Use of Adult Pacific Lamprey Passage Structures at Bonneville and John Day Dams
2017 Annual Report

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On the cover: Two entrance ramps which feed into the Washington Shore Upstream Migrant Tunnel Junction Lamprey Passage Structure (WA-UMTJ LPS). This LPS was installed during the winter of 2016/17 and feeds into the existing Washington Shore Auxiliary Water Supply Lamprey Passage Structure (WA-AWS LPS). System names are determined by where the entrance ramps are located**.**

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Executive Summary

To improve adult Pacific Lamprey (*Entosphenus tridentatus)* upstream passage at Bonneville Dam, five alternative lamprey only fishways were built to help them avoid dead ends, bypass bottlenecks, and increase entrance efficiencies to the traditional salmonid fish ladder and reach the forebay. Our objectives were to operate the lamprey passage structures (LPSs) and the lamprey flume structure (LFS), improve passage estimates using video validation, and evaluate lamprey use during the 2017 migration season compared to previous years. Attraction water for the LFS was adaptively varied in an attempt to collect the most lampreys and those results are presented. Lamprey passage structures continue to be an important route of passage and proportional use by lampreys has increased over time.

Entrance ramps for the LPSs are located in four areas: the Bradford Island fish ladder's auxiliary water supply (BI-AWS) near the forebay, the Washington shore fish ladder's auxiliary water supply (WA-AWS), the Washington shore fish ladder's junction with the Upstream Migrant Tunnel (WA-UMTJ) downstream of the fish counting station, and the Cascades Island fishway entrance (CI-ENT). Both the BI-AWS and WA-AWS were dead-ends for lampreys prior to LPSs, and the CI-ENT is unique for allowing volitional passage from the spillway tailrace to the forebay. Finally, the lamprey flume structure (LFS) is attached to the Washington shore fish ladder's north downstream entrance and has two entrances just outside the fishway.

Corrected LPS passage at Bonneville Dam during the 2017 monitoring season (April – October) was 122,247 fish which is 42% of lamprey escapement. Proportional use was the WA-AWS LPS (74% of LPS passage), BI-AWS LPS (24%), and CI-ENT LPS, which is a single ramp at the fishway entrance (2%). Mechanical counters were corrected for over counting (correction factor < 1) and undercounting (correction factor >1). The average correction factors were 0.72 WA-UMTJ, 1.85 WA-AWS, 0.32 BI-AWS, and 0.81 CI-ENT. When LPS counts are added to daytime and night time window counts, and other collected lamprey moved upstream the estimated escapement in 2017 was 292,441 lamprey pass Bonneville Dam. This is the largest lamprey run since counting resumed in 1997 and the sixth largest yearly passage since the dam's completion in 1938.

Managers depend on timely, accurate counts at Bonneville Dam as an indication of the health of the Columbia Basin's lamprey population. The mechanical counting systems used on the LPSs are lower cost than direct live counts, and monitoring passage around the clock, but are imperfect. Using video to validate the mechanical counters adds greatly to the cost. To help meet the USACE Pacific Lamprey Passage Improvements Implementations Plan (2014) goal of developing techniques for lamprey counting we suggest trials of innovative counters such as proximity or photoelectric counters placed in line with the current paddle counters to determine the best path forward. Finally, as LPSs continue to pass a large proportion of all lampreys passing Bonneville Dam, these counts need to be integrated with the current on-line day and night window counts to better reflect actual lamprey passage at the dam. Changes in the Columbia Basin Pacific Lamprey population can be recognized through accurate and dependable monitoring and reporting.

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Introduction

Background

The U.S. Army Corps of Engineer's fish counting program is the primary source for enumerating anadromous Pacific Lamprey populations in the Columbia River Basin begging in 1938 at Bonneville Dam. From 1969 to 1996 lamprey and other non-salmonid fish were not counted, and when counting resumed in 1997, there were fewer lampreys passing the dams on the Federal Columbia River Power System (FCRPS) than previously tallied (USACE 2009). Scientists have attributed the decline to several causes including spawning and rearing habitat loss, irrigation diversions stranding juveniles, intentional kill offs using chemicals, ocean conditions leading to decreased prey, and the difficulty adults have passing dams (Close et al. 2002, Murauskas et al. 2013).

As a result of this decline, there has been significant regional concern regarding the stability of lamprey populations in the Columbia Basin causing the State of Oregon to list Pacific Lampreys as State sensitive species in 1993. Regional Native American tribes have repeatedly voiced concern about the decline of lampreys, culturally an important species, and developed a recovery plan (CRITFC 2011). In 2003 the USFWS was petitioned to list the Pacific Lamprey under the Federal Endangered Species Act. However, no funds were committed in 2003 or 2004 to make a determination. As a result, an "intent to sue" was filed by 11 environmental groups in March 2004 for failing to act on the petition, and in June the suit was filed. In January 2005, a "finding of insufficient information to evaluate status" was determined by the U.S. Fish and Wildlife Service (50 C.F.R Part 17).

