely to overwinter in the reservoir, any fish captured in subsequent years will be retrospectively added to the ODS estimate for their release year. The ODS calculation under the intended operations (i.e., after completion of the Release Ponds) is shown in Equation 3.7-1. The ODS calculation used in the 2017 study (absent of S_{TRAN}) is shown in Equation 3.7-2.

$$\boldsymbol{ODS = S_{RES} * S_{COL} * S_{TRAN}} \qquad \textbf{Equation 3.7-1 (with release ponds)}$$

Where:

S_{RES} = Survival probability through reservoir;
S_{COL}= Survival probability through the collector;
S_{TRAN} = Survival probability through the smolt transport system

$$ODS = S_{RES} * S_{COL}$$ **Equation 3.7-2 (without release ponds - 2017)**

Where:

S_{RES} = Survival probability through reservoir
S_{COL}= Survival probability through the collector
S_{TRAN} = Survival probability through the smolt transport system.

3.7.2 Results/Discussion

Only PIT tag interrogations at the FSC recorded on or before December 31, 2017 were included in the 2017 ODS calculations (Table 3.7-1). No dead PIT tagged spring Chinook, cutthroat, or steelhead used in the ODS study were found in the FSC. Hence, S_{COL} was considered 100% for these species during 2017. Out of the 71 recaptured PIT tagged coho, two were mortalities, resulting in an S_{COL} of 0.97. S_{TRAN} was not calculated and was assumed to be 100% in 2017.

The M&E Plan calls for 996 tagged fish per species to be released over a six week period during the particular species respective run-timing in order to achieve the desired statistical power. To capture fish for tagging, a single 8-foot-diameter screw trap was operated in the upper Lewis River near Eagle Cliff from April 20 to July 30, 2017. Low numbers of fish were captured by the screw trap in 2017. Because of inadequate numbers of fish to tag, no species received the required 996 tags. During the study period, only 398 coho, 494 Chinook, 56 cutthroat, and 269 steelhead were PIT tagged and released. Of the PIT tagged fish, 282 coho, 110 spring Chinook, 17 cutthroat, and 175 steelhead were non-naïve fish that were captured and tagged at the FSC then transported and released back at the head of the reservoir. The resulting annual ODS estimates are 18% (± 3.4%) for coho, 10% (±3.0) for spring Chinook, 5.4% (± 5.9%) for cutthroat and 10% (± 3.6) for steelhead (Table 3.7-1). The ODS estimate for cutthroat should be interpreted with the understanding that little is yet known about the life-history patterns of cutthroat in the Upper Lewis River watershed.

Table 3.7-1. Annual ODS estimate for each species (functionally S_{RES}). ODS performance standard for all species is ≥ 80 percent.

Species	Tagged and Released in 2017	FSC Recaptured in 2017	2017 ODS (%) with ±95% CI
Coho	398	71	18 ± 3.4
Spring Chinook	494	64	13 ± 3.0
Cutthroat	56	3	5.4 ± 5.9 [1]
Steelhead	175	27	10 ± 3.6

[1] Lower bound of cutthroat ODS 95% CI should be interpreted as zero (0) percent.

The M&E Plan addresses the fact that a portion of tagged fish are likely to overwinter in the reservoir and that any fish captured in subsequent years will be retrospectively added to the ODS estimate for their release year. The adjusted 2016 ODS estimates are summarized below in Table 3.7-2. An additional six tagged coho and one steelhead from the 2016 ODS study were captured by the FSC during 2017. No additional tagged spring Chinook or cutthroat from the 2016 ODS study were detected in 2017.

Table 3.7-2. 2015 adjusted annual ODS estimate for each species (functionally S_{RES}) is shown. ODS performance standard for all species is ≥ 80 percent.

Species	*Tagged and Released in 2016*	FSC Recaptured 2016	2016 ODS (%) with ±95%CI	FSC Recaptured 2017	Total Recaptured (Combined Years)	2016 Combined ODS (%) with ±95%CI
Coho	686	227	33 ± 3.5	6	233	34 ± 3.5
Spring Chinook	2	0	0	0	0	0
Cutthroat	22	1	4.5 ± 8.6	0	0	4.5 ± 8.6
Steelhead	79	12	15 ± 7.8	1	13	16 ± 8.2

4.0 UPSTREAM COLLECTION AND PASSAGE METRICS

4.1 Summary

The historic adult fish trap at Merwin Dam was operated by PacifiCorp staff until June 28, 2013, when it was decommissioned for construction of the new passage facility. The new upstream sorting facility at Merwin Dam was considered substantially completed in April 2014, and has actively operated since.

All adult salmonids collected were identified to species and sorted by origin (i.e., hatchery or wild), broodstock (i.e., hatchery or supplementation), or as upstream target species.

A total 17,551 fish were captured at the Merwin Trap in 2017 (Table 4.1-1). Among the species collected, winter steelhead accounted for the largest proportion of fish captured (n=3,706) followed by early run coho (n=3,678), summer steelhead (n=3,593), late coho (n=2,999), spring Chinook (n=2896), fall Chinook (n=575), cutthroat (n=54), sockeye (n=24), pink salmon (n=4), and chum salmon (n=3). Of the fish captured, several were recaptured fish that hard already passed through the trap once. Recaptured fish counts include 1,080 hatchery summer steelhead, 116 blank wire tag winter steelhead, 28 early wild coho, 7 wild sockeye salmon, 2 wild fall Chinook, 2 wild late coho, 2 wild winter steelhead, and 1 pink salmon.

A total of 2,495 hatchery summer steelhead were captured at Merwin Trap and marked with a caudal clip. These fish were transported and released back into the lower Lewis River as part of the Washington Department of Fish and Wildlife Fish Recycle Program. A total of 1,080 summer steelhead were then recaptured at Merwin Trap. Once recaptured, fish were then sent to surplus.

There was a notable increase in the proportion of wild early run coho that returned to the Merwin Trap in 2017, when compared to previous years. Approximately 54.4% of all early run coho that returned in 2017 were of wild origin, compared to 34.5% in 2016, 6.5% in 2015 and 11.2% in 2014. A number of PIT tagged adults returned to Merwin Trap in 2017, after being tagged at Swift FSC in previous years.

A total of 3,557 early coho, 3,257 late coho, 592 blank wire tag winter steelhead, and 54 cutthroat were transported upstream and released above Swift Dam as part of the reintroduction program in 2017 (Table 4.1-2). Of the 3,557 early coho that were transported upstream, 2,582 were collected at the Merwin Trap and 975 were collected at Lewis River Hatchery. Of the 3,257 late coho that were transported upstream, 2,282 were collected at the Merwin Trap and 975 were collected at Lewis River Hatchery. All wild early

coho collected at both locations were transported upstream. Wild origin late coho were transported upstream only after meeting brood incorporation goals. All wild winter steelhead that were transported upstream were collected at the Merwin Trap. All transported winter steelhead were blank wire tag fish; no true wild winter steelhead were transported upstream. All 54 adult costal cutthroat captured were transported upstream.

Table 4.1-1. Total fish collected at Merwin Trap during 2017. Resident rainbow trout and cutthroat were not gender-typed.

Characteristic	*AD Clip*			*CWT*			*Wild*			*Wild Recap*			*Wild-BWT*		*Recap*		*Misc*	Total	%
Species	M	F	J	M	F	J	M	F	J	M	F	J	M	F	M	F	Not sexed		
Spring Chinook [a]	997	1316	545				21	13	4									**2896**	16.5
Fall Chinook	160	155	8				85	103	62	1	1							**575**	3.3
Early Coho	597	756	105	62	130	28	832	1123	16	12	16	0						**3,678**	21.5
Late Coho	1020	1087	176	227	239	19	91	112	26	1	1	0						**2,999**	17.1
Summer Steelhead	1100	1395					1	17							399	681		**3,593**	20.5
Winter Steelhead	1496	1363					48	47			2		346	288	67	49		**3,706**	21.1
Sockeye Salmon							9	8		5	2							**24**	0.1
Chum Salmon							1	2										**3**	0.01
Pink Salmon							3	1		1								**4**	0.02
Cutthroat (>13 inches)																	54	**54**	3.1
Cutthroat (< 13 inches)																			
Rainbow (< 20 inches)																			
Bull Trout (> 13 inches)																			
Bull Trout (< 13 inches)																			
															Total			**17,551**	100

[a] Counts of male and female spring Chinook may vary slightly from those reported by WDFW broodstock counts.

Table 4.1-2. Total fish transported above Swift Dam in 2017.

Species	Male	Female	Jack	Not sexed	Female:Male Ratio	Jack:Adult Ratio	Total
Spring Chinook	370	430	310	-	0.63	0.39	***1110***
Early Coho	1652	1870	34	-	1.11	0.01	***3556***
Late Coho	1602	1624	31	-	0.99	0.01	***3257***
Winter Steelhead	331	261	-	-	0.79	-	***592***
Cutthroat >13"	-	-	-	54	-	-	***54***
Bull Trout >13"	-	-	-	-	-	-	***0***
						Total	***8,569***

4.2 Adult Passage Survival

4.2.1 Overview

Section 9.2.1(h) of the Settlement Agreement requires upstream passage survival (UPS) of adult salmonids and bull trout to be equal to or greater than 99.5%. The methods to calculate adult passage survival are outlined in Objective 9 of the M&E Plan. Adult bull trout and cutthroat trout are defined as fish with fork length greater than 13 inches (330 mm). UPS is defined as the survival from the time adult target species enter the adult upstream facility to their release above Swift Dam. UPS is calculated based on Equation 4.2-1:

$$UPS = 1 - \frac{AD_{TRAP} + AD_{REL}}{N} \qquad \textbf{Equation 4.2-1}$$

Where:

N = Number of total adults collected
AD_{TRAP} = Number of dead adults in trap
AD_{REL} = Number of dead adults at release site

4.2.2 Results/Discussion

A total 8,569 adult salmonids (3,556 early coho, 3,257 late coho, 1,110 spring Chinook, 592 winter steelhead, and 54 cutthroat) were transported upstream throughout the migration period in 2017. All cutthroat trout survived the trapping and transport processes, resulting in an UPS of 100 percent. One blank wire tag winter steelhead mortality was observed during upstream transport from the Merwin Trap, resulting in a 99.82 percent UPS. A total of 18 coho mortalities were observed during transport in 2017, the majority of which were jump-outs. A total of 9 spring Chinook mortalities were observed at Merwin Trap in 2017, resulting in a 99.2% UPS. A total of 28 mortalities were observed across all species, resulting in an UPS of 99.6 percent (Table 4.2-1).

Table 4.2-1. Overall upstream passage survival for Merwin Trap in 2017.

Species	Number Transported	Trap Mortalities	Transport Mortalities	Upstream Passage Survival (%)
Early Coho	3,556	12	2	99.6
Late Coho	3,257	4	0	99.9
Spring Chinook	1,110	9	0	99.2
Winter Steelhead	592	0	1	99.8
Coastal Cutthroat	54	0	0	100
Total	**8,569**	**25**	**3**	**99.6**

4.3 Adult Trap Efficiency

4.3.1 Overview

Adult trap efficiency (ATE) is defined in Section 4.1.4 of the Settlement Agreement as:

> *The percentage of adult Chinook, coho, steelhead, bull trout, and sea-run cutthroat that are actively migrating to a location above the trap and that are collected by the adult trap at Merwin Dam.*

The M&E Plan defines a performance standard of 98% collection efficiency, or ATE, for fish that enter the Merwin Dam tailrace.

Following the methods outlined in Objective 10 of the M&E Plan, the first year of study began in spring 2015. During that initial year, all three study species were evaluated including: winter steelhead, spring Chinook salmon, and coho salmon. However, 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. Results of the 2015 evaluation indicated a relatively high success rate for tagged fish at locating the trap entrance, but lower rates of fish being successfully captured by the fish crowder and lift assembly.

In 2016, PacifiCorp implemented a second year of study. In addition to generating core passage metrics, the 2016 study focused efforts on resolving fish behaviors in and around the fish crowder and lift assembly using an ARIS sonar camera. 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 (Stevens et al. 2016; Caldwell et al. 2017) indicated a relatively high success rate for tagged fish at 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 appeared that (A) fish passage was constrained at the hopper, and that (B) the frequency of fish crowder operation strongly affected the 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.

The primary goal of the 2017 Merwin ATE study was to continue to evaluate the performance of the Merwin Trap 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 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 and coho salmon because it was anticipated that low numbers of spring Chinook would be returning to the Lewis River in 2017.

4.3.1 Results/Discussion

A detailed report of the third year of data collection (2017) for winter steelhead is provided in Appendix C and the second year of data collection on coho salmon is provided in Appendix D.

Similar to the observations made in 2015 and 2016, results of the 2017 evaluations also indicated a relatively high success rate for tagged fish locating the trap entrance (P_{EE}), but slightly lower rates of fish being successfully captured (ATE_{test}) (Table 4.3-1). However, the discrepancy between these two metrics was significantly lower in 2017 than in previous years for both winter steelhead and coho salmon. This difference was directly correlated to the presence of the fyke in Pool 2, which prevented fish from returning to the tailrace once they had entered the trap. Although collection efficiency increased for both species in 2017, it was still below the performance standard of 98 percent. Cross-year comparisons using three years of data on winter steelhead (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 results of this study also suggest there may be negative bias in estimating ATE_{test} using the current study design associated with: 1) using trap non-naïve test fish; 2) using hatchery origin fish rather than fish from the upper basin; and 3) not accounting for natural straying rates and fish condition. These possible factors will be evaluated in 2018.

Table 4.3-1. Summary of passage metrics for tagged fish released into the tailrace of Merwin Dam in 2017.

Metric	Coho Salmon	Spring Chinook	Steelhead
Total Tagged (n)	149	NA	150
Entered the Tailrace	60	NA	139
Entered the Trap	42	NA	116
Trap Entrance Efficiency (P_{EE})	70% (60%-83%)	NA	84% (77% – 90%)
Captured	38	NA	106
Collection Efficacy (P_{CE})	63% (50%-74%)	NA	77% (70% - 84%)

4.4 Spawn Timing, Distribution, and Abundance of Transported Fishes

4.4.1 Overview

Section 9.2.2 of the Settlement Agreement identified the need to determine the spawn timing, distribution, and abundance for transported anadromous species that are passed upstream of Merwin Dam. The primary objective of this task is to identify preferred spawning areas in order to: 1) inform revisions to the Hatchery and Supplementation Plan (H&S Plan; PacifiCorp and Cowlitz PUD 2009) and the Upstream Transport Plan (PacifiCorp 2009); and 2) guide the ACC in determining how to direct restoration efforts with the Aquatics Fund.

Two methodologies for determining spawn timing, distribution, and abundance of transported fishes were developed. For adult coho salmon and spring Chinook, comprehensive spawning ground surveys were conducted in the potentially accessible river and stream reaches upstream of Swift Dam in 2017. Due to limited access and anticipated heavy snow accumulations during the spawning season for winter steelhead, a combination of aerial radio telemetry surveys, fixed-station radio antennas, aerial red counts, and single pass electrofishing surveys for young-of-the-year steelhead (during the following summer) were conducted. A detailed description of each method is outlined in Objective 15 of the M&E Plan.

In addition to evaluating spawn timing, distribution, and abundance of transported species, PacifiCorp also continued to implement a seed plant program in 2017. This program was developed based on results of earlier observations which indicated that distributing a proportion of the adults further upstream appeared to improve fish distribution (summarized in detail in Appendix F in the 2015 Annual Fish Passage Program Report (PacifiCorp 2015)). Three releases sites were established in the upper watershed of Swift Reservoir in 2017. These release sites were the Muddy River Bridge, the Clear Creek Bridge, and the upper Lewis River Bridge near Crab Creek. Heavy snow pack in the upper basin limited access to release sites during the early spring that prevented seed plant efforts for winter steelhead; only spring Chinook seed plants were completed in 2017 (Table 4.4-1.). Radio telemetry combined with a number of aerial surveys was used to evaluate winter steelhead behavior and movement. Spawning surveys were used to determine distribution of coho salmon and spring Chinook.

Table 4.4-1. Summary of fish releases upstream of Swift Reservior as part of the 2017 seed plant evaluation.

Spring Chinook	Eagle Cliff	Upper Watershed				Combined Total
		Muddy River Bridge	Clear Creek Bridge	Upper Lewis (Crab Creek)	Total	
Total	1,075	19	9	7	35	1,110

4.4.2 Results/Discussion

Data collection on the spawn timing, distribution, and abundance of transported fishes was completed the end of December, 2017. Data entry was completed in January and February. 2018. Data QA/QC, summary and analysis are scheduled to be complete by April, 2018. At the time of this initial review draft, PacifiCorp has not received the results of this 2017 effort. When complete, the results will be attached as Appendix E to this report.

5.0 OCEAN RECRUIT ANALYSIS

5.1 Overview

An analysis of ocean recruitment is stipulated in the Settlement Agreement to determine when the hatchery and natural adult production targets established for the upstream passage program were met. These targets were defined in Section 8.1 of the Settlement Agreement and described as:

> *"…total escapement (fish that naturally spawned above Merwin Dam and hatchery fish) plus harvest (including ocean, Columbia River, and Lewis River Harvest)."*

For this analysis, the average number of ocean recruits over a five-year period will be evaluated (i.e., five consecutive brood years). These data will be evaluated to determine if and when hatchery production levels should be altered. A detailed description of the methodology for this analysis is outlined in Objective 12 of the M&E Plan. The M&E Work Group settled on using three different methods of estimation including: 1) return-year recruitment estimates; 2) brood year recruitment estimates; and, 3) fishery plus escapement. These three approaches will be used to supply information for run-reconstruction estimates of each return year. Steelhead are an exception because of their multi-year life cycle so WDFW recommended using a catch plus escapement approach. Some of this work depends on

an accurate creel census program to estimate fishery-related mortalities, but a creel program will not be implemented until adequate numbers of spring Chinook return to warrant the effort.

5.2 Results/Discussion

Ocean recruit analysis was initiated in fall of 2013 and continued through the rest of the year. Halfway through the process of determining a methodology, investigators realized that the use of coded-wire tags (CWT) and the Regional Mark Information System (RMIS) does not account for CWT detection in fish that still have their adipose fin. The alternative methods for estimating ocean recruits are outlined in the latest version of the M&E Plan **(**PacifiCorp and Cowlitz PUD 2010**)**. It will take at least five years of analysis before investigators can confidently report ocean recruit numbers and begin evaluating hatchery goals for the Lewis River.

6.0 PERFORMANCE MEASURES FOR INDEX STOCKS

6.1 Overview

The H&S Plan (PacifiCorp and Cowlitz PUD 2009) recommends that other Lower Columbia River stocks be used as index groups to determine whether the success or failure of the Lewis River reintroduction program is the result of in-basin or out-of-basin factors. This would be determined by comparing the survival rates of hatchery and natural-origin fish produced in other basins (such as the Cowlitz River) with releases made in the Lewis River.

6.2 Results/Discussion

Since adult returns of natural-origin fish from the upper Lewis River have not occurred in numbers large enough for meaningful analysis, this metric will be postponed until larger natural-origin adult returns are realized.

7.0 REINTRODUCED AND RESIDENT FISH INTERACTIONS

7.1 Overview

As called for in Section 9.7 of the Settlement Agreement, PacifiCorp will monitor the interaction between reintroduced anadromous salmonids and resident fish species. Of specific interest to the Settlement parties was the possible effect resident trout released in Swift Reservoir may have on reintroduced salmonids and the effect of anadromous fish introductions on the kokanee populations in Yale Lake. Additionally, concern was expressed that anadromous fish may impact the health and viability of ESA listed bull trout populations. This task is one of the assignments of the Fish Passage Feasibility Study conducted by the US Geological Survey and University of Washington, Department of Fisheries. The final report was issued in December 2016 (PacifiCorp 2016).

7.2 Results/Discussion

The USGS/UW group completed their analysis and provided results as follows:

1) Used existing data and empirical data to identify the structure of food webs in the three reservoirs;
2) Provided estimates of predation potential and consumption of juvenile salmonids by resident native and non-native species across different seasons;
3) Provided estimates of potential competition among different resident species and anadromous salmonids for resources;
4) Quantified spatial overlap within Pine Creek and habitat use by anadromous smolts and resident fishes; and,
5) Provided estimates of predation and competition among species in Pine Creek using stable isotope methods.

This effort covered a three-year period but the M&E subgroup suggested that this effort be repeated to assess interactions once the reintroduction program is fully operational.

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APPENDICES

APPENDIX A

SUMMARY OF 2017 ACCLIMATION FISH RELEASES AND EVALUATION RESULTS

2017 Spring Chinook Acclimation Planting Schedule and Evaluation Plan

Prepared by PacifiCorp

August 1, 2017

FINAL

Background

Section 8.8.1 of the Lewis River Settlement Agreement states:

> "*Beginning upon completion of the Swift Downstream Facility, the Licensees shall place juvenile salmonid acclimation sites in areas reasonably accessible to fish hauling trucks and in practical areas in the upper watershed above Swift No. 1 Dam, as determined by the Licensees in Consultation with the Yakima Nation and the ACC…"*

To meet this requirement, three acclimation sites were constructed in the upper Lewis River basin upstream of Swift Reservoir. Two of these sites (Muddy River and Clear Creek Acclimation Ponds) were designed to take advantage of natural habitat by reconditioning side channels and using flow control structures to manage in-flow from the main river channel and to maintain adequate water elevation in the ponds. Construction of these sites was completed in fall 2013. The third site diverted water from Crab Creek, which served as inflow to a holding tank placed downstream near the confluence of Crab Creek and the Lewis River. The Crab Creek site was completed in fall 2015. The original intent of all three sites was to hold fish in the early spring for up to 6-weeks before allowing for volitional passage into the river. A total of 38,000 spring Chinook were originally to be stocked at Muddy River site, 19,000 at the Clear Creek site, and 15,000 at the Crab Creek site annually.

Due to a number of unforeseen challenges, these sites were never utilized as intended. A procedural decision made by the Aquatic Coordination Committee (ACC) to begin releasing acclimation fish in the fall as opposed to holding them in the hatchery and releasing them the following spring has also complicated the use of these sites[1]. A brief summary describing each of these challenges is provided below:

- *Muddy River Acclimation Pond* – Following completion of the pond, the Muddy River site experienced too low of dissolved oxygen levels to support juvenile salmonid life (< 4 mg/L) due to high levels of iron-oxidation from iron bacteria. Aeration units were tried, but they did not increase dissolved oxygen to suitable levels. Pending actions to remedy the iron problem, acclimation fish were planted directly into the Muddy River. In December 2015, the infiltration gallery and water supply control structure to the pond were heavily damaged due to high water. After a site visit and information provided by the Gifford-Pinchot NF Staff on July 14, 2016, the ACC decided that the Muddy River Site would be decommissioned. No fish were ever stocked into this pond.

[1] During their June 2015 meeting, the ACC agreed that releasing acclimation fish earlier in the fall is a better strategy and more akin to the natural out-migration behavior that has been observed in the upper basin. It was also determined that fish released in the fall would be held a shorter amount of time in the hatchery and thus less susceptible to disease (i.e., Bacterial Kidney Disease – BKD) that has been observed in previous years.

- *Clear Creek Acclimation Pond* – Maintaining adequate inflow and pond elevation has been the largest challenge for this site. During spring 2014, approximately 9,000 smolts were stocked in to the Clear Creek Pond, however all fish were released the following week due to low river conditions and reduced inflow. In August 2015, rip-rap was added along the shore near the intake largely improve the structural integrity of the intake structure, but it was also thought to improve inflow. However, similar to the Muddy River Site, the Clear Creek Acclimation Pond sustained heavy damage during the December 2015 high water event. PacifiCorp in coordination with the ACC made the decision to decommission the Clear Creek Acclimation site are in the process of deciding the future of this site.

- *Crab Creek Acclimation Pond* – This site has not been used since its completion in fall of 2015. The Crab Creek site was designed and permitted for spring rearing and release of fish. Fall releases may be difficult at this site due to the hydraulic regime of Crab Creek, which may limit the timeframe in which smolts may be held. PacifiCorp in coordination with the ACC are in the process of deciding the future of this site.

Because of the challenges faced with the holding ponds, the vast majority of acclimation fish have been directly released near the acclimation sites, but not held in the ponds. Since 2012, approximately 401,000 spring Chinook have been directly released into the upper basin (Table 1). With the exception of 2016, all of these releases have been done using a large capacity fish hauling truck and releasing approximately 9,000 to 12,000 fish per load over a short period of time (1-2 days). A prolonged release strategy was incorporated during 2016, which is detailed in the Appendix A of the 2016 Annual Fish Passage Report. Overall, information regarding the effectiveness of these releases is largely unknown. Data from PIT tag detections (USGS Crab Creek site), collection numbers at the screw trap located at Eagle Cliff, and downstream collection numbers at the Swift Floating Surface Collector suggest that a large portion of these fish move out of the upper basin into the reservoir relatively quickly[2]. Additional information on the residency time following release particularly for fish released during the fall would be helpful for directing future release strategies for the program as well as help make decisions regarding the future of the remaining acclimation sites.

As a follow-up, it was decided during the August 10, 2017 ACC meeting that all three current acclimation sites would be decommissioned with the caveat that in the future other acclimation sites would be developed if it appeared through study and observing other programs that pond sites are necessary for successful reintroduction. In the meantime, the ACC elected to have all acclimation fish released directly into the upper Lewis River. A detailed monitoring plan will be developed for this interim measure (Lewis River Acclimation Pond Plan 2017).

[2] Detection histories collected at the confluence of Crab Creek in spring 2013 indicated that approximately 60% of tagged acclimation Chinook emigrate within the first seven days following release and 98% within 60 days. Observations at the Swift Floating Surface Collector have noted the arrival of acclimation fish as early as four days after release.

Planting Schedule and Evaluation Plan (2017)

Overview

This study plan was discussed and approved by the ACC during its July 13, 2017 monthly meeting. Overall, the release strategy for 2017 is similar in duration and plant sizes to the release strategy incorporated in 2016, however the release schedule for 2017 will occur earlier in the year (i.e., July and August in 2017, vs. September and October in 2016). In addition, no fish will be PIT tagged. Instead, operation of the screw trap at Eagle Cliff will be extended through the month of July to quantify the number of acclimation fish entering Swift Reservoir. Approximately 50,000 acclimation Chinook are scheduled for direct release in summer 2017 (Table 2). It is thought that by decreasing the number of fish stocked per planting event, smolts may stay in the system longer and move downstream at a slower rate due to decreased densities. Releasing fish over a slightly longer timeframe in conjunction with extending the screw trapping efforts at Eagle Cliff, will also allow for evaluation of whether timing of release affects residency time for fish released in the summer.

Table 1. A summary of spring Chinook releases as part of the Lewis River acclimation program since 2012.

Species	Brood Year	Plant Date	Number	Size (F/LB)	Plant Site
CK:SP	2016	9/14/2018	*500*	*N/A*	Drift Cr
		9/15/2016	*15,000*	*N/A*	Crab Cr
		9/16/2016	*8,000*	*N/A*	Clear Cr
		9/22/2016	*2,300*	*N/A*	Muddy R.
		9/28/2016	*1,850*	*N/A*	Clear Cr
		9/30/2016	*1,850*	*N/A*	Muddy R.
		10/12/2016	*200*	*N/A*	Clear Cr
		10/13/2016	*200*	*N/A*	Muddy R.
CK:SP	*2015*	*N/A*	*34,090*	*44.5*	*N/A*
CK:SP	2014	10/21/2015	14,739	23.3	Crab Cr
			33,261	23.3	Clear Cr
CK:SP	2013	3/3/2015	37,022	20	Crab Cr
		3/4/2015	72,644	20	Clear Cr
CK:SP	2012	10/7/2013	16,200	23.2	Crab Cr
		4/23/2014	18,416*	10.3	Clear Cr
		4/23/2014	21,012	10.6	Muddy R.
		5/1/2014	44,000	10.5	Clear Cr
		10/19/2012	15,440	23	Crab Cr

CK:SP	2011	4/1/2013	17,655	12.5	Muddy R.
		4/1/2013	13,665	12.5	Clear Cr
		4/3/2013	18,560	13.5	Clear Cr
		4/3/2013	18,560	12.2	Muddy R.
		4/4/2013	14,256	12	Crab Cr

**Note: Includes approximately 9,000 smolts released into the Clear Creek acclimation pond.*

Methods

Three upper basin locations will be used as release sites during the 2017 effort. These locations are (Figure 1):

1. Clear Creek Bridge;
2. Upper Muddy River just upstream of the Smith Creek confluence at HooHoo Creek Bridge;
3. Lewis River Bridge at Crab Creek

Acclimation fish will be released at each location beginning the third week in July, through mid-August (Table 2). Smolts will be released weekly, with release locations set on a rotating schedule to minimize the effects of overcrowding. Approximately 20,000 juvenile spring Chinook will be released at both the Upper Muddy and Crab Creek release sites during the four week planting schedule. Approximately 10,000 smolts are scheduled to be released at the Clear Creek release site. Clear Creek will receive fewer fish than the other two test sites due to its smaller overall size. The first three plantings at each site will contain fewer individuals (~4,000 fish at both Crab Creek and Upper Muddy River, and ~2,000 fish at Clear Creek). The last release event at each location will contain approximately double for each respective location (~8,000 at both Crab and Upper Muddy, and ~4,000 at Clear Creek).

Spring Chinook used for the acclimation program will be placed on a modified feeding schedule during rearing, which will allow them to more closely emulate the growth patterns exhibited by NOR smolts. This modified feeding schedule, coupled with earlier releases will result in significantly smaller fish at time of release (approximately 50 fish/lb, vs. 25 fish/lb in previous years). This modified feeding schedule, coupled with earlier releases, should also allow smolts to be released prior to smoltification and reduce the onset of Bacterial Kidney Disease (BKD).

Downstream passage of planted smolts will be monitored using the existing screw trap already installed at Eagle Cliff to assess fish migration timing into Swift Reservoir. The screw trap is scheduled to be installed early March and will be maintained through the end of July, which will allow the number of acclimation that enter Swift Reservoir in July to be monitored. Any noted increase in the frequency and number of spring Chinook collected at the screw trap after smolts

are released will be assumed to have been a direct result of release efforts. Any out-migration that occurs in August will not be monitored.

In addition to screw trap efforts, intermittent snorkel surveys will be performed downstream of release locations to determine if smolts remained in or near the release sites following release. It is thought that if large numbers of smolts remain in the release stream, they should be detectable to some degree. Survey efforts will be performed between mid-July and mid-September.

Figure 1. Location of Muddy River, Clear Creek, Lewis River (Crab), and Drift Creek release site(s) and PIT antennae arrays.

Table 2. Proposed 2017 Spring Chinook smolt release schedule for the three upper Lewis River Release sites.

Date	Upper Muddy	Clear Creek	Crab Creek
07/18/2017	**4,000**		
07/19/2017		**2,000**	
07/20/2017			**4,000**
07/25/2017	**4,000**		
07/26/2017		**2,000**	
07/27/2017			**4,000**
08/01/2017	**4,000**		
08/02/2017		**2,000**	
08/04/2017			**4,000**
08/08/2017			**8,000**
08/10/2017		**4,000**	
08/11/2017	**8,000**		
Total	**20,000**	**10,000**	**20,000**

Conover, W. J. 1999. Practical nonparametric statistics, 3rd edition. John Wiley and Son, Inc. New York, NY.

CBFWA (Columbia Basin Fish and Wildlife Authority). 1999. PIT Tag Marking Procedures Manual. Prepared by Columbia Basin Fish and Wildlife Authority, PIT Tag Steering Committee. Version 2.0. Pages 22.

PacifiCorp. 2017. Lewis River Acclimation Pond Plan - *Final*. Prepared by PacifiCorp. September 28, 2017.

MEMO

2017 Spring Chinook Acclimation Planting Schedule and Evaluation – Summary of Results

Prepared by PacifiCorp

January 28, 2018

FINAL

This memo provides a summary of findings related to the 2017 spring Chinook Acclimation Planting Schedule and Evaluation Plan, which was approved by the Aquatic Coordination Committee (ACC) during the July 13, 2017 meeting. The methodologies outlined in the approved plan were followed, however slightly more smolts were released than originally anticipated, due mostly to higher survival rates than anticipated during rearing.

A total of 53,470 juvenile spring Chinook were available for release in summer of 2017 (50,000 were anticipated). Releases occurred from mid-July through mid-August (Table 1). As outlined in the release plan, downstream passage was monitored via screw trap collection and snorkel surveys. Ultimately, collection totals at the Swift Floating Surface Collector were used to monitor passage timing and survival rates of smolts.

Table 1. Summary of Spring Chinook acclimation releases during summer of 2017.

Date	Upper Muddy	Clear Creek	Crab Creek
07/18/2017	**4,135**		
07/19/2017		**2,016**	
07/20/2017			**4,160**
07/25/2017	**4,250**		
07/26/2017		**2,100**	
07/27/2017			**4,000**
08/01/2017	**4,034**		
08/02/2017		**1,997**	
08/04/2017			**6,042**
08/08/2017		**4,119**	
08/10/2017			**8,247**
08/11/2017	**8,370**		
Total	**20,789**	**10,232**	**22,449**

Eagle Cliff Screw Trap

The Eagle Cliff screw trap remained in operation through July 2017. At that time, approximately 20,661 had already been released at various release site in the upper basin. The first spring Chinook out-migrants to be captured following release occurred less than 24 hours following the initial release into the upper Muddy River drainage. Spring chinook continued to be captured at the screw trap until it was taken out of operation at the end of July. By this time, 1,327 spring Chinook had been captured (Figure 1). After adjusting for trap efficiency, a total of 6,473 smolts were estimated to have passed the screw trap during the month of July (See Section 3.1 of the 2017 Lewis River Fish Passage Annual Report for details). This indicates that approximately 31.1% of the 20,661 smolts that had been released had emigrated out of their release stream by the end of July (Figure 2).

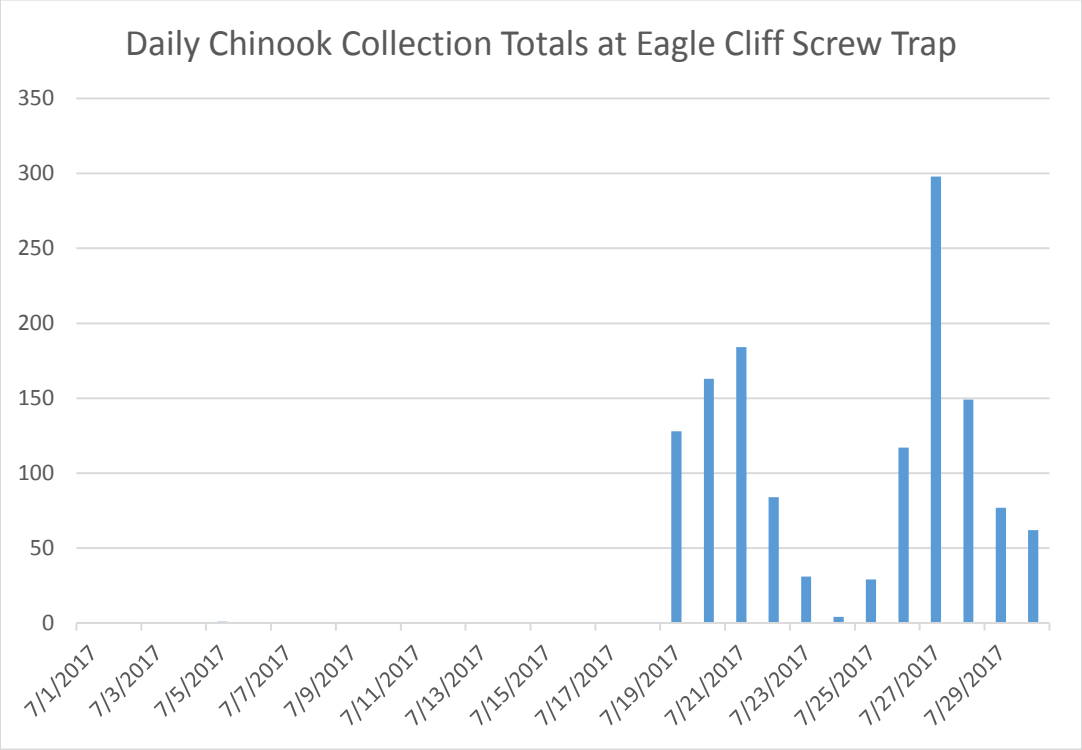

Figure 1. Daily spring Chinook collection totals at Eagle Cliff Screw trap in July 2017 (Actual).

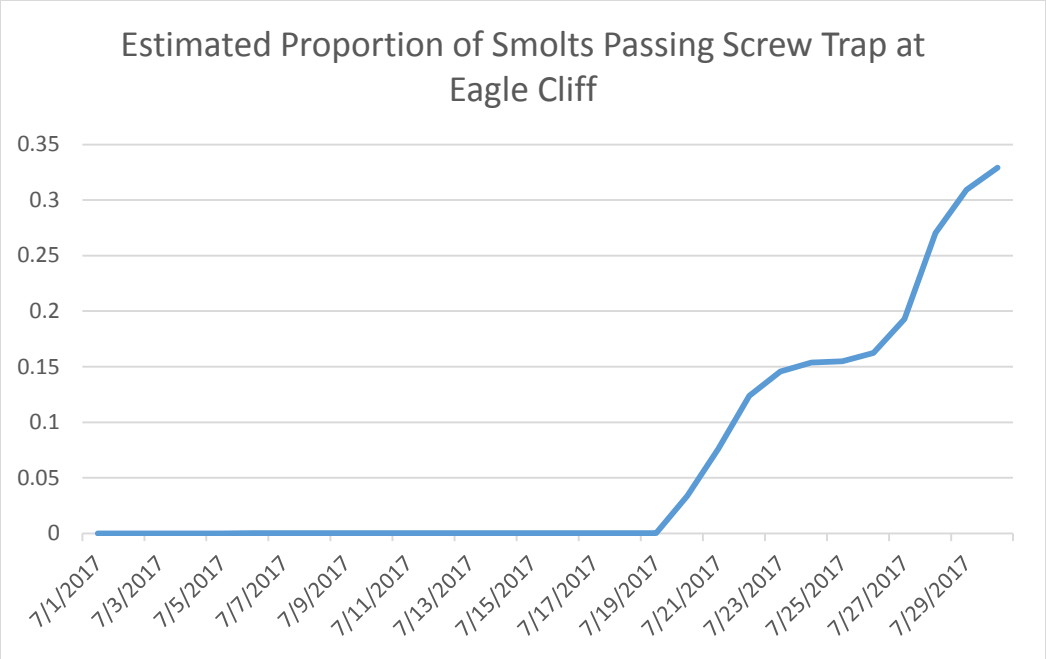

Figure 2. Out-migration timing curve of Spring Chinook Smolts following their release into the Upper Lewis River basin by the end of July.

Snorkel Survey Efforts

Snorkel surveys took place on four different occasions in the month of August. Two survey reaches were established and located immediately downstream of the release sites. The reach spanning the mainstem Lewis River from the confluence of the Muddy River to the confluence of Pine Cr was identified as one reach. The other reach was a ¾ mile stretch of Clear Creek immediately downstream of the NF-93 Bridge. The Clear Creek survey reach was only performed on one occasion, while the Muddy River site was snorkeled on three occasions. The number of juvenile spring Chinook observed during each snorkel survey was recorded (Table 2).

Results of the snorkel effort were mixed. During the single snorkeling event that occurred at the Clear Creek site on August 4, no juvenile spring Chinook were observed. This event occurred two days following the August 2 release just upstream of approximately 1,997 acclimation fish. In contrast, juvenile spring Chinook were detected during all three snorkel events immediately downstream of the Muddy River release site and up to 12 days following release.

Table 2. Spring Chinook snorkel survey efforts following acclimation plantings.

Date	Location	SPCH smolts observed	Comments
8/3/2017	Muddy/Upper Lewis-Pine/Upper Lewis	15	2 days after last release
8/4/2017	Clear Creek	0	2 days after last release
8/16/2017	Muddy/Upper Lewis-Pine/Upper Lewis	50	5 days after last release
8/23/2017	Muddy/Upper Lewis-Pine/Upper Lewis	25	12 days after last release

Discussion

Based on collection estimates at the Eagle Cliff screw trap, it appears that a proportion of smolts emigrate from their planted streams in a relatively short timeframe following release. However, these estimates also provide evidence that a substantial proportion of fish remain upstream. These results are similar in nature to those observed following the 2016 acclimation plantings using PIT tags in which an initial surge of fish was observed heading downstream immediately after release followed by fewer individuals out-migrating over a much longer period.

Although limited in scope, the snorkel surveys also confirmed in part that some proportion of acclimation fish do remain near the release sites following release. This was most evident at the upper Muddy River site in which acclimation were observed near the release site up to 12 days following release. It is currently unknown as to why no smolts were observed during Clear Creek snorkel efforts. However, given that the Clear Creek site was only surveyed on one occasion, it is possible that fish were present at the site but remained undetected. Effort should be made to complete multiple snorkel surveys at each site in future years.

Of particular note was the overall increased quality and condition of smolts released in 2017 when compared to smolts released in all previous years. The modified feeding schedule allowed smolts to grow at rate that was similar to NOR's, which seemed to have two-fold benefits. First, fish went through fewer smoltification periods relative to previous years resulting in an overall better conditioned fish. Secondly, having smaller fish reduced the occurrences of BKD, something that was prevalent in acclimation fish in years past. PacifiCorp recommends continuation of this modified feeding schedule for future acclimation fish rearing.

Given the relatively high detection efficiency of the screw trap at Eagle Cliff (18.6%), combined with the observational data collected during snorkel survey efforts, we can be fairly certain that a some proportion of released smolts remained in the Upper Lewis River Basin after being planted. However, the exact proportion of fish that remained upstream following August releases cannot be calculated with a high degree of certainty due to the removal of the screw trap at the end of July. Having the screw trap in operation during the entirety of the release period in future years may help determine the emigration behavior of smolts more accurately.

Observations made during the 2017 releases were generally consistent with those previously observed for juvenile spring Chinook released directly into the river in the Upper Lewis River basin. Future detections of smolts released as part of this evaluation at the Swift Floating Surface Collector (FSC) may provide additional information on smolt residency time when compared with detection histories in the upper basin. However, low collection efficiencies of spring Chinook at the FSC may limit a robust analysis.

PacifiCorp. 2016. New Information Regarding Fish Transport into Lake Merwin and Yale Lake *in* Task 4: Assessment of Juvenile Production and Outmigration Success. Prepared for PacifiCorp

APPENDIX B

SWIFT RESERVOIR FLOATING SURFACE COLLECTOR SMOLT COLLECTION EFFICIENCY EVALUATION – 2017 REPORT

February 2018

Swift Reservoir Floating Surface Collector Juvenile Salmon Collection Efficiency Study

ANCHOR QEA

2017 Annual Report

Prepared for PacifiCorp

February 2018
Swift Reservoir Floating Surface Collector Juvenile Salmon Collection Efficiency Study

2017 Annual Report

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ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
CFD	Computational Fluid Dynamics
cfs	cubic feet per second
Database	Lewis River Fish Passage Database
FBA	forebay
FERC	Federal Energy Regulatory Commission
FSC	Floating Surface Collector
M&E Plan	*Aquatic Monitoring and Evaluation Plan for the Lewis River*
mg	milligram
mm	millimeter
MS-222	tricaine methanesulfonate
NTS	net transition structure
P_{CE}	collection efficiency
P_{ENC}	encounter rate
P_{ENT}	entrance efficiency
PIT	passive integrated transponder
PRES	reservoir survival
P_{RET}	retention efficiency
Project	PacifiCorp Swift No. 1 Project
PTAGIS	Columbia Basin PIT Tag Information System
RST	rotating screw trap
SAF	Sorting Area Flow
SD	standard deviation
SFA	Swift forebay array
Study	2017 Swift Reservoir Floating Surface Collector Juvenile Salmon Collection Efficiency Study
SWC	Swift Creek
Teknologic	Teknologic Engineering LLC
ZOI	zone of influence

Executive Summary

The 2017 study measured the collection efficiency of the Swift Floating Surface Collector (FSC); assessed the behavior of juvenile salmonids released near the head of Swift Reservoir as they migrated downstream, approached, and interfaced with the Swift FSC; mapped flow velocity and direction in the area of attraction outside the entrance of the FSC using an Acoustic Doppler Current Profiler (ADCP); and measured underwater sound pressure levels generated by the FSC operations that may be within the hearing range of salmonids.

An array of nine acoustic receivers, called the zone of influence (ZOI) array, was installed in the Swift Dam forebay in front of the net transition structure (NTS) to provide 3D position estimates, two receivers, DB North and DB South (collectively called the Swift forebay array), were installed at the entrance to the forebay to determine when acoustic tagged fish entered the Swift Dam forebay, one receiver was installed near Swift Creek to evaluate approach behavior and movement, and an additional receiver was installed inside the entrance of the NTS to aid in determining entrance and retention efficiency.

A total of 520 fish were dual passive integrated transponder (PIT) and acoustic tagged and released between March 9 and June 2, 2017, to measure system performance and monitor fish behavior, including 108 Chinook Salmon, 232 Coho Salmon, and 180 Steelhead. A total of 461 fish were tagged and released with PIT tags between March 24 and May 19, 2017, to measure system performance, including 110 Chinook Salmon, 176 Coho Salmon, and 175 Steelhead. All study fish were released near Eagle Cliff at the upper end of Swift Reservoir.

In 2017, collection efficiency (P_{CE}) was 11.3% for Chinook Salmon, which was the highest recapture rate of any study year to date. Collection efficiency for Coho Salmon and Steelhead was 26.7% and 19.7%, respectively, which were at the low end of the range observed in previous years of study. Rate of reservoir survival (P_{RES}) was lower than previous years, ranging from 66.7% for Steelhead to 81.0% for Coho Salmon. Migration times from release to first detection in the forebay were relatively short, with median times ranging from approximately 3.9 days for Steelhead to 7.3 days for Coho Salmon. Though not statistically significant, travel times were longer for fish not collected compared to those collected for all three species. The FSC entrance encounter rate (P_{ENC}) was high, ranging from 82.7% for Chinook Salmon to 91.6% for Coho Salmon. Entrance efficiency (P_{ENT}) of the FSC was moderate, ranging from 46.8% for Chinook Salmon to 65.1% for Coho Salmon. Retention efficiency (P_{RET}) of the FSC was low to moderate, ranging from 24.1% for Chinook Salmon to 41.1% for Coho Salmon. Similar to previous studies, most fish were collected before forebay water temperature reached 15°C in late June, which was approximately 2.5 weeks before the end of the fish collection season.

Of the 520 acoustic-tagged juvenile salmonids released at Eagle Cliff, 73.6% made it to the forebay entrance (P_{RES}) but only 14.2% were collected in the FSC. Of the fish that made it to the Swift Dam

forebay, 89.0% were detected on the ZOI array in front of the FSC (P_{ENC}), 56.6% of these fish were detected at the receiver inside the entrance of the NTS (P_{ENT}), and 21.7% were collected (P_{CE}). These estimates were corrected for detection efficiency of the acoustic receiver arrays. Most of the fish entered the area in front of the FSC in the middle region between the barrier net and lead net, rather than approaching along either net. Overall, 28% of fish released at Eagle Cliff were never detected on the Swift Dam forebay entrance array, where receiver detection efficiency was 98.2% across all species, suggesting the non-detected fish were either preyed upon, died, or residualized in the reservoir.

Many study fish spent hundreds of hours in the ZOI, an area identified as a 150-foot arc radiating outward from the FSC entrance. Plots of fish locations indicated highest densities were near the entrance to the collector for all species, suggesting that fish are discovering the entrance. In addition to milling in front of the FSC, study fish made multiple excursions around the Swift Dam forebay to Swift Creek and back to the forebay entrance at Devil's Backbone, sometimes for long periods of time (days to over 3 weeks). None of the fish south of the lead net that were moving out of the ZOI appeared to pass under the lead net, but would move back upstream and pass around the end of the lead net. Fish approaching the FSC from Swift Creek encountered the lead net, appeared to hold on the north side of the lead net before moving around the net to the south side again, and oftentimes move back to Swift Creek. Fish north of the lead net did not appear to go under the net, nor did fish in this location appear to have entered the collector.

Water velocity measurements collected throughout the ADCP survey area (the top 33 feet of the water column in front of the FSC) were low and mostly ranged between 0.16 and 1.15 feet per second. Minimal differences in velocities were observed between FSC pump attraction flows of 600 cubic feet per second (cfs) and 1,000 cfs, although velocities collected north of the lead net were generally higher under 1,000 cfs attraction flows. Under 600 cfs attraction flows there was little variation in velocities across the survey area, especially in the top 20 feet of the water column. For both attractant flow scenarios, the highest velocities across the survey area were identified in the 20- to 33-foot depth interval. Flow direction was similar for both attractant flows tested and showed a general pattern of a southwestern direction towards the dam, even though both hydroelectric units were off and motoring for about 4 hours prior to during ADCP data collection. Flow heading towards the FSC entrance occurred mainly north of the lead net. Based on visual interpretation of the ADCP survey data and a lack of discrete thresholds or changes in velocity levels or direction, a specific ZOI could not be identified. In addition, during the ADCP, survey winds from the north moved the lead net to a more southerly position, which appeared to partially block the FSC entrance. Wind also appeared to influence direction of surface water flows.

In contrast with the ADCP survey results, a review of Computational Fluid Dynamics (CFD) model results identified a gyre northeast of the FSC, and as flow in the gyre circulated in a clockwise direction it swept past the entrance of the FSC in a northwesterly direction. Placement of the FSC relative to these data suggests the flow vectors in the gyre are directed toward and into the FSC. The

CFD model runs did not include the effects of installed barrier and lead nets. A review of the scientific literature of fish responses to hydraulic conditions and flow did not identify specific hydraulic or physical criteria that could be used, along with the ADCP and CFD data, to estimate a ZOI distance from the FSC.

Sound measurements collected near the entrance to the FSC had low frequency sound peaks similar in frequency to those near the Sorting Area Flow (SAF) pumps, whereas ambient sound levels were observed to be significantly lower than those observed near the SAF pumps and FSC entrance. The noise analysis concluded that sound within the hearing range of juvenile salmon may be generated on a regular basis by operation of the SAF pumps and could elicit behavioral responses by salmonids to avoid the FSC. Sound measurements conducted on December 19, 2017, during the ADCP survey, which were after PacifiCorp implemented measures to reduce noise levels, indicated that peak noise levels in the low frequency range were absent.

Of the fish released at Eagle Cliff, 64% found their way through 9 miles of Swift Reservoir to the ZOI, but something about the FSC caused fish not to enter or be retained in the collector. Future actions to improve collection efficiency could include:

- Conduct additional study using naïve fish (i.e., fish collected from the rotating screw trap near Eagle Cliff) to determine if changes made to dampen the noise generated by the SAF pumps improves collection efficiency. Naïve fish should be used because past results indicated that naïve fish had a higher conversion rate from release to the forebay and release to collection.
- Conduct additional sound measurements to determine if there are additional sources of sound and vibration that could influence fish behavior. Measurements showed that dampening the SAF pumps removed the high amplitude noise at 22.1 hertz. However, the background noise level around the collector is much higher than the ambient noise level of the reservoir away from the FSC.
- Find methods to reduce the "sound footprint" of the collector such that it reflects ambient sound levels.
- Reduce debris buildup in front of the collector to improve collection and potentially reduce predator habitat.
- Test alternative lighting types and locations to attract fish into the collector, including possible illumination under the NTS walkway to reduce shadows.
- Review approaches to evaluate and improve approach hydraulics and hydraulic conditions at and within the NTS.
- Evaluate potential predator interactions at the entrance to the collector and possible avoidance behavior of juvenile salmonids.
- Conduct observational studies at the entrance and inside of the NTS using an acoustic camera to evaluate movement and behavior of fish near the entrance and where fish are turning around inside the collector.

1 Introduction

1.1 Study Purpose and Objectives

The 2017 Swift Reservoir Floating Surface Collector Juvenile Salmon Collection Efficiency Study (Study) was conducted to provide data analyses to inform decisions related to the operation and performance of the Floating Surface Collector (FSC) relative to multiple performance metrics.