In May 2008, a Memorandum of Agreement (MOA) addressing actions to protect Pacific Lampreys was signed between the FCRPS Action Agencies, the Fish Accord Treaty Tribes (consisting of the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, and the Confederated Tribes and Bands of the Yakama Nation) and the Columbia River Inter-Tribal Fish Commission (CRITFC). Specific to the U.S Army Corps of Engineers (USACE), the MOA required collaboration with the Tribes and the U.S. Fish and Wildlife Service to develop and implement a 10-year lamprey passage improvement plan (USACE 2009). The goal of the Pacific Lamprey passage program within the Northwestern Division of USACE is to improve lamprey passage at Corps dams along the lower Columbia and Snake rivers. Bonneville Dam is the first hydroelectric dam on the main stem Columbia River that Pacific Lampreys must ascend to access upstream spawning habitat and therefore is a priority location for improving passage. In their review of several lamprey passage studies, Keefer et al. (2013) found the median fishway passage efficiency (unique lampreys that passed / unique lampreys that entered) from 1997-2010 was 0.52 at Bonneville Dam. Keefer et al. (2013) contrast lamprey passage efficiency to that of adult salmonids which is 0.95 at Bonneville Dam.

The swimming scope and anguilliform locomotion of Pacific Lampreys are very different from the sub-carangiform salmonids (*Oncorhynchus spp*.) for which the Bonneville Dam fishways were designed. The velocities and turbulence in these fishways often exceed Pacific Lamprey swimming scope (Clay 1994, Johnson et al. 2012) forcing them to attached with their oral sucker to hold, rest, and burst forward to the next attachment point. Salmon are stronger swimmers, attracted by high water velocities as they find their way upriver, and are unaffected by 90° corners typically found at fishway entrances. In contrast, Pacific Lampreys have difficulty with high velocities and may have to depend on their oral sucking disk as they move through fishways, making 90° corners difficult to navigate. Adult salmonid critical swimming (Ucrit) speeds can range from 101 to 165 cm/s, with Chinook salmon (*Oncorhynchus tshawytscha*) ranging from 155 to 165 cm/s (Geist et al. 2003). Adult Pacific Lampreys have a mean Ucrit of 86.2 cm/s at 15°C (Moser and Mesa 2009). However, they have been recorded in Bonneville Dam's fish ladders flow control section swimming through 240 cm/s velocities by Kirk et al. (2017) who suggest fatigue from multiple high velocities sections can lead to passage failure. A view also held by other researchers (Haro et al. 2004). Once inside fishways, adult salmon are guided and excluded from potential dead ends by diffuser grating and picketed leads (Clay 1994). Adult lampreys can pass through most diffuser gratings and picketed leads wider than ¾ inch and may get lost in areas migrating fish were not intended to enter (e.g. auxiliary water supply channels and diffuser pits). Thus, the salmonid focused fish ladders create impediments to Pacific Lamprey passage, in both structure and water velocity.

Several structural and operational changes have been made in the USACE Portland District adult fish ladders, including installation of Lamprey Passage Structures (LPS) and the addition of the Lamprey Flume Structure (LFS), a major modification at a fishway entrances to increase lamprey passage. There are four LPSs at Bonneville Dam and one at John Day Dam. The LPSs are alternative fishways designed specifically for lampreys. They have lower velocity and volume of water to ease lamprey passage, entrance ramps designed for climbing out of the salmonid fishway using their oral disk, rest boxes at the top of ramps, and exits that typically slide downward to the forebay. A keyhole shaped entrance bulkhead was installed at Cascades Island and the John Day North entrance to reduce velocity deep in the water column for bottom oriented lampreys while maintaining higher velocities near the top for salmonid attraction. A bollard field was also installed on the floor of these entrances to further reduce flows and provide an attachment surface. Operationally, night time flows have been reduced at Bonneville's Powerhouse 2 fishway entrances for lampreys, due to their nocturnal behavior passing dams. Recently there has been an effort to refine techniques for counting lampreys that pass USACE dams. Counts of Pacific Lampreys passing Bonneville Dam are the primary metric that regional fisheries managers use to assess the health of the Pacific Lamprey population in the Columbia River basin. Several other improvements are described in USACE (2009).

Life History of the Pacific Lamprey <u>Entosphenus tridentatus</u>

The anadromous Pacific Lamprey spend their first several years of life in rivers sediments as blind filter feeders then migrate to the ocean for a parasitic phase of high growth, and return to freshwater to spawn. They are found in rivers along the west coast of North America that drain to the Pacific Ocean as eyeless larvae, or ammocoetes. They burrow into fine sediments and filter feed for four to six years retaining and cycling stream nutrients (Kan 1975, Beamish 1980). Progressing to the macropthalmia phase, the lampreys undergo several physical metamorphoses such as growing eyes and teeth to prepare for life in the ocean. Adults spend 20-40 months in the ocean feeding as external parasites on fish and whales (Kan 1975). They return to fresh water in the spring and summer then typically overwinter before movement to spawning grounds. After spawning they die, returning valuable marine-derived nutrients to the riverine habitat (Beamish 1980, Wang and Schaller 2015).

Various biotic and abiotic factors associated with different locations could affect timing of migration and other aspects of life history. For example, in California, lampreys begin their migrations earlier than lampreys further north in Washington State (Clemens et al. 2010). The adult run at Bonneville Dam begins in April, peaks from June-July, and is complete by October. Their life history, especially the extended freshwater residency, exposes it to many threats and their anadromous nature may require them to pass man made obstacles from irrigation diversion to large hydroelectric dams. Lampreys are important prey species for both aquatic and terrestrial predators. Juveniles act as a buffer to predation of endangered juvenile salmon while adults are an important food source for sturgeon (Roffe and Mate 1984, Beamish 1980). Further research is needed to understand the passage requirements of lampreys at dams, helping them to reach spawning grounds, and in turn ensure a more diverse and stable ecosystem.

Objectives

To help increase lamprey passage and monitoring, the objectives of the USACE Fisheries Field Unit were to:

1) Operate the lamprey passage structures and lamprey flume structure at Bonneville Dam with regular inspections to insure functionality and safe passage.

2) Validate and correct for mechanical counters used to monitor these structures, improving passage estimates.

3) Evaluate use of the lamprey passage structures (number passed), between location and years, relative to window counts.

Due to a mechanical failure, the elevator used to access the John Day Dam LPS was out of service and that LPS was not operated during 2016 or 2017. Further information on lamprey passage through the traditional adult salmonid ladders at Bonneville Dam and John Day Dams (window counts) can be found in the Annual Fish Passage Report (USACE 2018). Here we report on passage through the Bonneville LPSs and LFS.

Methods

Study Area

Bonneville Dam, located on the Columbia River 146 miles from the Pacific Ocean, is the first main stem dam adult migrating lampreys encounter. They can use multiple passage routes through the dam including the fish ladders that were designed for salmonid passage and LPSs that were designed specifically for lamprey passage. During 2017, we monitored three LPSs at Bonneville Dam located at Bradford Island, Cascades Island, and the Washington shore as well as the LFS located at Washington shore's north downstream fishway entrance (Figure 1).

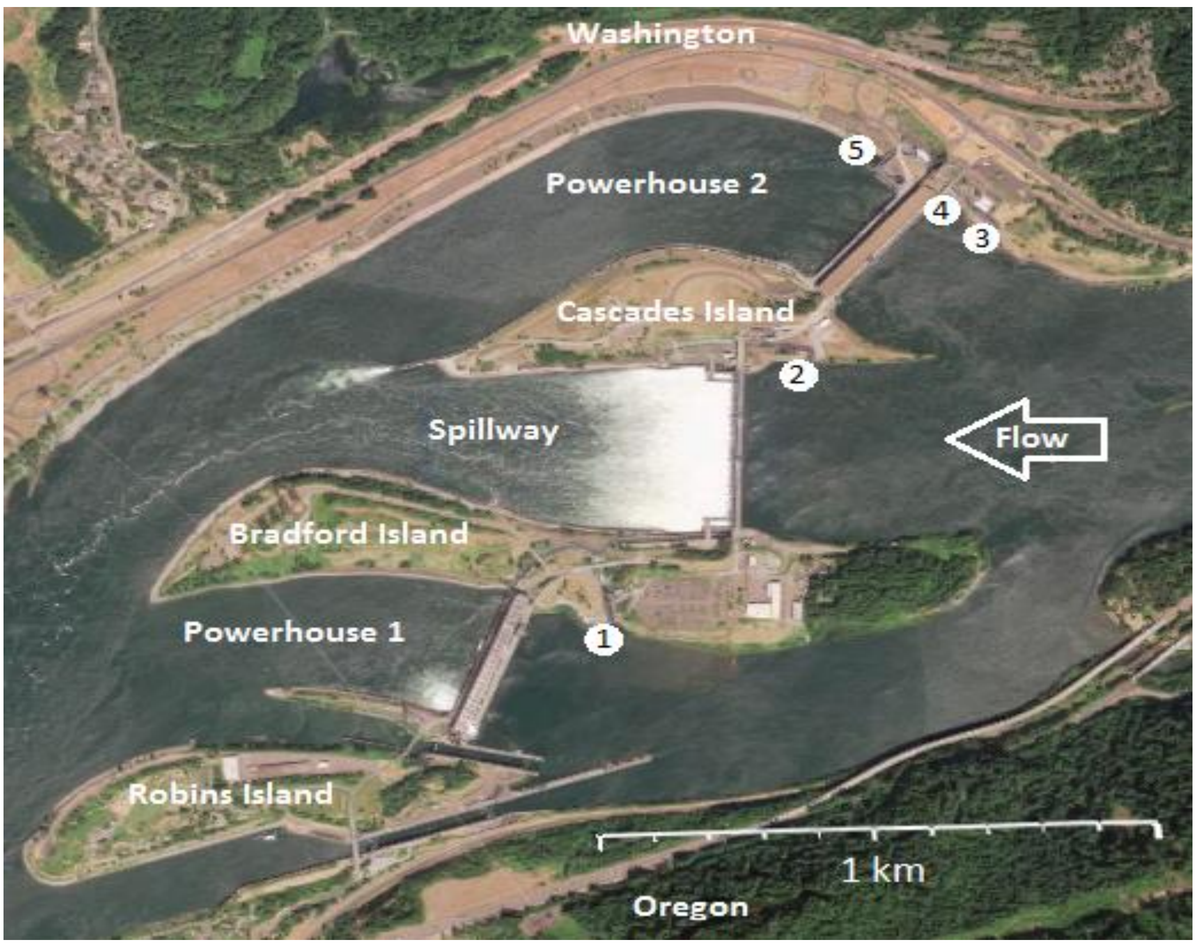

Figure 1. Lamprey passage structure locations at Bonneville Dam and year put in service. 1) Bradford Island AWS LPS in 2003 2) Cascades Island ENT LPS in 2009 3) Washington shore AWS LPS in 2010 4) Washington shore/UMTJ LPS in 2017 5) Washington shore Lamprey Flume System in 2013.