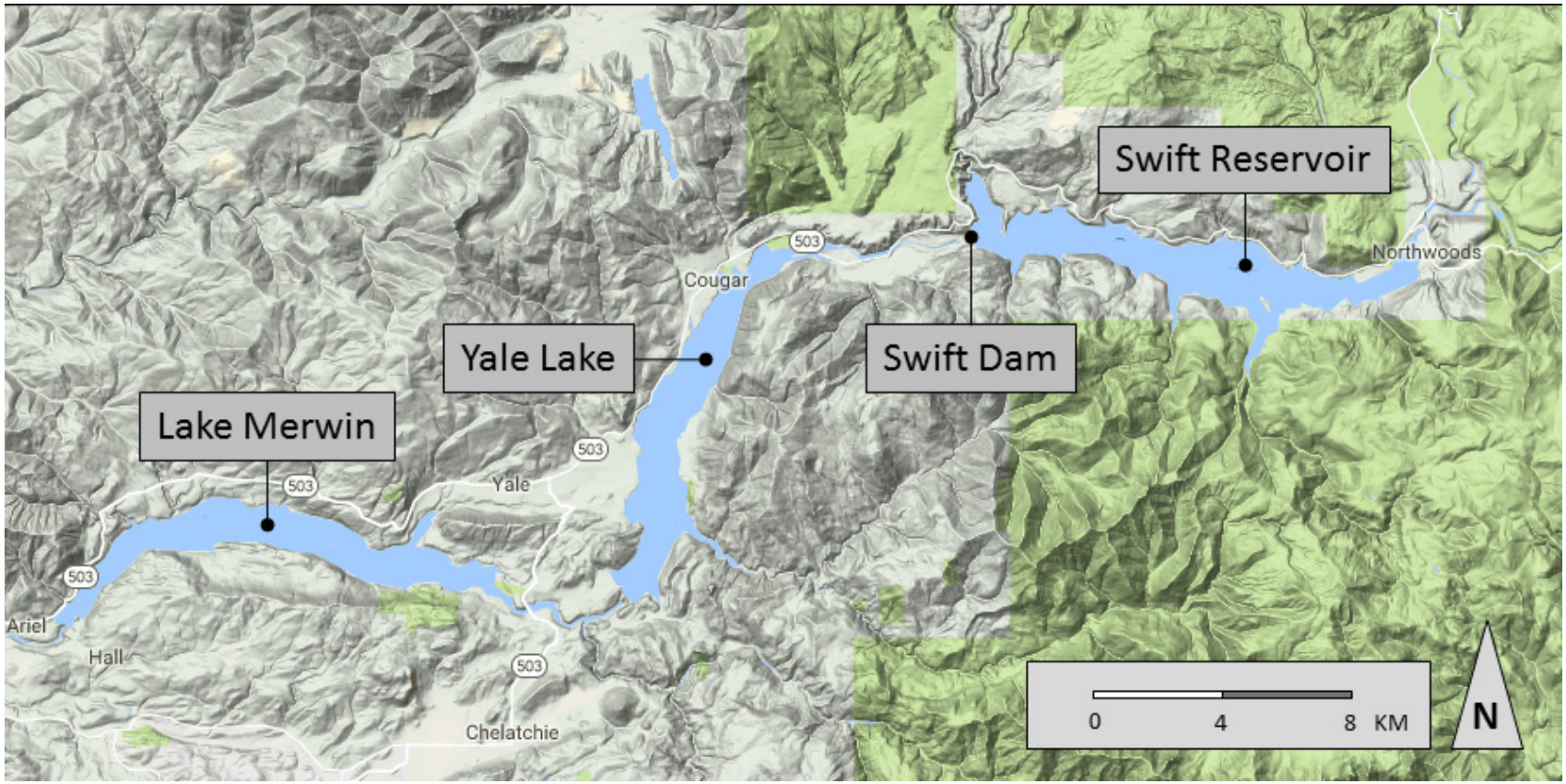
The 2017 Study continued to assess the migratory behavior of emigrating juvenile salmonids from release near the head of the reservoir to the forebay, and fine-scale behaviors as study fish approached, interfaced with, and potentially passed into the FSC. The overall purpose of the Study was to collect information to better understand factors influencing collection efficiency (P_{CE}). The 2017 Study builds upon previous years of study that used radio-tagged fish in 2013 and 2014, and dual passive integrated transponder (PIT)- and acoustic-tagged fish in 2015 and 2016 (Appendix A). In 2017, PIT-tagged and dual PIT- and acoustic-tagged study fish were used to achieve the study objectives for 2017, which included the following:

- Estimate the proportion and transit time of smolts released at the eastern end of Swift Reservoir, near Eagle Cliff, that migrate to the forebay of Swift Dam (P_{RES}).
- Estimate the encounter rate (P_{ENC}), which is defined as the proportion of downstream migrants that enter the FSC forebay and are detected in the FSC flow net attraction area immediately outside the Swift FSC, defined as the zone of influence (ZOI).
- Estimate entrance efficiency (P_{ENT}), which is the proportion of downstream migrants that enter the ZOI and the Net Transition Structure (NTS).
- Estimate retention efficiency (P_{RET}), which is the proportion of fish that enter the collector that are successfully collected.
- Estimate P_{CE}, which is the proportion of downstream migrants that enter the ZOI and successfully pass into the FSC and are collected.
- Describe the behavior of downstream migrants in the forebay of Swift Reservoir, specifically in relation to the lead net, ZOI, and entrance of the FSC.
- Map flow direction and measure flow velocity in the area of attraction outside the entrance of the FSC with the lead net installed.
- Measure underwater sound pressure levels within the hearing range of salmonids that may be generated within the ZOI by various FSC operations.

1.2 Background

The PacifiCorp Swift No. 1 Project (Federal Energy Regulatory Commission [FERC] Project No. 2111; [Project]) is the furthest upstream and largest hydro project in the Lewis River system. The Project consists of Swift Dam, which is a 412-foot-high by 2,100-foot-long embankment dam (Figure 1) that impounds a 4,600-acre reservoir known as Swift Reservoir.

Figure 1
Vicinity Map of the Swift Reservoir and Swift Dam on the Lewis River



Source: Google Maps 2017

In 2008, the Project was issued a new FERC license (FERC 2008) that includes provisions for restoring anadromous salmonids to the Lewis River Basin. As a component of the overall restoration goal, the license incorporates specific measures from the 2004 Settlement Agreement including the construction and operation of a modular FSC at the lower end of Swift Reservoir near Swift Dam to capture and collect migrating juvenile salmonids for subsequent transportation downstream of the Project. In addition, the 2004 Settlement Agreement requires monitoring and evaluation of the P_{CE} at the FSC, and the subsequent *Aquatic Monitoring and Evaluation Plan for the Lewis River* (M&E Plan) has identified a P_{CE} performance target of 95% for the FSC (PacifiCorp and CPUD 2017). For the purposes of the M&E Plan and the Study, P_{CE} is defined as:

> "The percentage of juvenile anadromous fish of each of the species designated in section 4.1.7[1] that is available for collection and that is actually collected."

1.3 Previous Studies

Since 2013, the performance of the FSC has been evaluated using radio telemetry, PIT, and combined PIT and acoustic telemetry methodologies (Courter et al. 2013; Stroud et al. 2014; Reynolds et al. 2015; Caldwell et al. 2016). Although there has been considerable variation in study design and year-to-year results, several trends have emerged from these studies. Most importantly, observed P_{CE} for all species tested has been consistently lower than the 95% performance target in all years and ranged from 7% (Courter et al. 2013) to 29% (Caldwell et al. 2016; Table 1). Chinook Salmon have had the lowest P_{CE} among the species tested and were not recaptured in the FSC in most of the previous study years.

The observed low P_{CE} at the FSC contrasts with high percentages (greater than or equal to 85%) of fish successfully transiting the length of Swift Reservoir from release sites at the eastern end of the reservoir to the Swift Dam forebay, defined as the area between Devil's Backbone and the face of Swift Dam (Table 1; Reynolds et al. 2015; Caldwell et al. 2016). These results suggest that a large proportion of released fish are surviving transit through the reservoir and are approaching but are not entering the FSC.

Previous studies also suggested that capture method and release location shape the probability of being detected at the forebay and ZOI, but do not appear to affect P_{CE} estimates. The ZOI is the FSC flow net attraction area immediately outside the FSC, which has been defined as a 150-foot arc measured from the NTS. Releasing tagged fish that were initially captured via rotary screw trap (RST) or hook and line at the eastern end of the reservoir, near Eagle Cliff, increased the likelihood of detection at the ZOI when compared to fish captured at the FSC and released closer to the FSC (Stroud et al. 2014).

[1] Species designated in Section 4.1.7 of the 2004 Settlement Agreement are spring-run Chinook Salmon, winter Steelhead, Coho Salmon, Bull Trout, and sea run Cutthroat Trout.

Water temperature and the presence of a fish lead net in front of the FSC may also influence P_{CE}. Most of the tagged fish have been collected at the FSC when temperatures were at or below 15°C (Stroud et al. 2014; Reynolds et al. 2015; Caldwell et al. 2016). In 2016, a large increase in estimated P_{CE} was associated with installation of a lead net; however, there is uncertainty related to the behavioral response of fish to the net and whether fish are swimming underneath it (Caldwell et al. 2016).

Finally, the recapture of tagged fish from previous years suggests that a proportion of test fish are overwintering in the reservoir. These delayed migrants may reduce or bias estimates of P_{CE} in each year if they are not accounted for (Caldwell et. al 2016). The focus and key results from the previous studies are presented chronologically in Appendix A.

Table 1
Summary of Results from Previous Swift Floating Surface Collector Collection Efficiency Studies Conducted Between 2013 and 2016

Study Attributes				Release Numbers		Detection Numbers (Total)			Detection Estimates (Total)		
Year	Study Type	Capture Location	Release Location	Species	Release Numbers	Detected Forebay	Detected ZOI	Captured at FSC	P_{RES} Estimate %	Rate of ZOI Detection %	P_{CE} Estimate %
2013	Radio telemetry	FSC	<3.1 miles east of FSC	Chinook Salmon	58	NA	46	0	NA	79.3	0.0
				Coho Salmon	82	NA	44	6	NA	53.7	6.0
				Steelhead	NA	NA	NA	NA	NA	NA	NA
2014	Radio telemetry	FSC	2 miles east of FSC	Chinook Salmon	20	NA	3	0	NA	15.0	0.0
				Coho Salmon	157	NA	31	9	NA	19.7	29.0
				Steelhead	16	NA	4	1	NA	25.0	25.0
2015	Dual PIT/acoustic telemetry	Eagle Cliff RST/Hook and Line	Eagle Cliff	Chinook Salmon	14	9	6	0	64.3	42.9	0.0
				Coho Salmon	139	126	110	13	90.6	79.1	11.8
				Steelhead	47	43	43	8	91.5	91.5	18.6
2016	Dual PIT/acoustic telemetry	FSC and Eagle Cliff RST	Eagle Cliff	Chinook Salmon	3	1	1	0	33.3	33.3	0.0
				Coho Salmon	156	140	98	30	89.7	62.8	30.6
				Steelhead	40	28	17	4	70.0	42.5	23.5

2 Methods

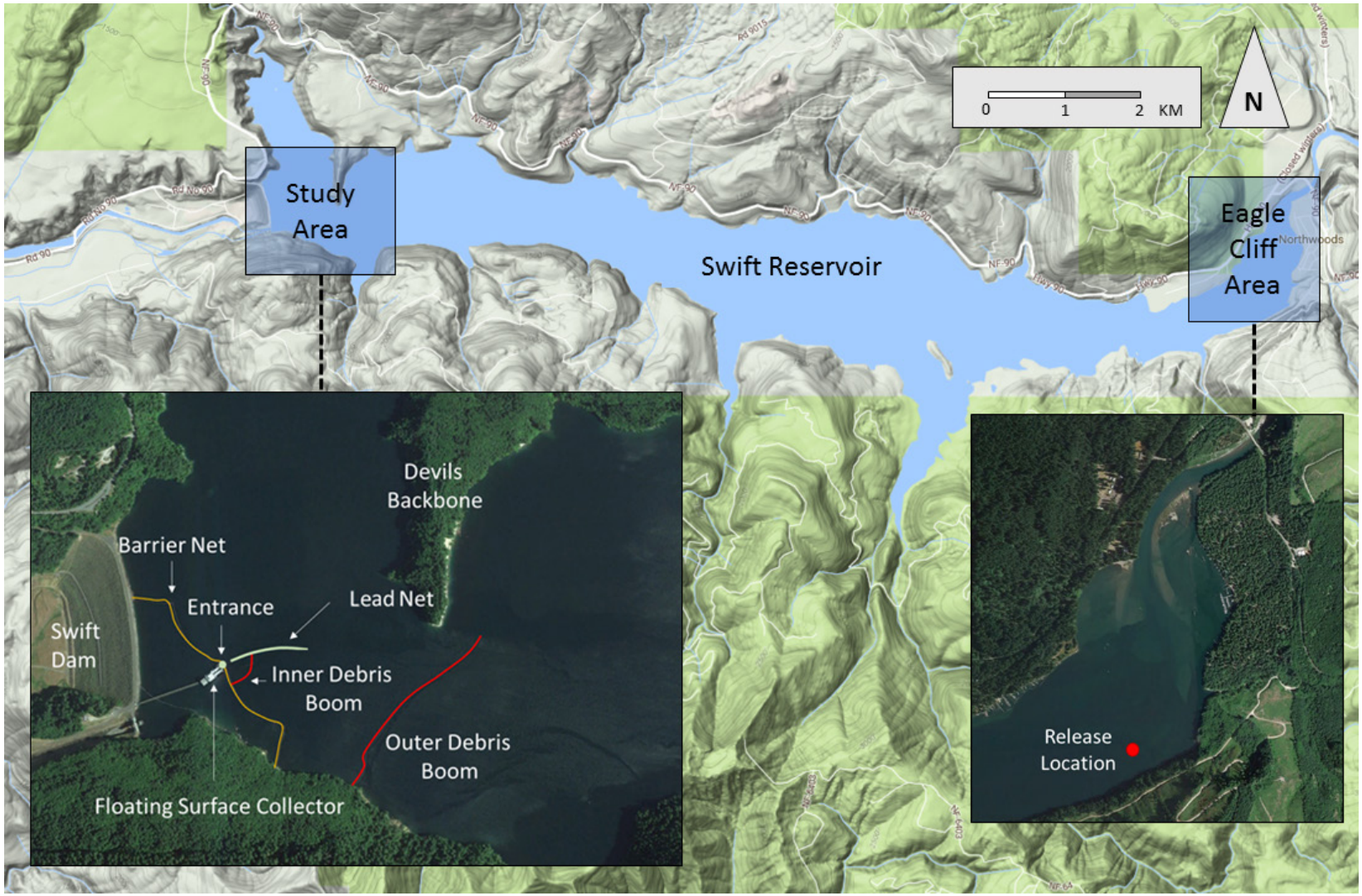
2.1 Study Location and Timing

The 2017 Study examined the behavior of PIT-tagged and dual PIT- and acoustic-tagged fish released near the head of Swift Reservoir and their fine-scale movements near the FSC adjacent to Swift Dam. Fish are guided to the FSC by attraction flows produced by the FSC and barrier and lead nets (Figure 2). Debris booms are in place to limit the accumulation of logs and other debris in the FSC entrance. The release location for tagged fish is approximately 9 miles upstream from the FSC near Eagle Cliff at the eastern end of the Swift Reservoir (Figure 2). Study fish were released between March 9 and June 2, 2017, and the last fish was detected in the ZOI on July 31, 2017. The period from first release to last detection in the ZOI is considered the study period. The acoustic receivers were removed on August 2, 2017.

2.2 Performance Metrics

The key performance metrics for the 2017 Study included P_{RES}, P_{ENC}, P_{ENT}, P_{RET}, and P_{CE}. The metrics are a proportion where the denominator is the number of fish released, detected in the entrance to the forebay, the ZOI, or entrance to the NTS (Table 2). Correction factors are applied to these proportions to account for receiver detection efficiency. In general, each "uncorrected" detection metric is calculated using observed detection numbers and then a correction factor is applied as shown in Table 2 to obtain the final "corrected" value. Seasonal estimates of performance using corrected values are reported in this annual report. Weekly estimates of performance using uncorrected values were provided throughout the fish passage season to PacifiCorp to allow FSC performance and implementation of the Study to be tracked. The methods and results for the weekly performance estimates are described in Appendix B.

Figure 2
Vicinity Map of the Floating Surface Collector and Release Area for Tagged Fish within Swift Reservoir



Source: Google Maps 2017

Table 2
Calculations for Uncorrected and Corrected Performance Metrics

Metric	Calculation (uncorrected)	Calculation (corrected)
Rate of Reservoir Survival (P_{RES})	$P_{RES} = \frac{DET_{Swift}}{R}$	$\hat{P}_{RES} = \frac{(DET_{Swift}/D_{EFF-Swift})}{R}$
Entrance Encounter Rate (P_{ENC})	$P_{ENC} = \frac{DET_{ZOI}}{DET_{Swift}}$	$\hat{P}_{ENC} = \frac{(DET_{ZOI}/D_{EFF-ZOI})}{(DET_{Swift}/D_{EFF-Swift})}$
Entrance Efficiency (P_{ENT})	$P_{ENT} = \frac{DET_{ENT}}{DET_{ZOI}}$	$\hat{P}_{ENT} = \frac{(DET_{ENT}/D_{EFF-ENT})}{(DET_{ZOI}/D_{EFF-ZOI})}$
Retention Efficiency (P_{RET})	$P_{RET} = \frac{C}{DET_{ENT}}$	$\hat{P}_{RET} = \frac{C}{(DET_{ENT}/D_{EFF-ENT})}$
Collection Efficiency (P_{CE})	$P_{CE} = \frac{C}{DET_{ZOI}}$	$\hat{P}_{CE} = \frac{C}{(D_{ZOI}/D_{EFF-ZOI})}$

Notes:
R = number of unique tagged fish released
DET_{Swift} = number of juveniles detected entering Swift Dam forebay (i.e., at DB North or DB South; Swift forebay array)
$D_{EFF\text{-}Swift}$ = the detection efficiency of the Swift forebay array
DET_{ZOI} = number of unique tagged fish identified in the vicinity of the FSC (i.e., in the ZOI)
$D_{EFF\text{-}ZOI}$ = the detection efficiency of the ZOI array
DET_{ENT} = the number of tagged fish detected at A (i.e., inside the entrance of the NTS)
$D_{EFF\text{-}ENT}$ = the detection efficiency of the NTS entrance array
C = number of unique tagged fish identified in the fish collection ponds inside the FSC (i.e., collected)

2.2.1 Zone of Influence

The ZOI was estimated by PacifiCorp to include the area within an arc that extends outward 150 feet from the NTS. Determination of fish inside this ZOI was done in ArcMap GIS software by clipping a layer of 2D (x, y) fish position points with a 150-foot semi-circle (Figure 3). Fish positions within the ZOI were then used to calculate performance metrics as described in Sections 2.2.3 through 2.2.7.

In addition, a literature review of fish responses to hydraulic conditions and flow was conducted. The purpose of the review was to determine whether potential response thresholds are available from the scientific literature that could be used to identify a revised ZOI for the Swift FSC based on Acoustic Doppler Current Profiler (ADCP) survey data, and inform interpretation of the 2017 ADCP data and results of previous modeling to modify or confirm the 150-foot ZOI. A total of 16 publications were reviewed and are summarized (Appendix C).

2.2.2 Array Detection Efficiency

Both acoustic receivers and PIT antenna arrays are assumed to have imperfect detection efficiency due to physical factors (e.g., signals reflecting off hard surfaces, tag collision, water temperature, debris, or algal fouling), speed of the fish, tag loss or malfunction, receiver malfunction, or signal corruption due to multipath or another phase disruption. Array or individual antenna detection efficiency can be estimated by comparing detection of individual fish at a specific array to the sum of

all downstream arrays. If a fish is detected at a downstream array, it is assumed to have passed through the detection range of the upstream array. For the purposes of estimating detection efficiency, the last detection location in the system is assumed to have 100% detection efficiency. Detection efficiency of an array is calculated using Equation 1.

Equation 1

$$D_{EFF} = \frac{N_{DET}}{N_{DET} + N_{MISSED}}$$

where:

N_{DET} = the total number of individual fish detected at least once at an array

N_{MISSED} = the total number of fish not detected at an array, but detected at least once at any downstream array

2.2.3 Rate of Reservoir Survival

The rate of reservoir survival (P_{RES}) is an estimate of the proportion of study fish that are released at Eagle Cliff and encounter the Swift forebay array by passing either the north or south receivers (i.e., DB North or DB South). The season-average estimate, corrected for the detection efficiency at the Swift forebay array, is calculated using Equation 2.

Equation 2

$$\hat{P}_{RES} = \frac{\left(DET_{Swift}/D_{EFF-Swift}\right)}{R}$$

Associated variance is estimated using Equation 3.

Equation 3

$$Var\left(\hat{P}_{RES}\right) = \frac{\hat{P}_{RES}(1-\hat{P}_{RES})}{R}$$

2.2.4 Entrance Encounter Rate

Entrance Encounter Rate (P_{ENC}) is the proportion of fish that enter the forebay and are detected within the ZOI throughout the season. Entrance into the Swift forebay is determined by detection at the Swift forebay array on either the north or south receivers (i.e., DB North or DB South). No distinction was made between a fish that entered the Swift forebay preferentially at the north or south ends of the Swift forebay array. The P_{ENC} serves to provide an estimate of the proportion of tagged fish that are available for collection throughout the season. The season average estimate, corrected for the detection efficiency at the Swift forebay array, was calculated using Equation 4.

Equation 4

$$\hat{P}_{ENC} = \frac{(DET_{ZOI}/D_{EFF-ZOI})}{(DET_{Swift}/D_{EFF-Swift})}$$

Associated variance is estimated using Equation 5.

Equation 5

$$Var(\hat{P}_{ENC}) = \frac{\hat{P}_{ENC}(1-\hat{P}_{ENC})}{(DET_{Swift}/D_{EFF-Swift})}$$

2.2.5 Entrance Efficiency

Entrance Efficiency (P_{ENT}) estimates of the proportion of fish in the ZOI that were detected at the entrance of the NTS, but may or may not have been collected. Both the entrance array (acoustic receiver 10) and the ZOI array have associated detection efficiencies. Thus, the corrected season average estimate of entrance efficiency was calculated using Equation 6.

Equation 6

$$\hat{P}_{ENT} = \frac{(DET_{ENT}/D_{EFF-ENT})}{(DET_{ZOI}/D_{EFF-ZOI})}$$

Associated variance is estimated using Equation 7.

Equation 7

$$Var(\hat{P}_{ENT}) = \frac{\hat{P}_{ENT}(1-\hat{P}_{ENT})}{(\frac{DET_{ZOI}}{D_{EFF-ZOI}})}$$

2.2.6 Retention Efficiency

Retention Efficiency (P_{RET}) estimates the proportion of fish collected once they have entered the NTS. The final season average, corrected for array detection efficiency, was estimated using Equation 8.

Equation 8

$$\hat{P}_{RET} = \frac{C}{(DET_{ENT}/D_{EFF-ENT})}$$

Associated variance is estimated using Equation 9.

Equation 9

$$Var(\hat{P}_{RET}) = \frac{\hat{P}_{RET}(1-\hat{P}_{RET})}{(\frac{DET_{ENT}}{D_{EFF-ENT}})}$$

2.2.7 Juvenile Collection Efficiency

Collection efficiency (P_{CE}) estimates the proportion of fish that are available for collection and that are collected. A study fish was defined as available for collection if it had entered the ZOI and as being collected if it was detected on either PIT antennae located inside the FSC or was recaptured and physically handled by PacifiCorp staff operating the FSC during the fish collection season. Thus, collection is based on PIT telemetry, whereas the presence of a fish in the ZOI is based on acoustic telemetry.

The final corrected season average of collection efficiency was calculated using Equation 10.

Equation 10

$$\hat{P}_{CE} = \frac{\mathrm{C}}{(DET_{ZOI}/D_{EFF-ZOI})}$$

Associated variance was estimated using Equation 11.

Equation 11

$$Var(\hat{P}_{CE}) = \frac{\hat{P}_{CE}(1-\hat{P}_{CE})}{(DET_{ZOI}/D_{EFF-ZOI})}$$

2.3 Acoustic Telemetry

Study fish that were dual PIT and acoustic tagged were used to evaluate fish behavior as the study fish moved through the reservoir towards the FSC.

2.3.1 Tagging and Release

Fish were collected by PacifiCorp for dual PIT and acoustic tagging at the FSC between March 9 and June 2, 2017. After collection, each fish was anesthetized with MS-222 (Tricaine methanesulfonate) and surgically implanted with an Advanced Telemetry Systems SS400 acoustic transmitter (15.0 x 3.38 millimeters [mm]; 216 milligrams[mg]) and a Biomark 12.5 mm, 134.2 kilohertz ISO FDX-B PIT tag using the methodology described in Reynolds et al. (2015). The SS400 acoustic transmitters were pre-set to emit an acoustic signal every 3 seconds. Following tagging, fish were transported by boat to the Eagle Cliff release site at the eastern end of Swift Reservoir (Figure 2) where they were subsequently released.

2.3.2 Detection and Recapture

An array of nine Teknologic Engineering LLC (Teknologic) Juvenile Salmon Acoustic Telemetry System (JSATS) Model 2/3D acoustic receivers, called the ZOI array, were installed in the Swift Dam forebay area defined by the front of the NTS, the lead net, and the south barrier net as shown in the Figure 3 inset for detection of acoustic-tagged fish approaching the NTS. This array was also configured to provide 3D position estimates of fish within the array for analysis of behavior of fish as they approached the NTS and were either collected or not collected in the FSC. Two Teknologic presence-absence receivers (DB North and DB South) were installed at Devil's Backbone at the

entrance to the Swift Dam forebay, called the Swift forebay array, in a north-south orientation to determine the number of acoustic-tagged fish entering the Swift Dam forebay and estimate reservoir travel time of tagged fish. One receiver was installed near Swift Creek for detection of fish that pass the lead net and FSC toward the Swift Creek arm of Swift Reservoir (Figure 3). An additional Teknologic cabled presence-absence receiver was installed inside the entrance of the NTS to aid in determining P_{ENT} and P_{RET} of acoustic-tagged fish.

The Teknologic acoustic receivers in the ZOI array were installed with 30-second interval beacon tags. The beacon tags were used to ensure that each receiver in the array could detect all other receivers and determine time gaps when detection efficiency was reduced. The beacon tags were also used during data analysis to correct for time drift between receivers and refine the GPS locations of the autonomous receivers within the array.

The spatial distribution of the acoustic ZOI array is shown in Figure 3 and depths and GPS locations are given in Table 3. The locations and depths of the acoustic receivers in the array were chosen to maximize spatial and observational redundancy (Vickery 1998), within the constraints of existing infrastructure at the site.

Table 3
Receiver Names, Locations, and Depths

Receiver Name	Location	Easting	Northing	Depth (feet)
1	ZOI array	368961.532	82386.719	90
2	ZOI array	368984.140	82396.095	20
3	ZOI array	369007.471	82339.484	90
4	ZOI array	368976.781	82325.088	20
5	ZOI array	368955.209	82310.588	90
6	ZOI array	368941.410	82356.164	20
7	ZOI array	368927.928	82371.256	20
8	ZOI array	368928.234	82370.492	30
9	ZOI array	368922.854	82377.457	22
10	NTS	368922.791	82373.658	3.5
DB North	Swift Dam Forebay Entrance	369511.770	82282.143	~ 98
DB South	Swift Dam Forebay Entrance	369279.357	82098.210	~ 98
Swift Creek	Swift Creek	369100.806	83146.328	~ 98

Note:
Easting and northing are given in NAD83 (2011) State Plane Washington South (meters).

Figure 3
Map of Western End of Swift Reservoir, Including Swift Forebay Array; Swift Dam Forebay with Floating Surface Connector, Lead Net, and Barrier Net Structures; and Locations of Acoustic Receivers

Additionally, all receivers except the NTS receivers were instrumented with pressure and temperature sensors. The temperature sensors were used to determine water temperature in the ZOI for use in calculating speed of sound used in estimating time-of-arrival of acoustic tag signals at the receivers, and the pressure sensors provided improved depth location accuracy of the receivers.

The four receivers mounted to the NTS were cabled to a power supply on the FSC, while all other autonomous receivers were powered by batteries. Installation of all receivers occurred during the week of February 20, 2017, and demobilization of the receivers occurred on August 2 and 3, 2017.

2.3.3 Data Processing and Quality Control

Raw detection data was downloaded from the cabled receivers weekly and backed-up on an Anchor QEA server. A complete download of raw detection data from all receivers occurred on 2 field days during the season (April 19 and May 31) and at demobilization (August 2). After downloading data from all receivers and ensuring backup of the data, the receivers' memory cards were cleared and internal clocks re-synchronized prior to redeployment of the receivers. Data downloaded from receivers in the field were backed up on an Anchor QEA server and were provided to Teknologic for 3D analysis using their proprietary software.

Data were checked to ensure receivers were functioning properly and detecting tags and beacons on adjacent receivers. Data were then filtered to remove multipath and false positive signals using methods described in Weiland et al. (2009). To be accepted as a valid tag detection, an acoustic tag had to be detected at least four times in 47.5 seconds on a receiver. This criterion was used for identifying detections at Swift forebay array, Swift Creek, and at the ZOI array in front of the FSC. Results of the 2D/3D analysis were used to determine the number of fish detected within the 150-foot radius of the ZOI in front of the FSC.

2.3.4 Range Estimation

A boat drag of acoustic tags was conducted at the presence-absence receivers (DB North, DB South, and Swift Creek) to determine detection range. The range test consisted of transects through the narrowest point of Devil's Backbone to ensure full acoustic coverage by the two receivers (DB North and DB South) in the Swift forebay array. For Swift Creek, the range test transects ran north-south beginning near the receiver to ensure that fish in the ZOI could not simultaneously be detected at Swift Creek, and fish near Swift Creek were not being detected on receivers in the ZOI.

Two static range tests were conducted in the field using three test tags held at 1.5-, 3-, and 6-meter depths on April 19 and May 31, 2017. During both tests, tags were held near receivers 1 through 6 for approximately 3 minutes each, and corresponding GPS points were also collected.

2.3.5 Presence-Absence Receivers (Data Quality Control and Storage)

Acoustic detection data from the presence-absence receivers (DB South, DB North, and Swift Creek) were filtered to remove multipath and single detections in R Statistical Software (Grolemund and Wickham 2011; R Core Team 2017; Wickham 2017). Filtered data were used to construct the fish migrant entrance route from the Swift forebay array into the ZOI. Methods for entrance route determination are described in Section 2.3.8. Filtered data were stored on an Anchor QEA server.

2.3.6 Net Transition Structure Entrance Receiver (Data Quality Control and Storage)

The presence-absence receiver just inside the NTS entrance (receiver 10, shown in Figure 3 inset) was baffled to limit detection of fish outside the NTS and reduce detection of multipath signals. Additionally, static range testing was performed in the field using acoustic test tags held at 1.5-, 3-, and 6-meter depths at locations inside and outside of the NTS. Data from the field test were used to construct amplitude distributions for test tag detections at all points. The purpose of comparing distributions was to develop an amplitude filter to further exclude detections from outside the NTS and multipath. Since there was overlap in amplitude distribution from detections inside and outside of the NTS, the filter was set to the minimum amplitude for test tags inside the NTS to exclude any outside detections. Data from receiver 10 were then filtered as described in Section 2.3.3. Data from the NTS entrance amplitude testing and filtered receiver 10 detection data were stored on an Anchor QEA server.

2.3.7 Hydrophone Array and Zone of Influence

Analysis of detections by the ZOI array, to determine 3D fish positions, was completed by Teknologic using their proprietary algorithms. A data file with tagcode, position, and time of detection for which a 3D position could be solved was provided by Teknologic to Anchor QEA for data quality control and further analysis of fish location in the ZOI, performance metrics, and fish behavior.

2.3.8 Acoustic Telemetry Behavior

2.3.8.1 Swift Dam Forebay Entrance

Acoustic presence-absence detection data were used to determine the study fish entrance route into the Swift Dam Forebay. If a fish tagcode was only heard on one receiver, that receiver was used to assign entrance route. If a fish tagcode was heard on more than one presence-absence receiver within a 12-hour window, the receiver with the higher detection amplitude was used to assign entrance route. Because of the arrangement of presence-absence receivers (Figure 3), entrance routes were assigned as follows: 1) South Bank for fish with only or the strongest detections on DB South; 2) Mid-Channel for fish with only or the strongest detection on DB North (located near

mid-channel as shown in Figure 6); and 3) North Bank for fish that had detections at Swift Creek as well as DB North or DB South in a short period of time.

2.3.8.2 2D Position Data

Before behavior analysis was conducted, 2D positions were used to calculate fish velocities and filtered to remove those greater than 6.5 feet per second. Velocities greater than this level would be unusual for smolts (Peake and McKinley 1998) and may indicate predator movement or an erroneous position estimate.

2.3.8.2.1 Fish Position

A heat map of all data points was generated to show the general position of fish within the ZOI array area by performing a 2D point density estimate and displaying the resulting contours. This analysis was conducted in R statistical software using base, ggplot2, and MASS packages (Wickham 2009; Venables and Ripley 2002; R Core Team 2017). An additional plot was created with separate density contours for collected versus non-collected fish to evaluate whether there was any geographic difference between the two groups.

2.3.8.2.2 Arrival Direction

To confirm the general arrival direction of fish into the ZOI, the same 2D point density estimate and contour plotting as described in Section 2.3.8.2.1 was used. A separate density plot for the first five and last five points for all fish was created and then overlaid to determine net movement direction. This process was also repeated for each species individually.

2.3.8.2.3 2D Based Residence Time

To evaluate how long fish remained resident in the ZOI array area, fish positions were organized by tagcode and the cumulative time difference between subsequent points was calculated. Fish were sorted by species and assigned to one of five residence time groups: 1) less than 1 day; 2) 1 day to 1 week; 3) 1 to 2 weeks; 4) 2 to 3 weeks; or 5) greater than 3 weeks. For each species and residence time group, fish positions were plotted scaling the point color from light to dark as residence time increased.

2.3.8.3 Time Gaps in Residency and Swift Creek Detections

Fish that were resident in the ZOI array area for more than 1 week were evaluated for time gaps of greater than 5 hours to determine if fish might be leaving the area of the FSC and then returning. Additionally, detections on the Swift Creek receiver were checked to determine if fish with extended residency near the FSC later traveled northward in the reservoir.

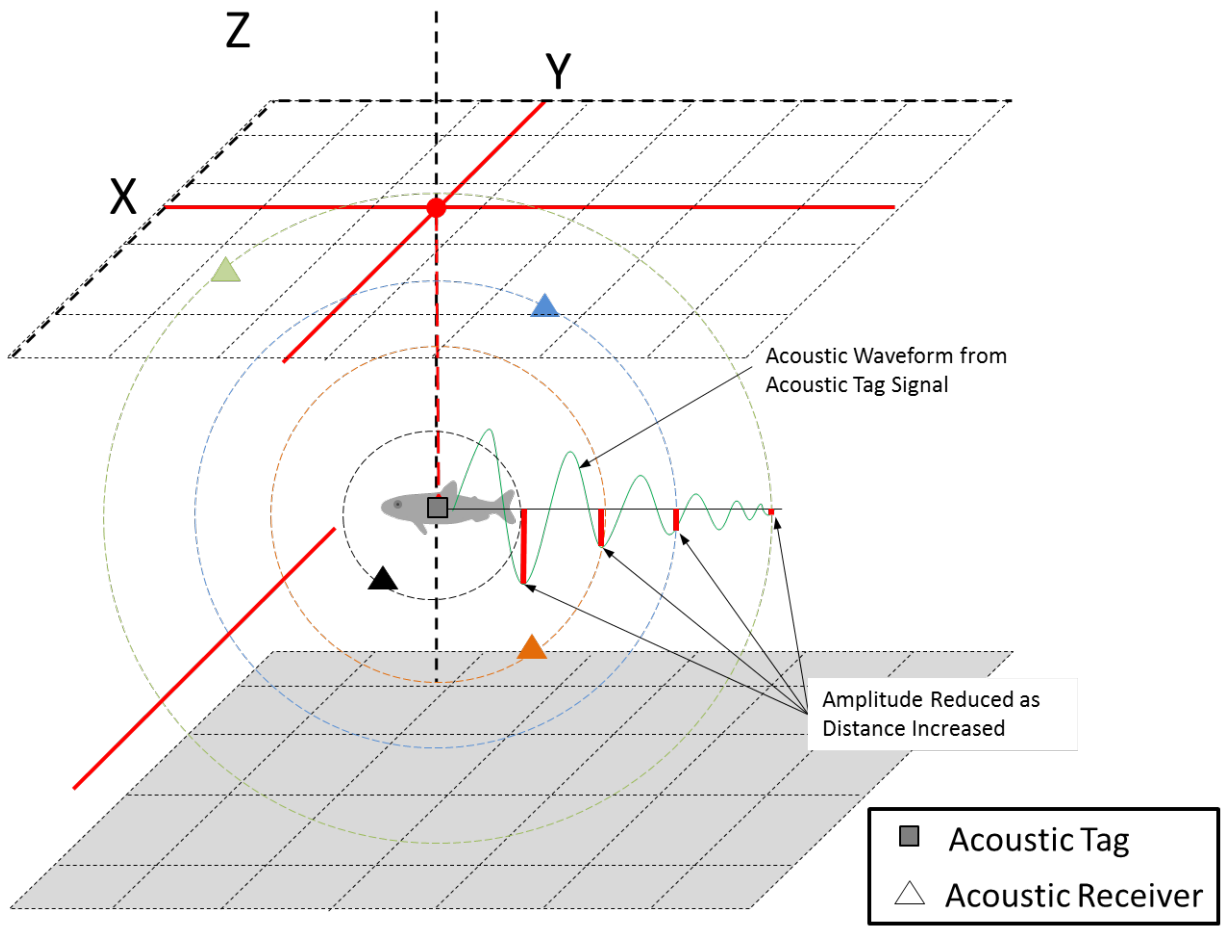
2.3.8.4 3D Position Data

Results of the Z-axis (depth) from the 3D position estimates calculated by Teknologic were not accurate due to movement of the receivers and the structures (nets and buoys) to which the receivers were attached. This movement was confounded by drift of the receiver clocks resulting in a circular logic problem of trying to calculate the position of a receiver with an unknown time and calculating time with an unknown receiver position.

Teknologic was able to estimate the position of the receivers and synchronize the receiver clocks using an iterative slant angle technique. Position estimates of fish in the X- and Y-axis were accurate to within several meters due to the configuration, size, and receiver redundancy of the array baseline. The depth component (Z-axis) of the position estimate could not be accurately resolved using the slant angle technique due to the limited vertical spacing of receivers and the error in the X- and Y-axis position estimates that are used in calculating the Z-axis. Errors in X- and Y-axis positions can result in large errors in the Z-axis estimate. Error in the depth estimate was up to 30 m.

To estimate the vertical movement of fish in the ZOI and behavior around the lead net and entrance to the NTS, the time of arrival and amplitude of the detected acoustic tag signal on receivers was incorporated with the 2D position estimates (X- and Y-axis) (Figure 4). Position of an acoustic tag was estimated from the amplitude of the acoustic signal and compared between receivers. Due to spherical spreading loss (Urick 1983; Leighton 1994) it was possible to estimate which receiver was closest to the acoustic tag signal. This additional information allowed for estimation of relative proximity of tagged fish to individual receivers, as well as evaluation of whether fish were migrating around or under the lead net. Using this technique, in combination with observation of which individual receiver the tag was last detected on (for data quality control) and estimating the direction of fish travel, route of travel and behavior around the lead net and entrance to the NTS could be estimated. This method is similar to one used to identify the epicenter and the magnitude of earthquakes by evaluating the amplitude and time of arrival of the acoustic signal. Another technique (Batel et al. 2003) to locate noise sources in machinery was adapted to estimate the depth component, but this method proved to be too complex (Batel et al. 2003).

Figure 4
Visualization of Fish Position Within the 3D Acoustic Volume



Note: Red lines are the calculated X- and Y-axis positions and the dashed black line is the position being estimated. The light green line represents attenuation of the acoustic signal with range that is detected by the acoustic receivers.

2.3.9 Transit Time

Transit time is defined as the period (in days) between release and the first detection in the forebay for acoustic tagged fish. Transit times of fish were compared across the study period and between collected and non-collected study fish, and general run timing data (e.g., moment of release, arrival in the forebay, and collection) were tabulated.

2.4 PIT Telemetry

2.4.1 Tagging and Release

Fish were collected at the FSC by PacifiCorp for PIT tagging between March 9 and May 19, 2017. Collected fish were anesthetized with MS-222 and then implanted with a Biomark 12.5 mm, 134.2 kilohertz ISO FDX-B PIT tag (115 mg) using the general methodology described in Reynolds et al. (2015). Following tagging, fish were transported by boat to the Eagle Cliff release site and released mid-channel (Figure 2). This contrasts with previous years, where a portion, or the majority, of test fish were collected for tagging at a RST located near Eagle Cliff (Reynolds et al. 2015; Caldwell et al. 2016). Similar to previous studies, paired holding studies were not conducted in 2017. A target minimum fish length of 90 mm was established as outlined in Section 2.2.1.1 (Methods) of the M&E Plan.

Release information including PIT-tagcode, length, species, and other identifying information about the fish were entered into the P3 software[2] and uploaded to the Columbia Basin PIT Tag Information System (PTAGIS) by PacifiCorp staff.

2.4.2 Detection and Recapture

PIT-tag detections for the Study occurred at three locations. The first two locations were two antennas within the FSC or in the collector at the time collected fish (recaptures) were handled. Automated PIT-tag detection at these locations occurred via two Biomark IS1001 (firmware version 1.6.1) antennas, known as the Port and Starboard Smolt Flume Antennas. Fish entering the FSC are shunted through either of these antennas to holding tanks on either side of the collector. Both antennas emit timer tags which were regularly monitored to ensure the antennas maintained high detection efficiency and did not experience malfunctions during the study season. Detections occurring at PIT-tag antennas were automatically uploaded hourly to the PTAGIS database via an internet connection. In addition, fish were manually sorted and scanned for PIT tags by PacifiCorp staff before being released from the FSC. These detections are identified as "recaptures" in PTAGIS. Fish were scanned with a Biomark HPR Plus reader and recapture information was uploaded to PTAGIS via the P3 software.

2.4.3 Data Processing and Quality Control

PIT-tag release, detection, and recapture data were automatically uploaded from PTAGIS to the Lewis River Fish Passage Database (Database), which gathers PIT telemetry, operations, fish count, and hatchery data for all PacifiCorp operations on the Lewis River. Automated quality control

[2] P3, also known as PITTag3, is a data entry, edit, and validation tool developed expressly to facilitate the collection of PIT-tag mark/recapture data in the Columbia and Snake river basins.

measures were established to verify that tagging and release locations, species, and other parameters were within accepted values after data were uploaded.

Data from PIT-tagged fish released prior to 2017 were also obtained from PTAGIS for comparisons with the 2017 study results. These data were reviewed to verify that individual tag records were consistent with release at LEWISR-Lewis River (river mile 87) and detection sites located within the FSC. Size data were additionally screened to remove fish that may have been adults (e.g., greater than 400 mm) or were potential transcription errors (i.e., less than 30 mm). PIT-tag data were exported from the database and processed using R statistical software (Grolemund and Wickham 2011; R Core Team 2017; Wickham 2017). Before processing, release counts and details of individual fish were compared to PacifiCorp field notes and any discrepancies were corrected with input from PacifiCorp staff.

2.4.4 PIT Tag Only Releases

Collection information for fish released with PIT tags only were summarized to inform and compare study results concerning dual PIT- and acoustic-tagged fish. The proportion of fish transitioning from release to collection (PIT antenna detection or recapture) was calculated and termed system survival, which represents the number of fish that were successfully collected without regard to fine scale movement patterns in the Swift Dam forebay. Transit time defined as the period (in days) between release and collection for PIT- and dual PIT- and acoustic-tagged fish were tabulated and compared across the study period and between collected and non-collected study fish.

In addition, PIT-tag detections from PIT only and dual PIT- and acoustic-tagged fish were summarized for the 2013 to 2017 period to compare the size of fish tagged and associated detection and recapture rates for FSC antennas among years. Size and PIT-tag detection data were also used to evaluate the contributions and significance of delayed migrants to the performance of the FSC and P_{CE} estimates.

2.5 Factors Affecting Performance

Methods used to collect information on environmental, physical, and timing factors that could affect P_{CE} are described in the following sections.

2.5.1 Noise

Underwater sound measurements were recorded at the FSC on August 3, 2017, to characterize the acoustic environment adjacent to the FSC and to identify whether sound and vibration originating from the FSC could elicit a behavioral response from salmonids. The hearing range of salmonids is limited to low frequencies extending from about 800 hertz down through infrasound frequencies that are below the range of human hearing (Hawkins 2015).

Modifications to the Sorting Area Flow (SAF) pump mounting systems were completed by PacifiCorp in fall 2017 to reduce low frequency sound and vibration measured on August 3, 2017, that were traced back to the SAF pumps. Underwater sound measurements were collected again on December 19, 2017, to characterize the acoustic environment adjacent to the FSC and to identify whether sound and vibration originating from the FSC had been reduced.

Sound measurements were collected with a Reson TC-4034 hydrophone. The signal was amplified and conditioned using a Bruel & Kjær 2635 charge amplifier. Data were recorded on a digital recorder and analyzed with Audacity and Autosignal software packages.

2.5.2 Woody Debris

Debris was removed from the face of the NTS by Advanced American Construction, Inc. during the study period on March 23, May 11, and May 31. The March 23 clearing date was not included in the analysis due to the lack of fish in the ZOI at that time. Given the low number of removal events, a qualitative assessment of trends and patterns was conducted. This included estimating: 1) mean lag time between when acoustically-tagged study fish first entered the ZOI and a fish was subsequently collected, and 2) the mean daily number of acoustically-tagged study fish in the ZOI before and after a debris clearing event. For both approaches, data for weeks when debris was cleared was compared to weeks where debris was present, debris was assumed to be present the week before the clearing event and completely absent the week following the clearing, and the volume of debris removed was not available or analyzed.

2.5.3 Water Temperature

Water temperature data were collected from March 3, 2017 to July 30, 2017, in the Swift Dam forebay with thermistors build into Teknologic acoustic receivers. Temperature data from the ZOI array receiver 7 were selected to represent the overall temperature of the forebay. Receiver 7 was located at a depth of approximately 20 feet (Table 3), which was assumed to represent the average swimming depth of salmon smolts (0 to 30 feet; Caldwell et al. 2016).

Data were plotted against the total number of fish collected for each species. Average daily temperature was qualitatively compared to weekly collection numbers to relate 2017 observations to results from previous studies (i.e., Reynolds et al. 2015; Caldwell et al. 2016), which found that most fish were collected when the forebay temperatures were below 15 to 16°C.

2.5.4 Collector Pump Operations

Data on pump operations at the FSC were gathered between March 6 and July 31, 2017, and transmitted hourly from PacifiCorp systems to the Database. Data included status for all ten primary collector pumps and the four secondary pumps by minute, which was recorded as 0 (pump off), 1 (pump on), or 2 (pump is in an unknown or fault state). A score was assigned to each for overall

collector operations as "on" (days when all primary pumps and secondary pumps were in full operation), "off" (days when all primary pumps and secondary pumps were not operating), or "other" (days when any of the primary or secondary pumps were in an unknown or fault state for the day).

Plots of P_{CE}, P_{ENT}, P_{ENC} for all species combined relative to collector operations were developed and interpreted visually to assess whether collector operations, and specifically lapses in regular operation, had an impact on the performance metrics.

2.5.5 Forebay Hydraulics and Flow

Flow direction and magnitude in the area in front of the FSC entrance were surveyed using ADCP technology on December 19, 2017. ADCP velocity data were collected to support the 2017 Study objective of describing the behavior of downstream migrants in the forebay of Swift Reservoir, specifically in relation to the lead net, ZOI, and entrance of the FSC. The survey area included the area of the ZOI both south and north of the lead net. Velocity data were also collected to validate the extent of the ZOI as defined in Section 2 of the M&E Plan. Surveys evaluated hydraulic conditions for both horizontal and vertical components of the flow field under two FSC operation regimes: 600 cubic feet per second (cfs) and 1,000 cfs attraction flow. Both hydroelectric units at the Swift Powerhouse were not generating power but were motoring for approximately 4 hours prior to, and during, ADCP data collection. Detailed methods used to conduct the ADCP survey are described in Appendix D.

3 Results

A total of 520 fish were dual-tagged with acoustic and PIT tags and released between March 9 and June 2, 2017, including 108 Chinook Salmon (mean length of 179 mm, range from 145 to 256 mm), 232 Coho Salmon (mean length 148 mm, range from 90 to 204 mm) and 180 Steelhead (mean length 215 mm, range from 110 to 325 mm) (Table 4).

Table 4
Summary of the Number and Length of Salmonids Tagged with Dual PIT and Acoustic Tags During the 2017 Study

	Chinook Salmon			Coho Salmon			Steelhead		
Release Date	Number Tagged	Average Length (mm)	SD	Number Tagged	Average Length (mm)	SD	Number Tagged	Average Length (mm)	SD
3/9/2017	1	162	-	3	136	15	0	-	-
3/10/2017	0	-	-	3	129	29	0	-	-
3/20/2017	1	171	-	4	131	18	3	265	6
3/24/2017	23	175	17	14	129	12	3	218	67
3/30/2017	5	205	44	14	127	19	1	266	-
3/31/2017	12	182	23	10	119	17	3	178	74
4/6/2017	31	183	19	3	126	10	1	295	-
4/13/2017	10	174	8	5	113	12	1	212	-
4/19/2017	13	186	19	16	136	21	4	203	82
4/20/2017	11	176	6	12	143	23	33	233	37
4/27/2017	1	165	-	17	148	26	12	207	50
5/4/2017	0	-	-	20	144	28	62	219	43
5/19/2017	0	-	-	20	158	17	36	196	28
5/24/2017	0	-	-	35	158	16	21	205	38
6/2/2017	0	-	-	56	165	14	0	-	-
Total	**108**	**179**		**232**	**148**		**180**	**215**	

In addition, a total of 461 fish were tagged and released with PIT tags between March 24 and May 19, 2017, including 110 Chinook Salmon (mean length of 176 mm, range from 139 to 270 mm), 176 Coho Salmon (mean length 196 mm, range from 70 to 320 mm), and 175 Steelhead (mean length 213 mm, range from 97 to 340 mm) (Table 5).

Table 5
Summary of the Number and Length of Salmonids Tagged with PIT Tags during the 2017 Study

Release Date	Chinook Salmon			Coho Salmon			Steelhead		
	Number Tagged	Average Length (mm)	SD	Number Tagged	Average Length (mm)	SD	Number Tagged	Average Length (mm)	SD
3/24/2017	15	167	10	27	120	14	7	159	81
4/6/2017	8	170	9	13	107	25	4	172	41
4/14/2017	7	180	27	16	116	22	6	175	86
4/20/2017	25	177	27	9	157	24	13	269	48
4/21/2017	22	183	30	15	128	20	5	192	70
4/27/2017	8	177	10	12	153	16	10	242	47
4/28/2017	15	175	8	10	147	33	8	229	53
5/4/2017	7	173	8	6	146	25	43	211	40
5/11/2017	1	150	-	1	137	-	49	216	40
5/19/2017	2	171	15	67	153	24	30	201	42
Total	**110**	**176**	**21**	**176**	**139**	**28**	**175**	**213**	**51**

3.1 Performance Metrics

The 2017 performance metrics are summarized in Table 6 and Figure 5. Overall, Chinook Salmon had the lowest P_{CE} (11.3%), and Coho Salmon had the highest (26.7%), consistent with previous studies. The 11.3% P_{CE} for Chinook Salmon was the highest recapture rate of any study year to date. The other performance metrics corrected for array detection efficiency that were calculated to evaluate fish behavior through the system include the following:

- Of the 520 fish released at Eagle Cliff near the upper end of Swift Reservoir, 376 (73.6%) were detected entering the Swift Dam forebay (P_{RES}), including 69.4% of Chinook Salmon, 81.0% of Coho Salmon, and 66.7% of Steelhead.
- A total of 333 out of 376 acoustic tagged fish entering the Swift Dam forebay were detected in the ZOI (P_{ENC}). Coho Salmon had the greatest number detected in proportion to total number entering the forebay (91.6%), followed by Steelhead and Chinook Salmon (89.2% and 82.7%, respectively).
- Of the 333 acoustic tagged fish that entered the ZOI, 176 were detected at the NTS (P_{ENT}), including 46.8% of Chinook Salmon, 65.1% of Coho Salmon, and 48.6% of Steelhead.
- Of the 176 fish that were detected passing into the NTS, 74 were collected (P_{RET}). Of the fish entering the NTS, 24.1% of Chinook Salmon, 41.1% of Coho Salmon, and 40.4% of Steelhead were collected.

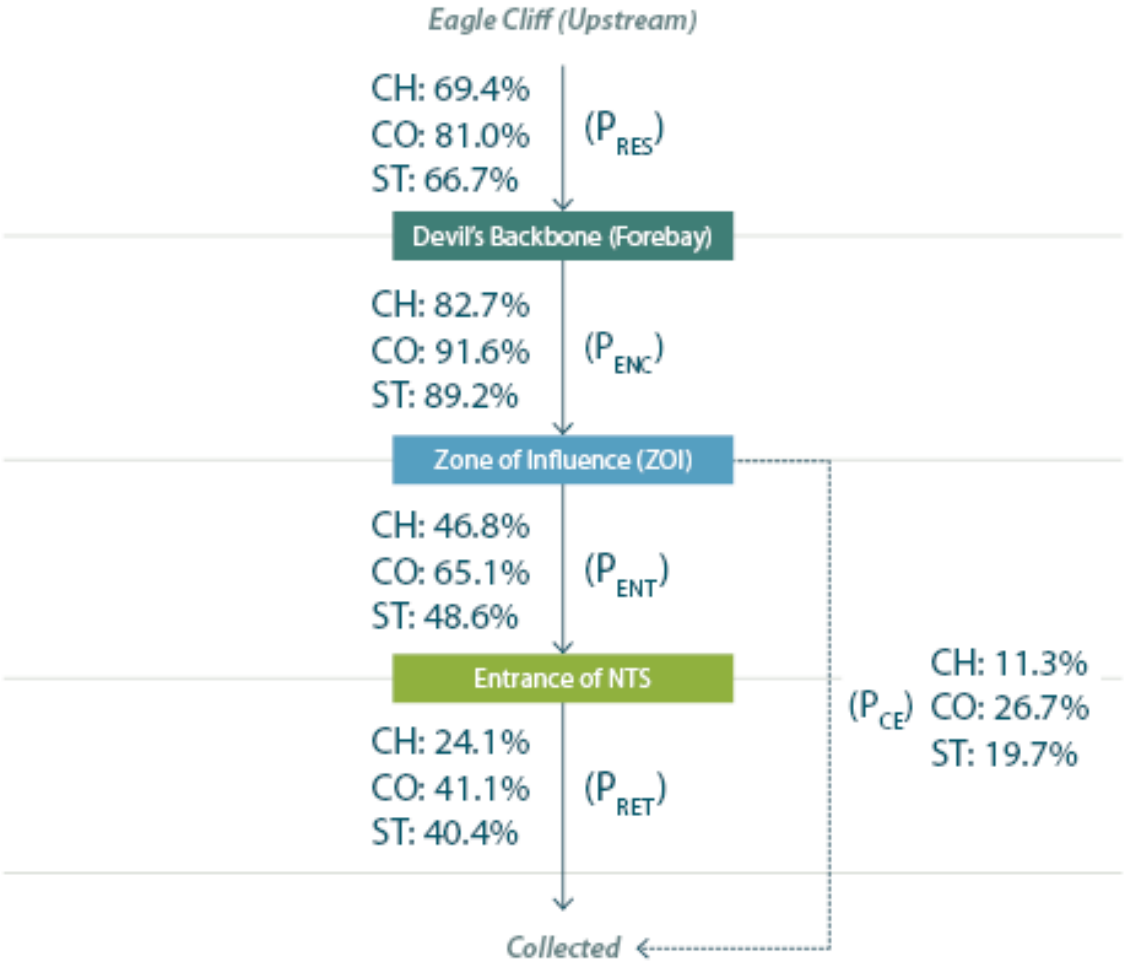
Table 6
2017 Performance Metric Summary

	Release and Detection Numbers								Corrected[1] Seasonal Performance Metrics				
	Released	**Detected at Swift Forebay**	**Detection Efficiency of Swift Forebay Array (%)**	**Detected at ZOI**	**Detection Efficiency of ZOI Array (%)**	**Detected at Entrance Array**	**Detection Efficiency of Entrance Array (%)**	**Collected**	$\widehat{P}_{RES}$ % (SD%)	$\widehat{P}_{ENC}$ % (SD%)	$\widehat{P}_{ENT}$ % (SD%)	$\widehat{P}_{RET}$% (SD%)	$\widehat{P}_{CE}$% (SD%)
Species	R	DET_{Swift}	$D_{EFF-Swift}$	DET_{ZOI}	$D_{EFF-ZOI}$	DET_{ENT}	$D_{EFF-ENT}$	C	$\frac{\left(\frac{DET_{Swift}}{D_{EFF-Swift}}\right)}{R}$	$\frac{\left(\frac{DET_{ZOI}}{D_{EFF-ZOI}}\right)}{\left(\frac{DET_{Swift}}{D_{EFF-Swift}}\right)}$	$\frac{\left(\frac{DET_{ENT}}{D_{EFF-ENT}}\right)}{\left(\frac{DET_{ZOI}}{D_{EFF-ZOI}}\right)}$	$\frac{C}{\left(\frac{DET_{ENT}}{D_{EFF-ENT}}\right)}$	$\frac{C}{\left(\frac{DET_{ZOI}}{D_{EFF-ZOI}}\right)}$
Chinook Salmon	108	75	100.0	62	100.0	29	100.0	7	69.4 (7.9)	82.7 (4.4)	46.8 (6.3)	24.1 (7.9)	11.3 (4.0)
Coho Salmon	232	184	97.9	164	95.3	96	85.7	46	81.0 (4.6)	91.6 (2.0)	65.1 (3.6)	41.1 (4.6)	26.7 (3.4)
Steelhead	180	117	97.5	107	100.0	51	98.1	21	66.7 (6.8)	89.2 (2.8)	48.6 (4.8)	40.4 (6.8)	19.7 (3.8)
All	520	376	98.2	333	97.7	176	91.2	74	73.6 (3.5)	89.0 (1.6)	56.6 (2.7)	38.3 (3.5)	21.7 (2.2)

Note:

1. Seasonal performance metrics have been corrected for array detection efficiency.

Figure 5
Summary of 2017 Performance Metrics



Note: CH (Chinook Salmon), CO (Coho Salmon), and ST (Steelhead)

3.1.1 Detection Efficiency

The detection arrays at Swift Dam forebay entrance, the ZOI, and the FSC entrance array were found to have less than 100% detection efficiency, although all arrays averaged greater than 90% detection efficiency across species (Table 7). Detection efficiency varied among species, and no Chinook Salmon were missed at any of the arrays. However, Coho Salmon accounted for a disproportionate (approximately 90%) proportion of all fish missed. The entrance array (acoustic receiver 10) had the lowest detection efficiency overall, likely due to location of the receiver within the entrance of the NTS where acoustic signals may escape detection due to multipath or physical barriers to transmission. Detection efficiency estimates were used to correct performance metric estimates to account for missed fish that were detected at a downstream array.