The Bradford Island auxiliary water supply (BI-AWS) LPS was installed in 2003 as a trap and haul site, and extended to the forebay in 2004 to provide a route of passage for lampreys that swim through or under the picket leads and into the auxiliary water supply channel dead-end. There are two entrance ramps in this channel that parallel the Bradford Island flow control (serpentine weir) section. It has a total length of 35.9 meters (118.1 feet) and height of 7.9 meters (25.9 feet) (Zobott et al. 2015, Table 1). The exit is located near the Bradford Island adult fish ladder exit in the forebay of Powerhouse 1.

The Cascades Island entrance (CI-ENT) LPS was installed in the winter of 2008-09 and is unique because of its length and location. The entrance to the LPS is just inside the Cascades Island fish ladder entrance in the spillway tailrace and the exit was extended into the spillway forebay in 2013. It has a total length of 162.4 meters (532.8 feet) and height of 27.0 meters (88.6 feet), the longest and highest climb of all USACE LPSs (Zobott et al. 2015 Table 1). It consists of one ramp creating a back eddy and competes with high flows to attract lampreys out of the fishway.

The Washington shore adult fish ladder auxiliary water supply (WA-AWS) LPS was installed in 2007 and modeled after the BI-AWS. It provides a passage route from the auxiliary water supply channel to the top of the fishway. It has a total length of 20.8 meters (68.2 feet) and height of 9.2 meters (30.2 feet) (Zobott et al. 2015, Table 1). For a more complete description of the BI-AWS and WA-AWS LPSs history see Moser et al. 2010.

In the winter of 2016-17 two additional LPS entrance ramps were installed at the junction of the upstream migrant tunnel and the Washington shore fishway (WA-UMTJ LPS). These ramps are connected to the existing WA-AWS via several meters of aluminum irrigation pipe. After traversing the pipe, lampreys swim through an upwelling box and descend a small section of irrigation pipe where they trigger a paddle counter on their way to rest box 3 of the WA-AWS LPS. From there they continue to the WA-AWS LPS exit and are counted again. Thus the sums of both counters is not additive but does indicate which entrance ramps were used.

The LPS installed at John Day Dam inside the north ladder entrance was not operated this year. An elevator is required to access the trap box but was out of service due to a failed motor. We mention that fact in this report as a way of documenting the fact it was not operated in 2017.

Operation and Inspection

Lamprey Passage Systems

The Lamprey Passage Systems are operated to encompass the adult lamprey passage season at Bonneville Dam and regularly inspected. The WA-AWS and WA-UMTJ LPSs were watered up in March after installation was complete allowing new parts to season. That is, allowing algae growth to begin and letting the water wash away smells associated with the fabrication process (e.g. welding) that is speculated to deter lamprey. The CI-ENT and BI-AWS LPSs were watered up 5 April and all four were dewatered on 31 October 2017. Inspections were conducted to assure water was flowing properly, counters were operational, sedimentation was not blocking movement, and lamprey mortalities were removed. Any malfunctioning parts, such as occasional pump screen fouling, of the LPS would be addressed or reported to USACE Bonneville project biologists who would coordinate repairs. Systems inspected on even numbered days Monday through Friday during April through September and once a week throughout October.

Lamprey mortalities were removed from the LPS rest boxes so passage was not delayed. Research on sea lampreys suggest they avoid pheromones produced by dead or dying conspecifics (Wagner et al. 2011). Lampreys that appeared moribund and did not respond to stimuli were removed with a dip net and further inspected to confirm mortality. The location, date, total length (cm), and inter-dorsal length (cm), as a measure of maturity, of mortalities were recorded and are reported in appendix A. They were then scanned for a Passive Integrated Transponder (PIT) tags, photographed, and either placed in a freezer for histological examination by USFWS Fish Health Lab or returned to the river if decomposition had progressed too far for histological evaluation. Mortality information was submitted to USACE Bonneville project biologists. They in turn included this information in a Memorandum for the Record for distribution to the Fish Passage Operations & Maintenance (FPOM) workgroup, a regional group of fish managers representing state, tribal, and federal fish and wildlife agencies.

Accessible LPS rest boxes and holding tanks were inspected for build-up of sediment and flushed if needed. Rest boxes would not be flushed if there were lampreys present, as some drains are not screened and they could be flushed out. The first two rest boxes in the lower section of CI-ENT LPS are not accessible during regular inspections. These rest boxes require a crane and man-basket to access and are checked if passage problems arise. They can be flushed remotely using a pneumatic system, removing silt and/or lamprey carcasses which could potentially lead to passage delays.

Lamprey Flume System

The Lamprey Flume System (Figure 2) was operated from 22 June to 24 August 2017 and inspected daily. Two well pumps mounted the NDE monolith provided water to the trap box and upper (LPS like) section of the flume while a large butterfly valve controls gravity feed attraction water that flowed through the lower LFS. This valve was varied from 15 to 60 percent open throughout the season to determine which setting would attract the most lampreys.

During inspections the following variables were recorded: the height of the river at tail water (feet above mean sea level), tank temperature (°C), auxiliary water butterfly valve opening (%), and number of lampreys in the collection. Lampreys captured in the collection box were either released upstream at the port of Stevenson, WA, boat launch, or placed in holding tanks at Bonneville Dam’s Adult Fish Facility for tribal biologists to collect and transport to upstream spawning areas (CRITFC 2011). To protect against temperature shock, a 1℃ differential between transport and receiving water temperature was maintained.

Figure 2. Lamprey Flume Structure (LFS) meets with rest box one (yellow arrow) and auxiliary attraction water grey pipe (blue arrow). Washington shore's north upstream fishway entrance at right and north downstream entrance (white arrow).

A missing access hatch was discovered in the fall of 2015 and the LFS was not operational again until 2017. Replacement took place the winter of 2016/2017 and internal changes were made to the water supply side of the flume to prevent water velocities that may have been too high for some lampreys to pass. When adding new material to these structures it can reduce passage until the material has time to season.

Passage Validation and Estimates

Lamprey Passage System

Two types of automated counting systems were used to track volitional lamprey passage this season. The original limit switch attached to a perforated paddle was used at BI-AWS and CI-ENT. A new counter, designed by Portland District engineers, uses a proximity detector to monitor a ferrous tab attached to the paddle's axle as an indicator of passage. When lampreys pass through either LPS counter system, they move the paddle completing a low voltage circuit. This voltage pulse was recorded by the data logger, which totals the number of pulses at pre-set intervals (60 seconds) and is then downloaded to a computer. Data logging of passage began at BI-AWS and CI-ENT on 5 April 2017 (T and D Wireless Data Recorder Model RTR-505) and at WA-AWS and WA-UMTJ on 1 May 2017 when communication was established between the Dwyer counter and the DATAQ DI-161 data logger. Data collection ended on 31 October 2017 when the LPSs were dewatered.

The components of the counting system were similar at BI-AWS and CI-ENT with a variance in paddle placement. They consisted of an eight inch diameter PVC pipe, light weight perforated plastic paddle, attached to a limit switch (Honeywell Heavy Duty Limit Switch model numbers: LSA1A-4M or LSA1A). When a lamprey activated the switch, a pulse signal was sent to a data recorder, and a network base station (T&D Corporation RTR-500NW) was used to download the counts to a laptop (Figure 3).

Figure 3. Mechanical counter components used to enumerate lamprey passage at Bradford Island AWS and Cascades Island Entrance including the limit switch attached to exit paddle and cushion, wireless data recorder, and network base station (from left to right at BI-AWS LPS).

This mechanical counting system was also used for CI-ENT, however, the location of the paddle is in-line within the PVC pipe as opposed to the end of the pipe at BI-AWS (Figure 4) eliminating paddle bounce induced count error.

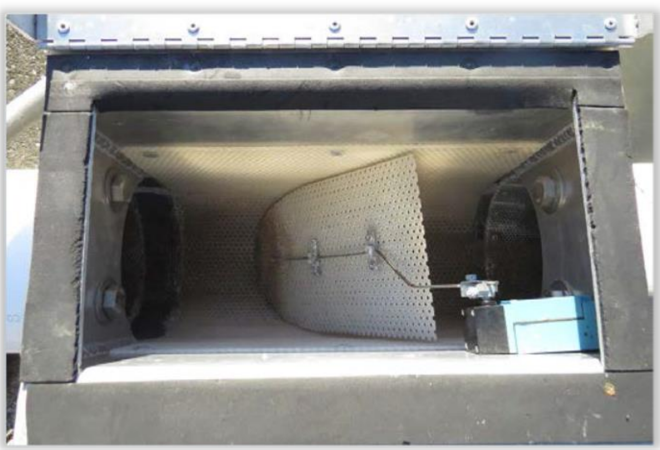

Figure 4. The in-line paddle and limit switch that make up the mechanical counter at Cascades Island Entrance lamprey passage structure.

During LPS inspections, tests were conducted to ensure the counting system was functioning properly, batteries were checked, and data was downloaded. The paddle was actuated ten times by hand and the counts on the data logger digital display were verified. The date, time, and number of these test pulses were recorded so they could be removed from the data set before analysis. The 3.6 volt batteries of the wireless data recorders, used at BI-AWS and CI-ENT, were also monitored and replaced as necessary. Finally, passage data was downloaded on even days during the peak season, and weekly at the beginning and end of the passage season. Passage data from the new DATAQ data logger at WA-AWS and UMTJ were written to a laptop as text files three times per day and transferred weekly. Occasionally power outages, low batteries, and inaccessibility to download due to the Eagle Creek fire led to gaps in the lamprey counts. The lamprey count estimates for these days were either taken directly from the data logger displays when available or interpolated from data records on either side of the gap.