Table 7
Autonomous Array Detection Efficiency Summary

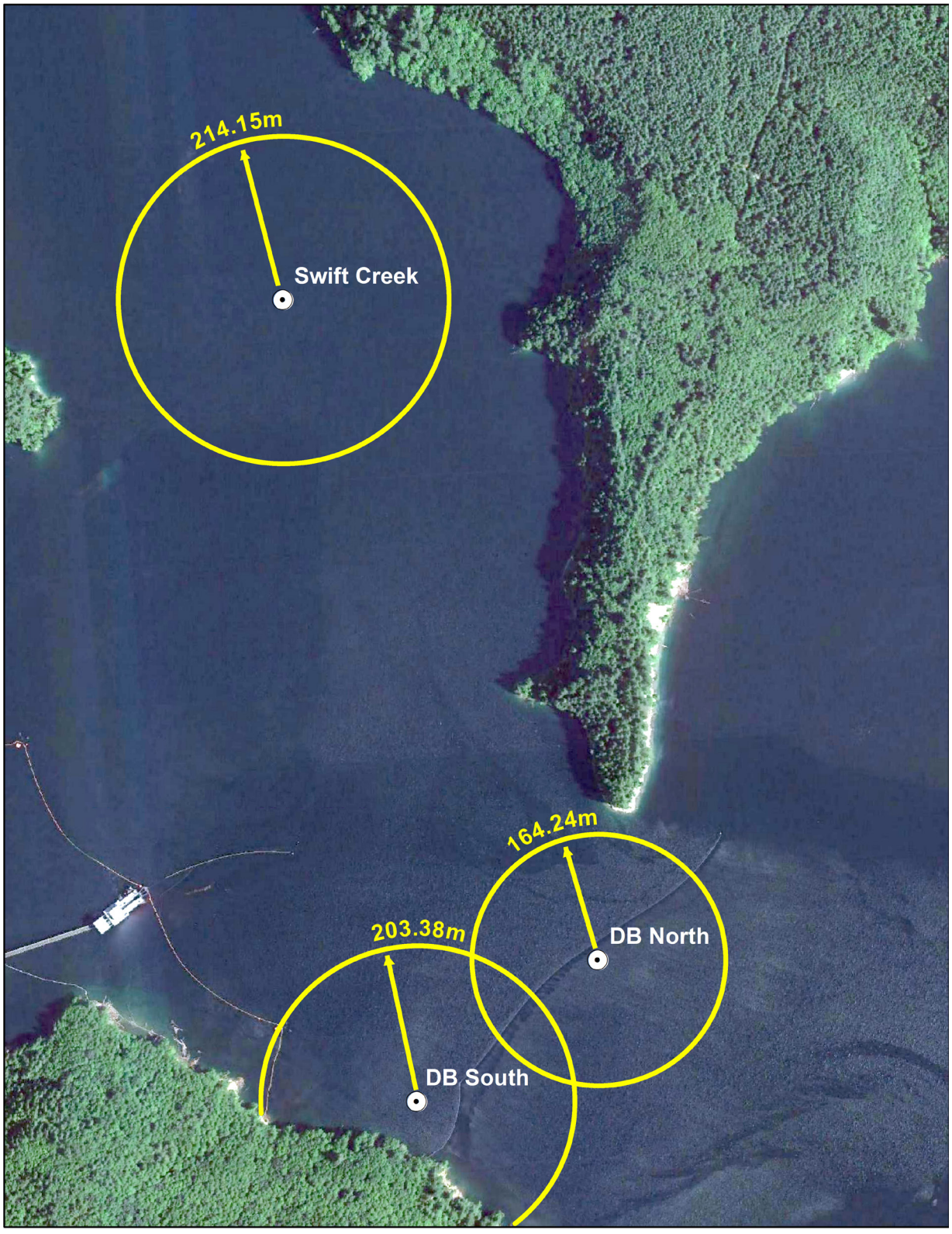
Species	Detection Efficiency of Swift Forebay Array (%)	Fish Missed at Swift Forebay Array	ZOI Array Detection Efficiency (%)	Fish Missed at the ZOI	Entrance Array Detection Efficiency (%)	Fish Missed at Entrance Array
Chinook Salmon	100.0	0	100.0	0	100.0	0
Coho Salmon	97.9	4	95.3	8	85.7	16
Steelhead	97.5	2	100.0	0	98.1	1
All (Weighted Average)	98.2	6	97.7	8	91.2	17

3.1.2 Range Testing

Range testing conducted on the presence-absence receivers at the Swift forebay array showed an approximately 30-meter distance at the extreme north bank where there was incomplete coverage by receiver DB North (Figure 6). Range testing conducted at Swift Creek showed that fish tagcodes near the ZOI array in front of the FSC could not be simultaneously heard at Swift Creek.

Range testing showed full coverage of the area within the ZOI array using 2D data. Final fish position data provided by Teknologic confirmed additional coverage of approximately 25 to 50 meters outside the boundary of the array.

Figure 6
Results of Acoustic Tag Range Testing Conducted at the Presence-Absence Receivers



3.1.3 Fish Behavior

Fish behavior described in the following sections were evaluated based on dual PIT- and acoustic-tagged fish.

3.1.4 Downstream Fish Distribution

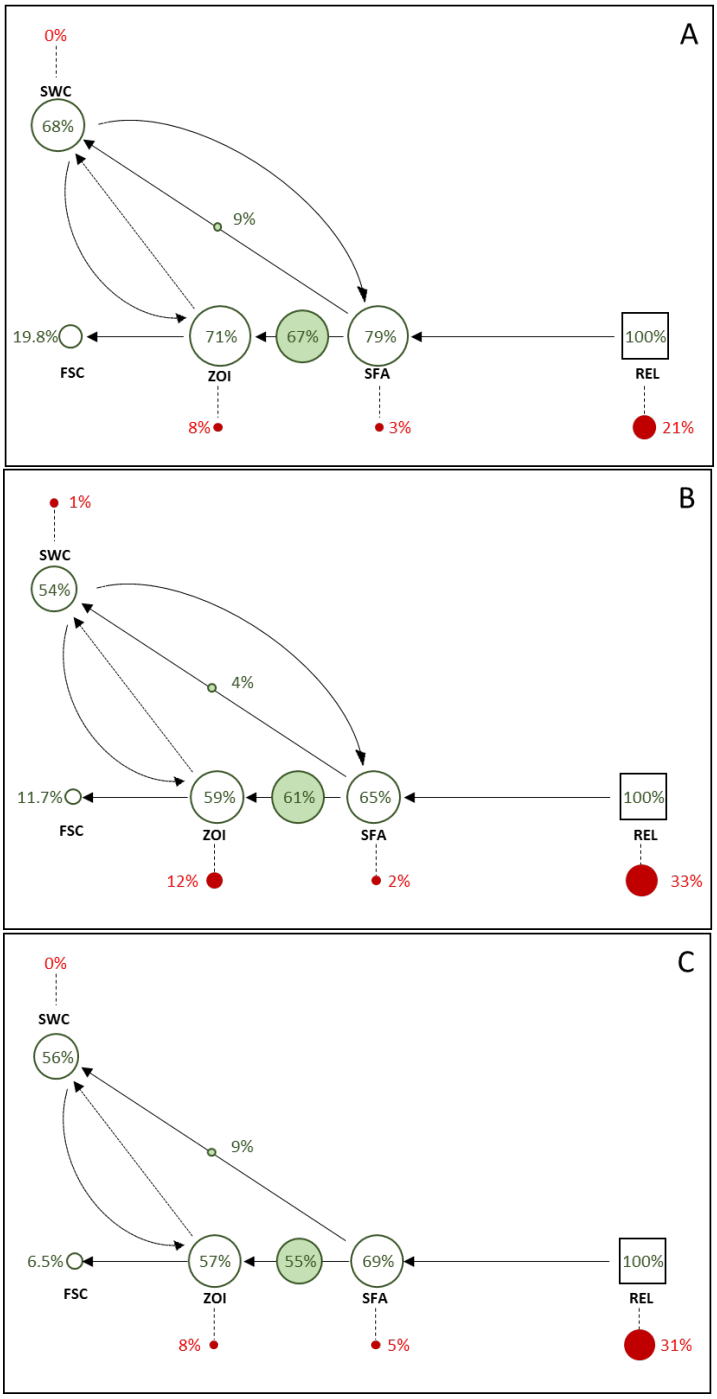
There was a progressive reduction in the number of acoustic tagged juvenile salmonids detected on receivers as they moved down the reservoir toward the FSC. Of the 520 juvenile salmonids released at the upper end of Swift Reservoir at Eagle Cliff, 376 (72%; uncorrected) were detected at the forebay entrance to Swift Dam and 333 (64%; uncorrected) were detected on the ZOI array within the 150-foot radius of the ZOI during the monitoring period. Only 74 (14.2%) of the total number of fish released were collected in the FSC. Of the juvenile salmonids that were detected in the ZOI, 77.8% were not collected (Table 8). Between 21% and 33% of fish released at Eagle Cliff were never detected on the Swift forebay array, and therefore were either preyed upon, died, or residualized in the reservoir (Table 8; Figure 7).

Table 8
Uncorrected Number and Percent of Juvenile Salmonids Released at Eagle Cliff, Detected at the Swift Forebay Array, Detected in the ZOI, Collected in the FSC, and Lost Between Reaches

Location	Chinook Salmon	Coho Salmon	Steelhead	Total	Loss
Eagle Cliff (release)	108	232	180	520	-
Swift Forebay	75 (69.4%)	184 (79.3%)	117 (65.0%)	376 (72.3%)	144 (27.7%)
ZOI	62 (57.4%)	164 (70.7%)	107 (59.4%)	333 (64.0%)	43 (8.3%)
FSC	7 (6.5%)	46 (19.8%)	21 (11.7%)	74 (14.2%)	259 (77.8%)

Note:
These numbers are not corrected for detection efficiency

Figure 7
Location of Release Point and Receiver Arrays in Swift Reservoir and Uncorrected Fish Detection Rates



Note: The percentage of fish not detected at the next downstream array are show in red; percentage of released fish passing Swift forebay array (SFA) and next detection location are shown in green circles; and the total percent of fish released and detected at SFA, ZOI, Swift Creek (SWC) or captured in the FSC are provided in the open circles for Coho Salmon (A), Steelhead (B), and Chinook Salmon (C).

To potentially inform the behavior of fish not collected in the FSC, the last known locations (i.e., last detection) of non-collected fish were assessed. Approximately 70% of the fish were no longer in the ZOI when last detected. A total of 62.1% were last detected at the Swift forebay array, possibly indicating these fish were migrating upstream into Swift Reservoir, and another 6.8% were last detected at Swift Creek. The remaining fish (31.1%) were last detected on the ZOI array in the Swift Dam forebay (Table 9). Fish last detected in the ZOI may have moved to areas of the forebay where the acoustic receivers would not detect the tag, and some of the tags potentially died while tagged fish were still in the array. The SS400 acoustic tag has a nominal tag life of 45 days. Many of the tags were still transmitting at 55 days, and one tag was detected at 73.6 days after tag activation. Some of these fish remained in the forebay for an extended period of time, so it is likely that some tags may have expired while the fish were still in the array.

Table 9
Final Distribution of Fish Not Collected at the Floating Surface Collector

Species	Swift Forebay Array	Swift Creek	ZOI Array
Chinook Salmon	33	7	28
Coho Salmon	93	8	41
Steelhead	66	6	27
All	192 (62.1%)	21 (6.8%)	96 (31.1%)

3.1.5 Transit Time

Transit time, defined as the number of days between when a fish was released and first detected in the forebay, was evaluated and no significant difference ($p>0.05$) was observed for fish that were collected versus not collected for any species (Table 10 and Figure 8a). Though there was not a statistically significant difference in time through Swift Reservoir, median travel times were longer for fish that weren't collected for all three species. Coho Salmon exhibited the overall longest transit time, with a median time of 7.34 days (standard deviation [SD] 11.36, range 1.09 to 53.36 days). Chinook Salmon exhibited a slightly faster transit time than Coho Salmon (median 5.55 days, SD 6.66, range 0.60 to 42.20 days). Steelhead had the shortest median transit time of 3.93 days (SD 5.00, range 1.00 to 41.2 days) (Table 10 and Figure 8a).

Table 10
Transit Time from Release at Eagle Creek to Swift Dam Forebay

Species	Collections Status	Minimum (Days)	25th Quantile (Days)	Median, 50th quantile (Days)	75th Quantile (Days)	Maximum (Days)
Chinook Salmon	Collected	0.83	2.22	2.79	10.61	23.06
Chinook Salmon	Not Collected	0.6	4.34	5.59	9.11	42.2
Coho Salmon	Collected	1.24	4.17	6.41	13.06	52.22
Coho Salmon	Not Collected	1.09	3.28	7.75	16.01	53.36
Steelhead	Collected	1.22	1.83	2.63	3.91	28.98
Steelhead	Not Collected	1	2.74	4.12	5.91	41.16

Time from the Swift forebay array to last detection varied between species and was longer for fish that were not collected than for fish that were collected for all species, except Steelhead. Chinook Salmon had the shortest duration in the forebay for collected fish, and Coho Salmon had the longest time before being collected (Table 11 and Figure 8b). For fish that were not collected, there was a significant difference in time until last detection between Chinook Salmon that were collected and ones that were not collected from first detection in the Swift Dam forebay ($p<0.05$). There was not a significant difference in time until last detection after entering the forebay ($p>0.05$) for Coho Salmon and Steelhead.

Table 11
Time from Entry into the Swift Dam Forebay to Last Detection

Species	Collections Status	Minimum (Days)	25th Quantile (Days)	Median, 50th quantile (Days)	75th Quantile (Days)	Maximum (Days)
Chinook Salmon	Collected	1.76	5.79	6.25	9.46	25.71
Chinook Salmon	Not Collected	0.00	6.18	17.61	35.14	57.08
Coho Salmon	Collected	0.81	12.73	25.4	36.08	63
Coho Salmon	Not Collected	0	10.97	26.09	38.79	57.54
Steelhead	Collected	0.78	5.69	13.56	27.37	65.15
Steelhead	Not Collected	0.02	3.75	8.79	18.38	61.48

Notes:
A minimum time of 0.00 for Chinook salmon represents a time that is very short (i.e., minutes), and when rounded to 2 decimal points results in a time in days of 0.00.
Chinook Salmon significant difference ($p<0.05$)
Coho Salmon and Steelhead no significant difference ($p>0.05$)

Figure 8a
Transit Time from Release to Swift Forebay for Collected and Not Collected Groups

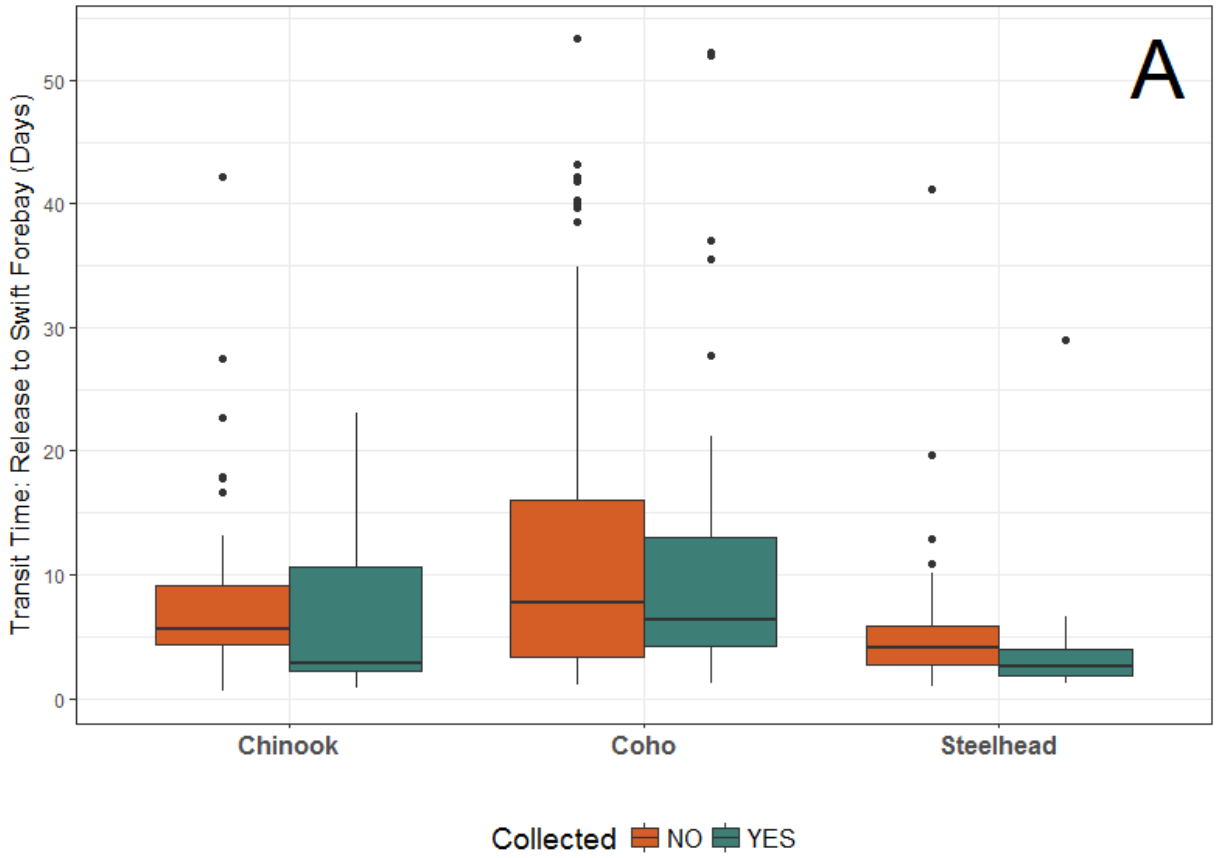
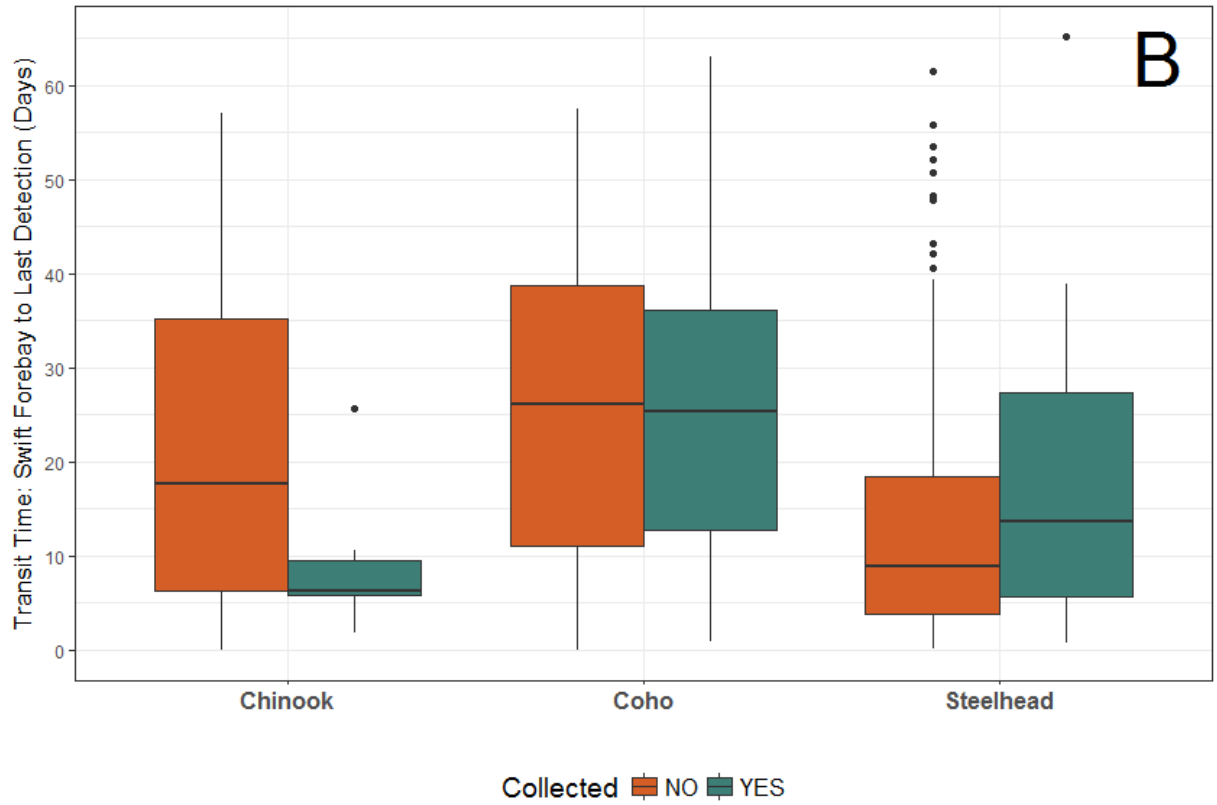


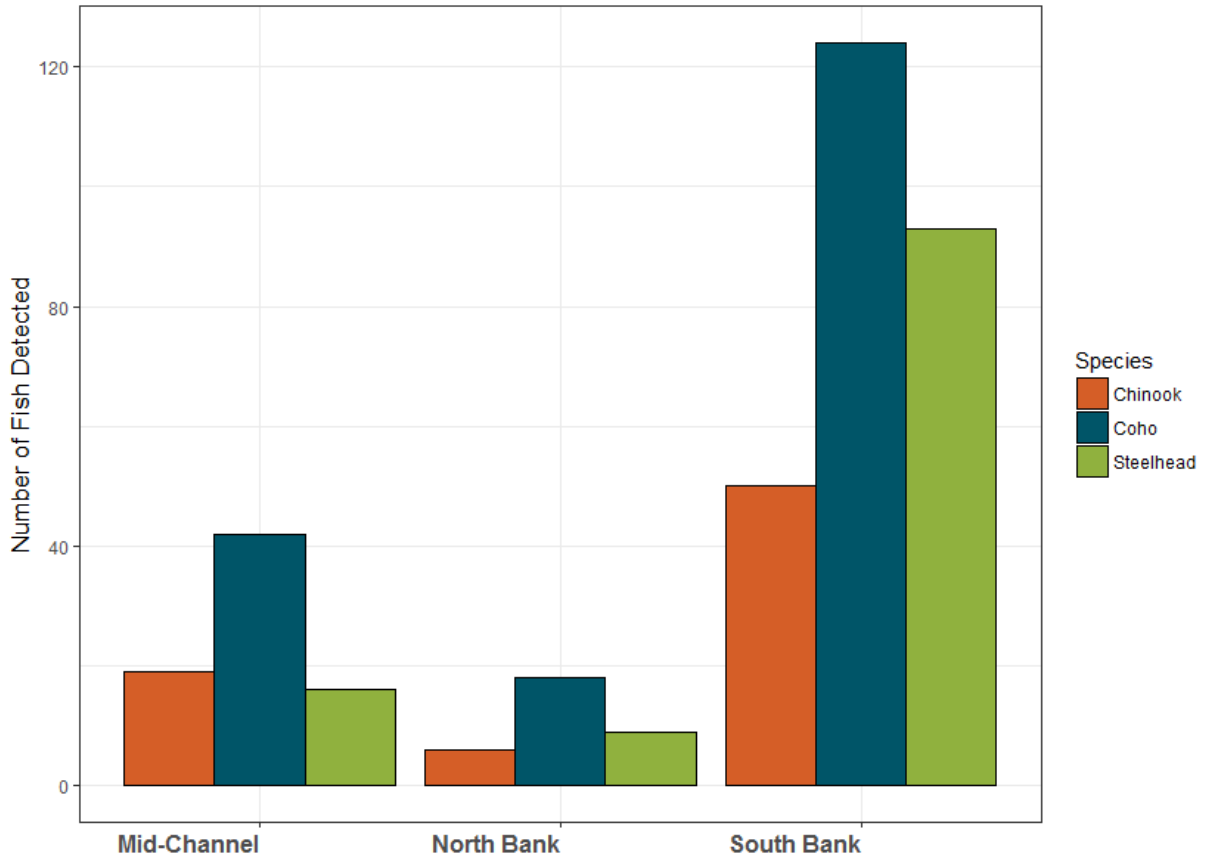
Figure 8b
Transit Time from Swift Forebay to Last Detection for Collected and Not Collected Groups



3.1.6 Swift Dam Forebay Entrance Route

For all species, most fish were first detected on the DB South receiver, indicating the fish entered the Swift Dam forebay from the south bank (Figure 9). Remaining fish entered the forebay either from mid-channel (i.e., first detected on DB North) or from the north (i.e., detected on both Swift Creek and Swift forebay receivers). For Chinook Salmon, 66.7% entered the Swift Dam forebay along the south bank, 25.3% from mid-channel, and 8% along the north bank. For Coho Salmon, 67.4% entered along the south bank, 22.8% from mid-channel, and 9.8% from the north bank. For Steelhead, 78.8% entered along the south bank, 13.6% from mid-channel, and 7.6% along the north bank.

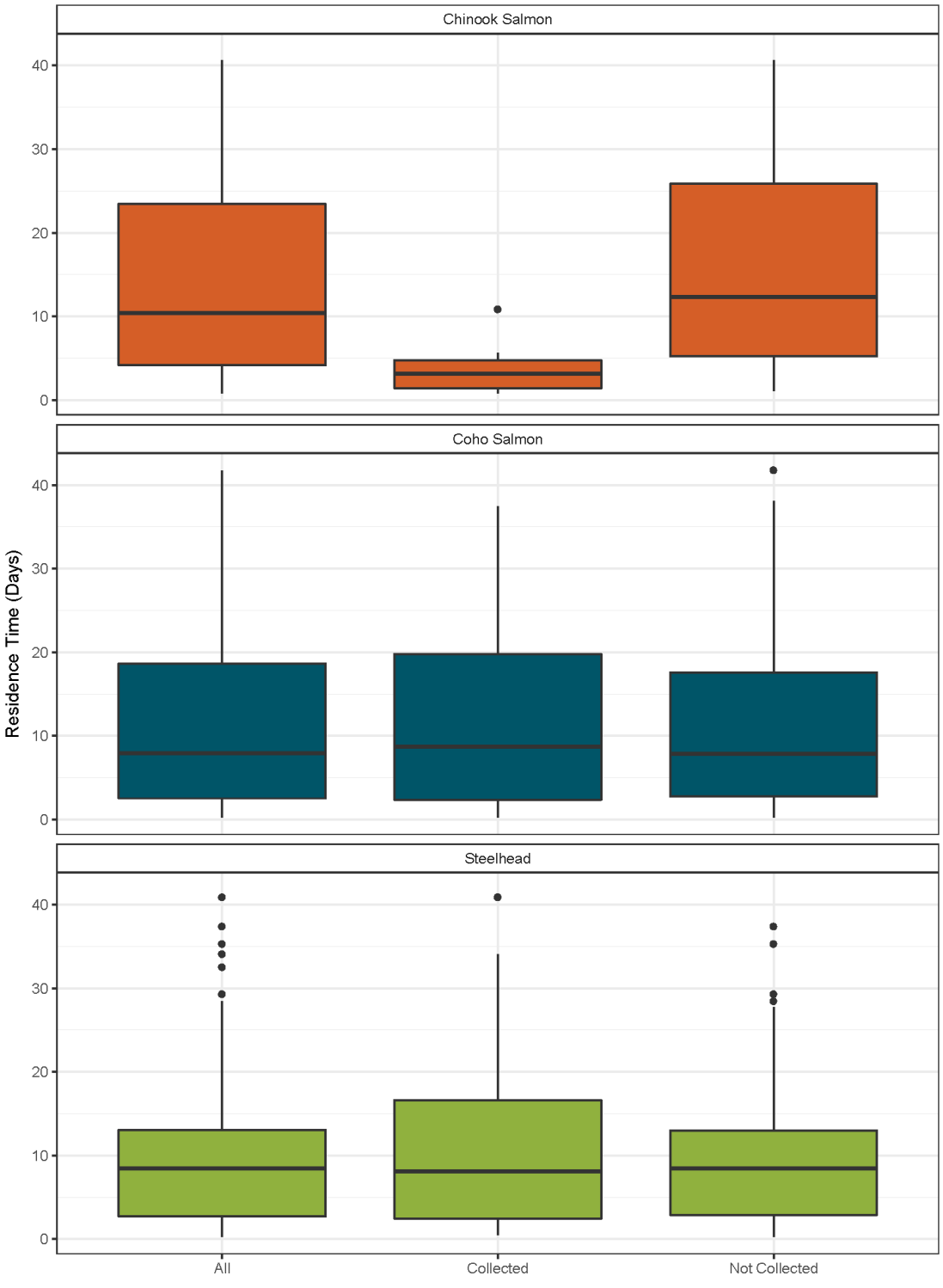
Figure 9
Likely Entrance Route of Fish by Species Entering the Swift Dam Forebay



3.1.7 Residence Time

Fish were resident in the ZOI array for times ranging from less than a day to several weeks. No Chinook Salmon that resided in the forebay more than 2 weeks were collected, while Coho Salmon and Steelhead continued to be collected after the first 2 weeks of residence. Chinook Salmon that were not collected had longer residence times in the forebay than collected fish, whereas there was no difference in forebay residence times for collected versus non-collected Coho Salmon and Steelhead (Figure 10). There was no relationship between arrival date in the ZOI array and residence time (See Appendix E, Figures E1, E2, and E3 for Chinook Salmon, Coho Salmon, and Steelhead).

Figure 10
Forebay Residence Times of Collected Versus Non-Collected Fish by Species



3.1.8 Forebay and Collector Approach Behavior

Fish that entered the Swift Dam forebay through the Swift forebay array at Devil's Backbone appeared to move extensively throughout the forebay whether they were collected at the FSC or were not collected. Of the juvenile salmonids entering the forebay, 10.6% initially were detected on the Swift Creek receiver (Table 12).

Table 12
Number and Percent of Juvenile Salmonids First Detected at Swift Creek or in the Zone of Influence Relative to Numbers Entering the Swift Forebay at Devil's Backbone

Movement	Chinook Salmon	Coho Salmon	Steelhead	Total
Swift Forebay Array to Swift Creek	10 (14.3%)	22 (12.4%)	7 (6.4%)	39 (10.9%)
Swift Forebay Array to ZOI	60 (85.7%)	156 (87.6%)	102 (93.6%)	318 (89.1%)

Many of these fish then moved toward the FSC or back up to the Swift forebay array. Many fish approached the FSC from Swift Creek, encountered the lead net, and appeared to move back and forth along the net before passing around it, or oftentimes head back up to Swift Creek. Few fish appeared to be entering the collector from the north side of the lead net. Many of the fish that initially entered the ZOI also were detected later at Swift Creek or back upstream at the Swift forebay array. None of the fish that initially entered the ZOI were collected on their first entrance into the ZOI (Figure 6 and Table 13).

Of the fish released at Eagle Cliff, 9% of Chinook Salmon initially were detected at the Swift Creek receiver and 57% were initially detected in the ZOI; 9% of Coho Salmon initially were detected at Swift Creek and 71% in the ZOI; and for Steelhead, 4% initially were detected at Swift Creek and 59% in the ZOI. Figure 6 shows the distribution of detections and fish loss as they move from release at Eagle Cliff through the reservoir and are detected on the Swift forebay array, ZOI, and Swift Creek receivers.

Analyses of acoustic-tagged fish movement using the first and last five 2D positions indicates that all three species generally approached the NTS from the south (Figures 11a through 11c). Chinook Salmon density was distributed throughout an area up to approximately 75 meters away from the NTS, suggesting these study fish may have been milling south and east of the NTS (Figure 11a). Conversely, the density plots for both Coho Salmon and Steelhead are more focused near the NTS, suggesting these fish had a more directed movement toward the NTS (Figures 11b and 11c).

Figure 11a
Collector Approach and Forebay Behavior, Chinook Salmon

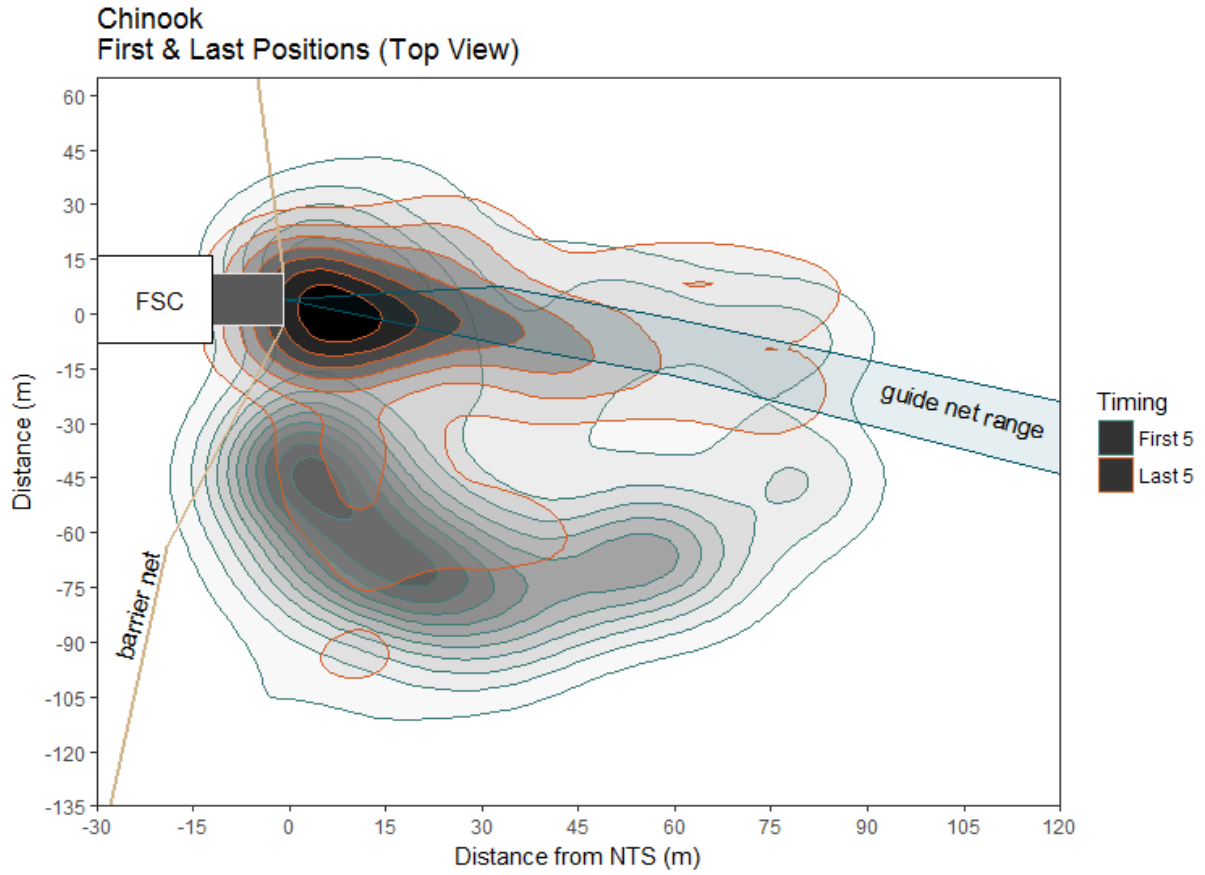


Figure 11b
Collector Approach and Forebay Behavior, Coho Salmon

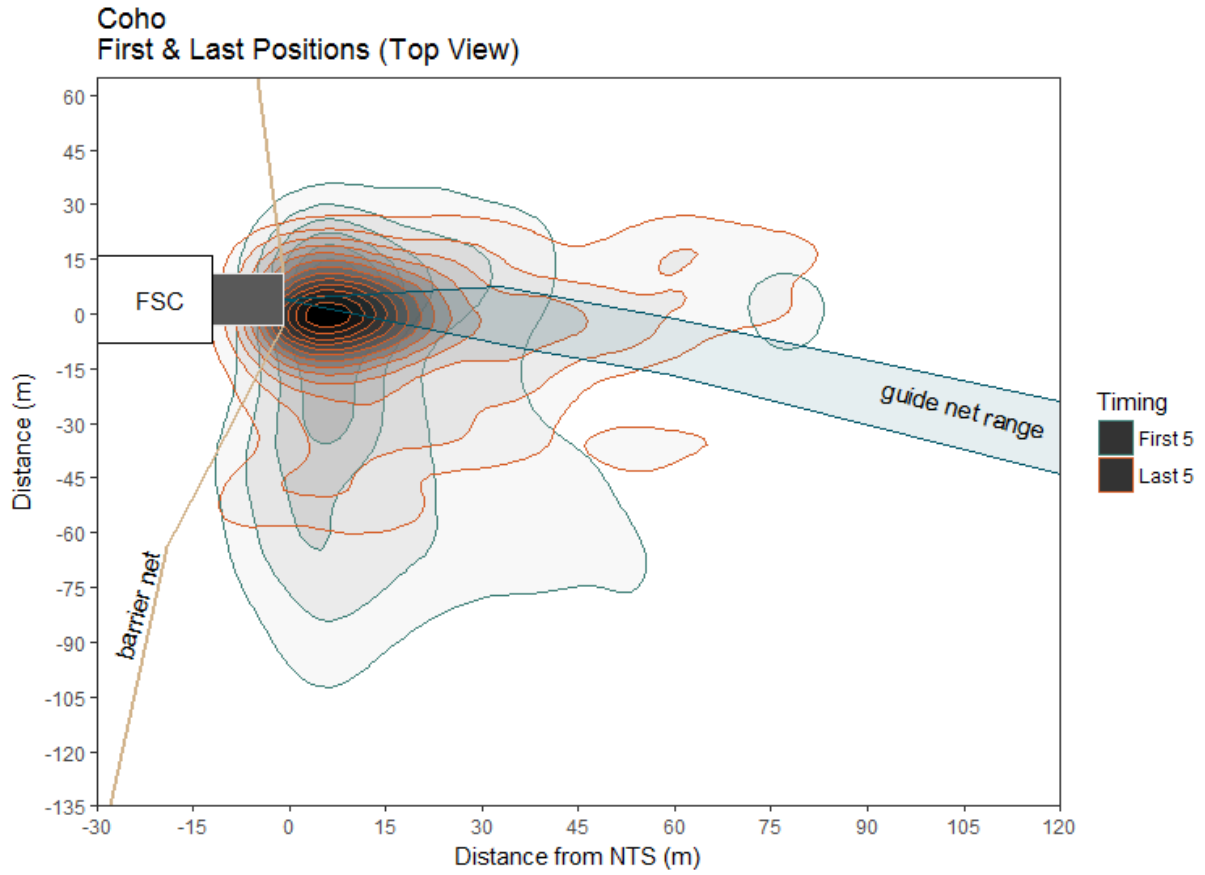
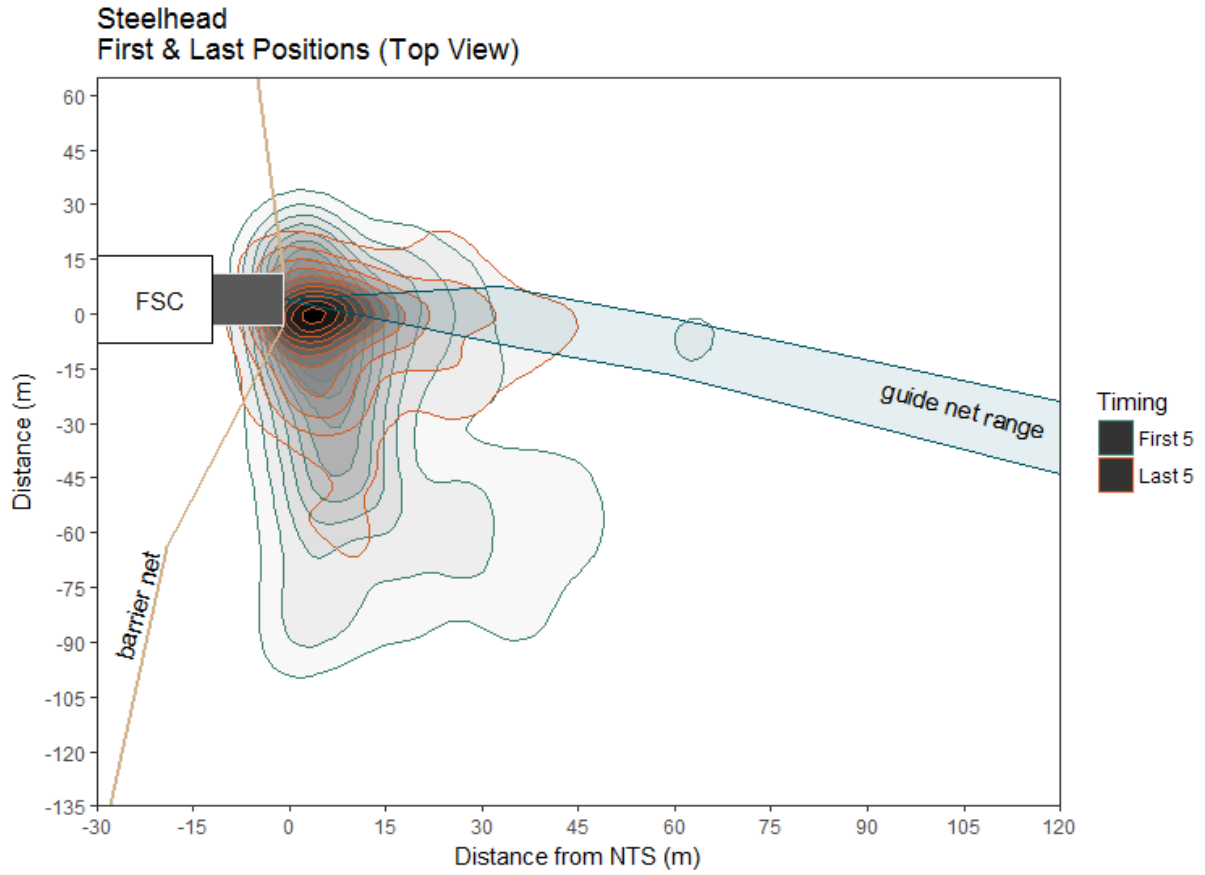


Figure 11c
Collector Approach and Forebay Behavior, Steelhead



Of the 267 fish of all residency time-periods that entered the ZOI array and were not collected, 63 (23.6%) were later detected at Swift Creek. The last three positions of the 63 fish in the ZOI array were examined for general directionality, but there were no clear patterns to suggest how the fish might be leaving the vicinity of the FSC.

Based on additional analysis of the 2D/3D and detection data, after entering the forebay, all fish made at least one if not many movements between Swift forebay array, the ZOI, and Swift Creek, or spent time in the forebay out of receiver detection range or between the Swift forebay array and ZOI receivers (Table 13). The number of movements fish made between locations varied from 1 to 22. The amount of time the juvenile salmonids resided at each location varied greatly from several minutes to over 933 hours (39.9 days) at a single location. Overall, Coho Salmon had the longest residence time at a single location. For all species, most of the time was spent in the ZOI.

Table 13
Number of Moves Juvenile Salmonids Made after Entering the Forebay and Residence Time after a Move

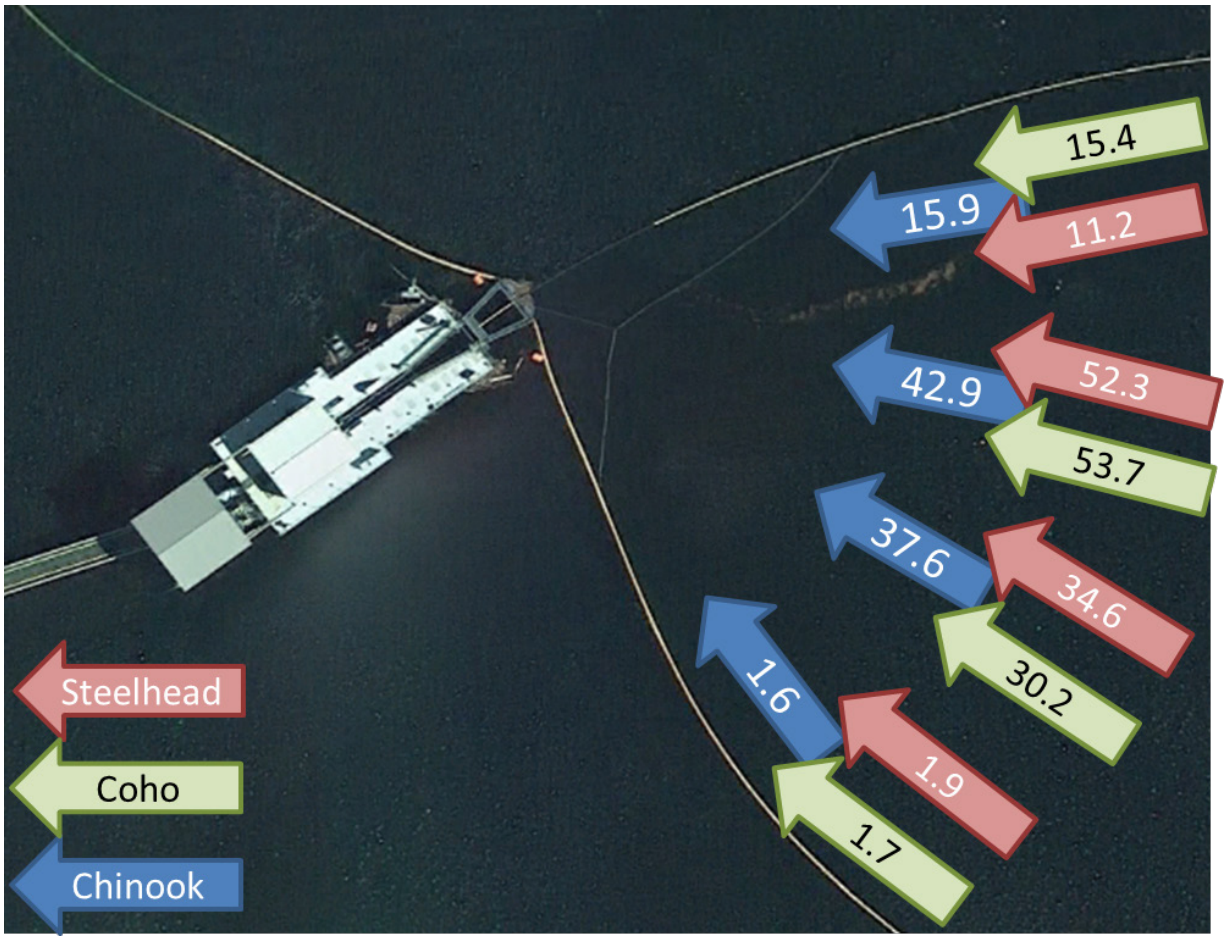
Species	Move	Number of Moves				Residence Time After Move (hour)				
		Mean	Median	Max	SD	Mean	Median	Max	Min	SD
Chinook Salmon	SFA-FBA	2.6	2	13	2.1	0.2	0.1	1.6	0.01	0.3
	SFA-SWC	1.4	1	3	0.6	22.7	5.9	113.7	1.0	33.9
	SFA-ZOI	4.7	4	13	3.2	25.9	4.7	476.6	0.1	70.8
	FBA-SFA	2.5	2	11	1.9	27.1	2.5	350.3	0.1	70.4
	FBA-SWC	1.9	1	6	1.3	13.0	5.0	124.0	0.8	25.3
	FBA-ZOI	3.8	3	21	3.5	12.8	1.0	143.4	0.1	34.9
	SWC-SFA	2.0	2	7	1.2	29.4	8.6	199.4	0.9	48.3
	SWC-ZOI	3.2	3	12	2.5	37.0	13.3	933.1	0.6	130.9
	ZOI-SFA	4.2	3	12	3.0	47.5	6.4	401.4	0.2	87.8
	ZOI-FBA	4.3	3	22	4.0	0.3	0.2	1.2	0.0	0.3
	ZOI-SWC	3.0	2	10	2.2	11.8	8.2	45.1	0.4	11.6
Coho Salmon	SFA-FBA	2.3	2	12	1.7	0.2	0.2	0.8	0.0	0.2
	SFA-SWC	1.5	1	5	0.9	38.7	8.4	353.2	0.1	66.0
	SFA-ZOI	4.2	3	16	3.2	54.6	2.8	879.0	0.1	137.6
	FBA-SFA	2.1	2	13	1.7	7.6	0.7	103.6	0.1	19.9
	FBA-SWC	1.8	1	6	1.1	29.9	4.6	344.4	0.1	61.0
	FBA-ZOI	4.1	3	19	3.3	45.8	2.0	479.8	0.1	100.8
	SWC-SFA	1.9	2	6	1.2	33.5	6.0	784.4	0.2	86.8
	SWC-ZOI	2.9	2	13	2.0	18.4	8.4	640.3	0.2	58.1
	ZOI-SFA	3.6	3	17	2.9	29.2	3.6	921.6	0.1	92.4
	ZOI-FBA	4.5	3	20	3.6	0.3	0.2	2.2	0.0	0.4
	ZOI-SWC	2.7	2	15	2.0	12.4	4.5	201.6	0.1	23.2
Steelhead	SFA-FBA	2.5	2	10	2.1	0.2	0.1	0.9	0.0	0.2
	SFA-SWC	1.9	2	6	1.2	17.8	3.6	184.3	0.7	37.7
	SFA-ZOI	5.0	4	16	3.9	22.3	1.8	479.1	0.1	58.7
	FBA-SFA	2.1	2	7	1.5	7.3	0.9	175.5	0.1	24.9
	FBA-SWC	1.7	1	8	1.2	10.4	4.3	83.5	0.2	17.3
	FBA-ZOI	3.9	3	15	3.0	12.6	1.1	150.6	0.1	29.8
	SWC-SFA	2.5	2	9	1.9	25.2	6.0	373.1	0.5	61.1
	SWC-ZOI	3.0	2	21	2.7	14.9	6.7	323.6	0.4	37.2
	ZOI-SFA	4.4	3	19	3.4	32.6	9.0	196.6	0.1	49.5
	ZOI-FBA	4.6	4	18	3.5	0.2	0.2	1.1	0.0	0.2
	ZOI-SWC	3.1	3	16	2.4	11.4	5.3	132.4	0.1	19.0

Notes:
FBA: forebay
SFA: Swift forebay array
SWC: Swift Creek
ZOI: zone of influence

3.1.9 Behavior Relative to the Lead Net and Zone of Influence

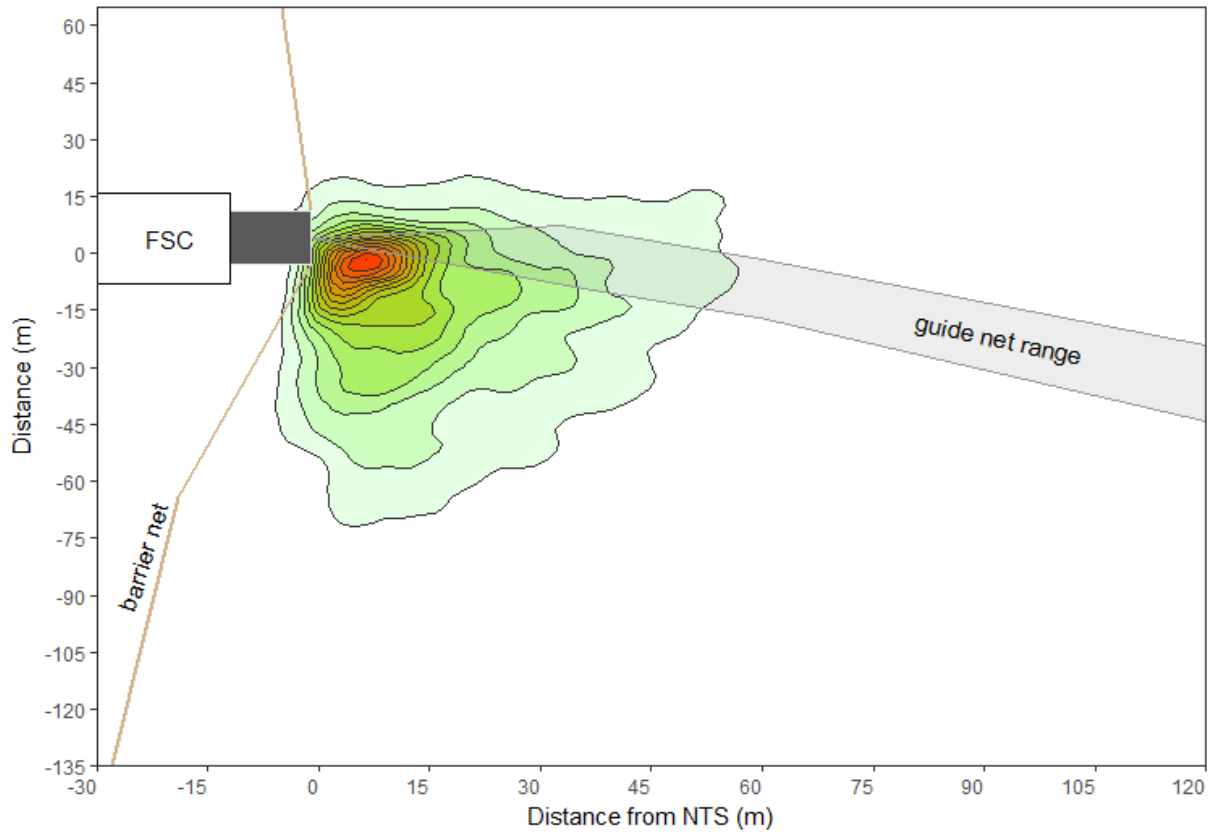
Entrance of juvenile salmonids into the ZOI from the Swift forebay array was consistent among all three species of salmonids. Only a small percentage of the fish (1.6 to 1.9%) entered the ZOI from the south along the barrier net. Between 11.2 and 15.9% of fish entered the ZOI along the lead net from the north. Most of the fish entered the ZOI in the middle between the barrier net and lead net (Figure 12).