We used video to validate the data from the mechanical counting systems. Cameras were deployed every other week and recorded from 20:00 at night to 06:00 in the morning - typical peak hours for lamprey passage. Video recording equipment was housed outside in a waterproof enclosure or inside a building. The components of the system depended upon access to power, lighting, and DVR size and compatibility with the cameras.

At the BI-AWS the DVR needed to be small enough to fit inside a waterproof metal box so a GANZ digital video recorder (DVR) (model number: DR4HD-2TD) was connected to an externally mounted camera. The Arm Electronics Bullet Color Camera (CFC6023VF) with waterproof lens (3.5-16.0 mm F/1.2) was mounted on a tri-pod and focused on the paddle at the end of the LPS exit pipe. Two incandescent 120 watt outdoor lights were used when filming so that the exit pipe, paddle counter, and falling lampreys were visible at night.

At the WA-AWS, WA-UMTJ, and CI-ENT LPSs we used a Pelco DX4708HD (DVR) connected to a Pelco Sarix IMP319-1ERS globe camera mounted above the paddle counters (Figure 5 and Figure 6).

Figure 5. WA-AWS LPS exit showing (left to right) PIT antenna, upwelling box with black latch, camera box & paddle, and Dwyer counter display with red warning tags. Right panel shows camera box with lid removed, globe camera, and proximity detector with blue tape pointed at curved metal tab indicating position of paddle (open/closed).

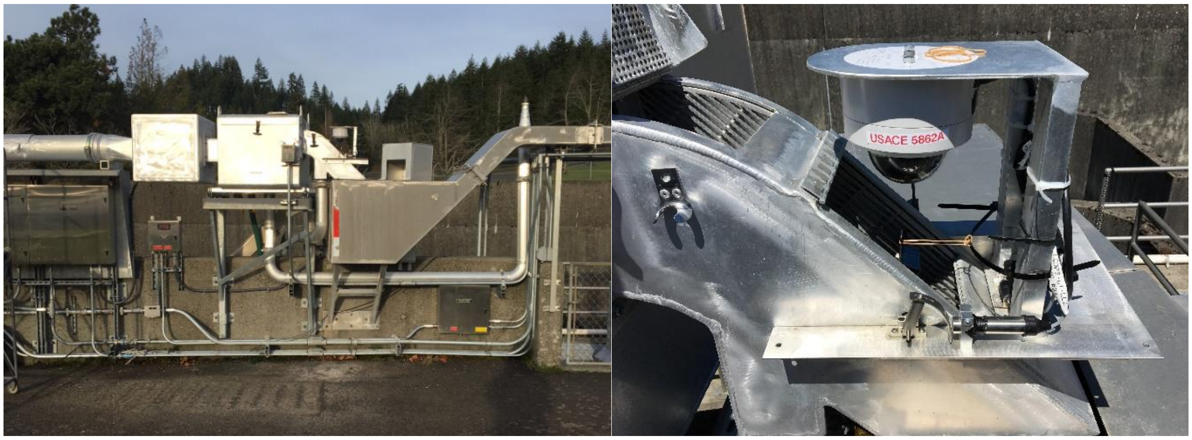

Figure 6. The WA-UMTJ LPS as it enters the older WA-AWS LPS rest box three. Left image: from left to right, traversing sections (aluminum irrigation pipe), PIT antenna, upwelling box (with black latch), camera box and counting paddle (lid removed). Right image: close up of globe camera pointing down on counter paddle (black plastic), binder clip and rubber band to help seat paddle, curved metal indicator tab attached to axel, and proximity detector that send count pulse when tab is not detected.

Video recordings for each observation period were reviewed either directly from the DVR or using VLC Media Player to validate the mechanical counters. Hourly lamprey passage was totaled using a hand counter (tally clicker), while the midnight hour (typically high passage) was reviewed in detail to determine the sources of over or under-counting. For the midnight hour, the time of each individual passage event was recorded to the second along with notable behavior. These counts were compared to the mechanical counter data and over-counts were discovered for the mechanical counters. The behaviors contributing to these over-counts include: lampreys attached at the end of an exit pipe or attached under the paddle and attempt to re-ascend the pipe. All of which triggered the counting paddle multiple times. Paddle bounce and water pulses also contributed to over-counts. Paddle bounces occurred when a lamprey exited at a high velocity causing the paddle to slam closed and bounce back open, whereas water pulses from lampreys holding upstream would back up water and occasionally trigger the counter with surges of water when the animal moved. Moreover, under-counting occurred too. Reviewers noticed that some lampreys passed under the paddle without triggering it and there were instances when the paddle was stuck open while lampreys passed uncounted resulting in under-counting.

Black binder clips and rubber bands were attached to the top of the paddles at WA-AWS and the WA-UMTJ on 29 June to reduce undercounts. The rubber bands helped to ensure the paddle would seat properly after lamprey passage and not stick in the "up" position or leave a gap that lampreys could slide under (Figure 6 right image).