Figure 12
Percentage Distribution of Juvenile Chinook Salmon, Coho Salmon, and Steelhead Approaching the Floating Surface Collector at Swift Reservoir



The lead net appears to be successfully preventing fish from migrating past the FSC. The density of detected positions for all species indicates that fish were residing in the area south of the lead net (Figure 13). Density plots of all positions for each species individually showed nearly an identical distribution to Figure 13.

Figure 13
Density of Detected Positions, All Species

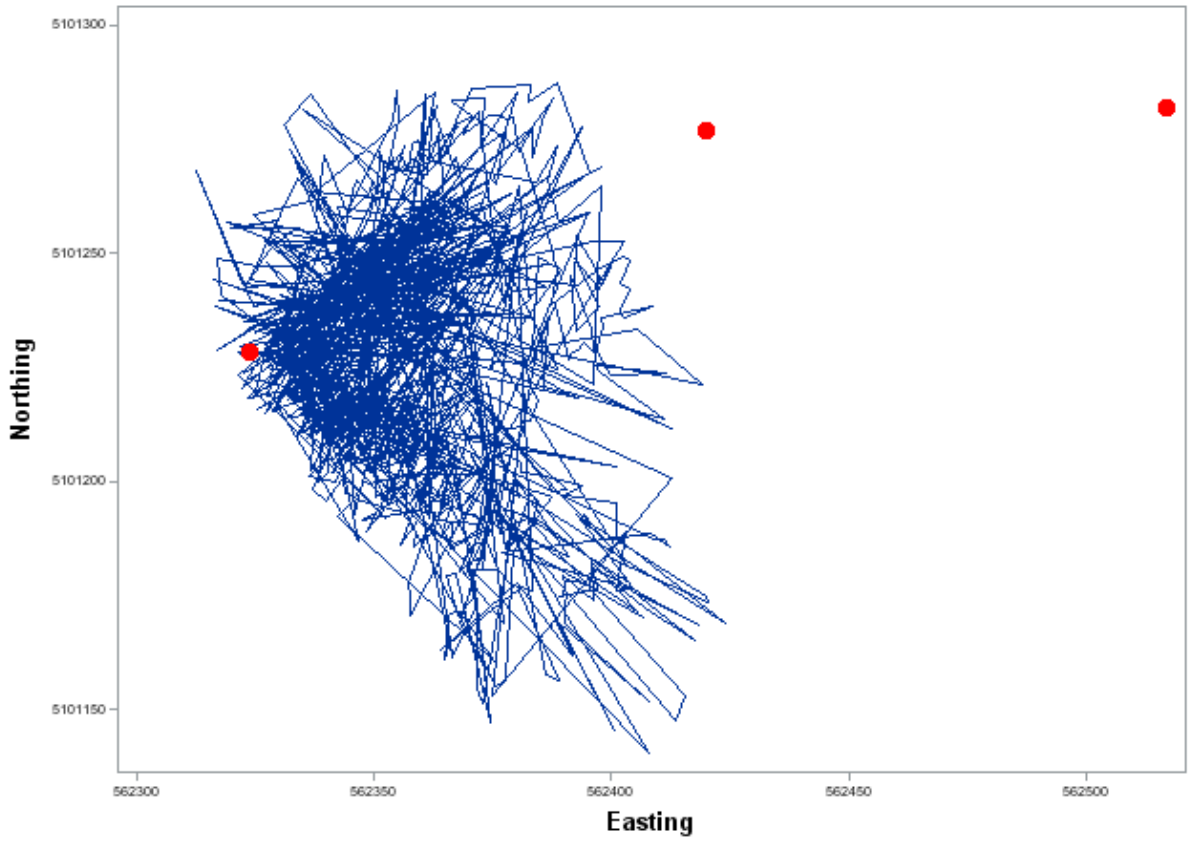


Juvenile salmonids approached but did not enter the FSC on the first approach and subsequently moved back upstream toward the Swift forebay array or toward Swift Creek. None of the fish observed moving out of the ZOI appeared to pass under the lead net. These fish moved upstream either along the lead net or back upstream away from the net. Fish movement was verified using amplitude and last detections to manually evaluate the final detections as these fish moved upstream away from the NTS. Most fish milling in the ZOI covered most of the area, but spent a majority of the time near the NTS entrance (Figure 13). Figure 14 shows a typical track of fish in the ZOI including the highest concentration in front of the NTS. The red dots represent, from left to right, the NTS entrance, midpoint of the lead net, and end of the lead net. Each dot represents an average net position, which is quite dynamic.

From the fish track, it appears as if the fish may be on the north side of the lead net; however, the fish is still on the south side of the lead net. The tracks appearing to be north of the lead net are mainly from when the net has bowed to the north. This was determined by time of arrival of the acoustic signal being detected on the shallow receivers first on these far north points. If fish were

sounding under the net, detections would first be observed on the deep receivers, which was not the case. Results of the 2016 study suggested that fish may be sounding under the lead net due to direction of movement between detection points on opposite sides of the net. It may be possible that due to different water years fish were behaving differently in 2017 compared to 2016. However, it may also be possible that due to array configuration, detecting movement of fish around the lead net was not possible in 2016.

Figure 14
Movement of Juvenile Chinook Salmon in the Zone of Influence at Swift Dam Floating Surface Collector



Note: Red dots represent, from left to right, the NTS entrance, midpoint of the lead net, and end of the lead net.

Fish that came back from Swift Creek toward the collector detected the lead net and exhibited milling behavior around the net on the north side, and either moved back toward Swift Creek or east and around the net. It doesn't appear that any of the fish collected came from the north side of the net or sounded back under the net to return to the ZOI.

In summary, most of the fish approached the FSC from the southeast. The lead net appeared to intercept fish as they approached the FSC from the south and east, and fish appeared to stay within

the ZOI for long periods of time, likely due to the net, even though collection was low. For fish approaching the FSC from the north, the lead net did not appear to provide a benefit (i.e., guide them into the FSC). After these fish encountered the net, some stayed along the net for a couple hours, but none entered the NTS from the north side of the lead net.

3.2 PIT Tag Only Releases

3.2.1 System Survival Estimates for 2017

System survival is defined as the proportion of PIT-tagged fish released at Eagle Cliff that traveled into the Swift Dam forebay and were detected within the FSC (Table 14). System survival does not take into account fish that remained in the reservoir but were not collected or overwintered in the reservoir. Therefore, it is an approximation of P_{CE}.

Table 14
System Survival of PIT Tag Only Fish

Species	Number Released	Number Collected	System Survival[1]
Chinook Salmon	110	8	7.3%
Coho Salmon	176	40	22.7%
Steelhead	175	26	14.9%
All	**461**	**74**	**16.1%**

Note:
1. Proportion of fish released at Eagle Cliff and collected

3.2.2 Comparison of System Survival Using PIT Tagged Only and Dual-Tagged Fish

System survival was higher for PIT-tagged juvenile salmonids than for dual-tagged fish, though not substantially higher. The trend by species was consistent between tag types with lowest system survival for Chinook Salmon and highest survival for Coho Salmon (Table 15).

Table 15
System Survival of PIT Tag Only and Dual-Tagged Fish

Species	System Survival	
	PIT Tag Only Fish	PIT- and Acoustic-Tagged Fish
Chinook Salmon	7.3%	6.5%
Coho Salmon	22.7%	19.8%
Steelhead	14.9%	11.7%
All	**16.1%**	**14.2%**

3.2.3 Comparison of Transit Time for PIT Tagged Only and Dual-Tagged Fish

Travel time for juvenile salmonids from release at Eagle Cliff until they were collected in the FSC varied between species but there was not a significant different in travel time between PIT tagged only and dual-tagged fish for any species ($p>0.05$) (Table 16).

Table 16
Transit Time from Release at Eagle Creek to Collection in the Floating Surface Collector

Species	Tag Type	Median (Days)	Mean (Days)	SD	Minimum (Days)	Maximum (Days)
Chinook Salmon	Dual-tagged	12.7	16.6	10.1	7.7	33.6
Chinook Salmon	PIT only	15.0	15.9	11.1	0.7	36.4
Coho Salmon	Dual-tagged	36.4	40.0	234.0	5.6	101.5
Coho Salmon	PIT only	37.9	43.5	23.8	7.5	104.9
Steelhead	Dual-tagged	22.9	22.2	17.5	3.5	71.8
Steelhead	PIT only	12.6	16.0	15.5	1.2	73.5

3.2.4 Behavior of Large PIT-Tagged Coho Salmon

A difference in the behavior of PIT- and dual-tagged Coho Salmon was observed when collection efficiencies of PIT only and acoustically-tagged fish were compared. The collection rates for Chinook Salmon and Steelhead were very similar between PIT- and acoustically-tagged fish, but for Coho Salmon the collection rates were quite different. A review of the data revealed that Coho Salmon greater than or equal to 220 mm in length were not representative of the size group of acoustically-tagged fish. These larger fish also appeared to behave differently than their smaller (less than 220 mm) cohorts (e.g., were not collected in similar proportions). The larger Coho Salmon may have residualized, and if included in P_{CE} estimates would have reduced overall P_{CE}. Since the Study focused on actively migrating salmonids, Coho Salmon 220 mm or greater in length were removed from the analysis.

3.3 Factors Affecting Performance

The factors affecting performance described in the following sections were evaluated based on dual PIT- and acoustic-tagged fish.

3.3.1 Noise

Sound measurements collected to determine whether sounds associated with the operation of the FSC pumps were at a frequency and level that could impact juvenile salmonid behavior and potentially the collection efficiency of the FSC were observed in the hearing range of salmonids.

Sound from the SAF pumps could be isolated from the other sound in the water around the collector because these pumps generated a distinctive sound with a low fundamental frequency. This low frequency sound, at least those components within the range of human hearing, was also quite loud and distinctive in air.

Sound measurements collected near the entrance to the FSC had sound peaks similar to those near the SAF pumps. Ambient noise was observed (underwater sound in a location where sound generated by collector pumps was absent) for comparison to underwater sound observations made near the SAF pumps and the entrance to the FSC. Ambient sound levels were observed to be significantly lower than those observed near the SAF pumps and FSC entrance.

Sound within the hearing range of juvenile salmon may be generated on a regular basis by operation of the SAF pumps. Any sound-induced behavioral responses associated with the pumps may influence the collection efficiency of the FSC. Additional details and noise data resulting from the collection of sound measurements at the FSC are provided in Appendix F.

Additional sound measurements were collected on December 19, 2017, after the sound from the SAF pumps was dampened. The new sound measurement data did not detect the 22-hertz sound frequency that radiated in the water during the initial measurements.

3.3.2 Woody Debris

Mean lag time between when Coho Salmon and Steelhead first entered the ZOI and were collected was shorter during weeks when debris was cleared compared to weeks where debris was present (no Chinook Salmon were collected the weeks following debris clearing). Mean lag time for Coho Salmon was 23.84 days when debris was present, compared to 11.71 days when debris was not present. For Steelhead the difference in lag time was small: 15.73 days when debris was present compared to 14.33 days when debris was not present.

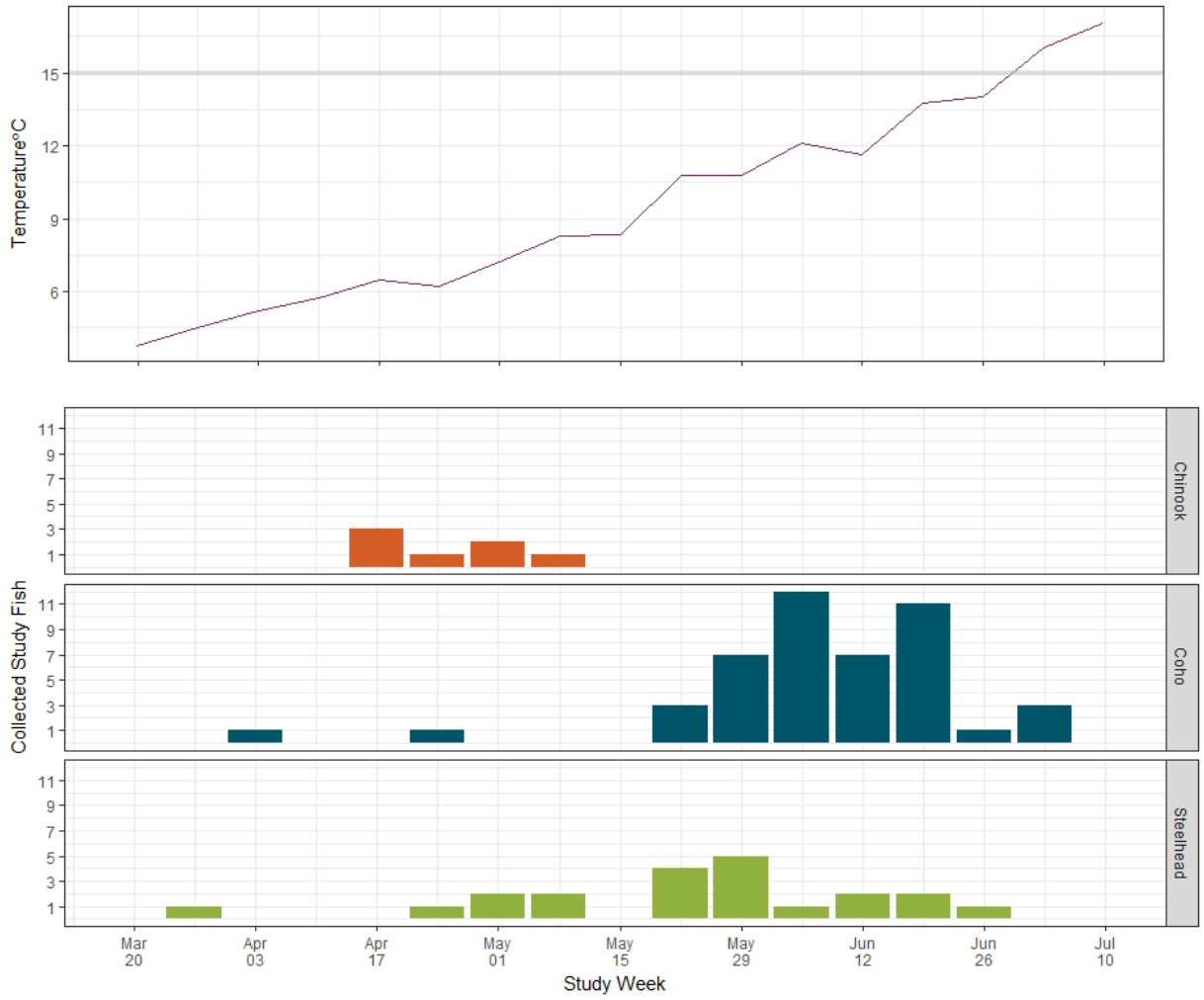
All species were found to have a lower number of detections of acoustically-tagged fish in the ZOI after a debris clearing event. Detections before and after clearing were 258 and 105 for Chinook Salmon, 589 and 408 for Coho Salmon, and 307 and 169 for Steelhead, respectively. Clearing debris tended to reduce the number of fish detected in the ZOI and shorten the time Coho Salmon and Steelhead took to enter the FSC from the ZOI.

3.3.3 Water Temperature

The relationship between water temperature and the number of study fish collected indicated that the number of Chinook Salmon collected peaked earlier than Coho Salmon and Steelhead and ceased by mid-May (Figure 15). Coho Salmon and Steelhead collection increased through the

season, peaked in late May, and remained high through late June before decreasing. The reduction in Coho Salmon and Steelhead occurred when water temperature was approximately 15°C.

Figure 15
Water Temperature Near Floating Surface Collector Entrance Shown with Collection Numbers and Collection Efficiency Data



Previous studies also observed that most collection occurred before the forebay water temperature reached 15°C and that most fish also arrive near the FSC before this temperature threshold is reached. In 2017, the forebay water temperature reached 15°C in late June, approximately 2.5 weeks before the end of the collection season.

3.3.4 Collector Pump Operations

The collector was in a fully operational state (all primary and secondary pumps running) 80.5% of the time (99 days) and in "other" operational states 19% of the time (23 days). During the study period the collector was off less than 1% of the time (1 day). Based on visually interpreting plots of Pce relative to collector operations, no trends were detected between operational state and P_{CE} for any species nor did collector operations appear to affect overall P_{CE}. Based on visually interpreting plots of P_{ENT} relative to collector operations, a decrease in overall P_{ENC} was observed for Steelhead and Coho Salmon after a period of 2 days of decreased operational state in early April, but a similar trend was not observed in Chinook Salmon or in all species as a group. Therefore, it is difficult to ascribe this change directly to collector operations and was likely a result of multiple factors. Visual interpretation of P_{RET} plots relative to collector operations indicated no trends for any species, suggesting collector operations did not appear to influence this metric.

3.3.5 Forebay Hydraulics and Flow

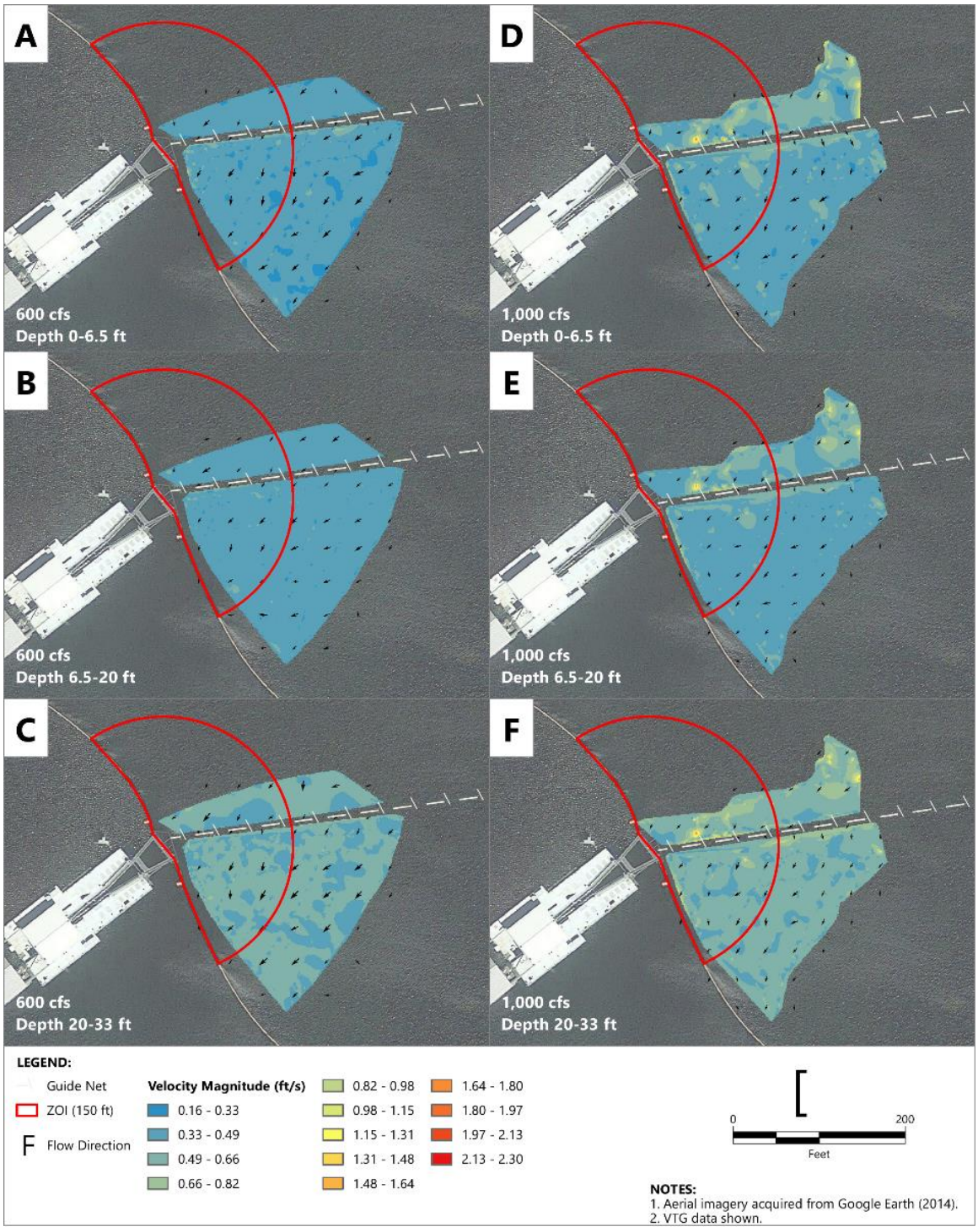
3.3.5.1 Acoustic Doppler Current Profiler Flow Data

ADCP survey data were collected on December 19, 2017, under conditions where both hydroelectric units were off and motoring for about 4 hours prior to and while the velocity data were being collected. Overall, the water velocity measurements collected in the survey area in the top 33 feet of the water column in front of the FSC were low and mostly ranged between 0.16 and 1.15 feet per second (Figure 16). Minimal differences in velocities were observed between FSC pump attraction flows of 600 cfs and 1,000 cfs, although velocities collected north of the lead net were generally higher under 1,000 cfs attraction flows. Under 600 cfs attraction flows there was very little variation in velocities across the survey area, especially in the top 20 feet of the water column. For both attractant flow scenarios, the highest velocities across the survey area were identified in the 20- to 33-foot depth interval.

Since data in the 0- to 6.5-foot depth range were influenced by surface winds, data from the 6.5- to 20-foot and 20- to 33-foot depths were primarily used to interpret flow direction. Flow direction was similar for both attractant flows tested and showed a general pattern of a southwestern direction towards the dam (Figure 16). Flow heading towards the FSC entrance occurred mainly north of the lead net. Under conditions of higher surface winds from the north (attractant flows of 1,000; panels D, E, and F in Figure 16) the lead net was positioned such that access to the FSC appeared to be partially blocked for fish approaching from the south.

Based on a visual interpretation of the ADCP survey data and a lack of discrete thresholds or changes in velocity levels or direction, a specific ZOI could not be identified in the forebay in front of the FSC.

Figure 16
Acoustic Doppler Current Profiler Velocity Data Collection Results in Front of the Floating Surface Collector at Swift Reservoir



Note: Panels A through C show water velocity and direction at the 600 cfs operating condition in the 0- to 6.5-foot, 6.5- to 20-foot, and 20- to 33-foot depth bins. Panels D through F show the same depth bins at the 1,000 cfs operating condition.

3.3.5.2 Computational Fluid Dynamics Model Data

Anchor QEA and Four Peaks Environmental staff reviewed Computational Fluid Dynamics (CFD) model data developed in 2007 on the Swift Reservoir Forebay provided by PacifiCorp. The review focused on model runs where the Swift Dam powerhouse was off, FSC pumped attraction flows were 960 or 1,000 cfs and discharged from the FSC to the north and south, no lead or barrier nets were incorporated into the model grid, and the velocity vectors were modeled at a depth of 20 feet. The results of the CFD were used by PacifiCorp to set the 150-foot ZOI for the FSC attraction flows.

Overall, the CFD model results indicated there is a gyre northeast of the FSC, and as flow in the gyre circulates in a clockwise direction it sweeps past the entrance of the FSC in a northwesterly direction. Placement of the FSC relative to these data suggests the flow vectors in the gyre are directed toward and into the FSC. In contrast, results of the ADCP measurements (Panels B to F; Figure 16) indicated flow at depth in front of the FSC was generally in a southwesterly direction toward the powerhouse. Also, the presence of the lead nets appears to interrupt that prevailing flow such that flow north of the lead net was partially directed toward the FSC entrance, whereas flow south of the lead net continued in a southwesterly direction. Compared to the CFD model runs, the ADCP data were collected at shallower depths with the lead net installed and were influenced by strong surface winds from the north under the 1,000 cfs pump operation.

3.3.5.3 Literature Review of Fish Responses to Hydraulic Conditions

Anchor QEA performed a literature review of fish responses to hydraulic conditions and flow to determine if potential response thresholds are available in the scientific literature that could be used to identify a ZOI for the Swift FSC based on the ADCP survey results and help inform the interpretation of the ADCP and CFD model data. The literature review did not identify specific hydraulic or physical criteria that should be used along with the ADCP and CFD data to estimate a ZOI distance from the FSC (Appendix C).

3.3.5.4 Presence of a Zone of Influence

Based on a visual interpretation of the ADCP survey data, a review of the scientific literature, a review of CFD model data, and results of acoustic telemetry studies, a definitive ZOI was not apparent nor was there any basis to suggest a ZOI other than 150 feet is more appropriate. Because juvenile salmonid sensory systems are capable of sensing changes in velocity at much smaller scales than can be observed using ADCP survey and CFD model results, and after consulting with PacifiCorp, all performance metrics based on a ZOI used a ZOI of 150 feet.

3.4 PIT-Tag Comparisons Among Study Years

PIT-tag data from 2017 were evaluated and compared to results from previous study years based on both PIT-tag and dual PIT- and acoustic-tag releases. In 2017, the average lengths of PIT-tagged Chinook Salmon and Steelhead were greater than previous years. Coho Salmon larger than 220 mm

were excluded from the analysis because fish above this threshold were only PIT tagged (none were dual PIT and acoustic tagged), and because of differences in collection efficiency between Coho Salmon above and below the threshold being observed during analyses (i.e., larger fish had a lower collection efficiency; see Section 3.3.4), which compromised the comparison of collection efficiency between the two tag groups. In 2017, the average length of PIT-tagged Coho Salmon was within the range of average lengths from previous years (Table 17). Similar to past years, in 2017, the average lengths of Chinook and Coho Salmon collected in the FSC were less than, and Steelhead were slightly larger than, the average lengths of all tagged fish in their respective cohort (Table 17).

Recapture rates of PIT-tagged Coho Salmon and Steelhead in 2017 were at the low end of the range observed in previous years of study, whereas Chinook Salmon had the highest recapture rate of any study year to date (Table 17).

Among all species and most release years, PIT-tagged migrants were detected in the FSC in at least 1 subsequent year following release, suggesting that a proportion of PIT-tagged fish are overwintering after release and are not contributing to within-year P_{CE} estimates. This pattern was observed initially by Caldwell et al. (2016). In 2017, a total of nine Coho Salmon and one Steelhead released in 2016 were collected and detected in the FSC.

Table 17
Average Lengths and Numbers of PIT-Tag Recaptures in the Floating Surface Collector among Sampling Years 2013-2017

Species	Release Year	Length (mm)[1]			Number		
		All Tagged Fish	FSC Collected Fish	Difference (tagged-collected)	All Tagged Fish	FSC Collected Fish	Recapture Rate
Chinook Salmon	2013	155.5	140.0	15.5	178	2	1%
	2014	166.7	156.0	10.7	197	1	1%
	2015	134.9	119.5	15.4	50	2	4%
	2016	175.0	-	-	3	-	0%
	2017	175.8	180.1	4.3	110	8	7.3%
Coho Salmon	2013	147.0	123.2	23.8	1144	204	18%
	2014	143.0	121.2	21.9	134	51	38%
	2015	127.5	122.7	4.8	508	129	25%
	2016	105.0	100.7	4.4	585	253	43%
	2017	138.5	142.0	3.5	176	40	22.7%
Steelhead	2013	158.4	167.0	-8.6	52	7	13%
	2014	165.6	165.9	-0.3	57	10	18%

4 Discussion and Recommendations

This section discusses the general results of the 2017 Study, compares the results among study years, addresses three principal questions related to the behavior and operation of the FSC, and provides recommendations.

4.1 General Comparison of 2017 Collection Efficiency Estimates to Previous Years

In 2017, P_{CE} estimates for all species were less than the Performance Goal of 95%. The total corrected P_{CE} estimate was 21.7% with individual species estimates ranging from 11.3% for Chinook Salmon to 26.7% for Coho Salmon. Within the context of historic studies, the 2017 P_{CE} estimate across all species falls within the range observed between 2013 and 2016: 6.7% (Courter et al. 2013) and 29.3% (Caldwell et al. 2016). Similarly, the 2017 P_{CE} estimates for Coho Salmon (26.7%); and Steelhead (19.7%) were also within the range observed in the most recent studies where dual PIT and acoustic tags were also used (Reynolds et al. 2015; Caldwell et al. 2016). In contrast, the estimate for Chinook Salmon was higher in 2017 than in any year previously studied.

Between 2013 and 2017, the study design evolved considerably, moving from radio telemetry to dual PIT- and acoustic-tag-based studies, and has focused more closely on specific factors that influence P_{CE}. In 2017, there were additional refinements that affect comparability to previous years. For all species, acoustic tag detection efficiencies were calculated for acoustic receivers and used to correct observed numbers of fish detected. Depending on the specific performance metric calculation, corrected counts could either increase the denominator, numerator, or both, and therefore increase or decrease the value of an uncorrected performance metric. In previous years, receiver detection efficiencies were not used to correct performance metrics. Year-to-year variation in P_{CE} could also result from changes in fish source, natural variation in fish behavior or environmental conditions, structural modifications to the FSC, or changes to FSC operations.

The use of study fish that were first collected at the FSC and then released at Eagle Cliff could also have reduced the likelihood of collection at the FSC. Stroud et al. (2014) observed that naïve fish collected, tagged, and released from a RST at Eagle Cliff had a much higher conversion rate from the release location to detection in the forebay (88%) versus non-naïve fish collected and tagged from the FSC (19.7%). Caldwell et al. (2016) determined that fish collected at the FSC in 2015 and 2016 were the least likely to be recaptured at the FSC and recommended using hook-and-line sampling or the Eagle Cliff RST for obtaining study fish. All the 2017 study fish were non-naïve (i.e., collected and tagged from the FSC) prior to release at Eagle Cliff. Additionally, the PTAGIS records for recaptured Chinook Salmon indicate they were primarily hatchery-origin fish, which contrasts with previous years and could account for differences in behavior.

In addition, more juvenile Chinook Salmon were tagged and released in 2017 compared to previous years, which may have affected P_{CE}. Prior to 2017, the annual Chinook Salmon release groups (radio telemetry or dual PIT and acoustic tag) ranged in size from 3 to 58 individual tagged fish, whereas the 2017 release group included 108 dual PIT- and acoustic-tagged fish.

The average lengths of PIT-tagged Chinook Salmon and Steelhead in 2017 were greater than previous years, whereas the average length of PIT-tagged Coho Salmon was within the range of average lengths of fish tagged in previous years. Like past years, the average lengths of Chinook and Coho Salmon collected in the FSC in 2017 were less than, and Steelhead were slightly larger than, the average lengths of all tagged fish in their respective cohorts. Because the migratory behavior and smolting process of juvenile salmonids is linked to juvenile size and rearing environment (Beckman et al. 1998), the "motivation" of juvenile fish to enter the collector may differ among different size classes of fish. Sorting out the relative contribution of fish size to P_{CE} could be considered in future years, particularly when study fish are larger or smaller than normal. Similar to the observations by Caldwell et al. (2016), PIT-tagged study fish from previous years were detected in 2017. This behavior of overwintering in the Swift Reservoir will affect overall P_{CE} for a given year and should be considered in future estimates of FSC performance relative to the performance standard.

Finally, the project has undergone substantial modifications that are expected to improve P_{CE}. Prior to the 2016 study, PacifiCorp installed a large lead net near the entrance of the FSC to improve juvenile salmonid collection efficiency (Caldwell et al. 2016). In the fall of 2017, vibration dampeners were installed on the SAF pump motors in the FSC to minimize pump vibration that transferred through the hull of the FSC and could potentially affect the behavior of juvenile salmonids and reduce P_{CE}. Additional sound measurements were collected on December 19, 2017, after the sound from the SAF pumps was dampened. The new sound measurement data did not detect the sound frequency that radiated in the water during initial measurements. The impact of the vibration dampeners cannot be addressed in this report because the work occurred after the acoustic tag study was complete, but could be evaluated in future monitoring efforts. In addition, the location of the lead net was observed to be blocking the entrance of the FSC, especially when the wind was blowing from the north as observed during the ADCP survey, and the location of the net was adjusted to avoid blocking the entrance.

4.2 Are Fish Finding the Collector Entrance?

Yes, data indicate most study fish found the FSC entrance, based on observed performance metrics, plots of 2D data, and multiple ZOI encounters. Study fish spent hundreds of hours in the ZOI, with the highest density near the entrance of the collector, and made multiple excursions around the forebay to Swift Creek and back to the Swift forebay array.

In 2017, 73.6% of all acoustic-tagged fish (69.4% of Chinook Salmon, 81.0% of Coho Salmon, and 66.7% of Steelhead) transited the 9-mile distance from the release site at Eagle Creek to the Swift forebay array (P_{RES}), and 65.5% of all acoustic-tagged fish (57.4% of Chinook Salmon, 74.2% of Coho Salmon, and 59.4% of Steelhead) made it from the release site to the detection arrays in the ZOI. In previous studies where acoustic tagging was used, the conversion of fish from release to the ZOI ranged from 58.2% (Caldwell et al. 2016) to 79.5% (Reynolds et al. 2015). This suggests that juvenile migrants are successfully orienting long distances to the western portion of Swift Reservoir and cueing on the FSC entrance. At a finer scale, a large percentage of the fish detected at the Swift forebay array in 2017 progressed through the ZOI to receiver 10 at the entrance of the NTS (P_{ENC}=89.0%). In addition to the quantified estimates of the number of fish near the entrance, the 2D contour plot (Figure 13) for the ZOI also highlights the concentration of detections immediately adjacent to the FSC entrance. If fish were randomly encountering the ZOI or FSC entrance (as opposed to moving toward the entrance), the density of detections would not be concentrated near the entrance of the FSC. Finally, the occurrence of multiple visits to the ZOI by fish that have longer residence times in the Swift Reservoir (greater than 1 week; Table 13) is an indication that these fish have likely found and approached the entrance on multiple occasions regardless of whether they were collected.

While there is clearly evidence that a proportion of the acoustic tagged fish are finding the FSC entrance, many fish are not detected on either the ZOI or entrance arrays. There are several plausible explanations for this observation, including: 1) avoidance of or consumption by predators; 2) non-naïve fish are less attracted to the entrance; 3) near-field factors, such as hydraulic conditions, sound, debris, and/or debris booms adjacent to the FSC, that deter fish from approaching; or 4) interactions among these factors.

With respect to predation, Bull Trout and other limnetic predators are adept at exploiting smolt outmigration events where large numbers of prey species are spatially concentrated for several weeks or months out of the year (Furey et al. 2015). In the Swift Reservoir, outmigrating juvenile salmonids are essentially funneled from a reservoir environment that is on the scale of miles to a single FSC entrance location where smolts and potential predators are concentrated in an area measured in feet. For example, Adams and Smith (2017) documented the regular presence of Bull Trout-sized fish near a floating surface collector in the North Fork Reservoir in Oregon. The authors suggest that the Bull Trout-sized fish are likely attracted to the abundance of outmigrating juvenile salmonids. If other piscivores consume juvenile salmonids or cause them to avoid the entrance vicinity, the net result would be a decrease in the number of juvenile migrants detected on the FSC entrance arrays.

The use of non-naïve, FSC-origin study fish may have resulted in decreased detections near the entrance. These fish would have found the entrance during their first capture, but after tagging and

subsequent release from the FSC they may have exhibited behavioral bias against approaching the FSC again (Caldwell et al. 2016).

The flow data collected during the ADCP survey did not show flow patterns with a direct path to the FSC entrance or any significant hydraulic signal for either attraction flow level (i.e., 1,000 cfs nor 600 cfs). Velocities overall were low and did not vary much across the survey area for either attraction flow level. The general direction of flow for both flow scenarios was to the southwest toward the dam, which contrasts with the CFD model that indicated flow vectors upstream of the FSC were generally directed toward the FSC in a northwesterly direction. As such, there was no evidence to suggest that a 150-foot ZOI exists. The results of the literature review (Appendix C) were also inconclusive as far as identifying a specific hydraulic condition or criterion that could be used to identify specific conditions that would consistently attract fish.

Other nearfield factors such as sound and debris and/or debris booms adjacent to the FSC could have disrupted juveniles from finding the FSC entrance. Sound monitoring conducted in 2017 demonstrated that the SAF pumps on the FSC were transmitting sound and vibrations to the surrounding aquatic environment. The 22.1-hertz peak sound level and the lower frequency components detected near the SAF pumps and at the entrance to the NTS are within the infrasound and near infrasound frequency ranges shown to elicit an avoidance response by juvenile salmonids (Hawkins 2015) whose hearing system responds primarily to the particle motion component of low frequency sound. The pumps probably vibrate the collector, which then is the source for low frequency sound detected in the surrounding water and near the entrance to the collector. This finding is important because any sound-induced behavioral responses associated with the pumps may influence the collection efficiency of the FSC. These pumps had been operating during the current and previous study years, so the improvements made by PacifiCorp to reduce the noise will need to be evaluated during future monitoring efforts.

In addition to noise, the accumulation of woody debris near the FSC entrance may have reduced the number of fish approaching the entrance. After debris was removed during 2017, Coho Salmon and Steelhead appeared to move more quickly from the ZOI to the FSC entrance. It is possible that the debris obstructs the approach to the entrance or may create shading or other predator habitats that dissuade juvenile outmigrants from approaching. Adams and Smith (2017) noted that Bull Trout-sized fish used structural and shade habitats at the floating surface collector in the North Fork Reservoir in Oregon to ambush prey during the day.

4.3 Are Fish Coming into the Collector?

Though most of the test fish spent hundreds of hours in the ZOI, with the highest density near the entrance of the collector, only a little over half of the fish in the ZOI entered the collector. The fish are finding the collector, but there is something about the FSC that is causing many to not enter it.

Fish entering the collector as far as the NTS were evaluated using the P_{ENT} performance metric, which examines the proportion of fish that moved from the ZOI to the entrance array receiver. Overall, the corrected P_{ENT} estimate for all species was 56.6%, meaning that just over half of the ZOI fish were successfully detected on the entrance receiver.

While many fish converted from the ZOI to the NTS entrance, slightly less than half of the fish (44%) did not. The same factors identified as potentially influencing fish finding the entrance are also relevant for fish coming into the collector. Specifically, avoidance of, or consumption by predators; non-naïve fish are less attracted to the entrance; and near-field factors that deter fish from entering the collector.

In addition, some of the juvenile fish may not be ready to migrate. Based on the PIT-tag analyses conducted for study years 2013 through 2107, all species of juvenile salmonids in Swift Reservoir exhibited some level of delayed migration or overwinter behavior.

Based on the 2017 study results that clearly show the SAF pumps are creating sound within the hearing range of juvenile salmon, it is reasonable to assume that this noise may disturb or dissuade fish from entering the collector. In addition, the location of the lead net was observed to be blocking the entrance of the FSC, especially when the wind was blowing from the north as observed during the ADCP survey.

4.4 Are Fish Staying in the Collector and Being Captured?

P_{RET} was the performance metric used to evaluate whether fish were staying in the collector and being captured. In 2017, P_{RET} was 38.3% across all species (24.1% for Chinook Salmon, 41.1% for Coho Salmon, and 40.4% for Steelhead), which indicates that a small to moderate proportion of fish are making it from the NTS entrance to collection. However, the fact that approximately 60% of the fish are not collected after entering the NTS indicates that the hydraulic or environmental conditions present are such that fish are reluctant to enter the FSC.

Many of the factors that influence fish finding the entrance or entering the collector are also relevant as to why fish were not collected. Predation, debris shading, noise, or even behavioral aversion from prior trapping experiences may all play a role. There is also the possibility that hydraulic conditions, acceleration, or other physical conditions within the entrance or ZOI are causing fish to reject the FSC as a migration route (Kemp et al. 2005a, 2005b).

4.5 Recommendations

Of the 520 juvenile salmonids that were acoustic tagged and released at Eagle Cliff, 73.6% arrived to the Swift Dam forebay and most of these fish were detected in the ZOI and resided directly in front of the NTS for long periods of time. Approximately half of the fish in the ZOI entered the collector

and no more than approximately 40% of these were collected. The following recommendations focus on potential reasons fish are not entering the collector and actions to reduce forebay residence times and increase the proportion of fish that enter and are retained.

Potential reasons study fish may not have entered the collector include the following:

- Physical factors
  - Flow velocity in the NTS is too low to entrain fish
  - Vibration or movement of the trash rack is keeping fish from entering the collector
  - Debris buildup on the trash racks changes the hydraulics and reduces entrance efficiency
  - Sound and vibration from pumps or other structures (low frequency particle motion) is affecting fish behavior and keeps fish from entering the collector
  - Debris mats in front of collector provide cover for predators and produce shaded areas that juvenile salmonids are known to avoid
  - Shading by the walkway over the NTS results in fish having to transition from a bright to a darkened migration pathway
- Biological factors
  - Predators are congregating in front of the collector to prey on milling salmonids and are using debris mats as ambush cover

Future actions to improve collection efficiency could include:

- Conduct additional study using naïve fish (i.e., fish collected from the rotating screw trap near Eagle Cliff) to determine if changes made to dampen the noise generated by the SAF pumps improves collection efficiency. Naïve fish should be used because past results indicated that naïve fish had a higher conversion rate from release to the forebay and release to collection.
- Conduct additional sound measurements to determine if there are additional sources of sound and vibration that could influence fish behavior. Measurements showed that dampening the SAF pumps removed the high amplitude noise at 22.1 hertz. However, the background noise level around the collector is much higher than the ambient noise level of the reservoir away from the FSC.
- Find methods to reduce the "sound footprint" of the collector such that it reflects ambient sound levels.
- Reduce debris buildup in front of the collector to improve collection and potentially reduce predator habitat.
- Test alternative lighting types and locations to attract fish into the collector, including possible illumination under the NTS walkway to reduce shadows.
- Review approaches to evaluate and improve approach hydraulics and hydraulic conditions at and within the NTS.

- Evaluate potential predator interactions at the entrance to the collector and possible avoidance behavior of juvenile salmonids.
- Conduct observational studies at the entrance and inside of the NTS using an acoustic camera to evaluate movement and behavior of fish near the entrance and where fish are turning around inside the collector.

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Appendix A
Key Findings from Previous Studies

Key Findings from Previous Studies

Starting in 2013, the performance of the Floating Surface Collector (FSC) has been evaluated using radio telemetry, passive integrated transponder (PIT), and combined PIT and acoustic telemetry and methodologies (Courter et al. 2013; Stroud et al. 2014; Reynolds et al. 2015; Caldwell et al. 2016). Although the study design varied among years, several key trends emerged from these studies. Most importantly, observed collection efficiency (PCE) for all species tested has been consistently lower than the 95% performance target in all years and ranged from 7% (Courter et al. 2013) to 29% (Caldwell et al. 2016; Table 1). Also, Chinook Salmon have had the lowest PCE among the species tested and were not recaptured in the FSC in most of the previous study years. The focus and key results from the previous studies are presented chronologically in the following sections. The 2017 study objectives were based on results of these studies.

2013 Study

In 2013, Courter et al. conducted a pilot study to evaluate the effectiveness of using radio telemetry to determine P_{CE} of the FSC. The key results from this study include the following:

- 140 radio tagged fish were released (58 Chinook Salmon and 82 Coho Salmon); 90 fish were detected by the zone of influence (ZOI) receivers; and 6 Coho Salmon were collected by the FSC for an overall P_{CE} of 7%.
- Forty-six Chinook Salmon and 44 Coho Salmon, comprising 80% and 54%, respectively, of the total number of each species released during the study, were detected within the ZOI at least once.
- Although Chinook Salmon were much more likely to enter and remain inside the ZOI compared to Coho Salmon, no tagged Chinook Salmon were captured in the FSC.
- Most radio-tagged fish arrived at the telemetry array within 2 to 3 days of release; however, of the fish collected in the FSC, travel time from release to capture ranged from 0.4 to 40 days.
- Fish approached the FSC from both the north shoreline and south shoreline in roughly equal proportions.
- A separate test group of 22 Chinook and Coho salmon were released near and within the entrance of the FSC, of which 5 fish were subsequently collected in the FSC.

2014 Study

In 2014, Stroud et al. used radio telemetry technology to evaluate: 1) the attraction and P_{CE} of Chinook Salmon, Coho Salmon, and Steelhead smolts at the FSC; 2) the preferred FSC approach

behaviors of smolts; 3) the possible tagging effects on smolts; and 4) the potential environmental effects on passage success rates. Key results of the study include the following:

- 193 radio tagged fish were released (157 Coho Salmon, 20 spring-run Chinook Salmon, and 16 Steelhead); 38 fish were detected near the ZOI; and 10 were subsequently collected by the FSC for an overall P_{CE} of 26.3%.
- The tagged fish detected at the ZOI included 31 Coho Salmon, 3 spring-run Chinook Salmon, and 4 Steelhead.
- The tagged fish collected in the FSC included 9 Coho Salmon and 1 Steelhead.
- Similar to the 2013 study, no tagged Chinook Salmon from the main release groups were collected in the FSC.
- The largest proportion of fish approached the FSC from the southern shoreline.
- The majority of tagged fish were collected in the FSC during May when reservoir surface temperatures were below 10°C.
- The average passage rates were 4.2% (SD 20.3%) and 5.8% (SD 23.5%) for fish gastrically and surgically implanted with radio transmitters, respectively. Sample sizes were too small for statistical comparison.
- A small test group of 8 fish released 14.5 kilometers upstream of the FSC at Eagle Cliff had higher detection probabilities in the forebay than the main group of test fish released within 1 kilometer of the FSC (88.0% and 19.7%, respectively).

2015 Study

In 2015, Reynolds et al. used acoustic telemetry and PIT technology to evaluate: 1) the attraction and calculated P_{CE} of Coho Salmon, spring-run Chinook Salmon, and Steelhead smolts at the FSC; 2) the preferred approach behaviors of smolts; and 3) the potential thermal effects on passage success rates. Key results of the study include the following:

- 200 dual-tagged smolts were released (139 Coho Salmon, 14 spring-run Chinook Salmon, and 47 Steelhead); 159 were detected near the ZOI; and 21 were subsequently collected by the FSC for an overall P_{CE} of 13.2%.
- Eighty-nine percent of tagged fish released near Eagle Cliff successfully transited the reservoir to the forebay.
- Tagged fish detected in the ZOI included 110 Coho Salmon, 6 spring-run Chinook Salmon, and 43 Steelhead.
- Tagged fish collected in the FSC included 13 Coho Salmon and 8 Steelhead.
- Similar to 2013 and 2014, no tagged Chinook Salmon were collected in the FSC.
- Although greater than 75% of smolts passed when temperatures were less than 15°C, temperature did not have a significant effect on P_{CE}.
- Once in the forebay, the largest proportion of fish approached the FSC from the south.

- Compared to the main release groups evaluated in 2014, a much larger percentage of tagged fish were detected in the ZOI in 2015 (79.5% in 2015 compared to 19.7% in 2014). The higher percentage was attributed to the use of the distant Eagle Cliff release site in 2015.
- Two PIT-tagged fish were collected in November and December after being released in May and June, respectively.

2016 Study

In 2016, Caldwell et al. used acoustic and PIT technology to: 1) determine P_{CE} for Coho Salmon, spring-run Chinook Salmon, and Steelhead smolts at the FSC; 2) evaluate how outmigrating smolts interact with the newly installed FSC lead net; and 3) evaluate other factors contributing to the observed P_{CE}. Key results of the study include the following:

- 199 dual-tagged smolts were used in the study (157 Coho Salmon, 3 spring-run Chinook Salmon, and 40 Steelhead); 116 were detected near the ZOI; and 34 were subsequently collected by the FSC for an overall P_{CE} of 29%.
- Eighty-five percent of tagged fish released near Eagle Cliff successfully transited the reservoir to the forebay.
- The tagged fish detected at the ZOI included 84 Coho Salmon and 13 Steelhead.
- The tagged fish collected at the FSC included 23 Coho Salmon and 4 Steelhead.
- Tracking data did not indicate a strong behavioral response to the lead net.
- Ninety-nine percent of all fish passed before water temperatures in Swift Reservoir exceeded 16°C.
- Tagged fish originating from the FSC had a lower recapture rate than fish collected by hook and line or those collected using a rotary screw trap at Eagle Cliff.
- Coho Salmon and Steelhead had higher recapture rates than Chinook Salmon and no dual-tagged Chinook Salmon from the main release groups were collected in the FSC.
- Fish transiting the forebay tended to approach the FSC from the north rather than the south, which contradicts patterns observed in previous years.
- A substantial number of fish appeared to overwinter in the reservoir based on the recapture of 9.5% of the test fish released in 2015 in 2016.

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Appendix B
Weekly Performance Metrics – Methods and Tables

Weekly Performance Metrics – Methods and Tables

Methods

Two types of performance metrics were estimated as part of the 2017 study: 1) seasonal averages; and 2) weekly estimates. Seasonal average methods and results are presented in Sections 2.2 and 3.1 of the main report and are the basis of overall system performance in 2017. In addition, PacifiCorp required that weekly estimates of performance be provided throughout the fish passage season to track Floating Surface Collector (FSC) performance and implementation of the study. This appendix outlines the methods used to develop weekly estimates of performance and the results.

Because of delayed transition times between specific detection arrays and the collection array, it is not practical to calculate weekly efficiency estimates of performance that are corrected for detection array efficiency. For example, a fish may transition from the ZOI to collection several weeks after first entering the ZOI. If this fish is never detected in the ZOI, it is impossible to know how to correct the estimate of P_{CE} is in the weekly estimates. As such, corrected weekly estimates were not calculated for the study. Instead, performance metrics are presented as uncorrected weekly estimates (Tables B-2 through B-5) based on the formulas presented in Table B-1.

Table B-1
Calculations for Uncorrected Performance Metrics

Metric	Calculation
Rate of Reservoir Survival (P_{RES})	$P_{RES} = \frac{DET_{Swift}}{R}$
Entrance Encounter Rate (P_{ENC})	$P_{ENC} = \frac{DET_{ZOI}}{DET_{Swift}}$
Entrance Efficiency (P_{ENT})	$P_{ENT} = \frac{DET_{ENT}}{DET_{ZOI}}$
Retention Efficiency (P_{RET})	$P_{RET} = \frac{C}{DET_{ENT}}$
Collection Efficiency (P_{CE})	$P_{CE} = \frac{C}{DET_{ZOI}}$

Notes:
R = number of unique tagged fish released
DET_{Swift} = number of juveniles detected entering Swift Dam forebay (i.e., at Devil's Backbone [Swift forebay array)
$D_{EFF\text{-}Swift}$ = the detection efficiency of the Swift forebay array
DET_{ZOI} = number of unique tagged fish identified in the vicinity of the FSC (i.e., in the ZOI)
$D_{EFF\text{-}ZOI}$ = the detection efficiency of the ZOI array
DET_{ENT} = the number of tagged fish detected at A (i.e., inside the entrance of the NTS)
$D_{EFF\text{-}ENT}$ = the detection efficiency of the NTS entrance array
C = number of unique tagged fish identified in the fish collection ponds inside the FSC (i.e., collected)

Results

Collection Efficiency (P_{CE})

Table B-2
Uncorrected Collection Efficiency by Week

Week Of	Chinook Salmon	Coho Salmon	Steelhead
3/20/2017	0.0000	0.0000	0.0000
3/27/2017	0.0000	0.0000	0.3333
4/3/2017	0.0000	0.1000	0.3333
4/10/2017	0.0000	0.0833	0.1667
4/17/2017	0.0667	0.0667	0.0833
4/24/2017	0.0702	0.0800	0.0800
5/1/2017	0.1000	0.0488	0.1026
5/8/2017	0.1129	0.0400	0.1034
5/15/2017	0.1129	0.0345	0.0857
5/22/2017	0.1129	0.0490	0.0990
5/29/2017	0.1129	0.1062	0.1442
6/5/2017	0.1129	0.1655	0.1524
6/12/2017	0.1129	0.1938	0.1714
6/19/2017	0.1129	0.2577	0.1887
6/26/2017	0.1129	0.2638	0.1981
7/3/2017	0.1129	0.2805	0.1981
7/10/2017	0.1129	0.2805	0.1963

Entrance Encounter Rate (P_{ENC})

Table B-3
Uncorrected Entrance Encounter Rate by Week

Week Of	Chinook Salmon	Coho Salmon	Steelhead
3/20/2017	0.0000	0.0000	0.0000
3/27/2017	0.0000	0.5000	0.3333
4/3/2017	0.0938	0.3125	0.2500
4/10/2017	0.1176	0.2778	0.4286
4/17/2017	0.1905	0.1923	0.2667
4/24/2017	0.2676	0.1463	0.1379
5/1/2017	0.3600	0.1094	0.1731
5/8/2017	0.3867	0.1268	0.1972
5/15/2017	0.3867	0.1728	0.2353
5/22/2017	0.3867	0.2109	0.2632
5/29/2017	0.3867	0.2628	0.3534
6/5/2017	0.3867	0.3886	0.3879
6/12/2017	0.3867	0.4699	0.3966
6/19/2017	0.3867	0.5683	0.4224
6/26/2017	0.3867	0.5902	0.4310
7/3/2017	0.3867	0.5956	0.4359
7/10/2017	0.3867	0.6087	0.4444

Entrance Efficiency (P_{ENT})

Table B-4
Uncorrected Entrance Efficiency by Week

Week Of	Chinook Salmon	Coho Salmon	Steelhead
3/20/2017	0.0000	0.0000	0.0000
3/27/2017	0.0000	0.5000	0.3333
4/3/2017	0.1875	0.4000	0.3333
4/10/2017	0.1765	0.3333	0.5000
4/17/2017	0.2667	0.2667	0.3333
4/24/2017	0.3333	0.1600	0.1600
5/1/2017	0.4500	0.1220	0.2308
5/8/2017	0.4677	0.1400	0.2414
5/15/2017	0.4677	0.2069	0.2857
5/22/2017	0.4677	0.2353	0.2970
5/29/2017	0.4677	0.2743	0.3846
6/5/2017	0.4677	0.4069	0.4190
6/12/2017	0.4677	0.4688	0.4286
6/19/2017	0.4677	0.5399	0.4528
6/26/2017	0.4677	0.5644	0.4623
7/3/2017	0.4677	0.5671	0.4717
7/10/2017	0.4677	0.5854	0.4766

Retention Efficiency (P_{RET})

Table B-5
Uncorrected Retention Efficiency by Week

Week Of	Chinook Salmon	Coho Salmon	Steelhead
3/20/2017	0.0000	0.0000	0.0000
3/27/2017	0.0000	0.0000	1.0000
4/3/2017	0.0000	0.2500	1.0000
4/10/2017	0.0000	0.2500	0.3333
4/17/2017	0.2500	0.2500	0.2500
4/24/2017	0.2105	0.5000	0.5000
5/1/2017	0.2222	0.4000	0.4444
5/8/2017	0.2414	0.2857	0.4286
5/15/2017	0.2414	0.1667	0.3000
5/22/2017	0.2414	0.2083	0.3333
5/29/2017	0.2414	0.3871	0.3750
6/5/2017	0.2414	0.4068	0.3636
6/12/2017	0.2414	0.4133	0.4000
6/19/2017	0.2414	0.4773	0.4167
6/26/2017	0.2414	0.4674	0.4286
7/3/2017	0.2414	0.4946	0.4200
7/10/2017	0.2414	0.4792	0.4118

Appendix C
Literature Review of Fish Responses to Hydraulic Conditions

Literature Review of Fish Responses to Hydraulic Conditions

Anchor QEA performed a literature review of fish responses to hydraulic conditions and flow to determine if potential response thresholds are available in the scientific literature that could be used to identify a zone of influence (ZOI) for the Swift Floating Surface Collector (FSC) based on results of the Acoustic Doppler Current Profiler (ADCP) survey conducted in 2017. A secondary purpose of the review was to gather information to help inform the interpretation of the ADCP data and results of Computational Fluid Dynamics (CFD) modeling conducted during design of the Swift FSC. A total of 16 publications were reviewed.

While information is available about fish behavior in response to flow velocity and spatial and temporal distribution, little information is available about distinct hydraulic, biological, or physical thresholds for how attraction flows in front of surface-flow outlets influence fish collection efficiency. The interaction between hydraulic, physical, and biological features determines a fish's response to a surface collector. However, the relationship between these features is complex, it varies with ambient conditions, and most often is unknown. Based on the literature reviewed, zones were not determined based on a certain hydraulic or biological threshold that can be widely applied across species, life stages, systems, or flow rates. Goodwin et al. 2006 suggested that thresholds are not set values, but vary depending on background levels of flow and the fish's prior experience.

Research by Haro et al. (1998) and Enders et al. (2009, 2012) focused on thresholds where flow acceleration (the rate of change in velocity over distance) reached a rate of change that juvenile salmonids rejected the flow level. Research conducted at the U.S. Army Corps of Engineers' dams on the Snake and Columbia rivers resulted in the general goal of accelerating flow into surface-flow outlet entrances gradually and using an adequate capture velocity to retain collected fish. For example, Johnson et al. (2005) concluded that facilities should plan to gradually increase water velocity (less than 3.3 feet per second per 3.3 feet) with increasing proximity to surface bypass structures and have a high enough velocity at the entrance to entrain juvenile fish (greater than 9.8 feet per second). While useful for designing an FSC entrance, these guidelines do not address how far out into the forebay a hydraulic profile from FSC pumped attraction flows can be detected by fish using their sensory systems, or how fish will respond to the attraction flows.

Goodwin et al. 2006 suggested that biological response thresholds are not set values and must be modeled; the modeling must incorporate hydraulic, physical, and biological data to determine where and how far away surface-flow outlet entrance attraction flows influence fish behavior; and modeling fish responses is based on energetic cost, expected utility of the action, and the probability of gaining from that action. For example, Goodwin et al. 2014 combined a CFD model with a fish behavior model to simulate how fish adjusted swim orientation and speed to modulate their experience to water acceleration and pressure.

In summary, the literature review did not identify specific hydraulic or physical criteria that should be used along with the ADCP and CFD data to estimate a ZOI distance from the FSC.

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Appendix D
Acoustic Doppler Current Profiler Survey Methods

Acoustic Doppler Current Profiler Survey Methods

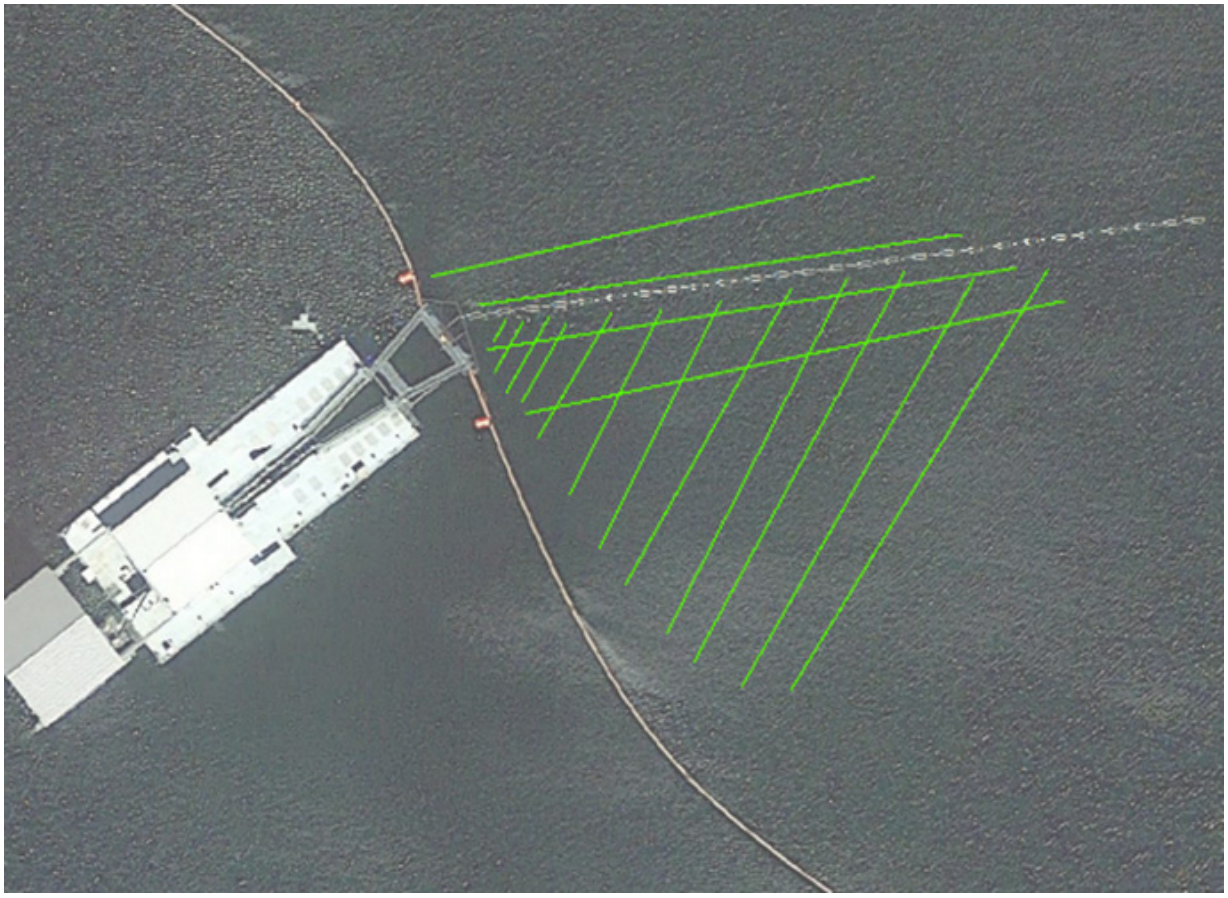
Forebay hydraulics and flow were surveyed using Acoustic Doppler Current Profiler (ADCP) technology on December 19, 2017. ADCP velocity data were collected to support the 2017 study objective of describing the behavior of downstream migrants in the forebay of Swift Reservoir, specifically in relation to the lead net, zone of influence (ZOI), and entrance of the Floating Surface Collector (FSC). The survey area included the area of the ZOI, and velocity data were collected to map water flow patterns to validate the extent of the ZOI, as defined in Section 2 of the *Aquatic Monitoring and Evaluation Plan for the Lewis River* (PacifiCorp and CPUD 2017). Surveys evaluated hydraulic conditions for both horizontal and vertical components of the flow field under two FSC operation regimes, 600 cubic feet per second (cfs) and 1,000 cfs attraction flow, at a set powerhouse turbine operating load. Both hydroelectric units were off and motoring for about 4 hours prior to and while the velocity data were being collected.

Water velocity data were collected from an 18-foot Alumaweld Stryker boat operated by PacifiCorp. Weather at the National Weather Service Station at Kelso, Washington, on the survey day consisted of rainfall that accumulated 0.6 inches and winds that ranged up to between 5 and 10 miles per hour. Wind and rainfall during the survey appeared to be significantly more severe in the morning than during the afternoon. Local weather data were not collected as part of the survey.

Survey Transects

Target transects for the survey are shown in Figure D-1. Velocity data were collected along the actual transects shown in Figure D-2 between 11:30 and 12:40 with FSC attraction flows of 1,000 cfs. The water level within Swift reservoir during this sampling period was approximately 956.53 feet above the National Geodetic Vertical Datum (NGVD) of 1929. Velocity data were collected along the actual transects shown in Figure D-3 between 13:50 and 15:05 with FSC attraction flows of 600 cfs. The water level within Swift reservoir during this sampling period was approximately 956.66 feet above NGVD 1929.

Figure D-1
Target Acoustic Doppler Current Profiler Water Velocity Survey Transects



Note: Transects were developed for collecting water velocity data under FSC pump operations of 600 and 1,000 cfs.

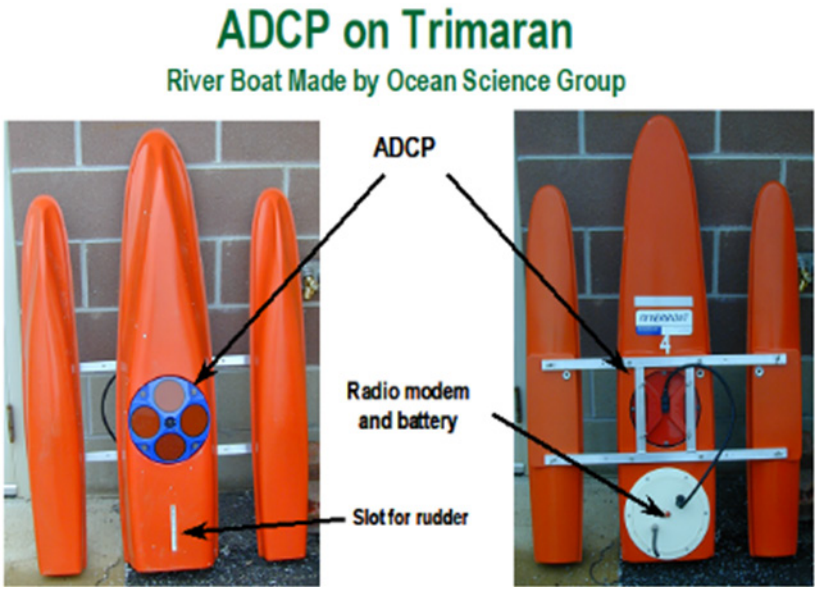
Figure D-2
Actual Acoustic Doppler Current Profiler Water Velocity Survey Transects Under Floating Surface Collector Pump Operations of 1,000 cfs and Windy Conditions

Figure D-3
Actual Acoustic Doppler Current Profiler Water Velocity Survey Transects Under Floating Surface Collector Pump Operations of 600 cfs

Instrumentation

Water velocity data were collected using an RDI 1200 kHz Workhorse Rio Grande ADCP that was mounted on an Ocean Science Trimaran (Figure D-4). The ADCP was connected to a Tough Book field computer via a 12-foot ADCP cable. A Trimble GEO XH GPS with external antenna was hard wired to the Tough Book via a serial connector, and WinRiver II software was used to gather and store both the ADCP and GPS data. The Trimaran containing the ADCP was tied to the starboard side of the Stryker boat with ropes approximately two thirds of the way to the rear. The GPS antenna was mounted to the side rail on the starboard side of the boat, very near the ADCP unit location.

Figure D-4
Acoustic Doppler Current Profiler Unit Mounted on an Ocean Science Trimaran



Test Performance

Initial test runs were completed to test the performance of the ADCP equipment and to fix any identified issues prior to commencing the data collection survey. Although the ADCP equipment used for the survey can collect velocity data to depths of 50 to 80 feet under ideal conditions, the maximum depth of any velocities collected during the test runs was 25 to 30 feet. This limitation was most likely due to high turbidity resulting from steady rain (approximately 0.4 inches) the day before the survey and significant rain (up to 1.2 inches) on the day of the survey. Several changes were made to the equipment to try to increase the depth where velocities would be recorded, but none were successful. After attempts to increase the survey depth beyond 30 feet were unsuccessful, the survey team decided to gather velocity data despite the limitation.

GPS Data

Satellite coverage for the GPS data was fair to good with 10 to 13 satellites used by the GPS for determining position. GPS data were synchronized with ADCP data, and both were recorded in the WinRiver II program at 1-second intervals.

Transect Data Methods and Quality

The transect plan shown in Figure D-1 was followed during the survey, and the actual transects sampled were as shown in Figures D-2 and D-3. Anchor QEA kept field notes of times for each transect and corresponding transect numbers with ADCP file names and collected transect data from

a separate GPS unit that was a few feet away from the GPS used to collect the ADCP data. During the morning portion of the survey, gusting winds made it difficult for the boat to stay on a straight course on each transect line.

The quality of the ADCP data collected was generally good-to-excellent between the first depth bin at 2.3 feet and the last depth bin at a depth between approximately 25 and 30 feet. On several adjacent transects taken in the morning when the FCS attraction flows were 1,000 cfs, there were areas of each transect that showed lower quality velocity data from near the shallowest bin to depths up to 8 feet. It is unclear what caused this condition. Since velocity data on the same transect both before and after these locations was good quality, it appears that some unknown interference condition in the water caused the lower quality data. Possible causes may be entrained air from surface waves or some sediment or debris locally entrained near the surface of the water.

Data Processing

The raw ACDCP data were collected, reviewed, and post-processed using WinRiver II software (Version 2.17). Velocity measurement locations that contained data flagged as invalid or were missing a large percentage of measurements in the water column were filtered out. Areas with invalid data primarily occurred where the boat heading was changing rapidly during the morning survey (i.e., during 1,000 cfs flow conditions) due to the high wind conditions. A few velocity measurements that were observed at a depth below 30 feet were sparse and were therefore excluded from the final results. Computer programming was then used to group the velocity measurements from each transect into the target depth bins (0 to 6.5 feet, 6.5 to 20 feet, and 20 to 33 feet). The average velocity magnitude and vector-averaged flow direction was then computed for each depth bin.

For each attractant flow condition and depth bin, the processed ADCP transect data were imported into GIS software as a point feature class and used to generate two separate rasters, one for velocity magnitude and one for velocity direction, using natural neighbor interpolation. The velocity magnitude raster was displayed as a heatmap with blue indicating low velocity and red indicating high velocity. The vector field layer was constructed by combining the velocity magnitude and direction raster files, which allowed for the display of both characteristics of flow, direction (arrow orientation), and magnitude (arrow size). The density of arrows was thinned using vector averaging in a 30-foot radius to improve readability and facilitate data interpretation.

References

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Appendix E
Total Residence Time Figures

Figure E-1
Chinook Salmon Fish Positions in Top View Broken Down by Total Residence Time Within the Array

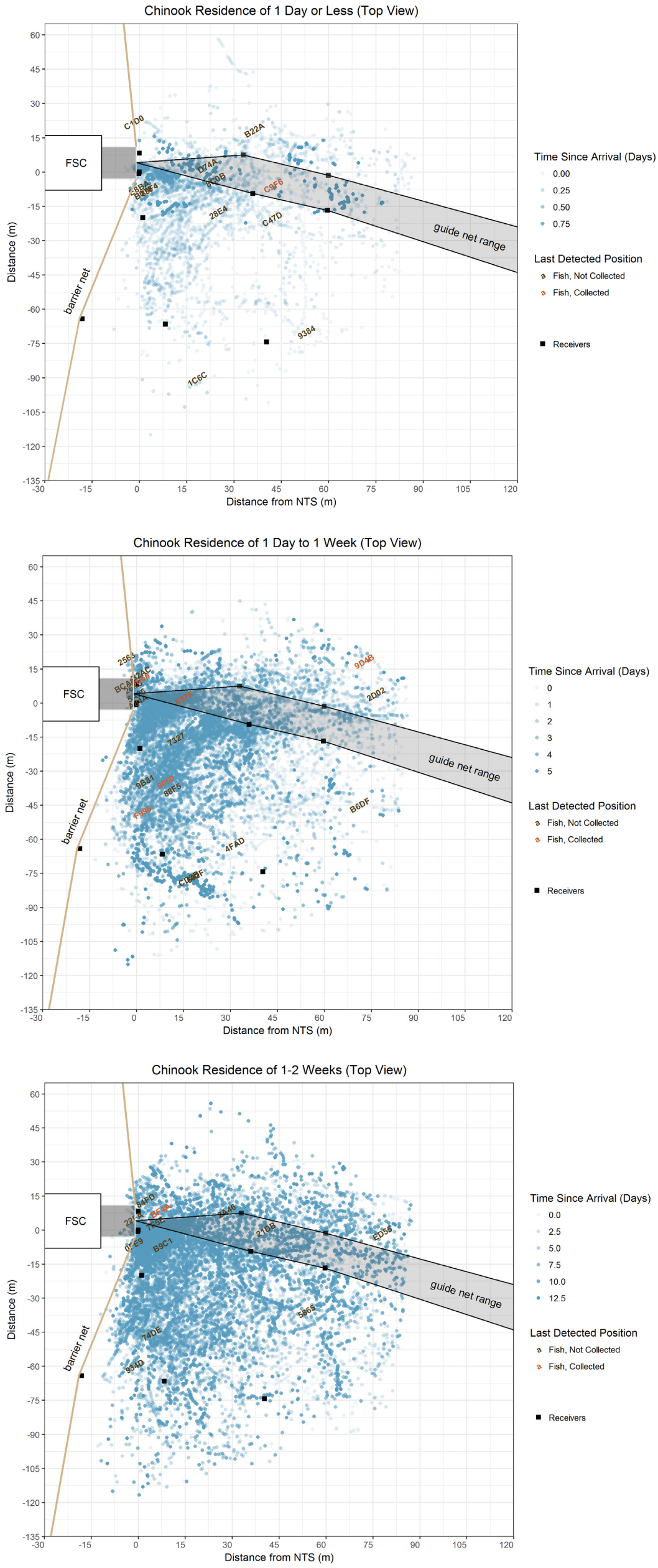
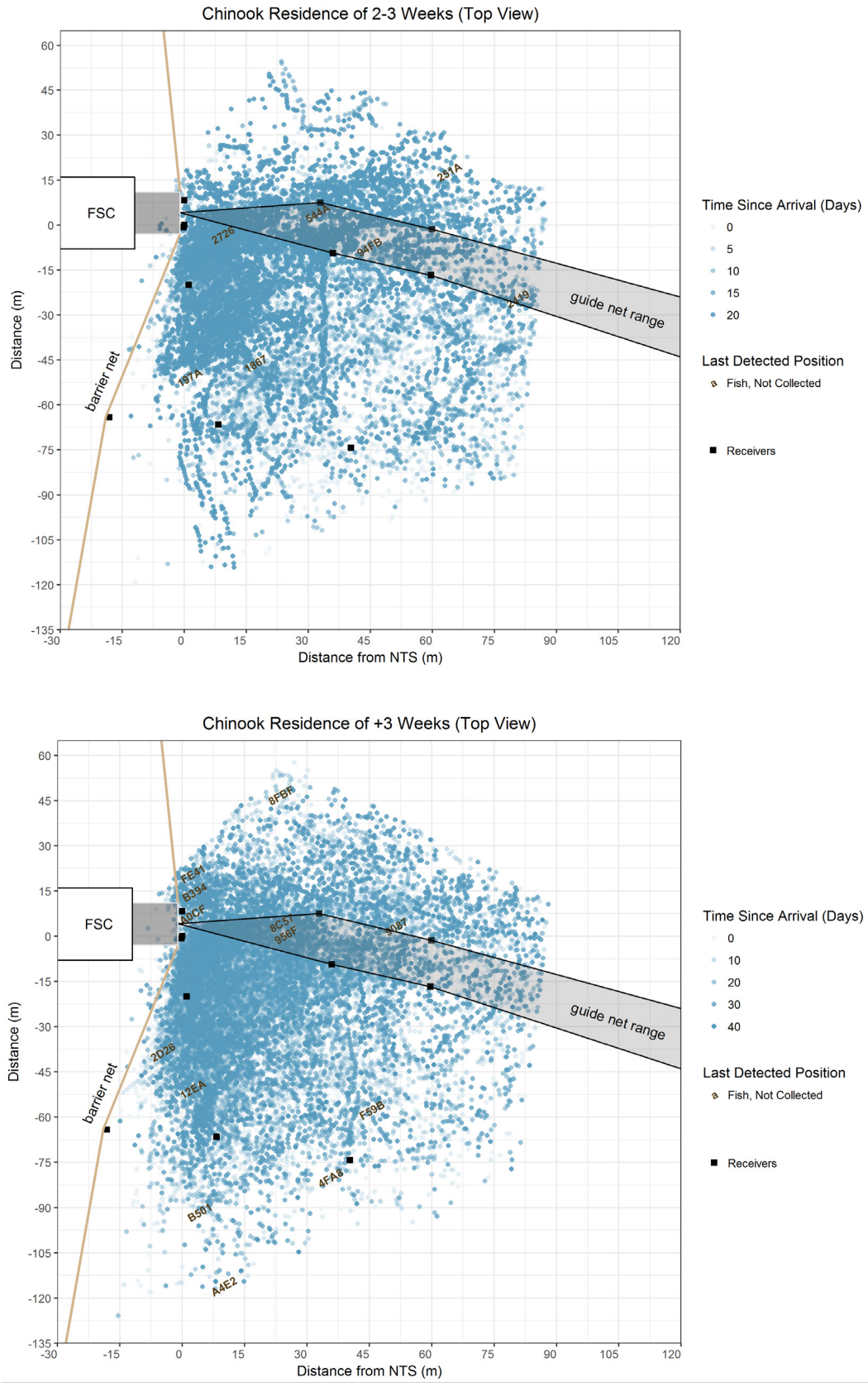
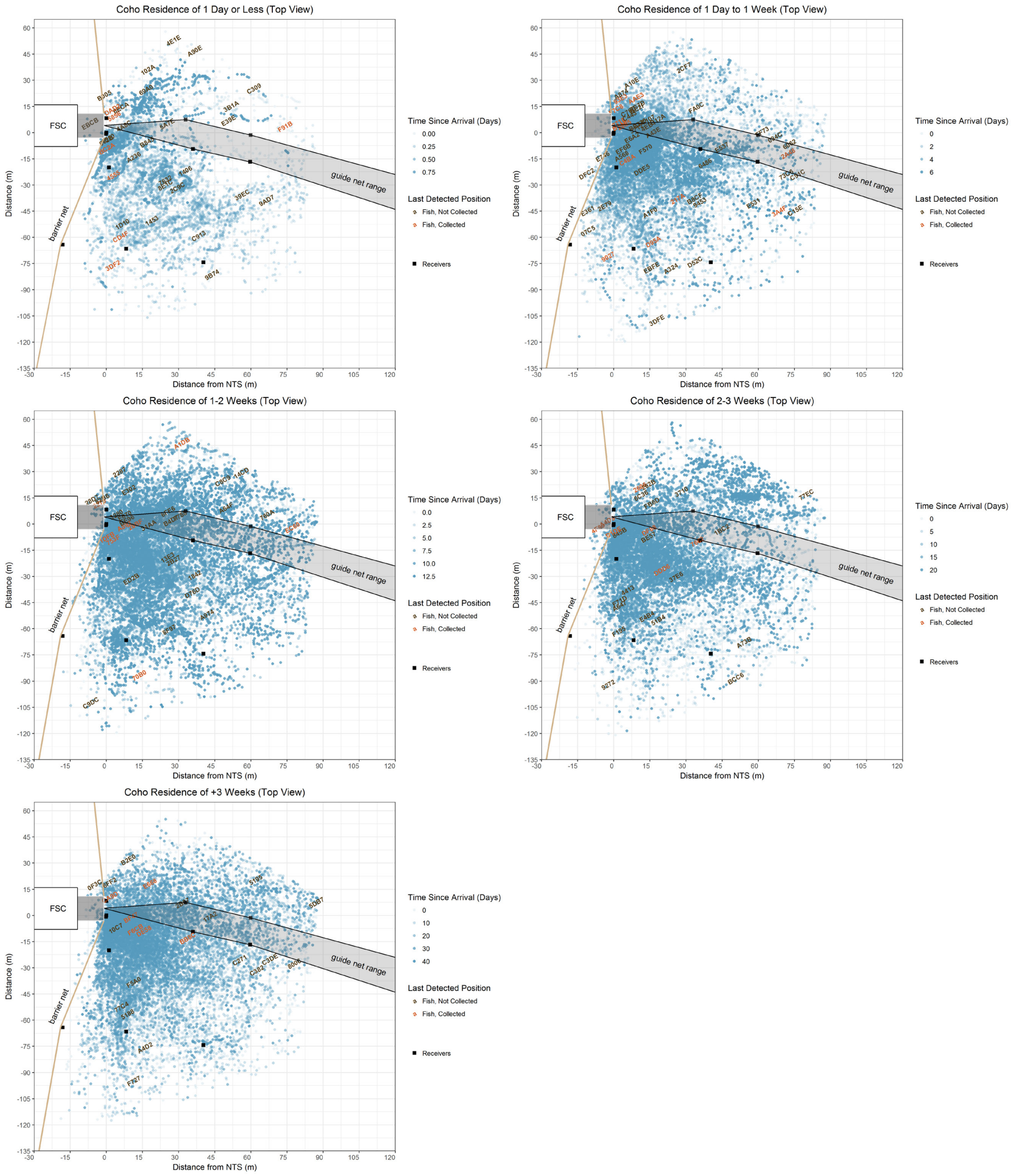


Figure E-1
Chinook Salmon Fish Positions in Top View Broken Down by Total Residence Time Within the Array (continued)



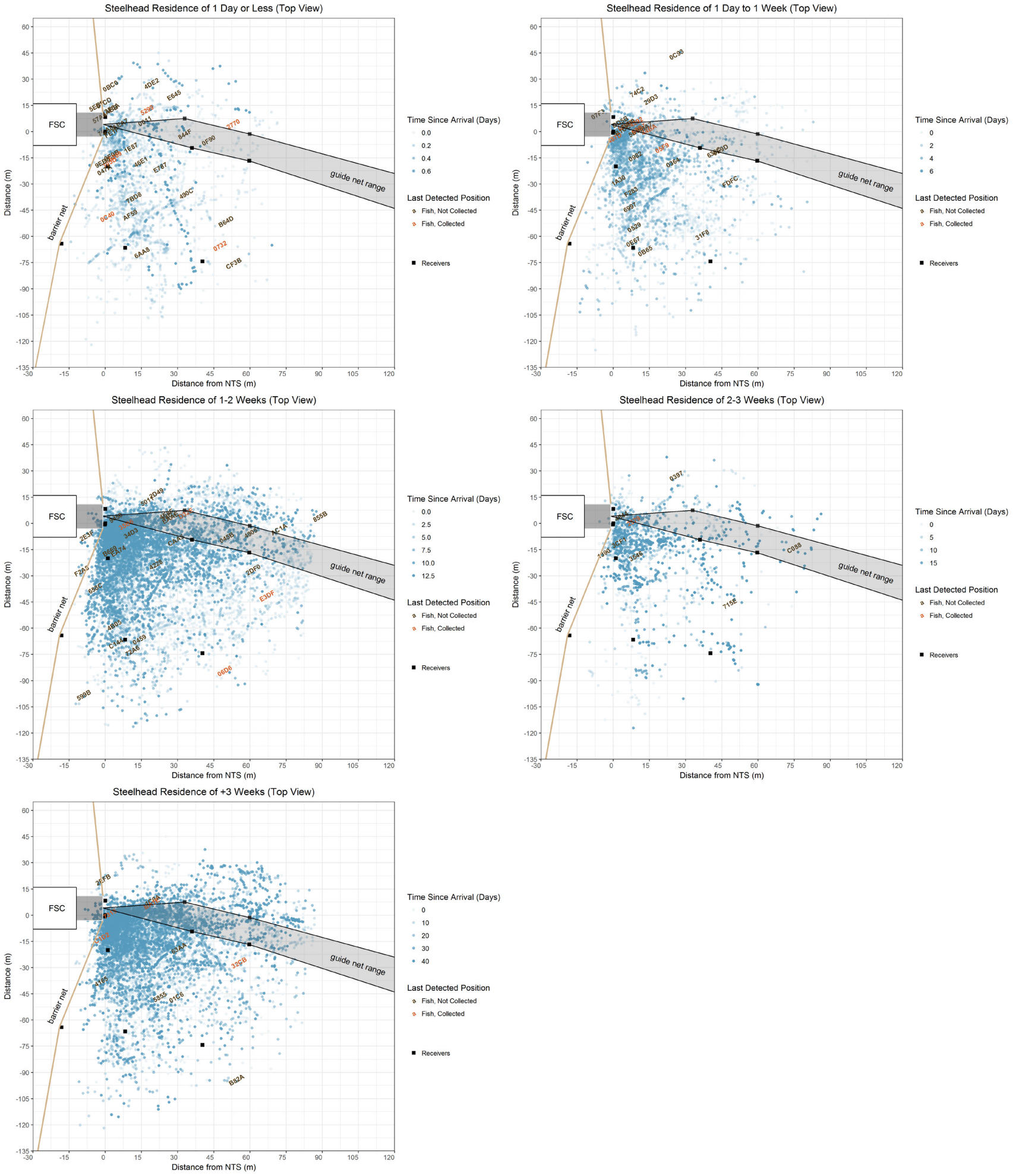
Note: Blue circles represent individual fish positions and color is scaled by position age. Last detected position for each fish is indicated by colored tagcode text with collected fish shown in orange, and uncollected fish shown in brown.

Figure E-2
Coho Salmon Fish Positions in Top View Broken Down by Total Residence Time Within the Array



Note: Blue circles represent individual fish positions and color is scaled by position age. Last detected position for each fish is indicated by colored tagcode text with collected fish shown in orange, and uncollected fish shown in brown.

Figure E-3
Steelhead Fish Positions in Top View Broken Down by Total Residence Time Within the Array



Note: Blue circles represent individual fish positions and color is scaled by position age. Last detected position for each fish is indicated by colored tagcode text with collected fish shown in orange, and uncollected fish shown in brown.

Appendix F
Detailed Summary of Noise Measurements Collected at the Floating Surface Collector

720 Olive Way, Suite 1900
Seattle, Washington 98101
206.287.9130

ANCHOR QEA

Memorandum

February 28, 2018

To: Chris Karchesky, PacifiCorp

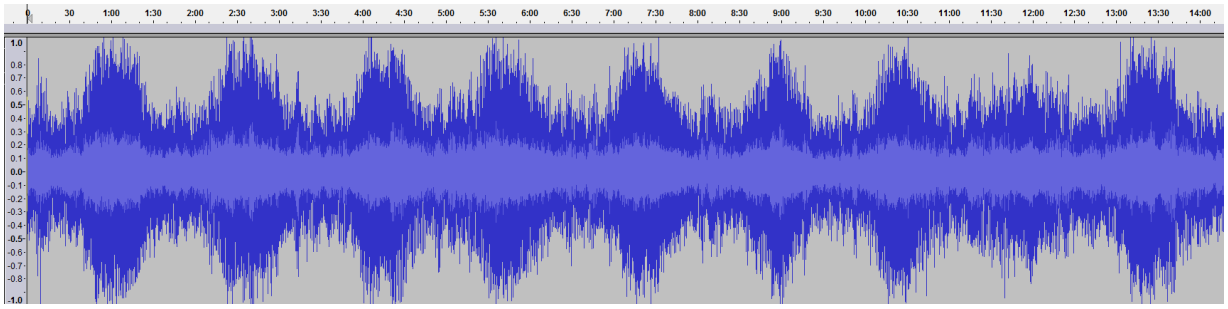
From: Mark Weiland

Re: Updated Sound Measurements at Swift Floating Surface Collector

Underwater sound measurements were conducted on August 3, 2017, at the Swift Dam Floating Surface Collector (FSC) to: 1) characterize the acoustic environment adjacent to the FSC; and 2) to identify whether sound and vibration originating from the FSC can elicit a behavioral response from salmonids. Infrasound and near-infrasound frequency underwater sound have been shown to cause behavioral avoidance responses by juvenile salmonids. The hearing range of salmonids is limited to low frequencies extending from about 1 kilohertz down through infrasound frequencies that are below the range of human hearing.

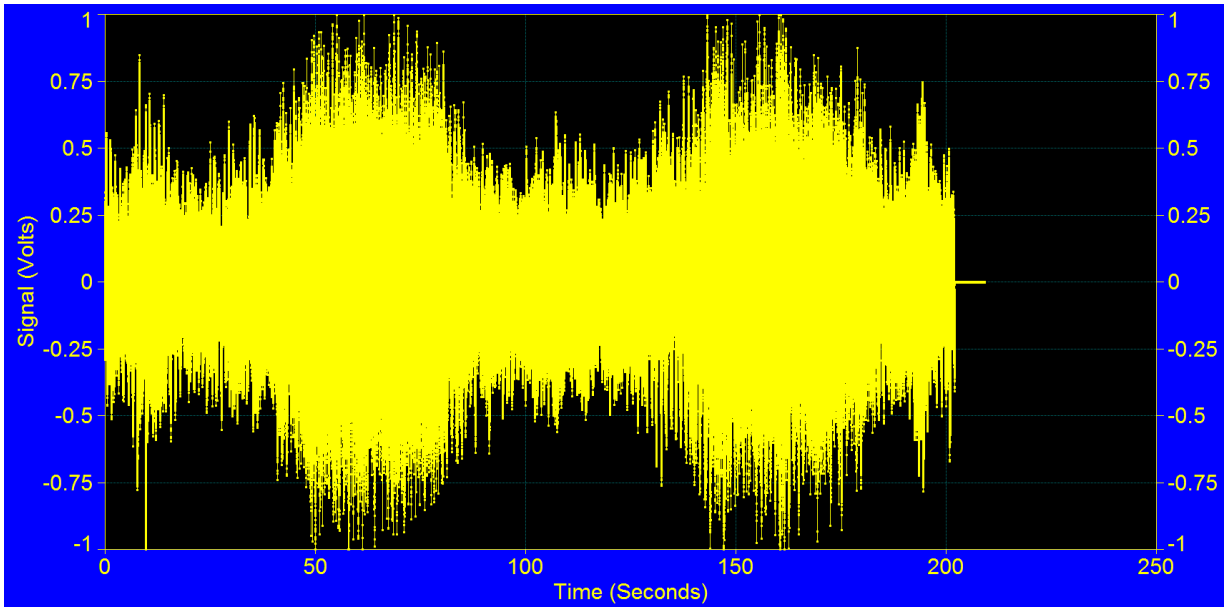
Low frequency sounds were observed in association with the operation of FSC pumps. Specifically, sound from the Sorting Area Flow (SAF) pumps could be isolated from the other sound in the water around the collector. The two SAF pumps generate a distinctive sound with a low fundamental frequency. This low frequency sound, at least those components within the range of human hearing, was also quite loud and distinctive in air (Figures 1 and 2). The observations shown below are in electrical units (volts), not calibrated to a standard reference, and are directly comparable between all data collected because they were acquired using the same measurement system with identical through system gain for all observations.

Figure 1
In Water Sound Levels near the Sorting Area Flow Pumps



Notes: High amplitude signals in the water correlate with high amplitude signals detectable in the air when the pumps were running. Much of the other sound in the signal is likely from several sources, including water spilling from the pipe at the back of the collector.
X-axis: Time (minutes)
Y-axis: Measured value (volts)

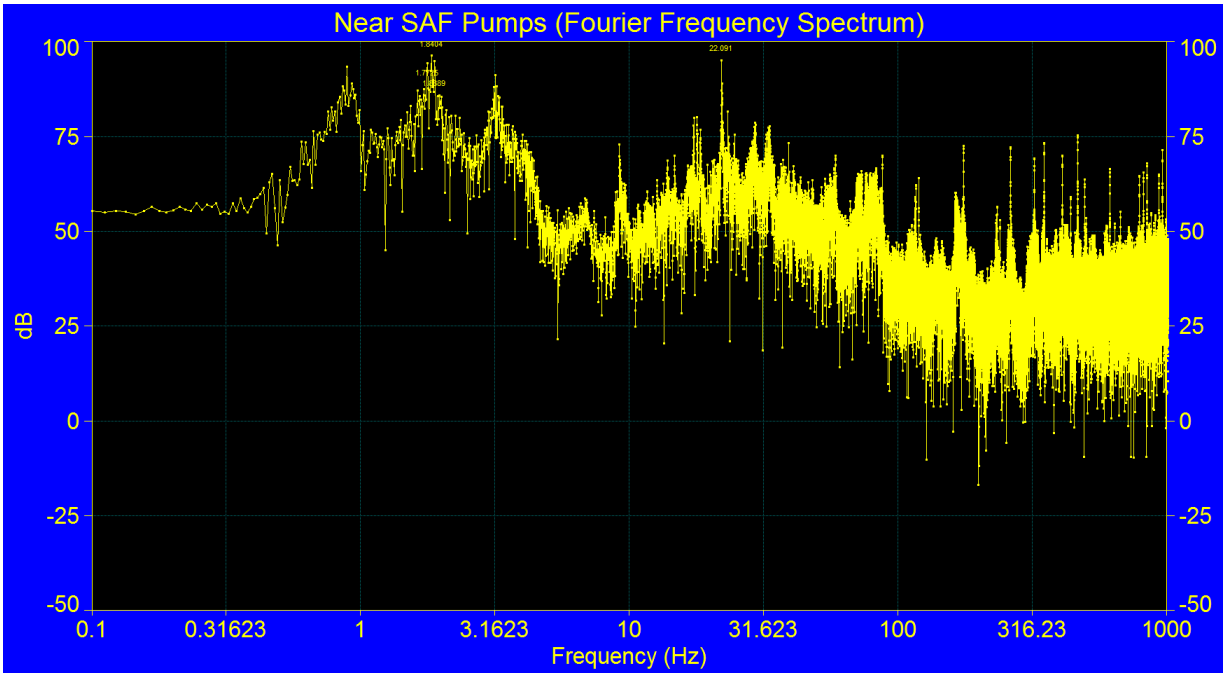
Figure 2
Two Cycles of the Pump Showing Cycling Between High and Lower Amplitude Sound Levels



A 50-second time interval from when the pump was ramping up to when it was ramping down again was isolated and analyzed to estimate the frequency content of the sample (Figure 3). This time interval is equivalent to one on/off cycle of the pump. A peak at about 22 hertz (Hz) and 3 peaks between 0.9 and 2 Hz had the highest amplitude. The 22.1-Hz peak and the lower frequency components are within the infrasound and near infrasound frequency ranges that have been shown to elicit an avoidance response from juvenile salmonids (Hawkins 2015[3]), whose hearing system responds primarily to the particle motion component of low frequency sound. The sound generated by the pumps probably vibrates the collector, which then is the source for low frequency sound detected in the water around, and near the entrance to, the collector.

[3] Hawkins, A.D., 2015. Sound and Vibration Effects on Migrating Adult and Juvenile Salmon at Hydropower Projects, Construction Projects, and in the Natural Environment: Lower Granite Dam. Prepared for U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

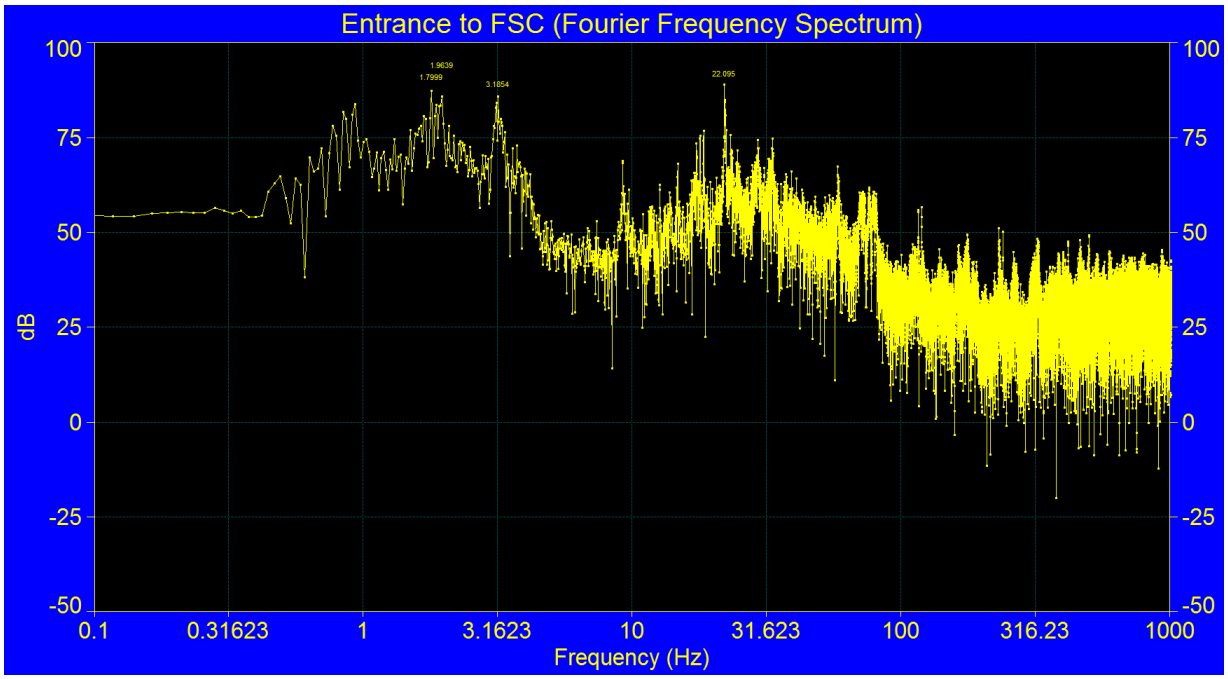
Figure 3
Frequency Versus Amplitude for One 50-Second Interval When Sorting Area Flow Pumps Were Running



Notes:
X-axis: Frequency (hertz [Hz])
Y-axis: Amplitude (decibels [dB])

Sound measurements collected near the entrance to the FSC had sound peaks at both near infrasound (22.1 Hz) and infrasound (1 and 3 Hz) frequencies, as was the case for sound measurement near the SAF pumps. The spectra of sound observed at the two locations were similar with some differences in frequency content, probably a result of changes in the vibratory motion of the collector near the in-water locations where measurements were made (Figure 4).

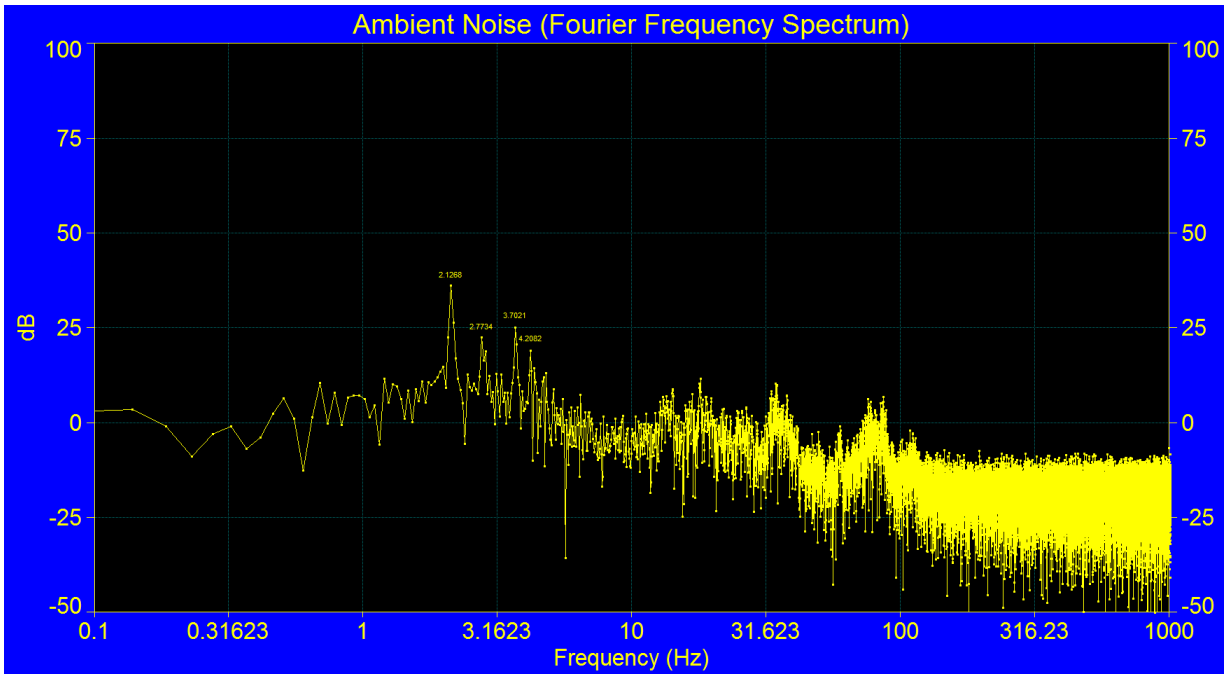
Figure 4
Frequency Versus Amplitude Measured Near the Entrance to the Floating Surface Collector During Operation of the Collector Pumps



Notes:
X-axis: Frequency (hertz [Hz])
Y-axis: Amplitude (decibels [dB])

Ambient noise was observed (underwater sound in a location where sound generated by collector pumps was absent) for comparison to underwater sound observations made near the SAF pumps and the entrance to the FSC (Figure 5). Ambient sound levels were observed to be significantly lower than those observed near the SAF pumps and FSC entrance. Low frequency sound in the 1 to 4 Hz range was present in the ambient noise observation, but at much lower levels, while the energetic sound at 22.1 Hz and nearby frequencies observed near the collector was not present in the ambient sample.

Figure 5
Ambient Underwater Sound Levels for Reference to Measurements Collected Near the Sorting Area Flow Pumps and Floating Surface Collector Entrance



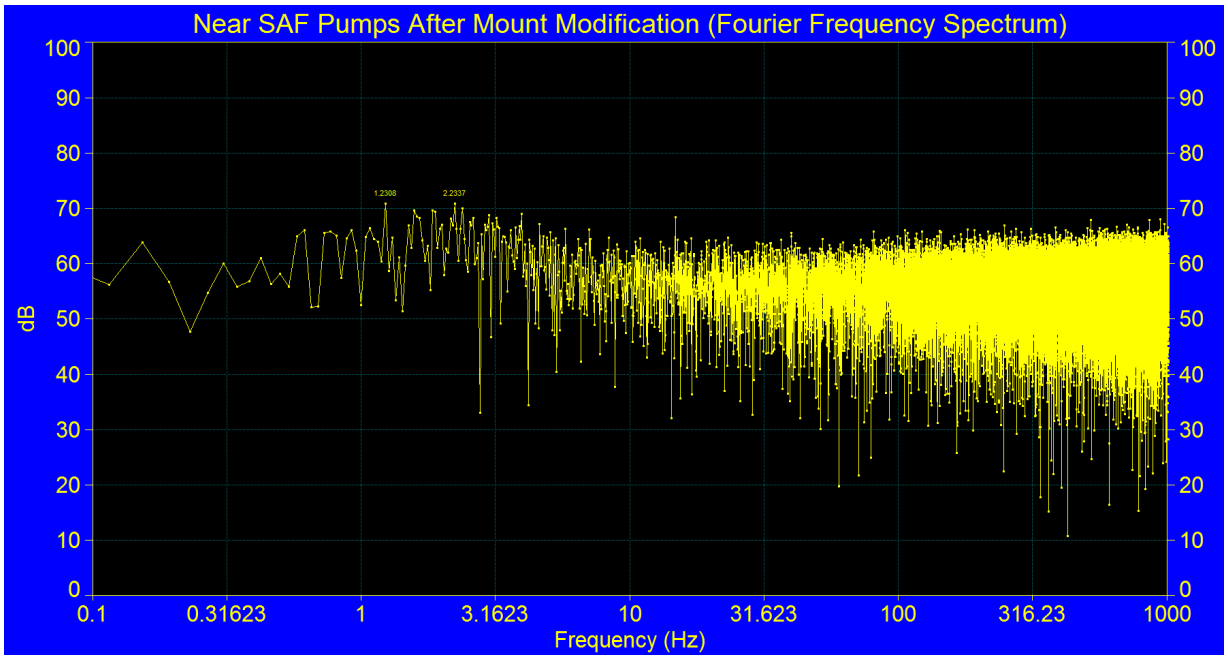
Notes:
X-axis: Frequency (hertz [Hz])
Y-axis: Amplitude (decibels [dB])

In conclusion, the data shown here indicate that sound within the hearing range of juvenile salmon may be generated on a regular basis by operation of the SAF pumps. This preliminary result is important because any sound-induced behavioral responses associated with the pumps may influence the collection efficiency of the FSC. Additional sound and vibration measurements and behavioral monitoring would be necessary to evaluate this hypothesis.

Sound Measurement After SAF Pump Dampening

After modification of the SAF pump mounts to isolate the pumps from the hull of the FSC, sound measurements were collected on December 19, 2017, to evaluate if the low frequency sound peaks were still present or if mitigating for the SAF pumps removed the low frequency sound peaks. Low frequency sound peaks were not detected during the December measurement near the SAF pumps (Figure 6). The pulsating low frequency sounds were also not present.

Figure 6
Frequency Versus Amplitude Near the Sorting Area Flow Pumps While Running, After Mount Modification



Notes:
X-axis: Frequency (hertz [Hz])
Y-axis: Amplitude (decibels [dB])

It appears the modifications to the mounting of the SAF pumps resolved the vibration issues caused by the SAF pumps. It is still uncertain if sound from the FSC is affecting fish behavior and collection efficiency. The background noise level in the water at the FSC is still higher than ambient noise levels in the water away from the FSC (Figure 5).

APPENDIX C

MERWIN ADULT TRAP EFFICIENCY EVALUATION (WINTER STEELHEAD) – 2017 REPORT

Responses to Comments Received on Merwin Upstream Passage Adult Trap Efficienty: 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

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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*.

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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

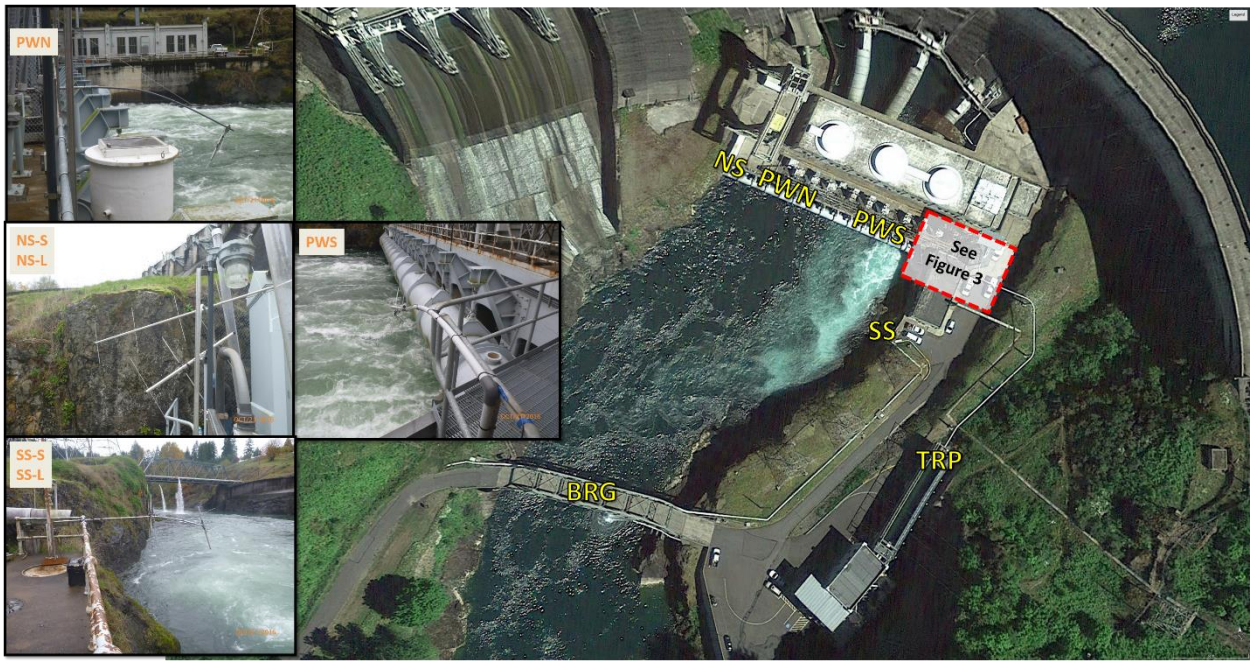

Figure 2. Merwin Dam tailrace area with locations of stationed RT antennas and pictures of select antenna orientations. All RT antennas listed in this figure are aerial, except for the Trap. Details of antennas deployed within the trap are shown on the trap schematic in Figure 3. North Shore and South 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.