A correction factor was calculated and applied to the raw mechanical counts to increase the accuracy or the LPS passage estimate. To calculate the correction factor we divided the number of lampreys that were observed passing in each video review period by the number of lampreys that were logged by the mechanical counter. Daily counts were multiplied by correction factors from the nearest review night. An R script (R version 3.3.2 R Core Team 2016) was used to: stitch together raw files, remove paddle tests, and sum daily passage. Microsoft Excel 2013 was used to apply correction factors, report counts to the region, and generate graphics.

Run timing is represented using box and whisker plots (seasonal) and histograms (hourly). To determine seasonal run timing, the corrected daily passage estimates for each LPS was used to identify the first and last passage event, and calculate 10%, 50%, and 90% passage completion day. For historic context, these values are also presented for previous years. Examining run timing of the LPSs and windows across several years provides perspective on when to operate these structures.

Lamprey Flume System

Passage validation and for the LFS were not required. Total lampreys trapped were counted by hand, not using an automated counting system. Therefore they did not require video validation and are counts not estimates of passage.

Evaluation of Performance

Lamprey Passage System

Lamprey Passage System performance was evaluated using total passage at each LPS, proportional passage at each LPS, and relative use compared to total dam passage. A summary of annual LPS passage is presented as an indicator of relative use in Appendix A and a bar graph is used to show proportional routes of LPS passage to compare among locations and between years.

Relative use was calculated to compare between lamprey fishways locations and years 2015-17. It was calculated by dividing passage at each lamprey fishway by the estimate of total passage at the nearest count window (day time + night time + LPS).

Also, a linear regression model developed in 2015 was used to estimate overall dam passage in 2017 (regression model) and compare to the total dam passage estimate presented in this report (sum method). Percent mortality was calculated as the number of mortalities removed from an LPS divided by total passage at that LPS.

Lamprey Flume System

Lamprey Flume System performance was evaluated for each of the attraction water settings (percent open) based on the catch per unit effort (CPUE as number of lampreys collected / night). Each treatment condition (percent open) lasted for 24 hours from 10:00 hours on day one to 10:00 hours on day two. We assume that lamprey were typically moving at night and would enter and pass the LFS within a 24 hour treatment. However, there is potential to confound this assumption. For example, if lamprey entered the LPS during one treatment, and then moved into the trap box during another.

Previous research found it took one PIT tagged lamprey 10.5 minutes to pass the lower portion of the LFS which we assume to mean swimming from the entrance to the first rest box which if fitted with a HDX antenna (Kirk et al. 2015). Looking to CI-ENT LPS, the longest and highest LPS, median passage times there were 6.6 hours (range 3.9-7.3 h, n=16) for PIT tagged lamprey and 5.0 hours (range 1.1-6.6 h, n=21) for radio tagged lamprey (Corbet et al. 2014). Corbet et al. (2014, 2015) report transit time for BI AWS and WA AWS typically less than an hour. Given this information we assumed that lamprey captured in the trap box had indeed entered the LFS during the previous night's treatment.

We used a Shapiro-Wilks test for normality followed by the Wilcoxon ranked sums test for non-normal data to compare CPUE at the 30% and 60% valve open treatments. We also report the number of lampreys trapped at all valve settings. Statistical analyses were conducted using R version 3.3.2 (R Core Team 2016) and significance evaluated at alpha < 0.05 level.

Results

Operation and Inspection

The Bonneville LPSs operated between 184 and 210 days in 2017, while the LFS was operational for 64 days (Table 1). The new counting system at WA-AWS and UMTJ began collecting counts on 1 May. However, the LPSs were operational with water flowing through them on 1 March giving the new material two months to season prior to the first lamprey's arrival.

Table 1. Operation dates of Lamprey Passage Structures and Lamprey Flume Structure (LFS) during 2017.

Location*	Start Date	End Date	Days of Operation
Bradford Island-AWS	4/5/2017	10/31/2017	210
Cascades Island-ENT	4/5/2017	10/31/2017	210
Washington-AWS	5/1/2017	10/31/2017	184
Washington-UMTJ	5/1/2017	10/31/2017	184
LFS – PH2 NDE	6/22/2017	8/24/2017	64

*AWS = Auxiliary Water System, ENT = entrance, UMTJ = upstream migrant tunnel junction with the Washington shore fishway, PH2 NDE = north downstream fishway entrance at powerhouse 2.

Lamprey Passage System

Water flow within the LPSs at BI-AWS and WA-AWS was found to be sufficient for the entire passage season. However, on the weekend of 10 July, the west pump at CI-ENT was not operating and the east pump did not supply enough water to keep it flowing through the exit pipe. The project biologist restarted the pump and informed Fish Field Unit staff of the issue, after a second inspection that day, the pump was found off and returned to service again and the maintenance crew was informed. Maintenance pulled the pump, cleaned it of debris and it was returned to service and performed well for the remainder of the season.

Passage was not effected by sediment loading in the LPSs this season, however, to aid visibility in the rest boxes during inspections, sediment was occasionally flushed. The WA-UMTJ rest boxes 1 and 2 had the most sediment buildup towards the end of the 2017 season. The screen at CI-ENT pond (a transition between the climbing section and traversing section) was regularly scrubbed with a stiff brush to clean off algal growth.