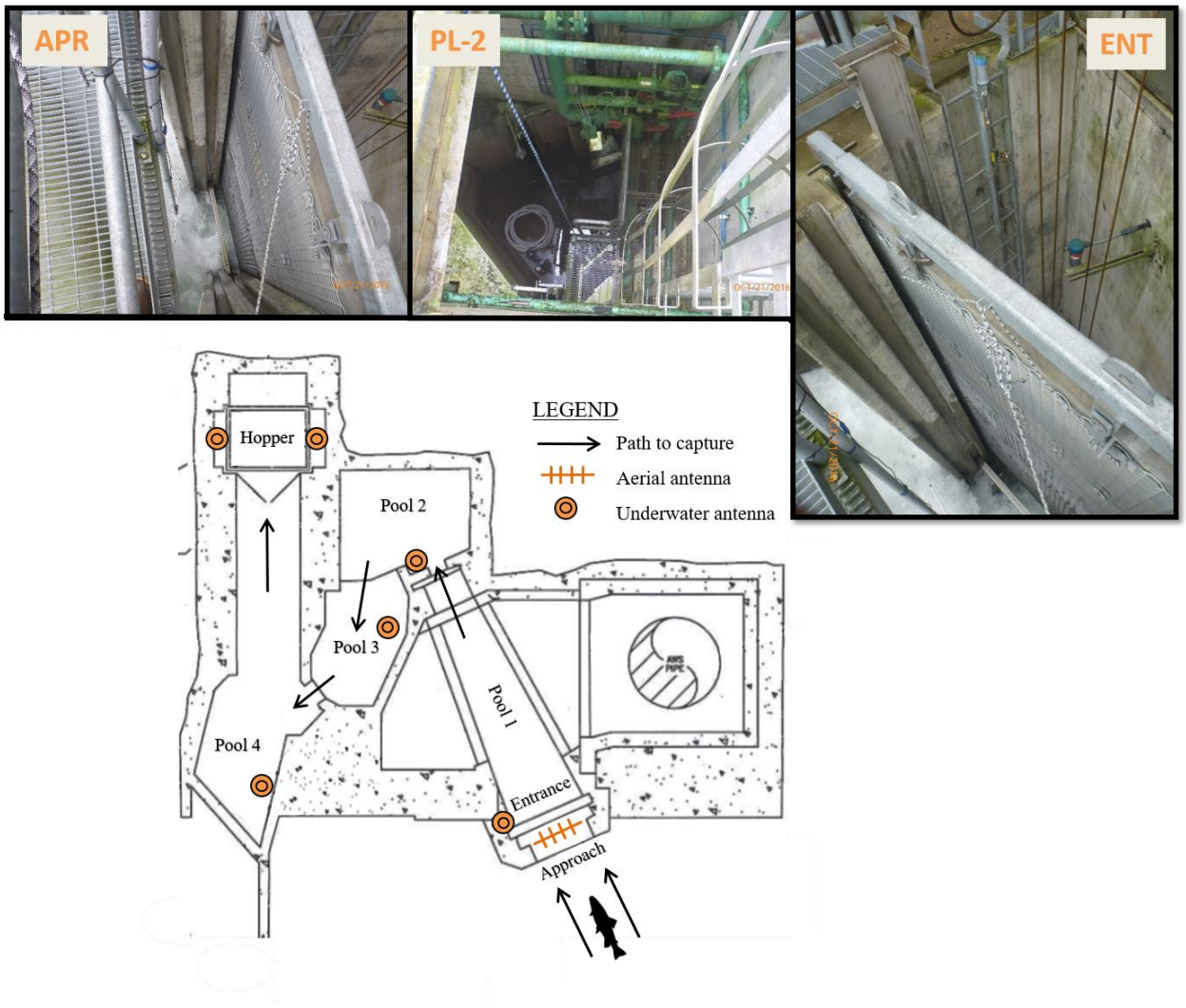

Figure 3. Trap schematic showing the locations of antenna arrays, with arrows showing the progressive movements fish make to reach the hopper and pictures of select antenna orientations. The approach antenna is aerial, and the entrance site comprised two underwater dipole antennas located on the left-hand 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.

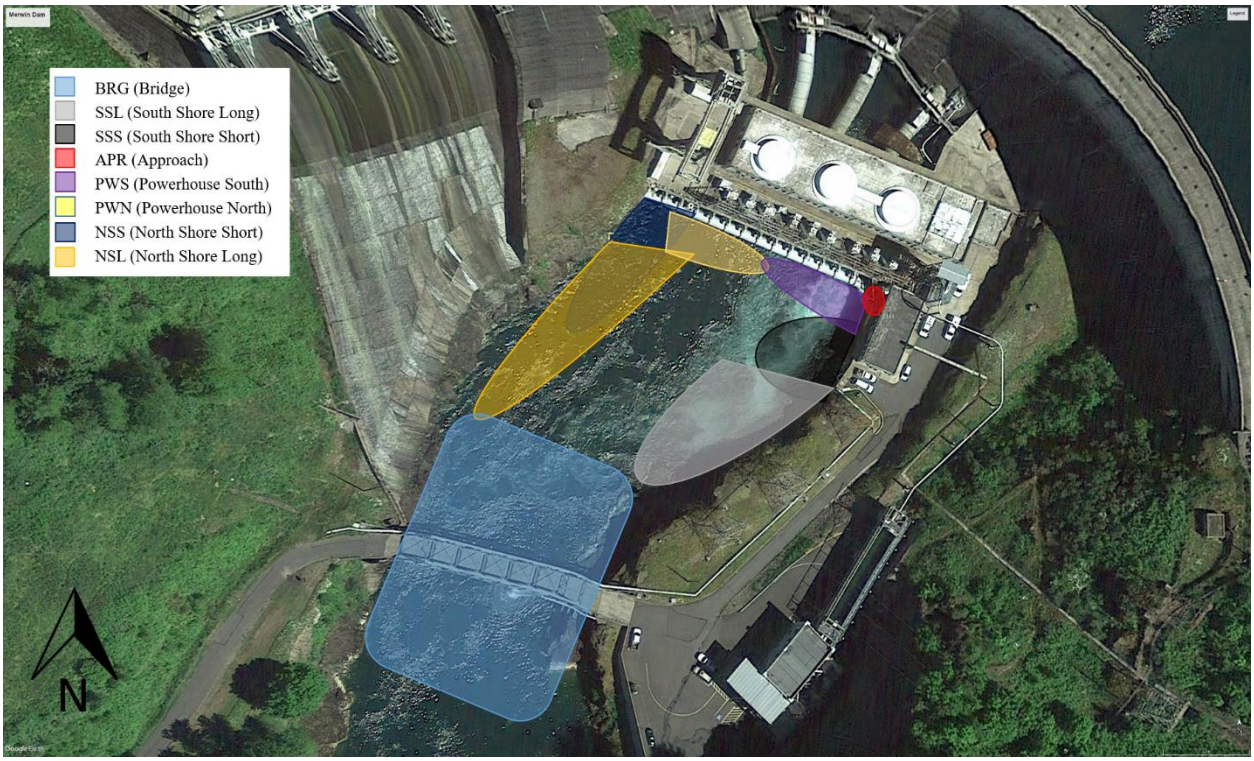

Figure 4. Locations of detection regions for 8 radio receivers located from the bridge upstream and into the fish passage facilities at Merwin Dam.

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^{o}) tag detection area, while the 8-element antenna has a longer but much narrower (~30^{o}) 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.

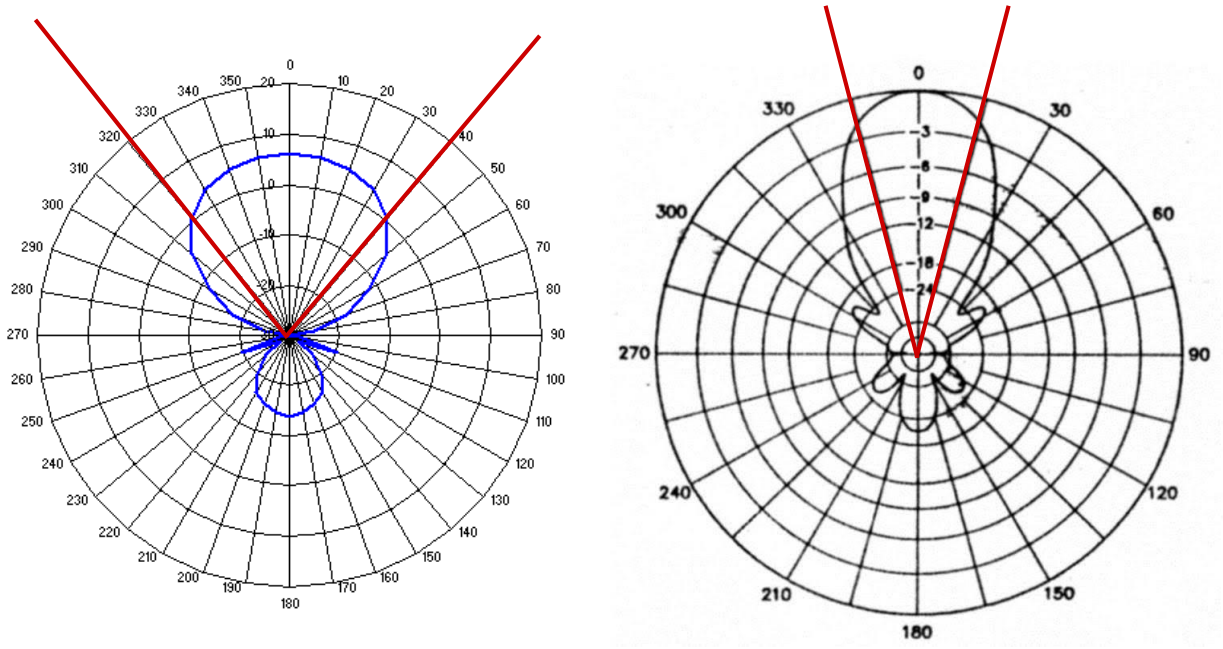

Figure 5. Reception radiation patterns (tag detection areas) for short-range 3-element (6.0dBd) and long-range 8-element (11.8dBd) Yagi antennas. Numbers around the perimeter of each figure represent directional degrees.

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:

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

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:

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

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:

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

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.

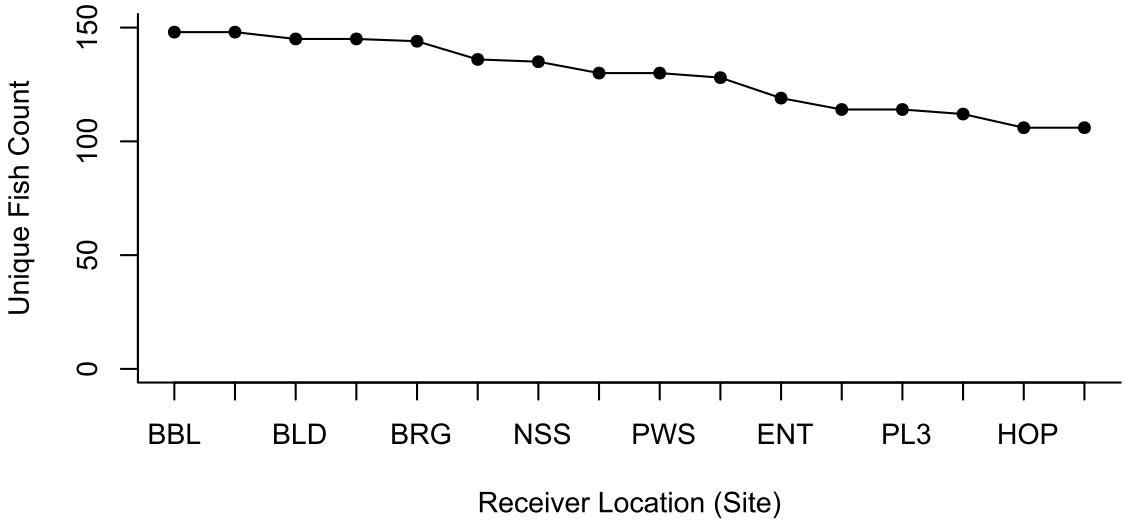

Figure 8. Sequence of frequencies of unique fish detected within the Merwin RT array, presented as total number (on left axis) of all tagged fish entering the study area (top panel) See Figure 2 and Figure 3 for receiver locations within the array. Among the 106 fish that were re-captured, five fish 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%).

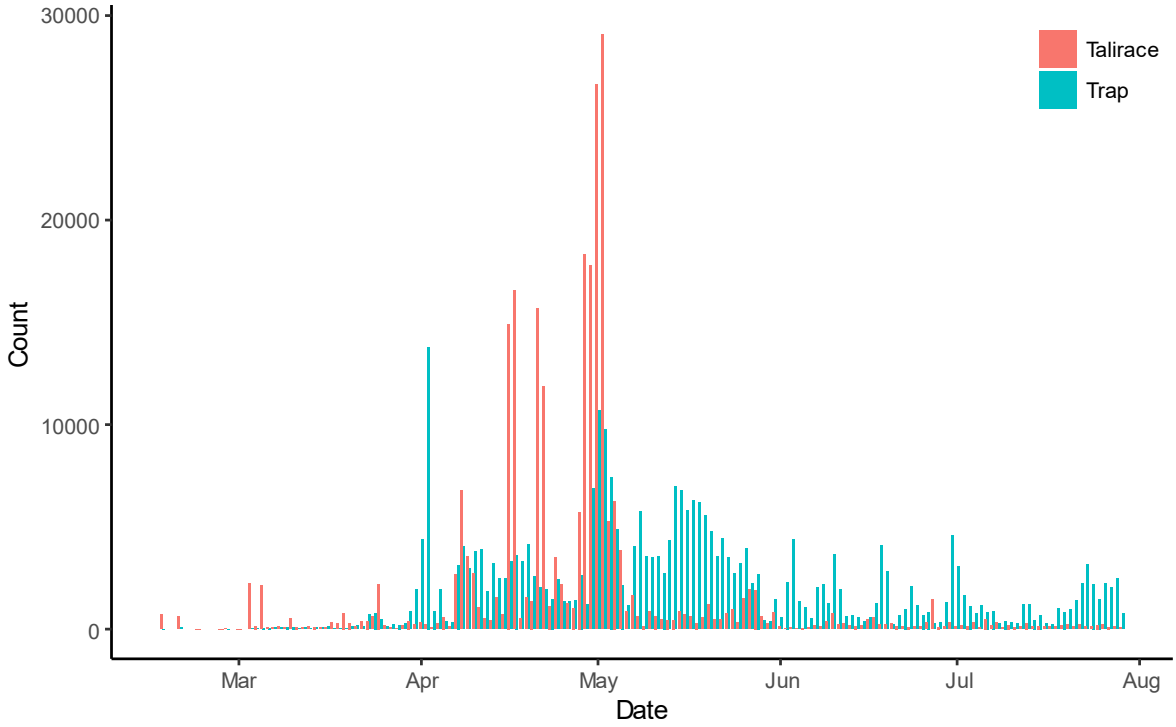

Figure 9. Total number of noise detections for trap (red) and tailrace (blue) receivers.

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**

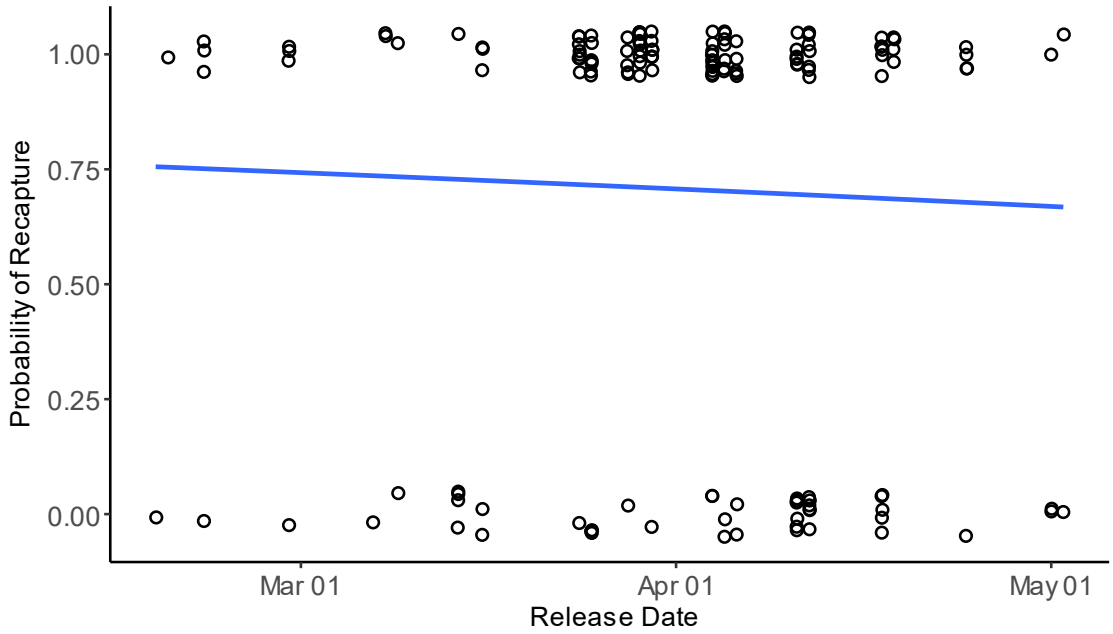

Figure 10. The probability of recapture for individual fish plotted as a function of release date. Open circles represent individual fish. The blue line indicates the predicted probability of recapture across release date based on logistic regression.

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.

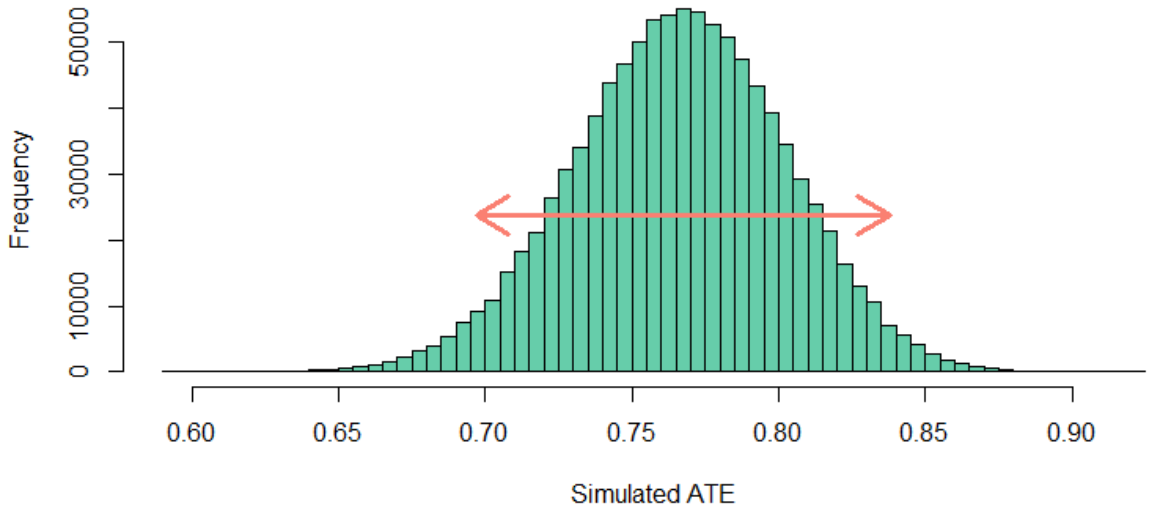

Figure 11. Bootstrap simulated frequencies of *ATE* calculated from one million iterations of randomly resampling (with replacement) the sample of 139 fish that reached the Merwin Dam tailrace. Horizontal bi-directional gray arrow indicates BCA 95% CI (69.7 – 83.8%); vertical gray line indicates target *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%.

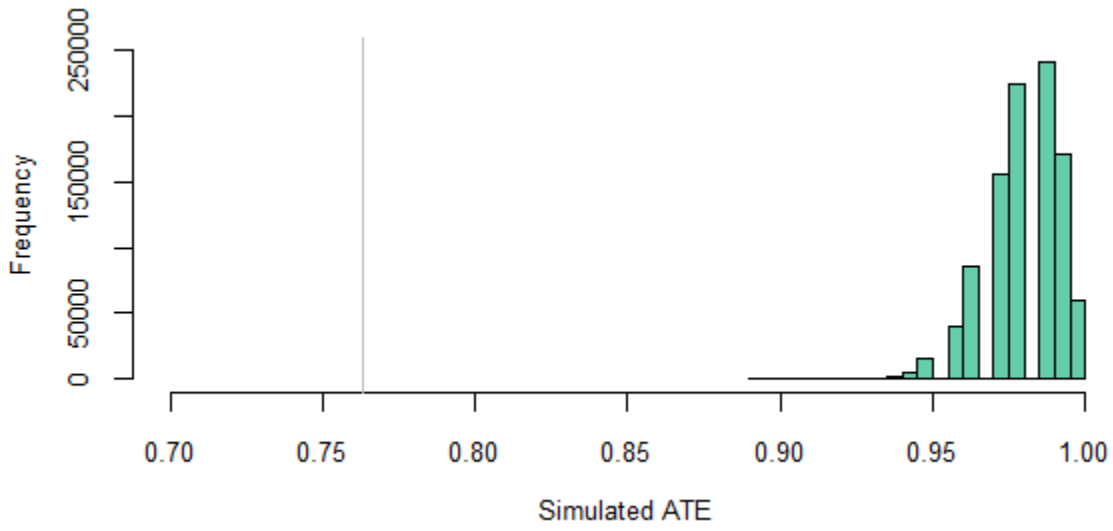

Figure 12. Simulated frequencies of *ATE* calculated from one million iterations of randomly subsampling a set of 139 fish from a simulated "urn" population of 10,000 fish that truly exhibited 98% *ATE*. Vertical gray line indicates observed ATE_{test} of 76.3%. Note that ATE_{test} reported here for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

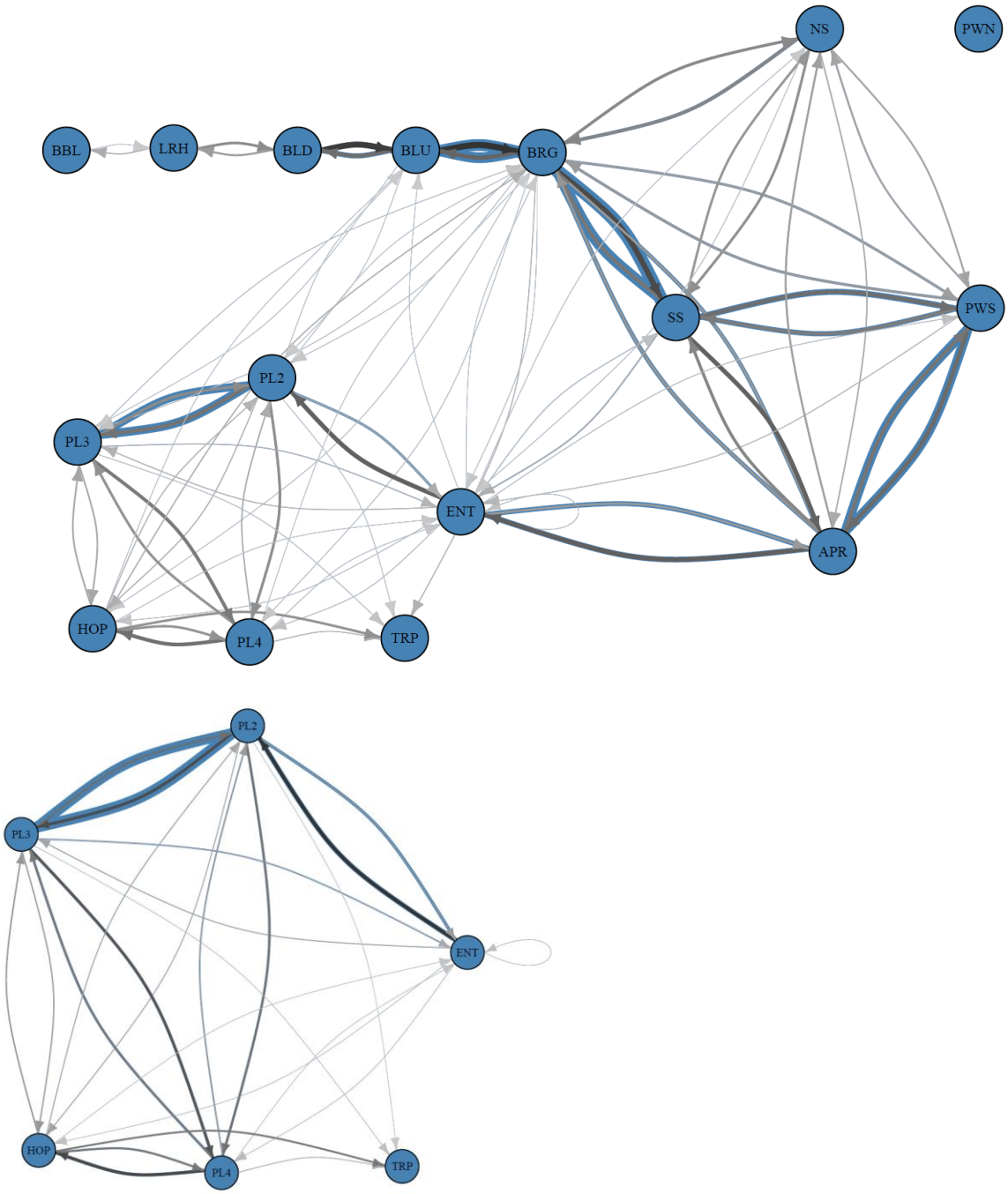

Figure 13. Network diagram of fish movement within study area. Path thickness and color are scaled based on the total number of individual fish traveling the paths (e.g., thicker paths represent a higher number of fish taking the path at least one time across their detection history). Grey paths are 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.

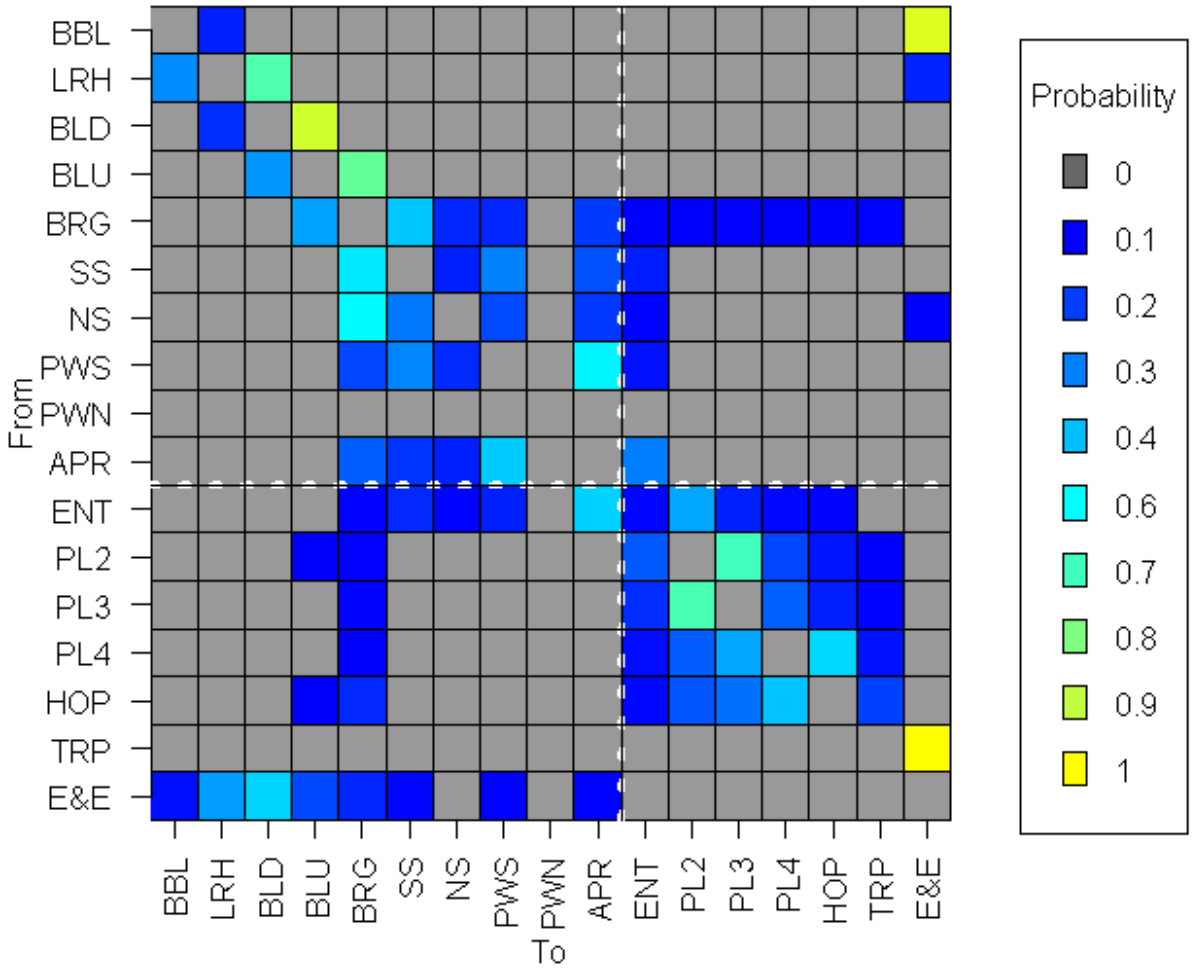

Figure 14. Heat map of the transition probabilities of fish moving from an origin site to all potential destination sites, where each row sums to a probability of 1.0. The black reference lines are added between the receivers Approach and Entrance to show the distinction of a fish being located within 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.

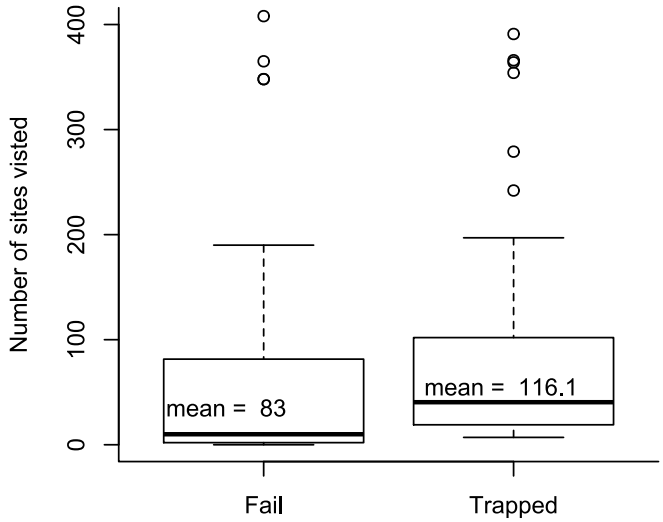

Figure 15. Number of sites visited before being captured (Trapped) or not captured (Fail).

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).

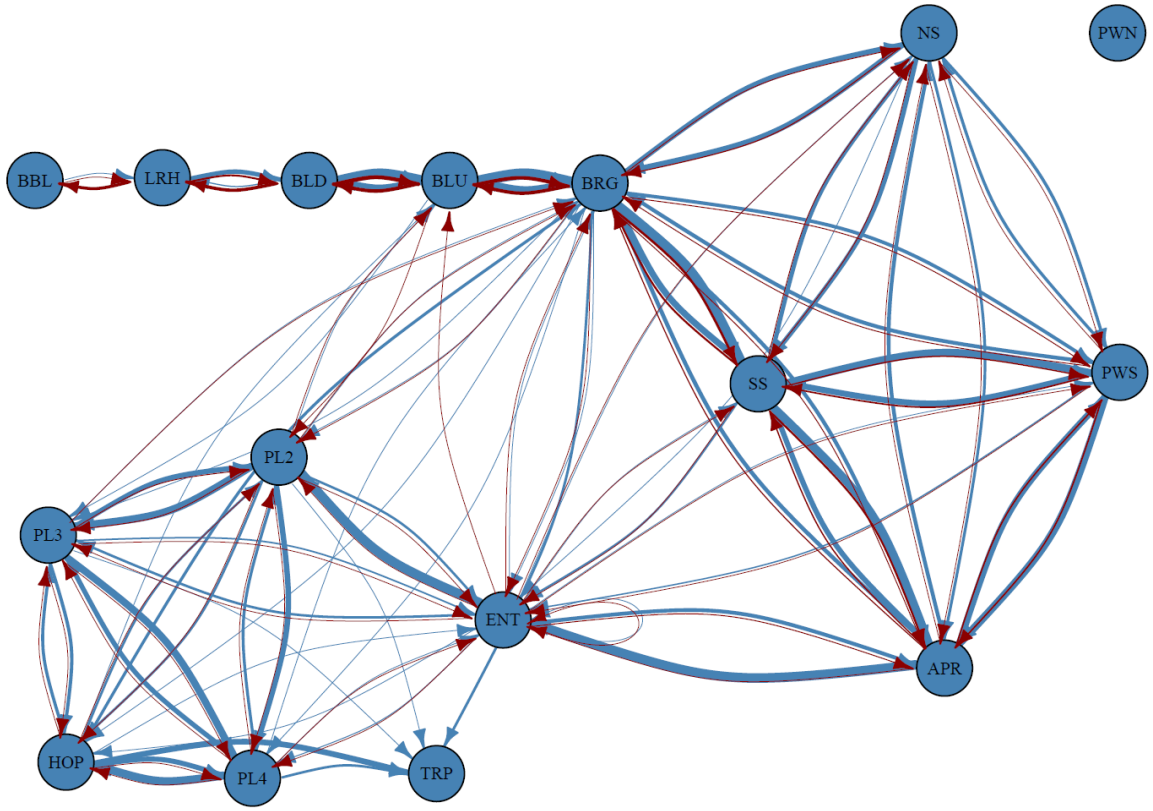

Figure 16. Network diagram of fish movement within the study area at Merwin Dam grouped by fish that ultimately are trapped (blue) or failed to be trapped (red) from 2017. Path thickness and color are scaled based on the total number of transitions which occurred between sites with fish as the sample 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.

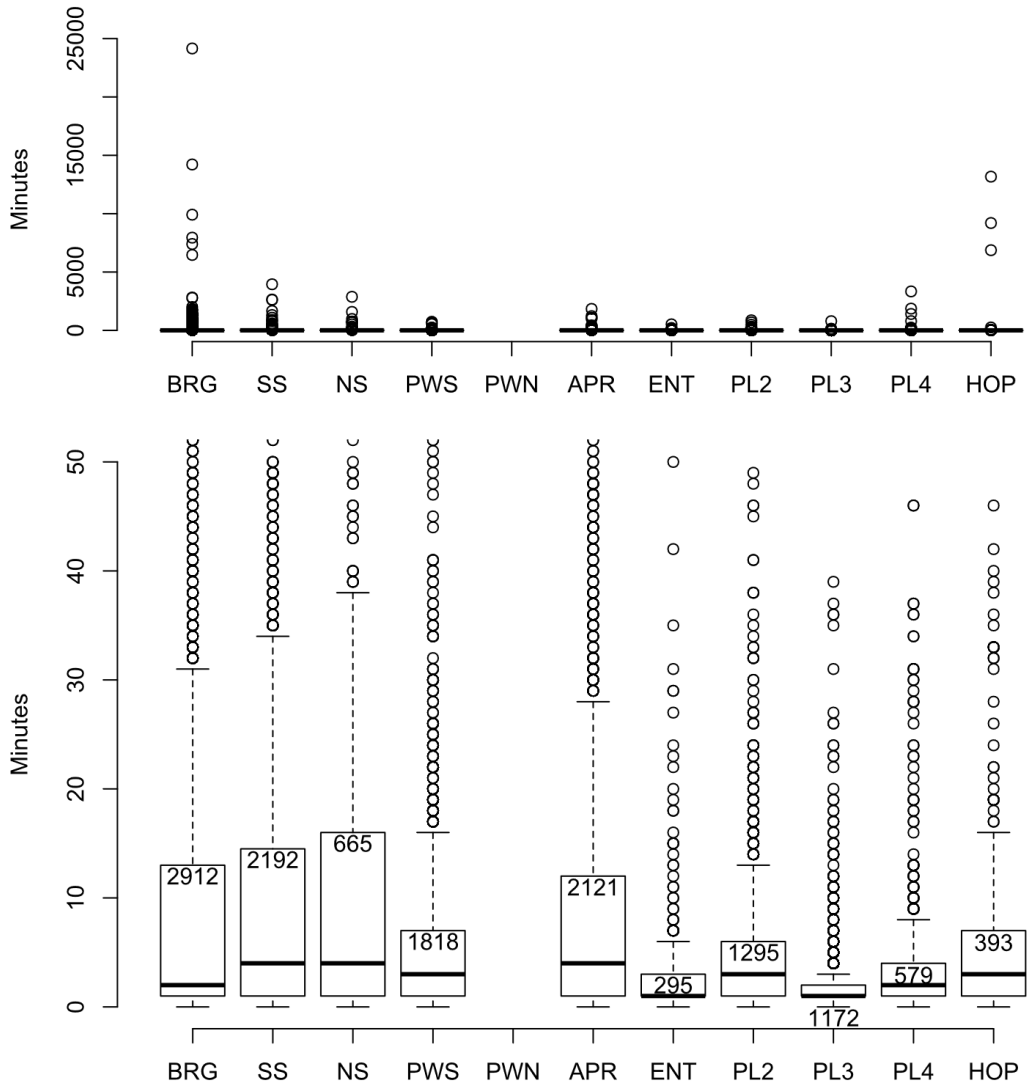

Figure 17. Median residence times by site. The top figure shows the full range of data, including outliers, while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Sample size (n) is displayed in the top of the box plots for each site. Caveat: these data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

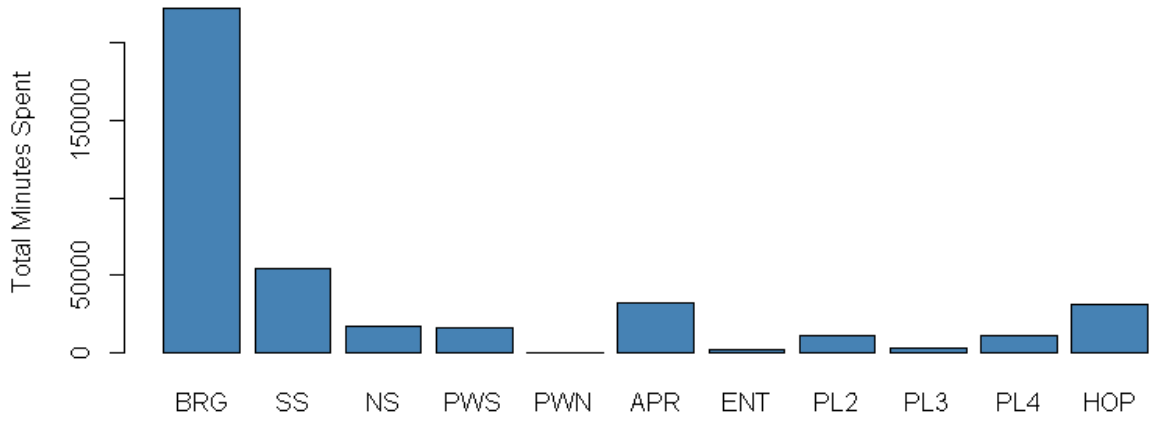

Figure 18. Total time spent by all winter steelhead in each site. Caveat: these data are not scaled based on the detection ranges of each site.

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).

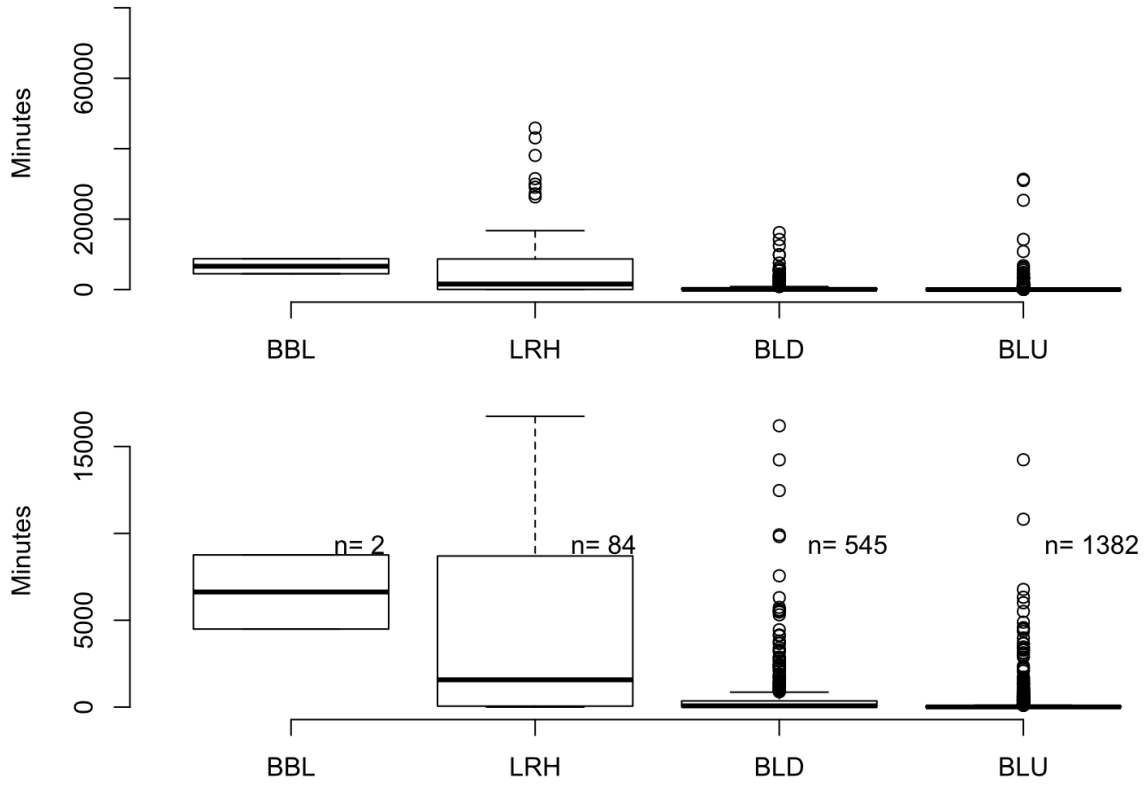

Figure 19. Median residence times for downriver sites. The top figure shows the full range of data, including outliers, while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Sample size (n) is displayed in the top of the box plot for each site. Caveat: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

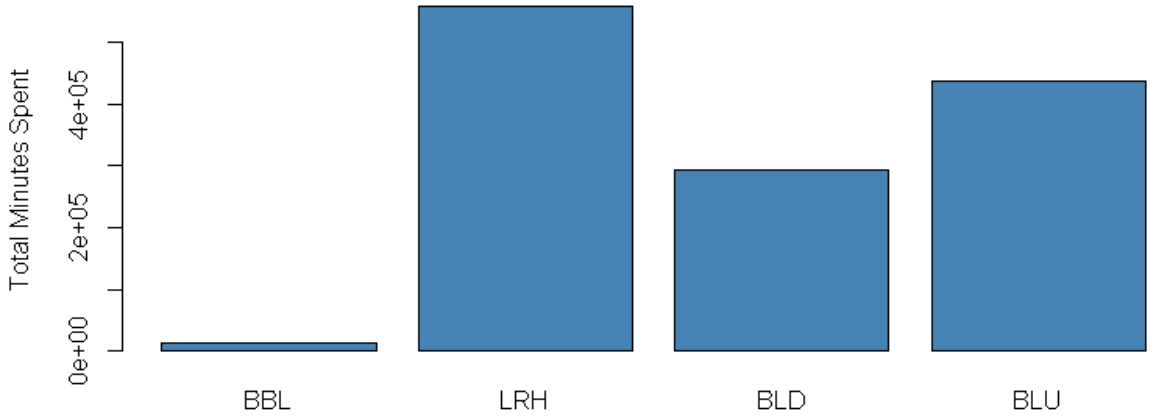

Figure 20. Total time spent by all winter steelhead in each downriver site. Caveat: these data are not scaled based on the detection ranges of each site.

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

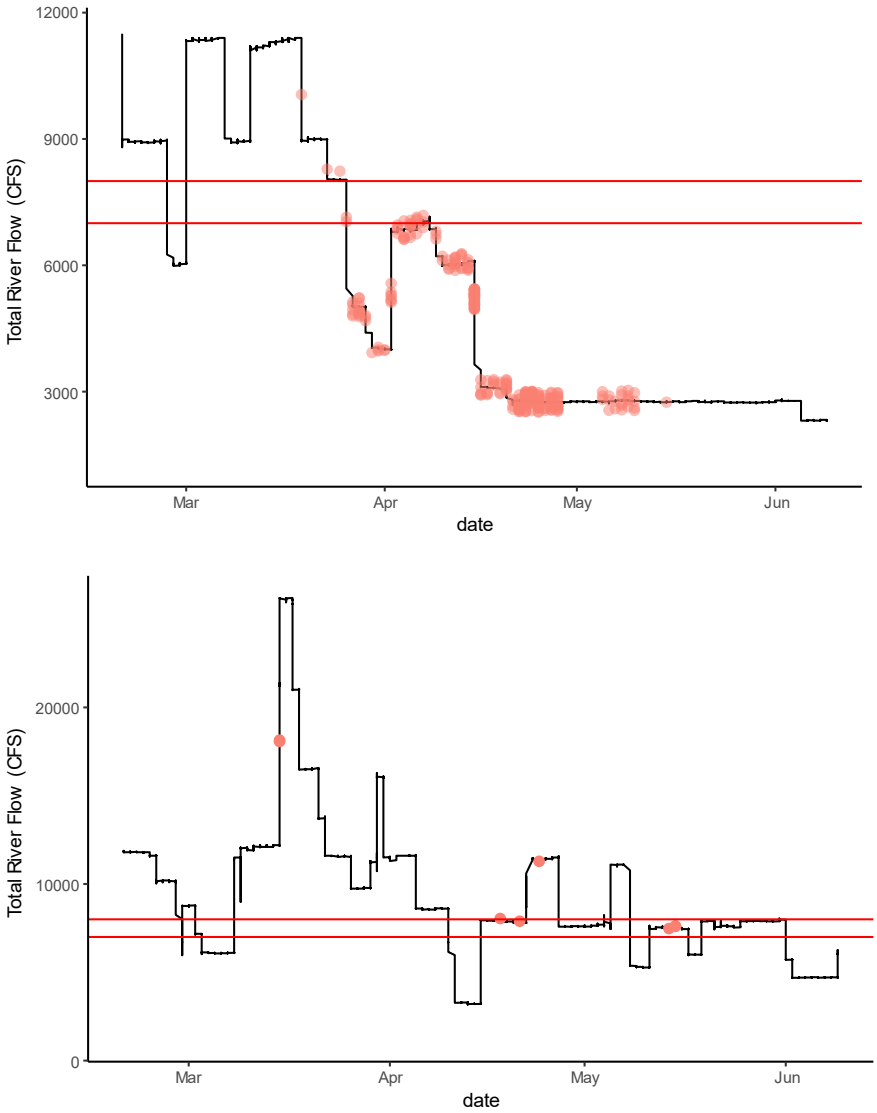

Figure 21. Timing of PL2→ENT transitions (i.e., backwards through the fyke) during varying levels of total river flow over two study years, 2016 (top panel) and 2017 (bottom panel). Horizontal red bars denote flow less than 7,000 cfs and greater than 8,000 cfs. Red dots indicate PL2→ENT transitions.

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).

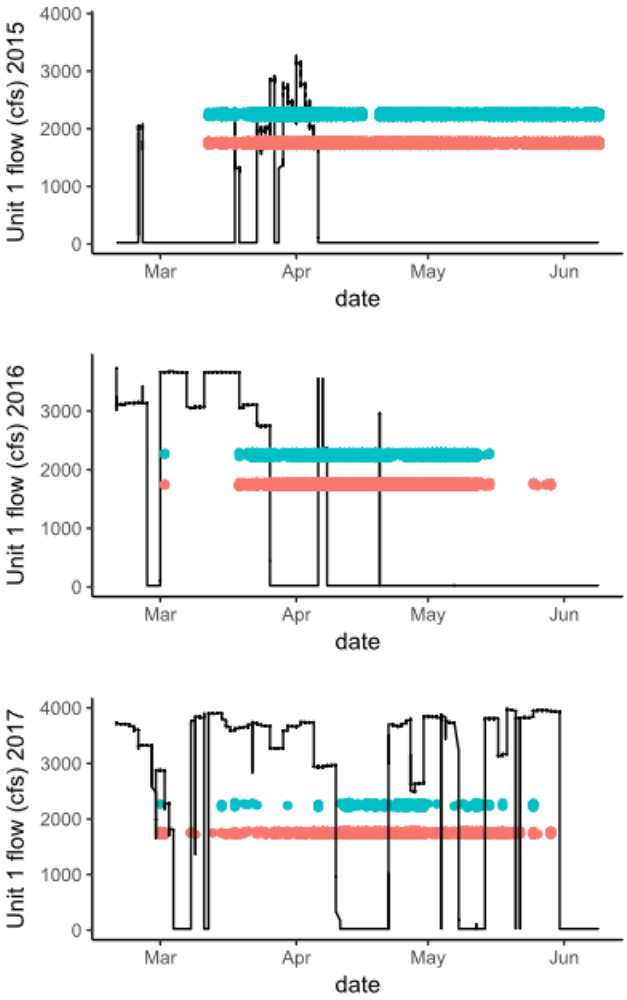

Figure 22. Unit 1 discharge over time for three years of study. Solid black line indicates discharge. Red and blue dots indicate individual detections at the Approach and Entrance sites, respectively. Data for total river flow was collected from PacifiCorp. See Appendix A, Figures A-1 to A-4 for plots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

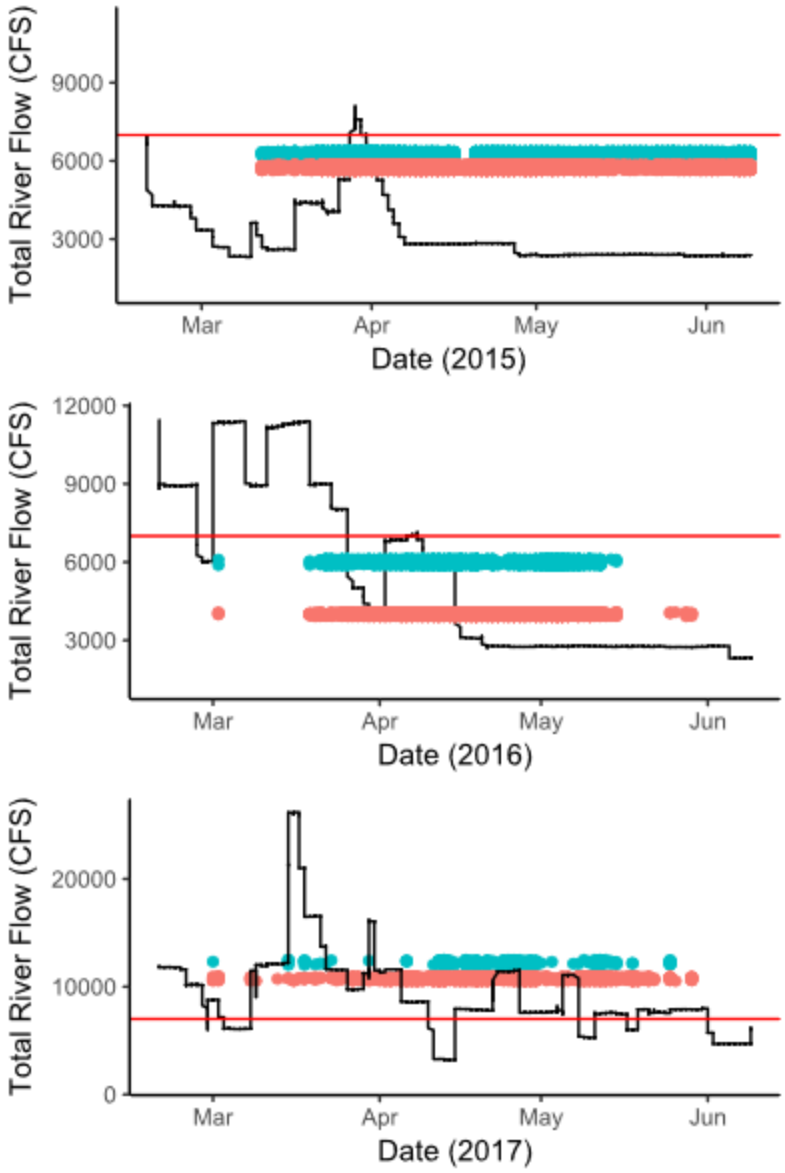

Figure 23. Total river flow over time for three years of study. Solid black line indicates discharge. Red and blue dots indicate individual detections at the Approach and Entrance sites, respectively. Data for total river flow was collected from USGS (USGS 2017). See Appendix A, Figures A-1 to A-4 for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

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APPENDIX A: SUPPLEMENTARY FIGURES AND TABLES

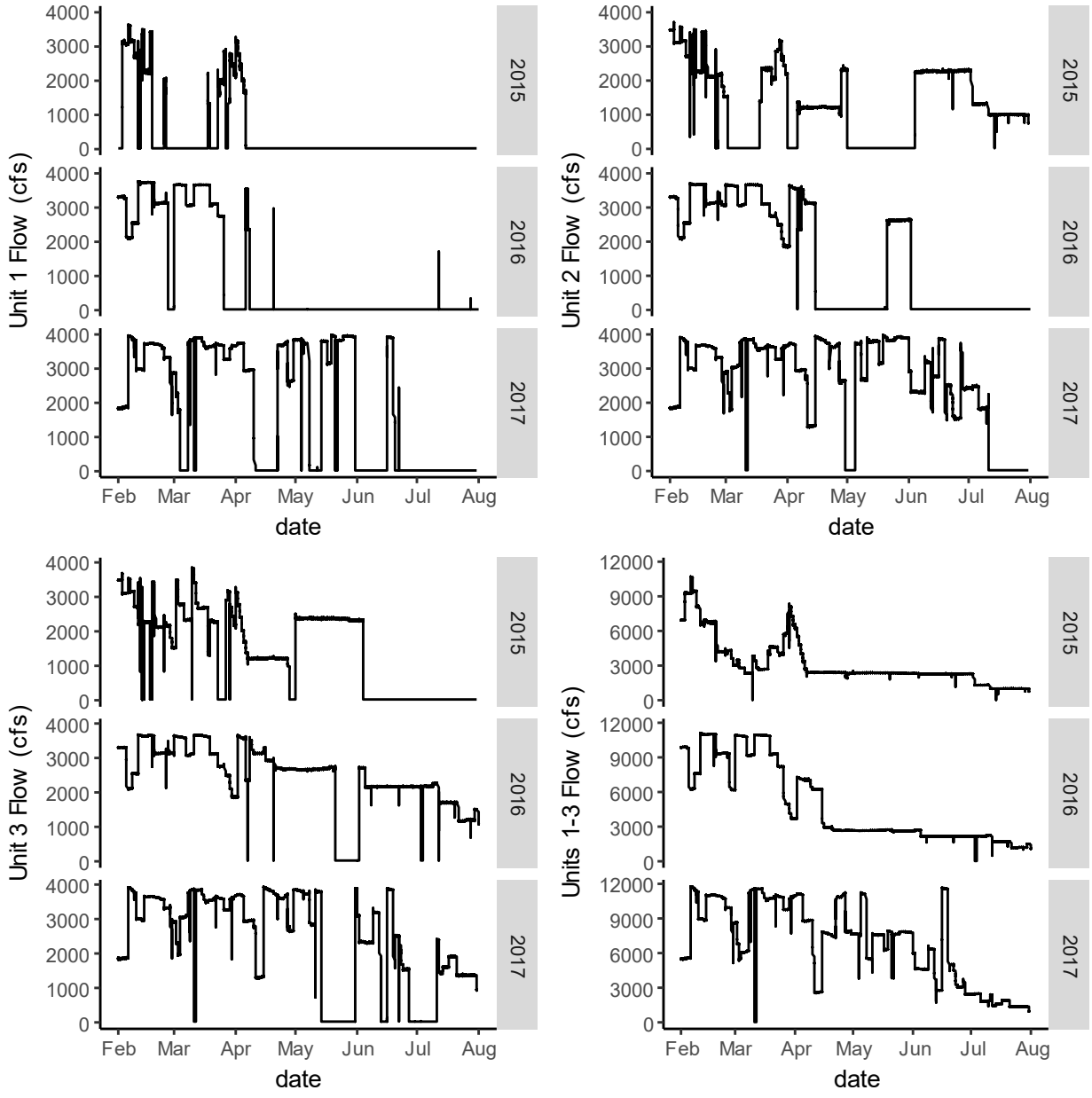

Figure A-1. Hourly mean discharge from Merwin Dam power generation Units 1-3 during months of winter steelhead tagging across three years (2015, 2016, 2017).

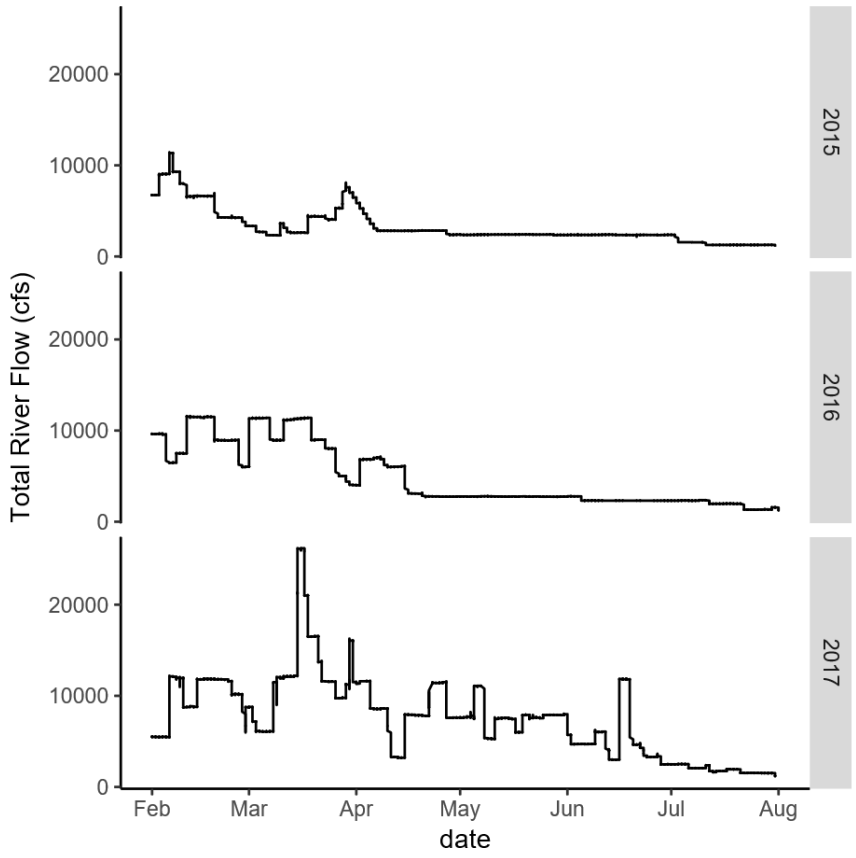

Figure A-2. Hourly mean Lewis River discharge below Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017).

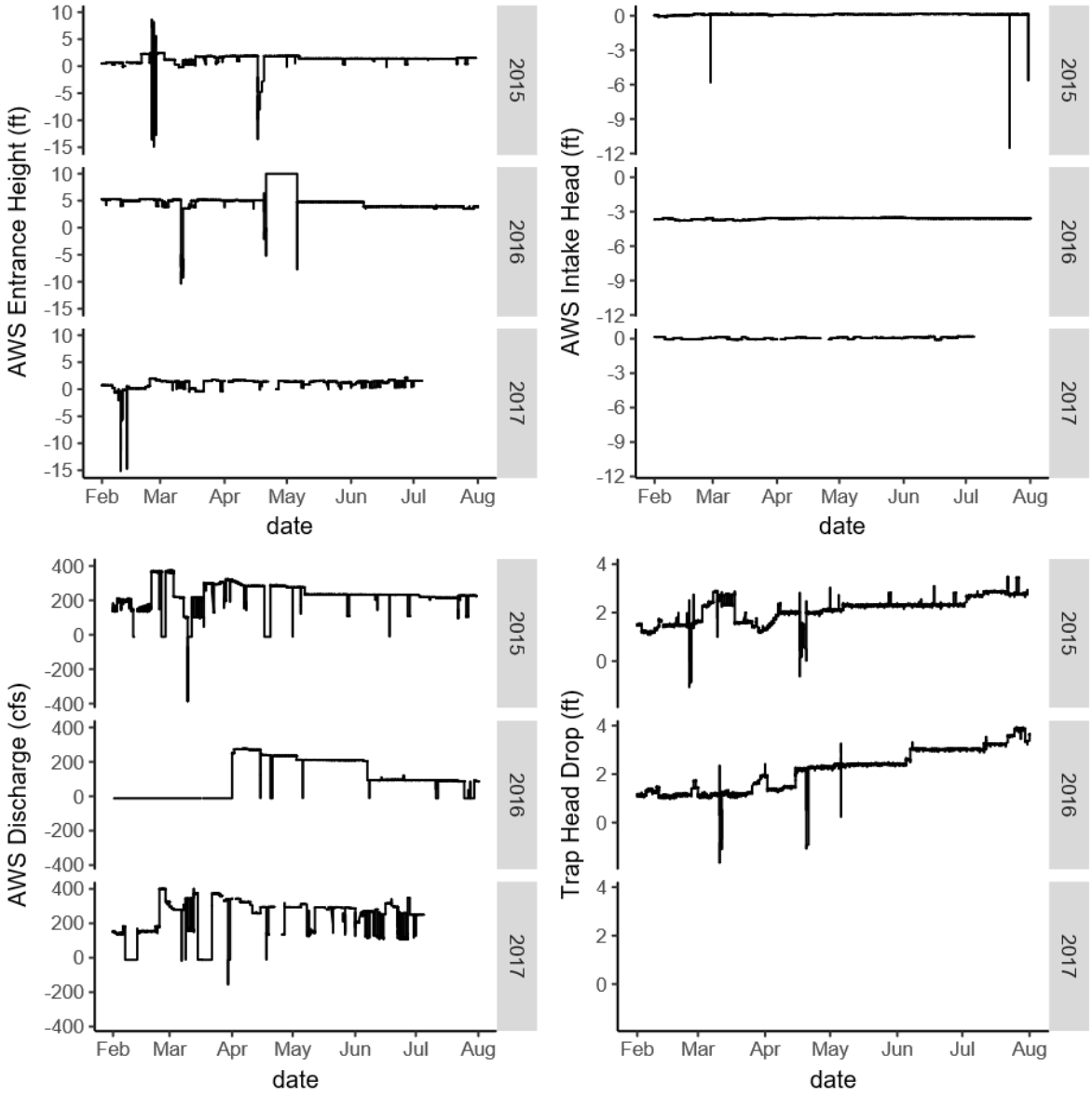

Figure A-3. Hourly mean AWS entrance height (top left), AWS intake head (top right), AWS discharge (bottom left), and trap head drop measured in the trap area at Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017).

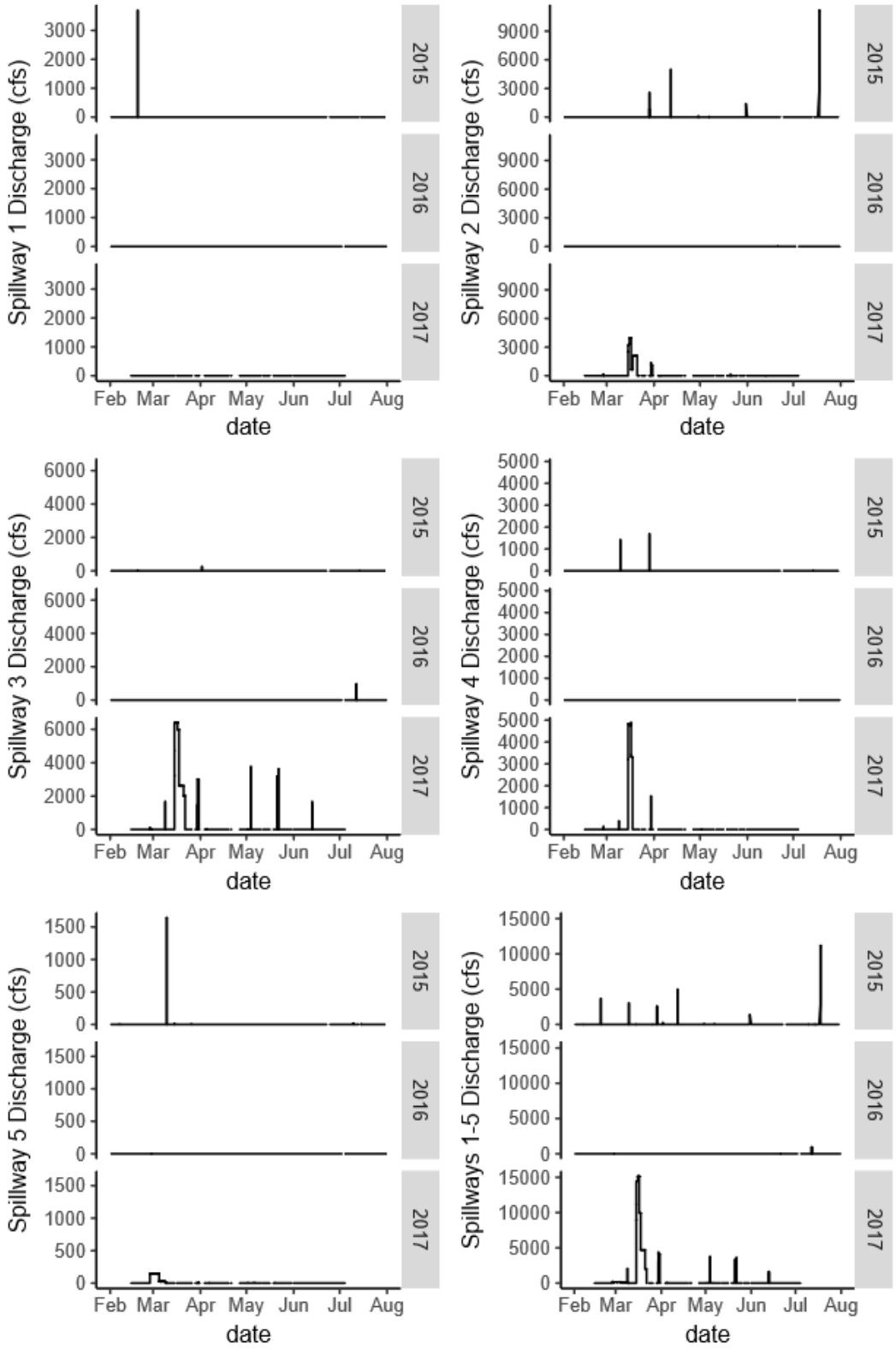

Figure A-4. Hourly mean discharge from five Spillways at Merwin Dam during months of winter steelhead tagging across three years (2015, 2016, 2017).

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

APPENDIX D

MERWIN ADULT TRAP EFFICIENCY EVALUATION (COHO SALMON) – 2017 REPORT

MERWIN UPSTREAM PASSAGE ADULT TRAP EFFICIENCY – COHO SALMON

2017 Final Annual Report

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February 28, 2018

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 coho salmon and is the second study year for coho salmon.

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. Overall population *ATE* is estimated from a tagged group of study fish, for which ATE_{test} is calculated. Aside from ATE_{test}, two additional core metrics are presented for evaluating Merwin Dam trap effectiveness. Trap entrance efficiency (P_{EE}) quantifies the proportion of fish entering the Merwin Dam tailrace that subsequently entered the trap, regardless of whether they were eventually captured or exited the trap and returned downstream. P_{EE} indicates the ability of study fish to locate and enter the trap from the tailrace. We also report trap ineffectiveness (T_i), which is the difference between P_{EE} and ATE_{test}. Evaluation of T_i can reveal 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 as follows:

1) Determine ATE_{test} for 2017 and compare this value to the performance standard of 98%.
2) Evaluate directional movement of fish in the tailrace, trap, and downstream.
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.

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

Core passage metrics from 2015-17 are summarized in Table 1, below. Note that trap efficiency for coho salmo was only evaluated in 2015 and herein. Estimates of ATE_{test} and P_{EE} for coho salmon in 2017 were greater than 2015. However, we caution that low samples sizes of coho salmon, low water conditions and the use of hatchery coho salmon in 2015 (NOR coho salmon were used in 2017) could have also influenced ATE_{test} estimates between years, and therefore, comparisons between years are essentially qualitative. Given low sample size for coho in 2015, it thus makes sense to consider 2017 as the first year with reliable coho salmon tracking data for the Merwin *ATE* project.

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% (12-40%)	9% (4-28%)	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	149	70.0% (60-83%)	63.3% (50-74%)	9.5%

Key results from the 2017 study pertaining to the core passage metrics for coho salmon include the following:

- 149 natural origin (NOR) coho salmon were tagged after being initially captured at the Merwin Dam Adult Fish Collection Facility between September 18th and October 25th, 2017
- 137 coho salmon were detected within the entire study area detection array
- 60 coho salmon entered the tailrace of Merwin Dam (composing the group of fish that were included in estimates of core metrics)
- 42 coho salmon entered the trap, for an overall P_{EE} of 70% (42/60)
    - 2017 P_{EE} for coho salmon (70%) is three times (approximately 47 percentage points) greater than P_{EE} in 2015 (approximately 23%)
- 38 coho salmon were successfully recaptured, for an overall ATE_{test} of 63% (38/60)
    - 2017 ATE_{test} for coho salmon (63%) is seven times (approximately 54 percentage points) greater than ATE_{test} in 2015 (approximately 9%)

We also compared the amount of time that fish were present in the tailrace to *ATE* performance standards. Median residence time was 5.6 hours, which is below the performance standard of 24 hours. In addition, 2% (n = 1) of fish exhibited tailrace residence times greater than 168, which is below the maximum 5% performance standard for fish residing within the tailrace for this long. Thus, performance standards for median tailrace time of less than or equal to 24 hours with less than 5% of fish taking longer than 168 hours to pass were met for coho salmon in 2017.

Consistent with previous years, during the 2017 study year, coho salmon appeared to locate and enter the trap at a higher rate (P_{EE} of 70%) than the rate at which they were captured (i.e., ATE_{test}). This observation is reflected by a trap ineffectiveness (T_i) of 9.5% for 2017. Reduction in trap ineffectiveness compared to previous study years is likely a result of the addition of a fyke to the trap prior to 2017 studies. Only four coho salmon were able to exit the trap through the fyke in 2017 providing additional evidence for the effectiveness of the fyke in reducing numbers of exit events from the trap.

Another key finding of the 2017 study emerged from the network analysis, which indicated that fish do not follow clear pathways in the tailrace. Coho salmon in 2017 showed a slight preference for approaching the south side rather than the north side of the tailrace, but differences were minimal between route preference. Preference for either the south side or the north side of the tailrace by migrating salmon have been inconsistent among study years, which is surprising given attraction flows from the trap entrance are on the south side of the tailrace, and thus, we would expect fish to use the south side more frequently. Turbulent flows in the tailrace may disperse olfactory cues emitted from the trap, and therefore, may not provide a consistent path for fish to follow to locate the trap.

Model scenario simulations developed to inform recommendations for future operational or infrastructural changes to improve trap efficiency indicated relatively modest gains in ATE_{test} associated with the scenarios considered. The model simulating addition of a fyke between Pools 3 and 4 resulted in increased simulated ATE_{test} values by only one percentage point. The model simulating installation of a new trap on the north shoreline increased simulated ATE_{test} by 10 percentage points relative to the control model, to 72%. All model simulations resulted in ATE_{test} values below the target *ATE* of 98%.

The evidence below suggests that coho salmon in 2017 were not strongly attracted to the tailrace, and instead may have been more attracted to downstream locations:

1) Only 40% of tagged and released coho salmon re-entered the tailrace.
2) Coho regularly moved from the tailrace to downstream sites.
3) Coho spent relatively large amounts of time at the furthest downstream locations, Bed & Breakfast and Lewis River Hatchery sites.
4) Ninety-five percent of coho salmon that were not re-captured were last detected at downstream sites (Bed & Breakfast and Lewis River Hatchery).
5) Three coho salmon were found in other tributaries (two fish in the East Fork Lewis River and one fish in Cedar Creek).

Overall, the above suggests coho salmon may spawn in the Lewis River downstream of the tailrace or stray into neighboring tributaries. In addition, coho salmon may be less likely to return to the tailrace and trap because they were previously captured at that location (i.e., they are trap non-naïve). Until the effects of trap naïveté and straying rates are accounted for, current *ATE* estimates at Merwin Dam are likely biased low. We suggest tagging trap naïve fish and examining downstream behaviors (including movements into neighboring tributaries) of coho salmon in future years to understand how (1) using trap non-naïve fish and (2) straying both influence *ATE* estimates.

In conclusion, performance standards for adult collection efficiency at Merwin Dam were not met in 2017, but performance standards for the amount of time spent in the tailrace prior to passage were met. 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*.

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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 31.4 (RM 19.5) of the Lewis River[1], 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).

[1] Throughout the remainder of this document, all river distances refer to Lewis River, i.e., distance upstream from Lewis River confluence with Columbia River

Study Background

This report describes the third year (fall 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. A previous report (Drenner et al. 2017) described results for steelhead. The current report focuses exclusively on coho salmon and summarizes the second study year for coho salmon, the first study year to examine NOR coho salmon (hatchery coho salmon were examined in 2015).

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) 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.

In 2017, PacifiCorp implemented a third year of study that initially focused on winter steelhead only, results of which are reported on previously (Drenner et al. 2017). During summer 2017, PacifiCorp elected to include analysis of coho salmon, results of which constitute the subject matter of this report.

Study Objectives

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. For 2017, trap efficiency was assessed for winter steelhead (Drenner et al. 2017) and coho salmon only because spring Chinook returning to the Lewis River in 2017 were allocated to brood stock collection and/or transported upstream. This report focuses solely on results from evaluation of coho salmon passage performance and behavior as results for winter steelhead were provided in a separate stand-alone report (see Drenner et al. 2017).

The specific objectives for the 2017 coho evaluation included the following:

1) Determine *ATE* as defined in the M&E plan for coho salmon; compare estimates to the performance standard of 98%; and, compare trap attractiveness metric P_{EE} across study years.
2) Determine if coho salmon 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 coho salmon 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 coho salmon 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 coho salmon that do not enter or which choose to leave the Merwin Dam tailrace and move back downstream.
6) Determine the condition of coho salmon 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.

METHODS

Fish Collecting and Tagging

Natural origin (NOR) coho salmon were collected and tagged by PacifiCorp staff from mid-September through late October 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). Therefore, one explicit assumption of this study is that recapture rates of non-naïve study fish (ATE_{test}) accurately and appropriately reflect, and effectively equal, rates of initial capture among the parent population of naïve fish (*ATE*).

A maximum of 35 fish were tagged and released on any given day, with a total target of 149 individuals. 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 (0.4 mi) downstream from the trap entrance at the Merwin boat launch (Lewis RKM 30.8 (RM 19.1)). Due to the limited number of tag frequencies available for transmitters, transmission frequency has been changed during each study year to reduce the likelihood of picking up similarly numbered transmitters from previous years (e.g., from shed but still active tags or dead fish containing active tags).

Spatial design

During early September 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 had the ability to store approximately 1 million records each. 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

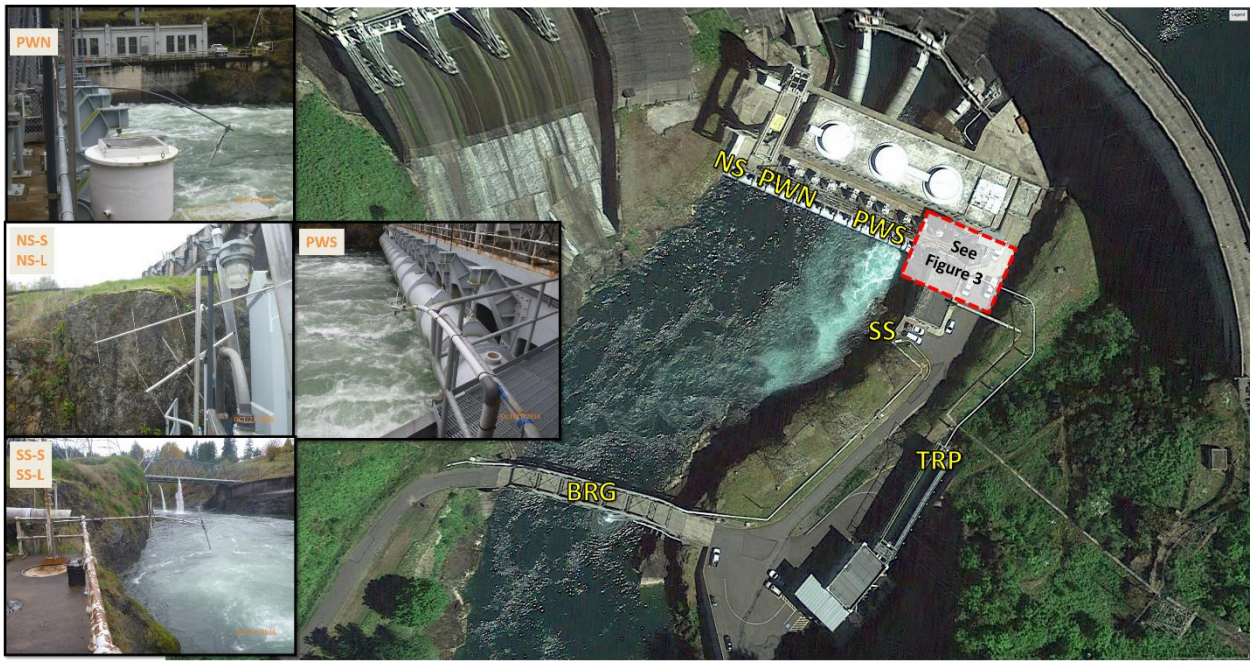

Figure 2. Merwin Dam tailrace area with locations of stationed antennas and pictures of select antenna orientations. All antennas listed in this figure are aerial, except for the Trap. Details of antennas deployed within the trap are shown on the trap schematic in Figure 3. North Shore and South Shore 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 Powerhouse North and Powerhouse South comprised one three-element antenna each, pointed towards the powerhouse and angled slightly down.

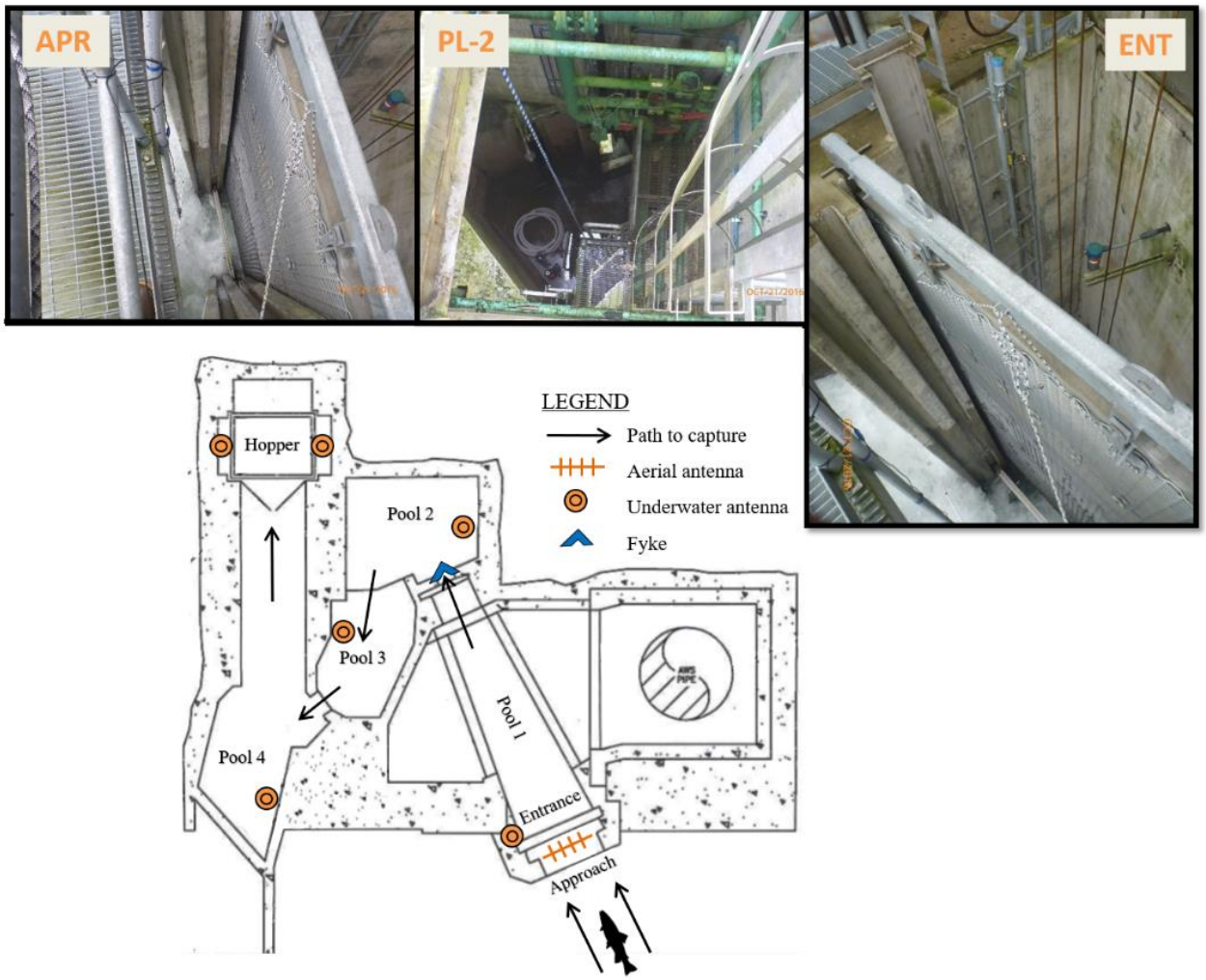

Figure 3. Trap schematic showing the locations of antenna arrays, with arrows showing the progressive movements fish make to reach the hopper and pictures of select antenna orientations. The approach antenna is aerial, and the entrance site comprised two underwater dipole antennas located on the left-hand 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. Additional technical details on antenna types and installation can be found in Appendix A-1.

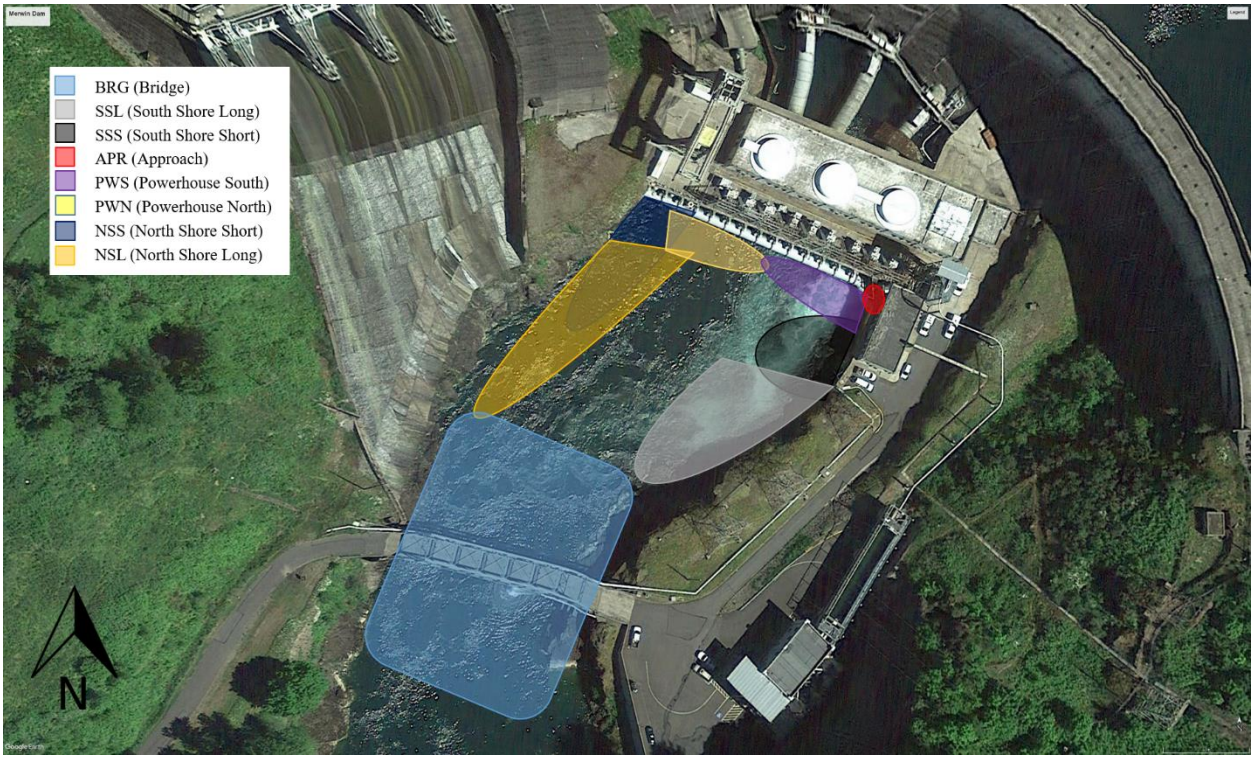

Figure 4. Locations of detection regions for eight radio receivers located from the bridge upstream and into the fish passage facilities at Merwin Dam.

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.

Data Management and Processing

Database Construction

Data from weekly 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, tags from past tracking efforts that remain within the system, 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:
    - A sequence of four detections within 15 minutes of each other was required to be a "credible" detection. If the four consecutive detections spanned more than 15 minutes, it was not considered a credible detection.
    - 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.
- Fish were assumed to exit the trap when they moved from any of the trap sites inside the fish ladder (i.e., Entrance, Pool 2, Pool 3, Pool 4, Hopper) to any of the sites outside the trap (i.e., Approach, Bed and Breakfast, Boat Launch sites, Bridge, Lewis River Hatchery, North Shore, Powerhouse North, Powerhouse South, 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.
- Detections at the Bridge site that occur between detections at the pool, hopper, and Trap sites were discarded. These detections were determined to be faulty as there is no way for fish to move between these sites and the bridge in a rapid succession.
- 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.

Following data filtration, all individual fish detection histories were visually inspected, and false detections were identified and excluded prior to analysis.

Analytical Approach

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

Adult trap efficiency (*ATE*) for Merwin Dam is the percentage of actively migrating adults that are caught in the Merwin fish trap. 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:

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

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:

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

where:

T is the number of fish that enter the trap, regardless of whether they were eventually captured or returned back to the tailrace (i.e., exited the tailrace) as 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:

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

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 60 coho salmon that entered the Merwin Dam tailrace (*M*), 38 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 60 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 60 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 60 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.
6) Determine the frequency of the observed ATE_{test} within the pool of simulated ATE_{sim} values.

[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%).*

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 re-captured) or one (re-captured).

Objective 2: Determine if coho salmon 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 were adjusted in the following ways:

- Downstream transitions were linearized.
    - e.g., (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.
    - e.g., (Boat Ramp→ Powerhouse South) became (Boat Ramp→Holding Pool; Holding Pool→Bridge; Bridge→ Powerhouse South), and likewise for the reverse.
- Transitions from the tailrace to the trap were forced to go through receiver Entrance.
    - e.g., (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 coho salmon 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 coho salmon 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 duration that coho salmon are present in Merwin Dam tailrace, and compare this 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 previous reports (Stevens et al. 2015; Caldwell et al. 2016; Drenner et al. 2017). Estimates for tailrace passage time are presented for:

- all fish that entered the tailrace;
- fish that entered the tailrace but not the trap;
- fish that entered the trap but were not re-captured; and
- fish that were re-captured.

Objective 5: Describe the movement and behavior of tagged coho salmon 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 coho salmon 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 (see Brémaud 2013 and Johnson 2004), meaning each transition was determined solely from the current location. In this way, transitions are "memoryless," and there is no momentum associated with the previous direction and magnitude of a fish passage 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 (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.

RESULTS

Summary

From 18 September – 25 October 2017, 149 adult coho salmon (74 females; 75 males, FL = 50 – 83 cm) were collected from the Lewis River at the Merwin Dam Adult Fish Collection Facility, implanted with radio tags, and released downstream at the Merwin Dam boat launch to continue their immigrations back to the Merwin Dam trap; consequently, all study fish were trap non-naïve. Of these 149 coho salmon, subsequent detections within the telemetry array study area are visualized in Figure 5 and summarized here along with instances of tag shed, tag failure and mortalities:

- Five fish were identified as mortalities, one of which was excluded from the data set due to irregular detection sequences potentially related to tag failure.
- One (dead?) fish was found at the Lewis River Hatchery.
- One fish shed its radio tag but was later re-captured and identified by PIT tag.
- Two fish were implanted with radio tags that appear to have failed, because these fish were captured with radio tags still in place, but there were no detections within the tailrace or trap area for these fish.
    - *Tag sheds and tag failures are accounted for in the core metrics presented herein (e.g., fish re-captured without detections in the trailrace or trap were added to total counts of fish that entered the tailrace and were trapped).*
- 137 fish (92% of total) were detected at least once somewhere within the detection array (12 fish were never detected in the array, three of which were identified as mortalities based on information provided by PacifiCorp personnel).
- Among radio telemetry sites, the Entrance (n = 5) and Pool 3 (n = 22) sites detected the fewest fish; the Lewis River Hatchery (n = 107) site detected the most fish.
- 60 fish (40% of total) entered the Merwin Dam tailrace. Eleven of these 60 fish were only detected at the Bridge site, and never further into the tailrace.
- 49 fish (33% of total) were detected in the Approach zone immediately outside the trap entrance, but never entered the trap.
- 42 fish (28% of total) entered the trap entrance.

- 38 fish (26% of total), comprising 21 females (28% of 74 tagged) and 17 males (23% of 75 tagged) were re-captured at the Merwin Dam Adult Fish Collection Facility, transported upstream, and released above Swift Dam.

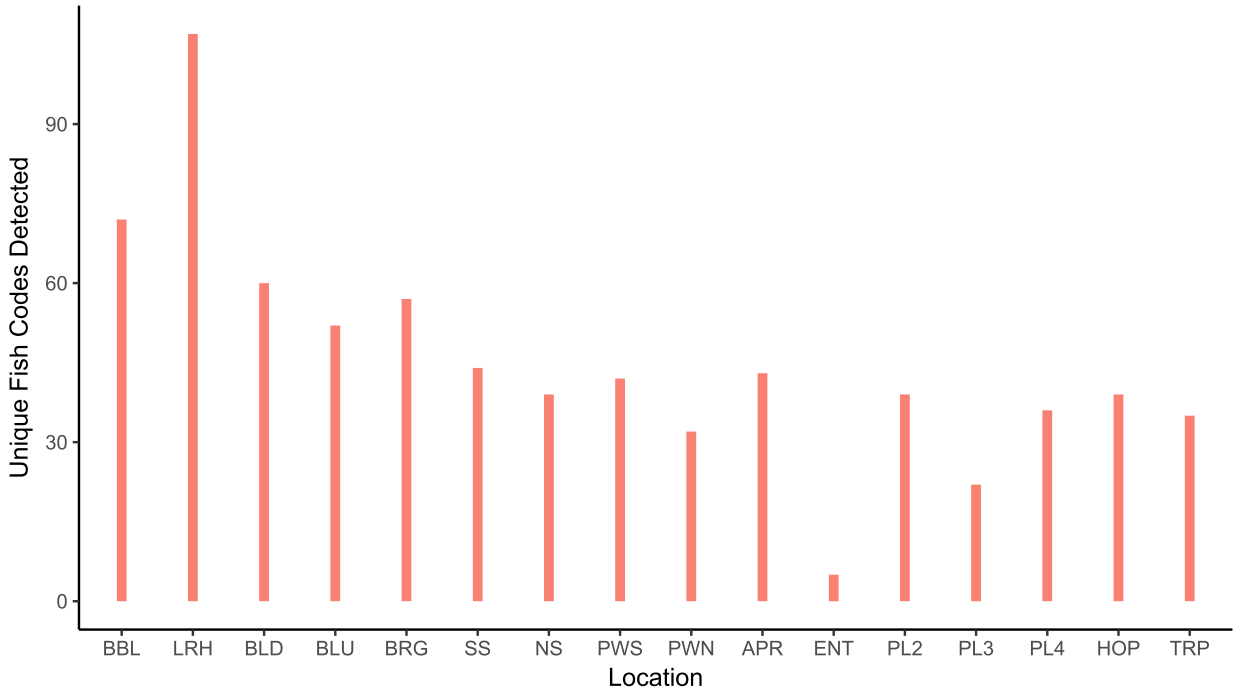

Figure 5. Numbers of unique fish codes (i.e., fish IDs) detected on each radio receiver site within the Merwin RT array. See Figure 2 and Figure 3 for receiver locations within the array.

Data Management and Processing

Database QA

There were 2,188,854 detections in the raw data, and 1,668,398 retained detections after the filter was applied.

Noise detections can prevent an antenna from detecting valid transmissions from a real transmitter (tag). In this study, noise accounted for 501,104 of total detections (23%). The number of noise detections was generally higher for sites in the tailrace compared to sites in the trap (Figure 6), with the Bridge receiver recording the majority of noise detections (68% of total noise detections).

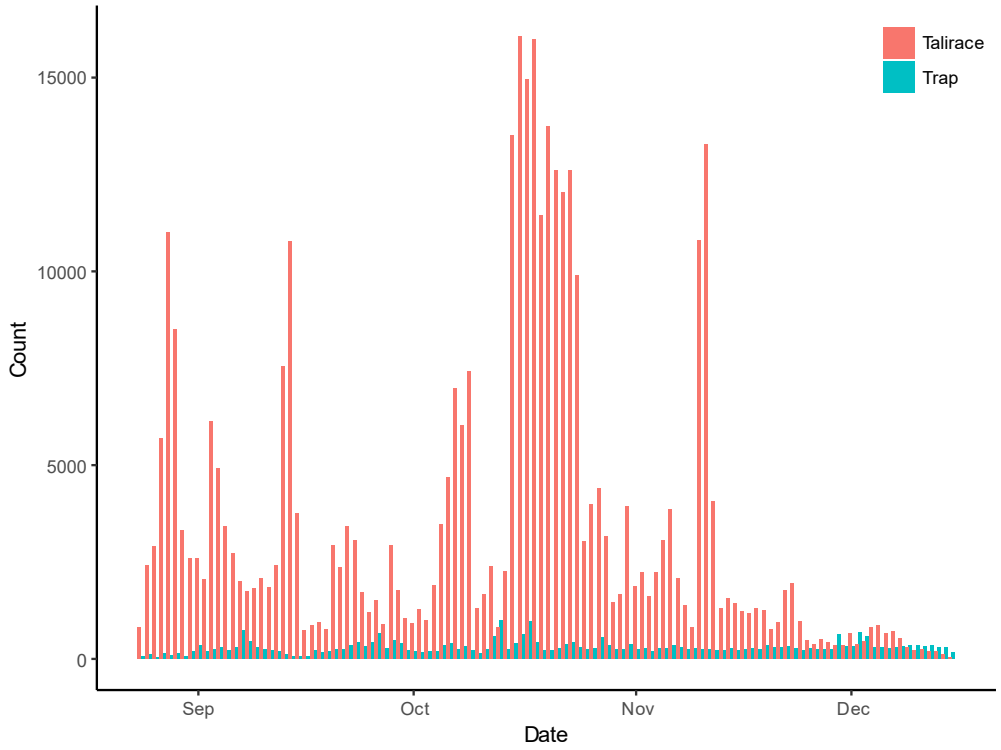

Figure 6. Total number of noise detections for trap (red) and tailrace (blue) receivers.

After removing noise detections at the BRG site, the number of noise detections were similar between receivers located at the trap and those located in the tailrace (Figure 7). The largest "peak" of noise detections came from the tailrace sites in early October (Figure 7).

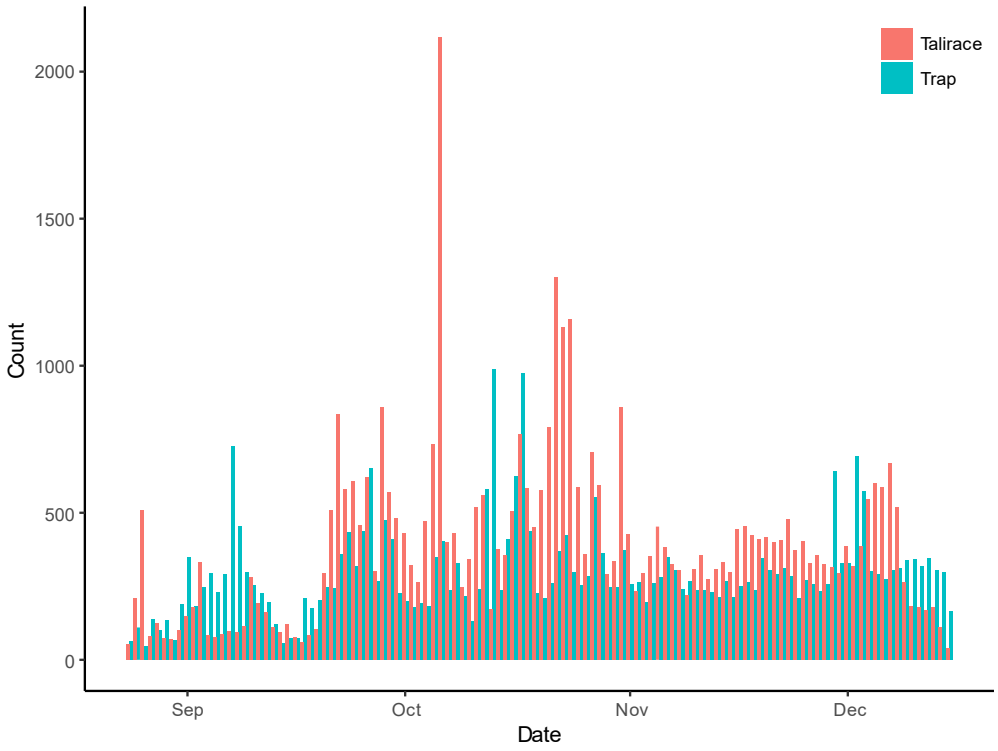

Figure 7. Total number of noise detections for trap (red) and tailrace (blue) receivers after removing noise detections that occurred on the Bridge site in the tailrace.

Upon visual inspection of detection histories for individual fish, it appeared that some of the noise detections at the Bridge site may have been false positives for tag codes used in the current study. To address this issue and reduce the number of false positive detections at the Bridge site, a more stringent filtering criterion was applied to Bridge detections (filtering criteria described in *QA Process* section above). Additionally, detection histories were visually inspected for 11 fish that were detected only as far upstream as the Bridge site and not further into the tailrace to confirm validity of inclusion of these fish in calculation of core passage metrics. Each of these 11 fish were verified as having positive detections on the Bridge site based on the following criteria:

a) the occurrence of long sequences of Bridge detections over short time intervals that matched burst rates of tags; and
b) evidence of fish leaving the Upper Boat Launch site with subsequent detection on the Bridge site within a biologically reasonable amount of time (i.e., no simultaneous detections on the Upper Boat Launch site and the Bridge).

It is important to note that large numbers of noise detections on the Bridge site indicates high sensitivity, which is by design to ensure fish entering the tailrace are not missed. This is the result of decisions made in the study design phase: post-data processing allows for identification and removal of false detections, whereas interpolating a synthetic detection(s) for a fish requires more assumptions.

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, 149 coho salmon were tagged (*N*), of which 60 were detected within the Merwin Dam tailrace (*M*), 42 were detected entering the Merwin Dam trap (*T*), and 38 were ultimately captured (*C*). These counts provide the basis for calculation of the core metrics P_{EE} = 70.0 % (42/60), ATE_{test} = 63.3% (38/60) and T_i = 9.5% (4/42; see Table 3).

During 2017, a higher proportion of coho salmon found and entered the adult trap (P_{EE} = 70.0%) compared to coho that were ultimately captured (ATE_{test} = 63.3%). This discrepancy is also reflected by the trap ineffectiveness metric, T_i = 10%, indicating that 9.5% (n = 4) of fish that entered the trap in 2017 were not ultimately captured.

Table 3. Summary of passage metrics for tagged coho approaching the tailrace of Merwin Dam during fall 2017.

Metric	Coho	Winter Steelhead	Spring Chinook
Total Tagged (*N*)	149	150	N/A
Entered the Merwin tailrace (*M*)	60	139	N/A
Entered the Trap (*T*)	42	116	N/A
Captured (*C*)	38	106	N/A
Trap Entrance Efficiency ($P_{EE} = \frac{T}{M}$)	70.0%	83.5%	N/A
Collection Efficiency ($ATE_{test} = \frac{C}{M}$)	63.3%	76.3%	N/A
Trap Ineffectiveness ($T_i = \frac{T-C}{T}$)	9.5%	8.6%	N/A

Among release groups, ATE_{test} values ranged from 0 – 100% (Table 4, Figure 8), with a non-significant relationship between release date and ATE_{test}, as determined by logistic regression of individual fish capture and release date (not shown).

Table 4. Passage metrics summarized by coho release group for 2017. See Table 3 for explanation of notation.

Release Date	*N*	*M*	*T*	*C*	Group ATE_{test} (%)
9/18/2017	10	9	8	7	78%
9/25/2017	10	6	5	3	50%
9/26/2017	10	3	1	1	33%
9/27/2017	10	4	4	4	100%
10/2/2017	10	3	2	2	67%
10/3/2017	20	5	5	5	100%
10/6/2017	5	2	2	2	100%
10/9/2017	10	0	0	0	NA
10/10/2017	7	4	2	2	50%
10/12/2017	7	4	2	2	50%
10/13/2017	10	5	4	3	60%
10/17/2017	10	5	1	1	20%
10/18/2017	10	6	4	4	67%
10/24/2017	10	3	1	1	33%
10/25/2017	10	1	1	1	100%
Total:	**149**	**60**	**42**	**38**	**See Table 3**

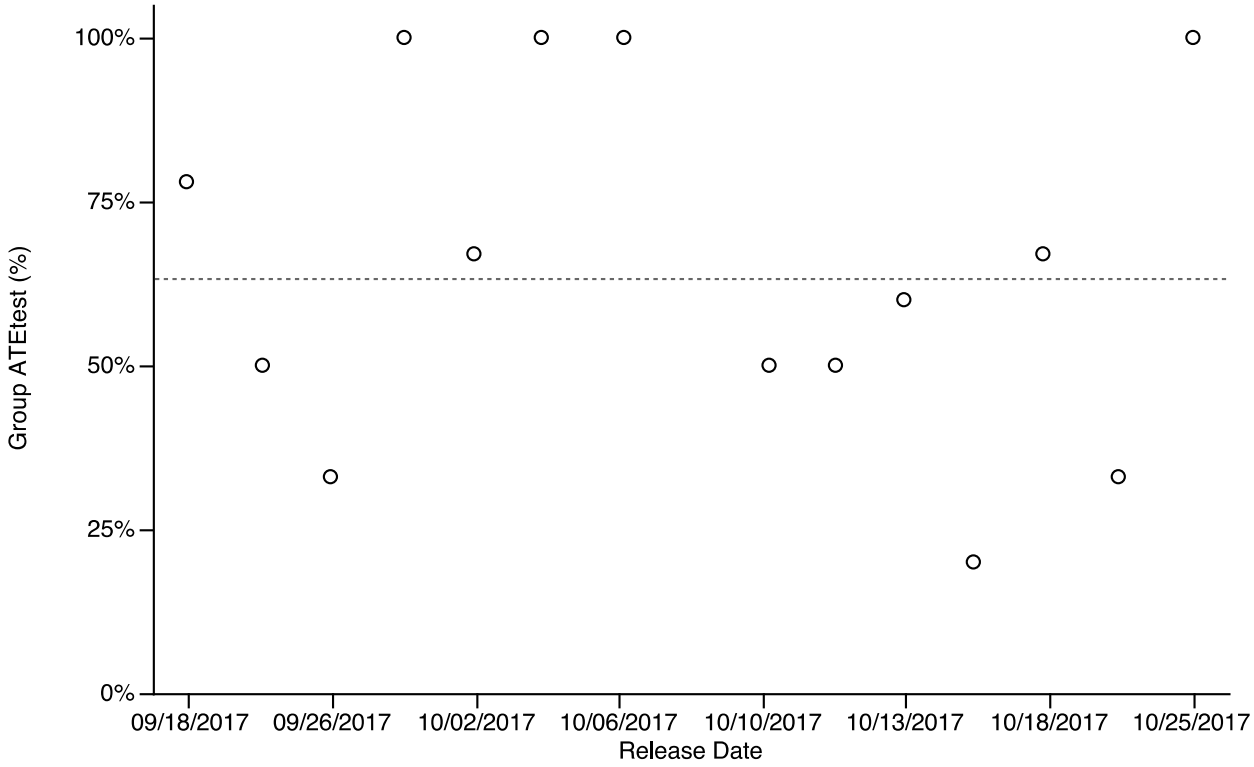

Figure 8. Release group ATE_{test} estimates over time, during 2017 coho tracking study. Dashed horizontal gray line indicates seasonal coho salmon ATE_{test} estimate for 2017.

Although we did not detect an effect of release date on ATE_{test},($\frac{C}{M}$), a significant effect (df = 148, p = 0.02) of release date on raw re-capture probability ($\frac{C}{N}$) was detected using a binomial GLM. The trend indicated a negative relationship between release date and re-capture probability [i.e., fish released later had lower probability of being re-captured (Figure 9)].

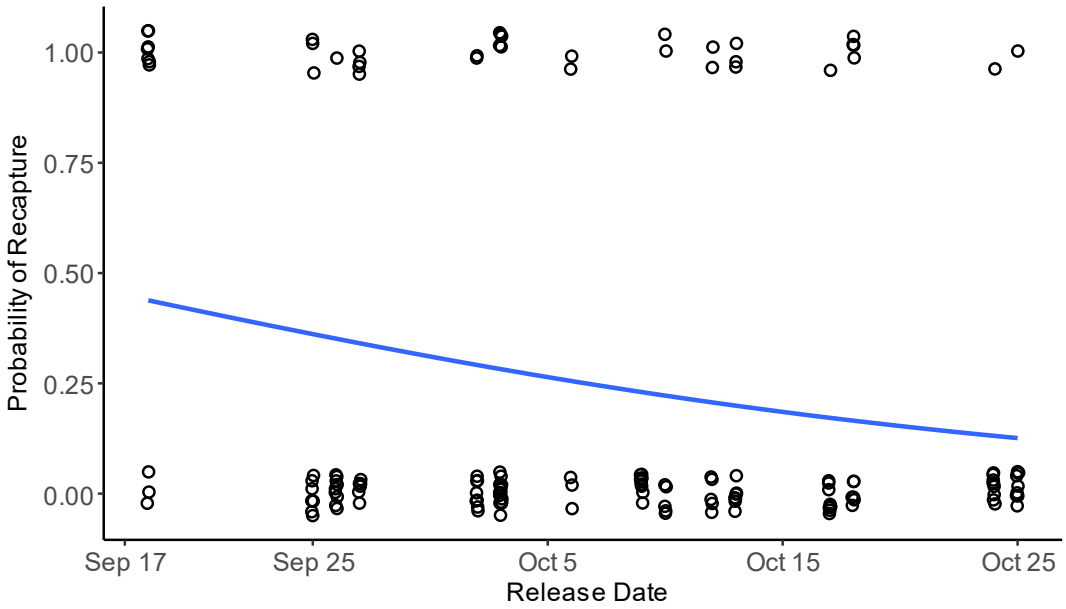

Figure 9. The raw probability of re-capture for individual fish, plotted as a function of release date. Open circles represent individual fish, and blue line indicates the predicted probability of re-capture across release date based on logistic regression. Note: all released fish were included in this analysis not just those fish that reached the tailrace.

Confidence intervals for passage metrics were generated using randomization and resampling techniques. Bootstrapping the fish passage dataset generated a BCA 95% CI of 49.7 – 74.4% that converged on stable estimates when the total number of randomized resampling iterations exceeded approximately 1,000 (Figure 10). This precision estimate enables the calculated ATE_{test} for 2017 to be contextualized appropriately: we are 95% confident that, for 2017, 49.7% < ATE_{test} < 74.4% for the study population of Lewis River coho salmon 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 coho salmon 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.

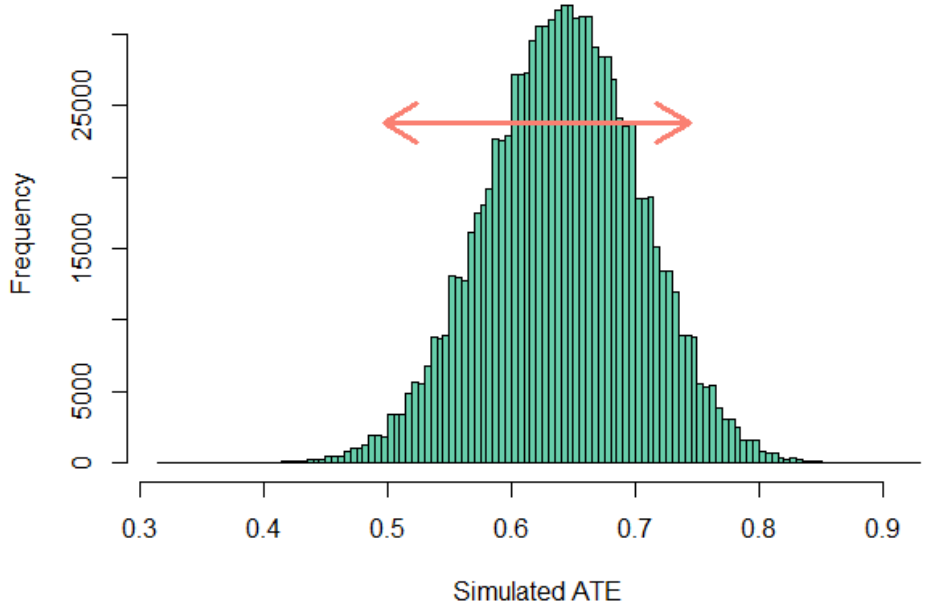

Figure 10. Bootstrap simulated frequencies of *ATE* calculated from one million iterations of randomly resampling (with replacement) the sample of 60 study fish that reached the Merwin Dam tailrace. Horizontal bi-directional arrow indicates BCA 95% CI (49.7 – 74.4%). Note that target *ATE* was reached in zero of one million simulations. 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 parent population of Lewis River coho salmon attempting to pass and spawn in reaches above Merwin Dam may actually have exhibited *ATE* = 98%, even though ATE_{test} = 63% for tagged fish that entered the Merwin Dam tailrace, we conducted an urn simulation. When simulated subsamples of 60 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 63% (Figure 11). Among this set of one million ATE_{sim} values, the lowest was 87%. Thus, it is highly unlikely that our 2017 observation of ATE_{test} = 63% for coho could have come from a parent population that truly exhibited 98% (ATE_{target}).

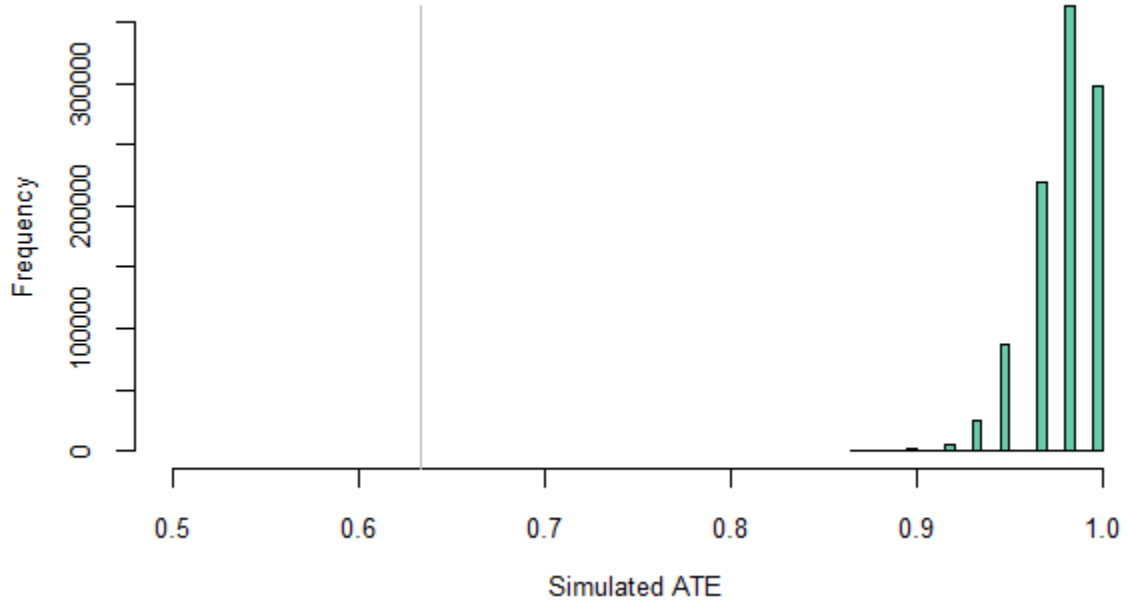

Figure 11. Simulated frequencies of *ATE* calculated from one million iterations of randomly subsampling a set of 60 fish from a simulated "urn" population of 10,000 fish that truly exhibited 98% *ATE*. Vertical gray line indicates observed ATE_{test} of 63.3%. Note that ATE_{test} reported here for 2017 was reached in zero of one million simulated subset samples of 60 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 coho salmon movements throughout the study area illustrates the tendency of fish to move widely within the tailrace (Figure 12). 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 12). However, there was very little difference between proportions of fish using either the South Shore or North Shore routes after leaving the Bridge.
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 12).
3) Individuals exhibit milling behaviors (blue lines in Figure 12) along both north and south sides of the tailrace, between receivers Bridge ↔ South Shore, and Bridge ↔ North Shore.
4) Within the trap, the majority of milling occurred between Pool 4 ↔ HOP.
5) Milling also occurs immediately downstream of the tailrace between receivers Upper Boat Launch ↔ Bridge.

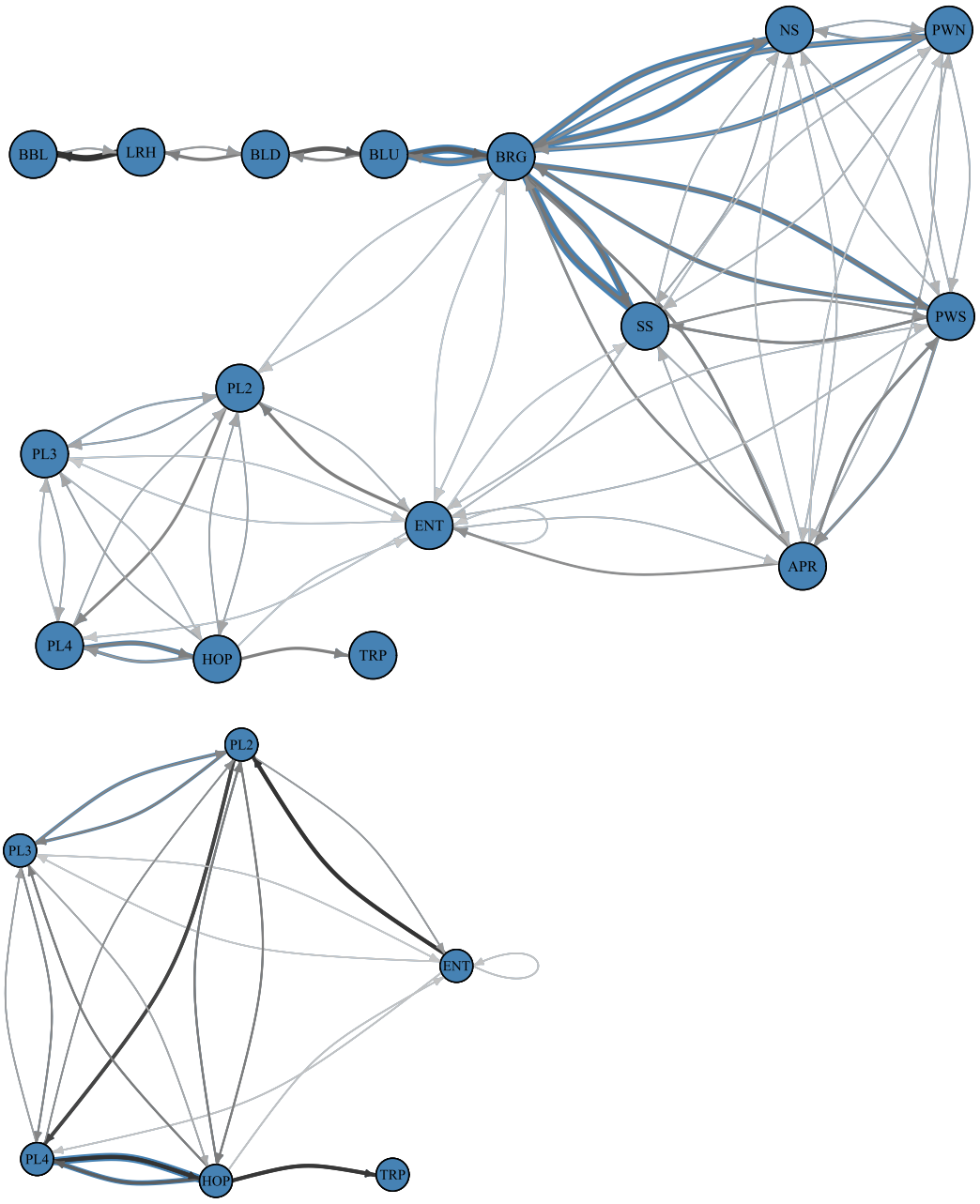

Figure 12. Network diagram of fish movement within study area. Path thickness and color are scaled based on the total number of individual fish traveling the paths (thicker paths represent a higher number of fish taking the path at least one time across their detection history). Grey paths are scaled to represent the total number of fish that traveled between sites (individuals as the sample unit). 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 13). 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 – 20% probability of next being detected at one of five sites within the tailrace. The probability of being detected next (after the Bridge) was similar for the South Shore site (with a 21% probability) and the North Shore site (with a 19% probability).
2) There was a 22% probability of fish at the Bridge site next being detected at downstream sites.
3) Once a fish has nosed into the trap at the Entrance receiver, there are eight potential sites at which a fish will be detected next, the most likely of which (with a 58% probability) is further into the trap at the Pool 2 site.
4) Once inside the trap and detected in Pool 2, there was a 93% probability of the fish being detected further into the trap, the most likely (with a 40% probability) being further upstream at Pool 3 receiver. Conversely, there was a low probability (6%) of fish moving from inside the trap at Pool 2 to the Entrance receiver, and an even lower probability (1%) of fish moving to other receivers in the tailrace.

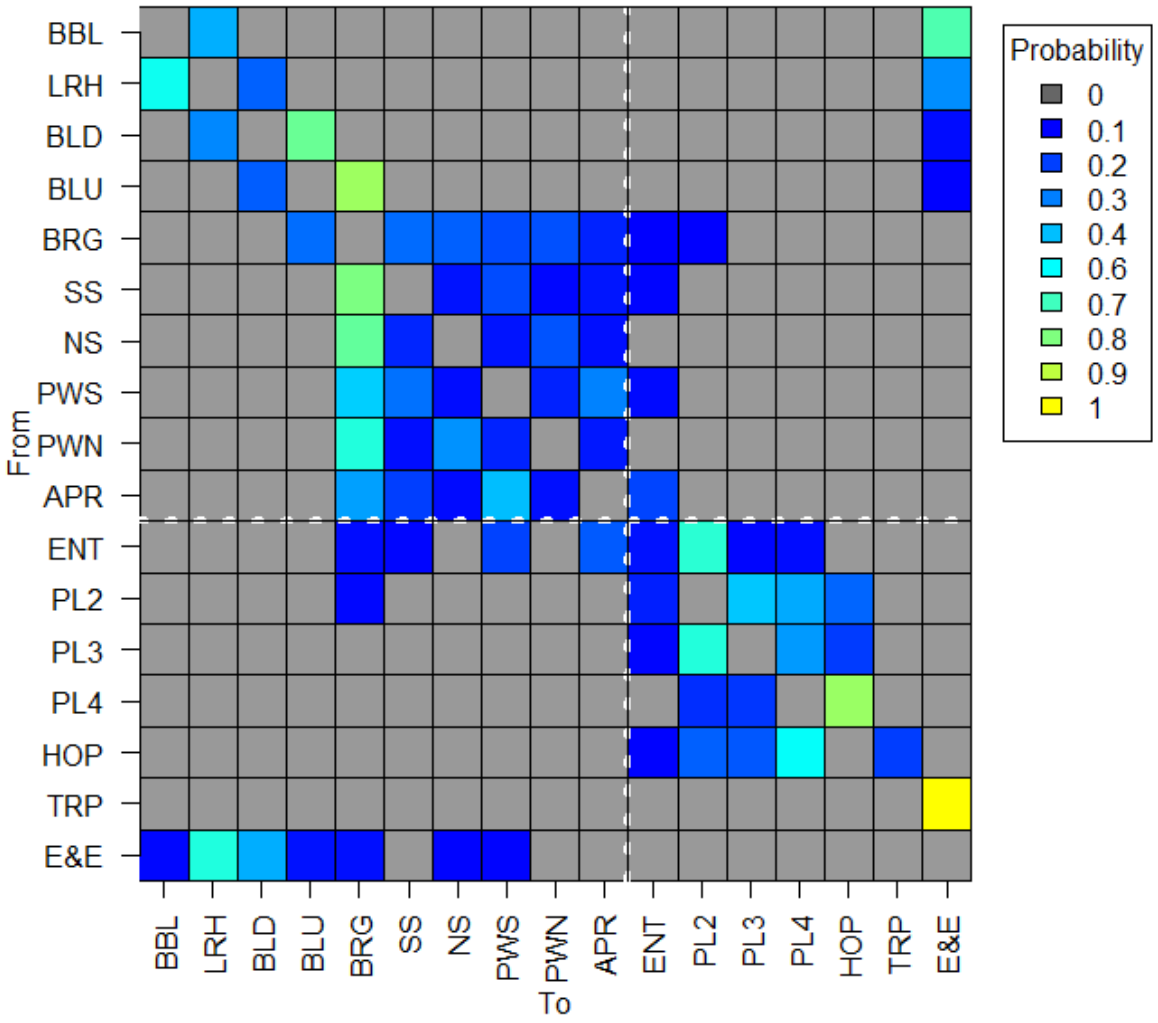

Figure 13. Heat map of the transition probabilities of fish moving from an origin site to all potential destination sites. Each row sums to a probability of 1. Dashed reference lines are added between the Approach and Entrance receivers to show the distinction of a fish being located within or outside of the trap. Matrix quadrants represent categorically distinct behavior patterns: Probabilities in the upper left box represent movements that begin and end in the river or tailrace. Probabilities 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. Probabilities in the lower left box begin in the trap and end in the river or tailrace. 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 14), it is apparent that fish do not tend to move directly into the trap. More than half of the fish that were eventually re-captured had performed 75 or more unique site visits before being trapped. Fish that were not re-captured visited 80 fewer sites on average than fish that were re-captured.

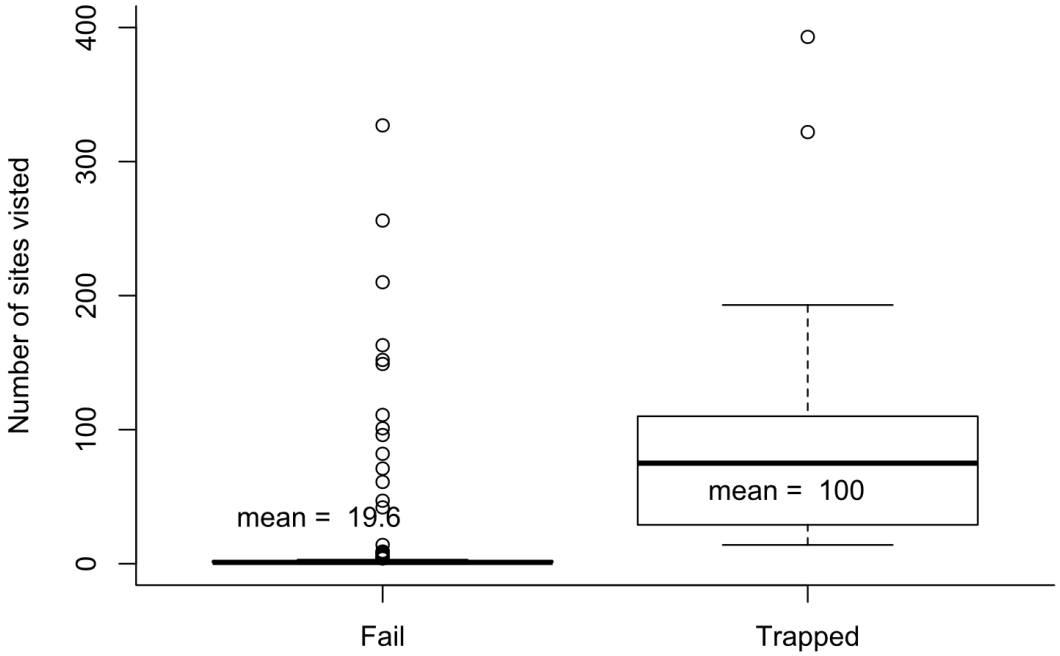

Figure 14. Number of sites visited before being captured (Trapped) or in the case of fish that were not captured, before the end of the study (Fail).

In general, fish tended to move upstream through the telemetry array study area from the Downstream Boat Launch to the tailrace, with most sites having a forward transition probability greater than 50% ($p \geq 0.50$) (Table 5). Once in the tailrace, fish tended to mill, only slowly moving forward into the system (if at all). Of note, fish at Pool 2 had the greatest probability of transitioning to receivers upstream. The three sites with the highest *MI* values (i.e., those where fish milled) for both collected and non-collected fish were: South Shore, North Shore, and Hopper.

Transition probabilities and milling behavior differed between collected and not collected fish (Table 5). Compared to fish that were collected, fish that were not collected had:

- lower probabilities of transitioning forward from all sites downstream of the tailrace;
- more milling behavior at the Bridge site;
- lower probabilities of transitioning forward into the trailrace from the Bridge sites; and
- lower probabilities of transitioning into the Entrance from the Approach site

Table 5. 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., *Fail*), for fish collected (i.e., *Pass*), and for collected and not collected fish combined (i.e., *Total*). For site abbreviations, see Table 2.

Receiver	$P_{single, Fail}$ (not collected)	$P_{all, Fail}$ (not collected)	MI_{Fail}	$P_{single, Pass}$ (collected)	$P_{all, Pass}$ (collected)	MI_{Pass}	$P_{single, Total}$ (collected and not collected)	$P_{all, Total}$ (collected and not collected)	MI_{Total}
BBL	0.197	0.254	-0.057	1.000	1.000	0.000	0.284	0.346	-0.062
LRH	0.103	0.133	-0.029	0.579	0.545	0.033	0.170	0.193	-0.023
BLD	0.397	0.648	-0.251	0.848	0.881	-0.032	0.560	0.707	-0.146
BLU	0.458	0.772	-0.314	0.811	0.921	-0.110	0.612	0.811	-0.199
BRG	0.681	0.559	0.122	0.901	0.918	-0.016	0.827	0.783	0.044
SS	0.556	0.318	0.237	0.486	0.189	0.297	0.505	0.219	0.286
NS	0.448	0.243	0.205	0.386	0.224	0.162	0.407	0.232	0.175
PWS	0.258	0.193	0.065	0.293	0.299	-0.006	0.285	0.275	0.010
PWN	0.192	0.065	0.127	0.113	0.041	0.072	0.139	0.047	0.092
APR	0.111	0.056	0.055	0.294	0.158	0.136	0.250	0.136	0.114
ENT	0.364	0.294	0.070	0.739	0.701	0.038	0.667	0.619	0.048
PL2	0.667	0.875	-0.208	0.862	0.937	-0.075	0.825	0.926	-0.101
PL3	0.667	0.535	0.132	0.563	0.383	0.180	0.585	0.421	0.164
PL4	0.444	0.712	-0.267	0.620	0.823	-0.203	0.593	0.802	-0.209
HOP	0.000	0.000	0.000	0.400	0.142	0.258	0.351	0.118	0.233

When evaluating transition probabilities at each site to determine how fish moved through the system, it becomes apparent that non-recaptured fish tended to move further downstream from the tailrace sites, especially between Lewis River Hatchery and Bed & Breakfast sites (Figure 15). In comparison, re-captured fish tended to move upstream through the array (Figure 15). However, within the tailrace, spatial behavior patterns are similar between successfully and unsuccessfully re-captured fish.

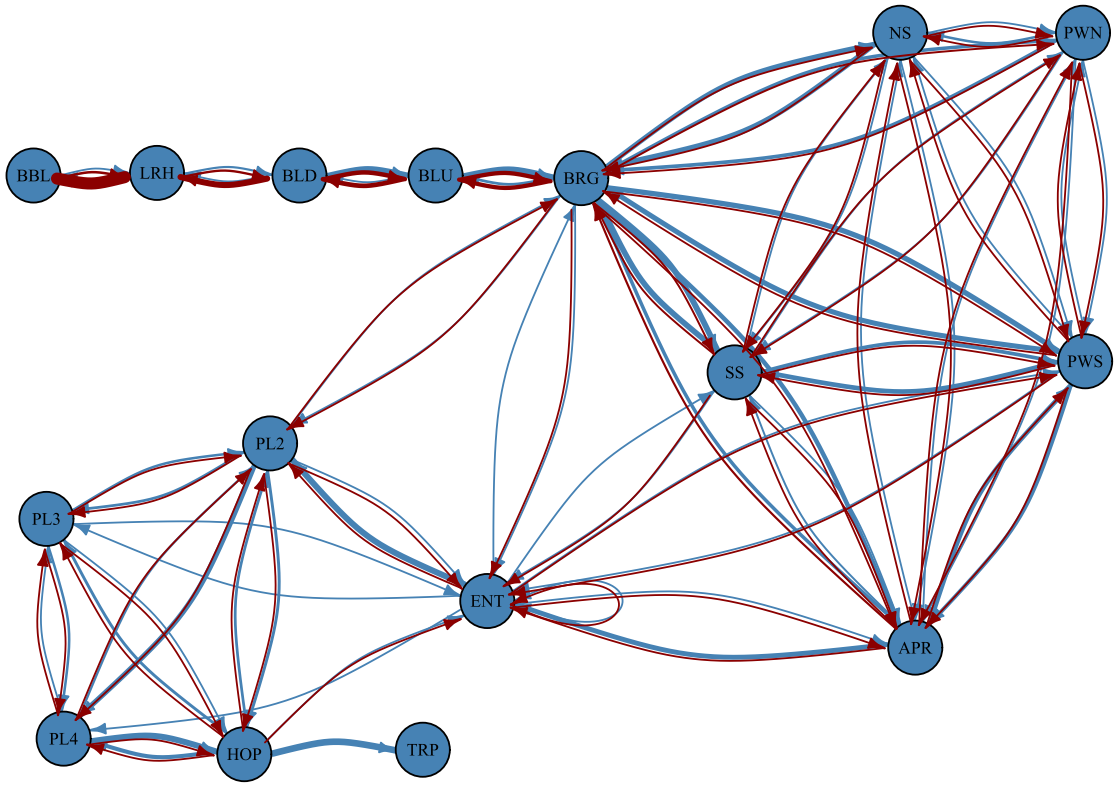

Figure 15. Network diagram of fish movement within the study area at Merwin Dam grouped by fish that ultimately are re-captured (blue) or failed to be re-captured (red) from 2017. Path thickness and color are scaled based on the total number of transitions which occurred between sites with fish as the sample unit. This graphic depicts the movements of 137 fish; 35 that were successfully re-captured (i.e., last detected at Trap) and 102 that were unsuccessful. This figure does not include movements of fish that experienced tag shed or tag failure.

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, there was not a clear difference between fish behaviors along the north and south side of the tailrace with both zones tending to have simlar numbers of visits (*n*) and high median residence times (Figure 16; Figure 17). Evaluation of coho salmon behaviors within the tailrace revealed the following observations:

1) Fish had the highest median residence time, total number of visits and were detected for the largest total amount of time at the Bridge receiver, suggesting a relativley large detection radius for the Bridge receivers (i.e., the Bridge recievers were detecting fish further in the tailrace).
2) Excluding the Bridge site, fish spent the most time within the tailrace holding at the Approach site, and to a lesser extent, the Powerhouse North based on high median residence time and releatively fewer total number of visits.
3) Fish spent more time milling along the south side of the tailrace compared the north side of the tailrace, based on higher numbers of visits to the South Shore and Powerhouse South sites compared to the North Shore and Powerhouse North sites.
4) Once inside the trap, fish spent the most time holding inside the Hopper and Pool 2, based on high median residence time at these sites.
5) Fish did not spend a large amount time holding at the Entrance or Pool 3 sites based on low median residence time, low numbers of visits, and low total time spent at these sites.

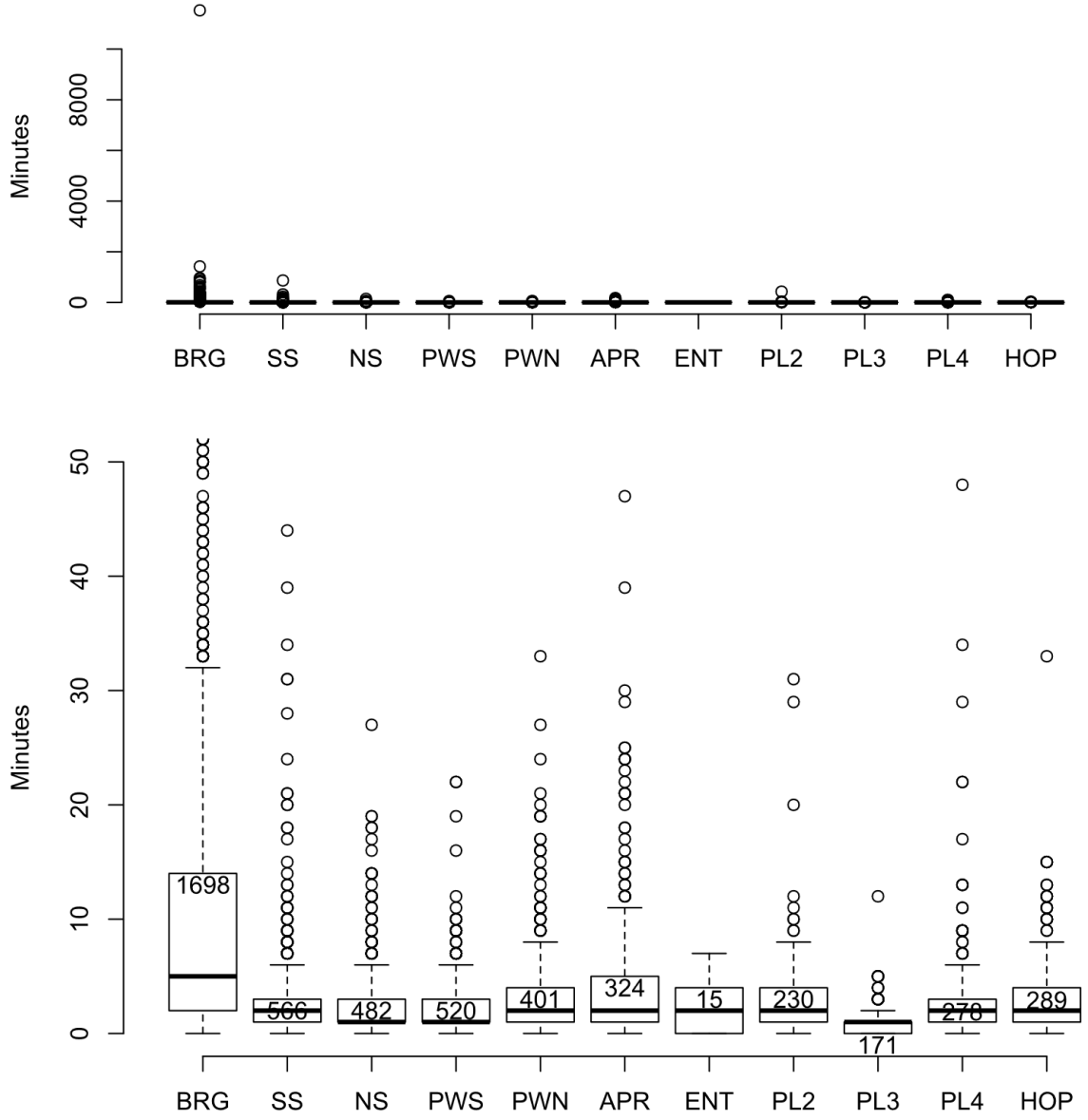

Figure 16. Median residence times by sites in the tailrace and trap. The top figure shows the full range of data, including outliers (open circles), while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Number of visits (n) is displayed in the top of the box plots for each site. (*Caveat: these data are not scaled based on the detection ranges of each site.*)

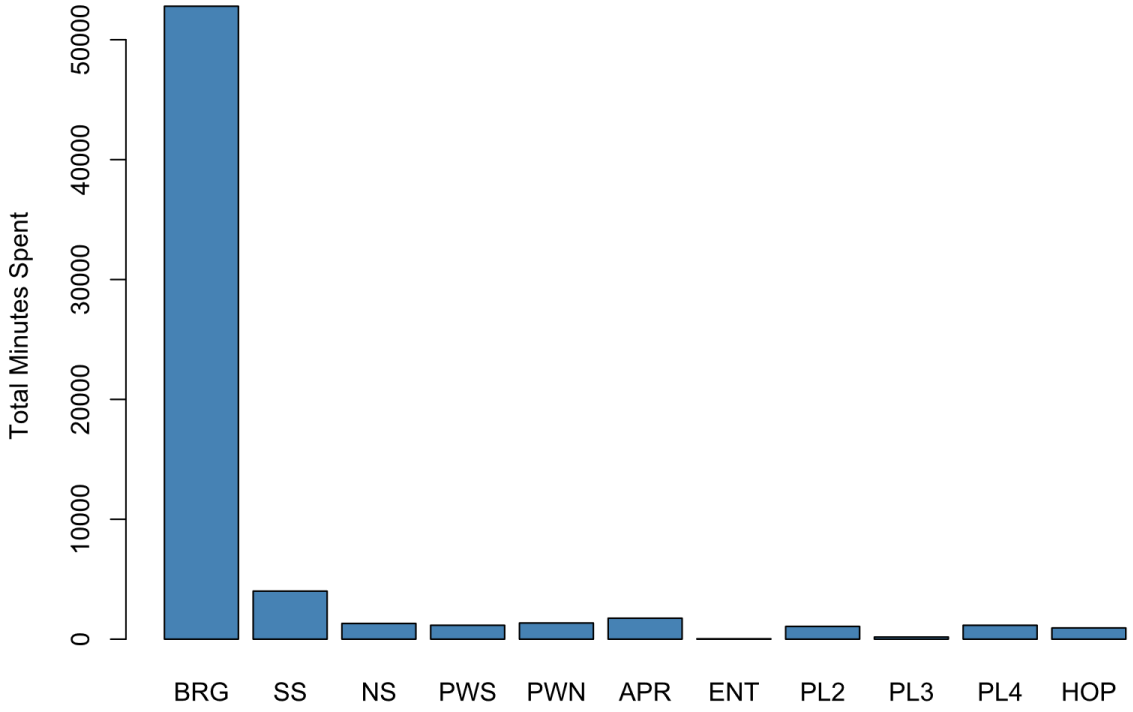

Figure 17. Total time spent by all coho salmon in each site in the tailrace and trap. *Caveat: these data are not scaled based on the detection ranges of each site*.

At locations downstream of the tailrace, fish held near the Bed & Breakfast location based on a low number of detections, high median residence, and total time spent at this location. Fish also held at the Lewis River Hatchery location (Figure 18). Once upstream of the hatchery, individual fish did not spend much time near the Boat Launch sites (Figure 18).

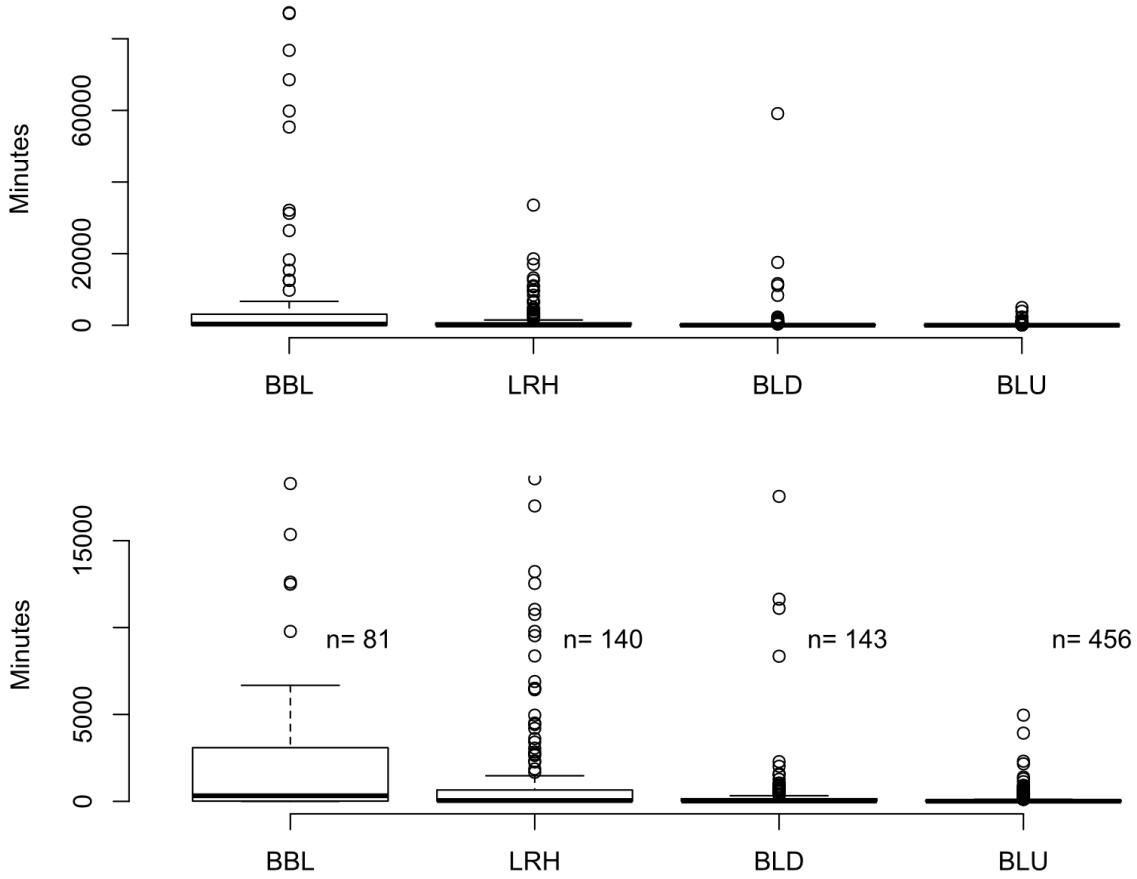

Figure 18. Median residence times for downriver sites. The top figure shows the full range of data, including outliers, while the bottom figure zooms in to show the box and whisker plots, focusing on inter-quartile range. Sample size (n) is displayed in the top of the box plot for each site. *Caveat: these data are not scaled based on the detection ranges of each site*.

When aggregated across all coho salmon included in the 2017 study, the total amount of time spent at the Boat Launch (177,909 minutes or ~ 124 days) accounts for only 17% of the total time spent at locations downstream of the trailrace (Figure 19).

Interestingly, fish spent a total of 657,275 minutes (~387 days) at the Bed & Breakfast location, which is 10 times greater than the amount of time spent in the tailrace (fish spent a total of 65,636 minutes or ~ 45 days in the tailrace).

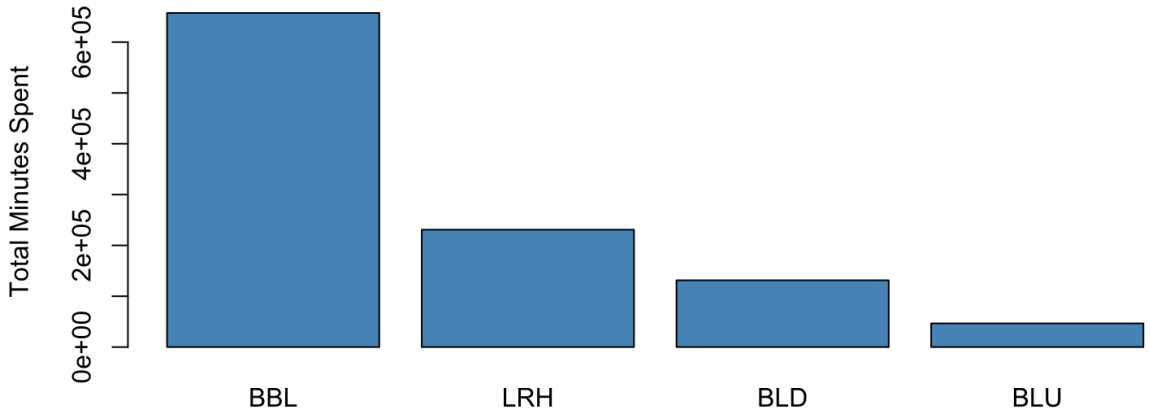

Figure 19. Total time spent by all coho salmon in each downriver site. *Caveat: these data are not scaled based on the detection ranges of each site*.

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 coho salmon in the Merwin Dam tailrace was 5.6 hours (range = <2 minutes – 192 hours). The upper end of this range may represent total time spent during multiple trips through the tailrace. Only 1 coho salmon (approximately 2% of the 38 fish that passed) had a tailrace residence time greater than 168 hours. Thus, both performance standard compliance metrics for safe, timely, and effective passage were met. For reference, in 2015, the performance standard for median tailrace residence, but not for percentage of fish with tailrace residence time >168 hrs, was met for coho salmon (Table 6).

Table 6. Achieved performance standard compliance metrics for safe, timely, and effective passage across three study years for three study species at Merwin Dam. Sample sizes (*N*) are for total number of fish tagged.

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	149	5.6 hrs (0.03-192 hrs)	2%

Additionally, the following insights regarding tailrace residence times were apparent from evaluation of the detection data:

- Eighteen coho salmon entered the tailrace but never entered the trap.
    - These fish exhibited a median tailrace residence time of 4.9 hours (range = 0.33 – 62 hours), with none exhibiting a tailrace residence time >168 hours.
- Four coho salmon entered the trap but were never captured.
    - These fish exhibited a median tailrace residence time of 5.9 hours (range = 4.17 – 49 hours), with none exhibiting a tailrace residence time >168 hours.
- Thirty-eight coho salmon entered the trap and were captured successfully.
    - These fish exhibited a median tailrace residence time of 5.7 hours (range = 0.52 – 86 hours), with none exhibiting 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

At total of 149 fish were tagged, of which 137 fish were detected somewhere in the study area, and thus had radio detection data available to describe movements downstream of the final Trap receiver. The following insights can be made on the movements of these 137 fish with detection data available, but it should be noted that the numbers presented below do not account for tag sheds and, therefore, do not correspond to those presented in Table 3 above. Also, the groups below represent intersecting (not mutually exclusive) sets, and thus do not sum to 137.

Of the 137 fish detected somewhere in the study area:

- 80 fish (58%) failed to enter the tailrace.
- 57 fish (42%) were detected somewhere in the tailrace. Of these 57 fish detected somewhere in the tailrace,
    - 7 fish (5%) returned to downriver sites (i.e., below the access bridge); 2 of these 7 (29%) were eventually successfully captured while the remaining 5 fish were not.
    - A total of 39 fish (28%) were detected somewhere in the trap ladder system. Of these 39 fish that were detected in the trap ladder,
        - 15 fish (39%) returned to the tailrace after first visiting the trap; three of these 15 fish never made it further than the Entrance before exiting.
        - Of those 15 fish that moved back downstream (into the tailrace) after their first post-tagging encounter with the trap,
            - 10 fish (67%) were eventually captured; the remaining 5 fish were not.
        - Approximately 62% of fish that entered the trap (24 of 39) continued through and were captured on their first post-tagging encounter with the trap.
- 102 fish (73%) were not re-captured but were detected somewhere in the study area. Of those 102 fish,
    - 95 fish (93%) were last detected at the furthest two downstream receivers, the Bed & Breakfast (n=53; 53%) and Lewis River Hatchery (n=42; 41%) sites (Table 7).

Table 7. Last known location for the 102 fish that were not re-captured but were detected somewhere in the telemetry array.

Site of Last Detection	n
Bed & Breakfast	53
Lewis River Hatchery	42
Boat Launch Downstream	4
Boat Launch Upstream	2
Bridge	1
Total	**102**

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

Only re-captured radio tagged fish were included in the injury assessment, because including maiden captured fish in injury assessments would be problematic, as, prior to being trapped, fish have traveled long distances and are subject to other sources of injury that cannot be separated from those caused by trapping operations. Only healthy coho salmon free of injury were tagged in the study. Once a radio tagged fish was re-captured, it was then inspected for injury and any found injuries were assumed to be caused by trapping effects.

No injuries were observed on any of the fish that were re-captured at Merwin Fish Trap. Similarly, no transport mortalities were observed for any of the re-captured fish. Therefore, it was determined that there was an observed trapping injury rate, as well as a transport mortality rate of 0% for coho salmon in 2017.

Objective 7: Operational Analysis

We performed four 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 similar percentage of captured fish and median number of sites visited compared to raw data values.

Model 1 (installation of trap located along the north shore): Compared to the control model, this scenario increased *ATE* by 16% (10 percentage points), to 72%, and reduced the average number of sites visited. 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 and therefore should be considered conservative.

Model 2 (installation of a moderately effective fyke between Pool 3 and Pool 4): Compared to the control model, this scenario increased *ATE* by 2% (1 percentage point), to 63%, and reduced the average number of sites visited by only one site.

Model 3 (installation of a highly effective fyke between Pool 3 and Pool 4): Compared to the control model, this scenario increased *ATE* by 2% (1 percentage point), to 63%, and reduced the average number of sites visited by only two sites.

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

Model	Description	*ATE*	Sites Visited (AVE)	Sites Visited (MED)
Raw empirical data	Values from data	63%	40	1
Model Un-modified	Control	62%	45	4
Model 1	Allow Powerhouse North to transfer to Entrance at a similar rate as Approach to Entrance	72%	37	4
Model 2	Reduce rate of travelling backwards from PL4 by 50% (Fyke potential)	63%	44	4
Model 3	Reduce rate of travelling backwards from PL4 by 90% (Fyke potential)	63%	43	4

DISCUSSION

This report focuses on coho salmon collected and tracked during 2017; results from 2017 steelhead were provided in a separate report (see Drenner et al. 2017).

In 2017, total of 149 coho salmon were tagged, of which:

- 137 were detected at least once somewhere within the detection array;
- 60 entered the tailrace of Merwin Dam (*M*);
- 42 entered the trap (*C*), resulting in a P_{EE} ($\frac{C}{M}$) of 70%; and
- 38 were successfully captured (*T*), resulting in an ATE_{test} ($\frac{T}{M}$) of 63%.

ATE_{test} for the 2017 study was 63% and BCA 95% CI for ATE_{test} ranged from 50.0 – 74.4. Thus, we are 95% confident that our observation of ATE_{test} was below the 98% ATE_{target}. Additionally, it is statistically unlikely that the parent population of Lewis River coho salmon truly exhibited $ATE \geq ATE_{target}$, given the sample of fish that reached the Merwin Dam tailrace exhibited an ATE_{test} of only 63%. Out of one million iterations of randomly drawn samples of 60 fish from an urn-style population modeled to truly exhibit 98% passage, zero samples exhibited ATE_{sim} as low as the ATE_{test} value measured during 2017.

Although *ATE* performance standards for were not met for coho salmon in 2017, performance standards for tailrace residence time were met. Median tailrace residence time for coho salmon (including both re-captured and not re-captured fish) in 2017 was 5.6 hours, which is less than the regulatory standard of 24 hours. In addition, only 2% of coho salmon in 2017 took longer than 168 hours to pass, which is less than the regulatory standard of 5%.

Accurate estimates of core passage metrics, such as ATE_{test}, depend on high detection efficiencies of radio receivers within the tailrace. The Bridge site acts as the "start line" for fish entering the tailrace, and therefore detection at the Bridge is the critical criterion for fish being included to estimate ATE_{test} (the number of fish trapped, *C*, out of the number of fish that enter the tailrace, *M*). In the 2017 coho salmon study, the Bridge receiver appeared to be highly sensitive based on evidence including the following:

1) Large amount of noise detections on the Bridge receiver (68% of total noise detections were from the Bridge receiver).
2) High median residence time, number of visits, and total time spent at the Bridge site.
3) Intermittent Bridge detections that occurred between detections at other sites within the tailrace, suggesting overlap between detection zones for Bridge and other tailrace sites.

Thus, steps were taken to minimize the effects of high sensitivity at the Bridge site including:

1) More stringent data filtering applied to the Bridge site requiring four or more detections in a sequence that occurred in less than 15 minutes.
2) Visual inspection of fish detection histories for eleven fish that reached the Bridge but were not detected on other receivers within the tailrace.

It should be noted that eleven fish were included as fish that "entered the tailrace" but were only detected at the Bridge site and never further into the tailrace. All fish that were assigned as "entered the tailrace", and therefore contributed to estimates of ATE_{test}, were confirmed based on multiple observations and lines of inference. Hence, we are highly confident in the estimates of core metrics presented herein. However, it is important to note that the number of transitions to and from the Bridge receiver from other sites within the tailrace, the total number of "visits" to the Bridge site, and residence time and total time at the Bridge site are likely inflated due to overlap between the Bridge site detection zone and zones of other sites in the tailrace, which are ≤ 300 m (1,000 ft) apart. These potentially inflated metrics do not influence overall results and interpretations of the data.

Passage metrics for coho salmon in 2017 were substantially improved compared to those for coho salmon in 2015, the only other study year to include coho salmon. However, we caution that comparisons of coho salmon ATE_{test} between years may not be appropriate due to large differences in samples sizes between 2015 (n=35) and 2017 (n=149). Additionally, hatchery fish were used in 2015 whereas NOR fish were used in 2017. Environmental factors could also contribute to observed differences in ATE_{test} between years. For example, 2015 was an exceptionally low-water year whereas 2017 was a high-water year. Accounting for interannual environmental variation and difference between hatchery and NOR fish would help resolve differences in passage metrics observed for coho salmon between years.

Consistent with findings in previous study years, during the 2017 study year, coho salmon appeared to locate and enter the trap at a higher rate (P_{EE} = 70%) than the rate at which they were captured (ATE_{test} = 63%). This observation is reflected by a trap ineffectiveness (T_i) of 9.5% for 2017, which was lower than values reported in 2015 and 2016 study years. Reduction in T_i for 2017 compared to 2015 and 2016 was likely the result of a fyke that was installed within the trap ladder prior to the 2017 tagging study and corresponds to findings presented in the 2017 steelhead report, which directly examined fyke effectiveness (Drenner et al. 2017). Despite improvement in trap retention, in 2017, 12 coho salmon were able to exit Pool 2, represented by a total of 21 exit events from Pool 2. Fish may have exited Pool 2 through a gap above the fyke present during periods of high discharge. PacifiCorp plans to block the gap prior to future studies.

Attraction, rather than retention, appears to be the primary factor limiting coho salmon 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% (this is true for all study years and species thus far). This observation is further bolstered by the urn simulation results described above, which indicated that zero of one million random subsamples of 149 fish from a parent population truly exhibiting *ATE* = 98% would exhibit ATE_{test} < 87%.

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 were modeled previously for steelhead salmon (Caldwell et al 2017; Drenner et al. 2017) and were modeled in this study for coho salmon. In this year's coho salmon study, this model showed an increase in *ATE* to 72% after addition of a second trap entrance, which remains below the performance standard of 98% *ATE*. It should be noted that these modeled differences in *ATE* does not account for hydraulic

changes associated with the addition of a second trap entrance, and therefore is likely a conservative estimate.

Additional simulation models from this study tested the effects of installing an additional fyke at the transition between Pool 3 and Pool 4. Results from these efforts indicated negligible increases in *ATE* values, which remained at 63% (only one percentage point higher than control models). 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 there was no clear pathway coho salmon took to locate the trap after entering the tailrace, which is consistent with results from previous studies across salmon species. Evidence to support this from 2017 and previous study years is summarized below:

1) After entering the tailrace, coho salmon most frequently took a path along the south side, however the percentage of fish detected at the South Shore versus the North Shore sites after entering the tailrace was 53% and 47%, respectively, indicating only minor differences between the paths taken.
2) Studies from previous years showed inconsistent results with coho salmon generally using the north shore more frequently in 2015 and the south shore more frequently in 2017, which may be related to differences in tailrace conditions among years.

Our observation that fish do not necessarily use the south shore more frequently than the north shore is somewhat surprising given the presence of attraction flows being discharged from the trap entrance on the south side of the tailrace. Navigational cues (e.g., odors) within attraction flows may become dispersed in the tailrace due to turbulent flows, and therefore, may not present a clear direction path fish can follow to locate the trap entrance. Alternatively, it has been suggested that coho salmon prefer slack water edges, and there is less flow along the north side of the tailrace, which may contribute to our observations that coho salmon use the north side more frequently.

Despite no clear pathway to the trap entrance, fish are still able locate the trap entrance at a higher rate than they enter the trap. Out of the 60 fish that entered the tailrace, 82% (n = 49) reached the Approach site located directly outside of the trap entrance in the tailrace, yet 14% (n = 7) of those fish never entered the trap area. Hypothetically, if all 49 fish that located the trap entrance were eventually re-captured at the same rate as fish that entered the trap in this study (90.5% of fish that entered the trap were eventually re-captured in this study), *ATE* estimates for coho salmon in 2017 would have increased by 11 percentage points to 74%. Nonetheless, this would still be below the *ATE* performance standard of 98%.

Only 40% (n=60) of tagged and released coho salmon reached the tailrace, despite being released less than one kilometer downstream of the tailrace. Of those fish that entered the tailrace, 22 (37%) were never re-captured. Among all coho salmon not re-captured (including fish that entered the tailrace and trap), 95% were last detected at the furthest downriver detection sites, the Lewis River Hatchery and Bed & Breakfast. Of note, fish that were not re-captured showed less exploratory behavior, visiting five-times fewer sites on average than re-captured fish. Overall, the above indicates that coho salmon in 2017 were not strongly attracted to the tailrace, and conversely, may have been more attracted to downstream locations, which could be associated

with genetic, physiological, or energetic factors. For example, fish that are more reproductively mature and/or have less energy reserves may be less likely to continue migrating rather than selecting to spawn downstream (assuming fish have some innate ability to sense longevity). Or, recovery following tagging may impede resumption of upstream migratory behaviors, and fish may instead volitionally (or semi-volitionally) swim/drift downstream until sufficiently recovered. Overall, NOR coho salmon used in this study are assumed to be from the upper basin, and therefore, should have the desire to migrate further upstream. Thus, it is surprising that more fish were not attracted to the tailrace and trap.

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 the ATE_{test} statistic is an appropriate surrogate for inferring the *ATE* parameter of the parent population). As discussed in previous reports (Caldwell et al. 2017, Drenner et al. 2017), fish used to estimate ATE_{test} are trap non-naïve: they had previously navigated to the Merwin Dam tailrace, located the trap entrance, ascended the trap ladder, and were successfully captured. The issue of using trap non-naïve fish continues to be a potential source of bias on observed ATE_{test}, and it is recommended that future studies attempt to tag trap naïve fish along with trap non-naïve fish to compare rates of re-capture between the two groups.

Straying may also negatively bias ATE_{test} observed at Merwin Dam, due to genetic and life history traits of coho salmon. Although straying rates of coho salmon are generally thought to be low (e.g., Westley et al. 2013), our study does include some evidence that coho salmon in this study may be straying, including the following:

1) A large number of movements of fish from the tailrace to downstream sites;
2) A relatively large amount of time spent at the downstream Bed & Breakfast and Lewis River Hatchery sites;
3) A high percentage (95%) of fish that are not re-captured are last detected at downstream sites (Bed & Breakfast and Lewis River Hatchery); and
4) Three radio tagged fish were found in other tributaries, including two fish in the East Fork Lewis River and one fish in Cedar Creek.

All of the above suggest straying occurs within the population of coho salmon returning to Merwin Dam. Future efforts that enumerate downstream spawning and straying into other tributaries would help resolve the potential effects of straying on observed *ATE* at Merwin Dam.

CONCLUSIONS

In 2017, estimated adult trap efficiency (ATE_{test}) for coho salmon at the Merwin Dam Fish Trap Facility was 63% (BCA 95% CI = 50-74%), which is below the performance standard of 98%.

However, the Merwin Dam Fish Trap Facility did achieve the performance standards for median tailrace residence time of less than or equal to 24 hours (median = 5.6 hours for coho salmon in 2017) and for less than or equal to 5% of fish taking longer than 168 hours to pass (2% of fish took longer than 168 hours to pass for coho salmon in 2017).

Estimated ATE_{test} in 2017 for coho salmon was substantially higher than estimates from 2015, however, it should be noted that there were only 35 coho salmon tagged in 2015 compared to 149 in 2017, and hatchery fish were used in 2015 whereas NOR fish were used in 2017.

A fyke installed at the entrance to Pool 2 appears to be effective in reducing the number of trap exit events, which supports findings from the previous report on winter steelhead in 2017.

Similar to previous study years, ATE_{test} appears to be limited by the ability of fish to locate and enter the trap from the tailrace.

After coho salmon entered the tailrace, there was no clear preference for fish using either the north or south side of the tailrace.

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 below the 98% *ATE* target.

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

Evidence from the current study indicate coho salmon were not strongly attracted to the tailrace; instead, coho showed preference for downstream locations, and a few fish were even found in other tributaries suggesting straying.

Until the effects of trap naïveté and straying rates are accounted for, current *ATE* estimates at Merwin Dam are likely biased low.

We recommend tagging trap naïve fish and examining downstream behaviors (including movements into neighboring tributaries) of coho salmon in future years to understand how using trap non-naïve fish and how straying rates influence *ATE* estimates.

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APPENDIX A: SUPPLEMENTARY INFORMATION

A-1 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^{o}) tag detection area, while the 8-element antenna has a longer but much narrower (~30^{o}) tag detection area (Figure 20), 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.

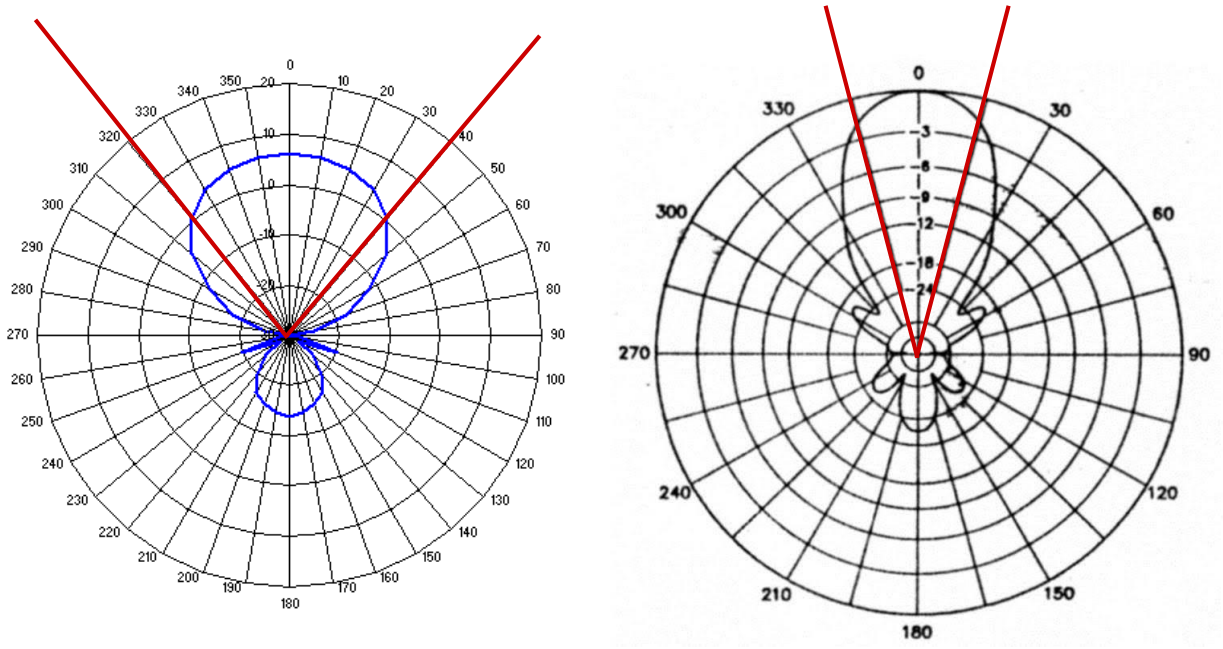

Figure 20. Reception radiation patterns (tag detection areas) for short-range 3-element (6.0dBd) and long-range 8-element (11.8dBd) Yagi antennas. Numbers around the perimeter of each figure represent directional degrees.

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.

APPENDIX E

SPAWN TIMING, DISTRIBUTION AND ABUNDANCE OF TRANSPORTED FISHES – 2017 REPORT

Report will be submitted here upon completion