Lamprey Flume System

The LFS was inspected seven days a week for the 64 days of operation and the trap tank was flushed regularly. Rest boxes one and two were also flushed throughout the season. The auxiliary water butterfly valve position was set between 15% and 60% open and the upper knife gate that controls flow to the upper entrance was opened between 0.3 and 1.2 meters (1 and 4.5 feet) see

Passage Validation and Estimates

Lamprey Passage System

Mechanical counting systems at BI-AWS and CI-ENT LPSs were reliable (i.e. in continuous operation), however the BI-AWS LPS continued to have poor accuracy due to over-counting. Initially the newly designed counters at Washington shore were not reliable as there are several parts attached to the axel that slid out of position, including the paddle. Modifications to secure the parts and seat the paddle enhanced the accuracy, but the system can likely be further improved. Unless stated otherwise, results presented here are based on corrected values.

Count validation was performed comparing 390 hours of video and 6,538 passage events to the mechanical count data to determine correction factors (Table 2). Correction factors were calculated from 10 hours of video review at each site about every two weeks. The correction factors ranged from 0.33 to 0.94 at the WA-UMTJ, 0.78 to 5.59 at WA-AWS, 0.17 to 1.00 at CI-ENT, and 0.24 to 0.5 at BI-AWS. Video validation could not be performed some weeks over the season due to equipment failure or rain. At the LFS fish were netted from a trap box and counted by hand so no validation was needed.

Table 2. Uncorrected mechanical counts, video counts, and associated correction factors (CF) for Bonneville Dam Lamprey Passage Structures from video validation 27 May to 28 September, 2017.

Observation Period	Bradford Island AWS			Cascades Island Entrance			Washington AWS			Washington UMTJ		
	Mechanical	Video	CF	Mechanical	Video	CF	Mechanical	Video	CF	Mechanical	Video	CF
1	59	na	na	4	3	0.75	26	93	3.58	34	na	na
2	922	463	0.50	10	na	na	41	229	5.59	32	na	na
3	620	na	na	35	25	0.71	666	1933	2.90	487	na	na
4[1]	1890	632	0.33	21	18	0.86	622	na	na	361	272	0.75
5	650	209	0.32	0	0	1.00	343	430	1.25	365	323	0.88
6	387	116	0.30	11	9	0.82	645	596	0.92	143	135	0.94
7	684	174	0.25	3	3	1.00	111	100	0.90	61	55	0.90
8	861	205	0.24	7	7	1.00	241	243	1.01	26	24	0.92
9	97	28	0.29	6	1	0.17	152	119	0.78	20	10	0.50
10	67	na	na	1	1	1.00	61	48	0.79	3	1	0.33
11	23	7	0.30	0	na	na	32	26	0.81	2	1	0.50

[1]Rubber bands added to WA AWS and WA UMTJ LPS paddles so they seat flush with the LPS floor.
Some validation could not be performed due to equipment failures or rain and are represented with 'na'.

The majority of mechanical counter error was due to under-counting at the new Washington shore count systems. Occasionally the paddle would stick in the upright position allowing lampreys to pass undetected. This was corrected by using rubber bands attached to the top of the paddle to help it seat properly after a fish passed. The majority of over-counts identified in video review periods were due to lampreys attaching while under the paddle and attempting to re-ascend the BI-AWS activating the limit switch multiple times for one passage event (Table 3 and Table 4). Overall, the Bonneville LPS passage estimate during 2017 was reduced by 9% from 134,099 to 122,109 when corrected for mechanical counting error. Using the methods of Gallion et al, (2017) the percent difference of the corrected estimate is Mechanical Counts minus the Corrected Estimate divided by the Mechanical Counts.

Table 3. Mechanical counts and corrected estimates for lamprey passage at LPSs during 2017.

LPS Location	Mechanical Count	Corrected Estimate	Difference (%)
Washington UMTJ	13,191	10,705	-19
Washington AWS	46,960	90,377	+92
Cascades Island ENT	3,901	2,889	-26
Bradford AWS	83,177	28,843	-65
Total*	134,038	122,109	-9

*Total does not include Washington UMTJ to prevent double counting. These fish swim into Washington AWS and are counted when exiting there.

To determine the sources of mechanical counting error, each passage event from the midnight hour from each review session was classified as: lamprey attaching, water pulse, paddle bounce, and comparing to counter data further noted if there was an over count or under count and amount. For example, a single lamprey attaching under the paddle could cause more than one over count. Lamprey attaching occurs when they use their sucking mouth to hold near the paddle and attempting to re-climb hitting the paddle causing over counts. In a water pulse event, there is no passage but excess water, sometime caused by lamprey moving through the LPS, hits the paddle causing over count. During paddle bounce, the lamprey passes cleanly with a higher velocity and that energy is transferred to the paddle causing it to close hard, then bounce open causing an over count. Under counts were defined as any lamprey passage seen in the video but not tallies by the mechanical counter. This was most prominent at the WA-AWS LPS when its paddle would stick open or small fish that passed under partially.

Table 4. Classification of mechanical counter error from video review during 27 May to 28 September. One hour from each night of video was reviewed. Events Viewed is the number of passage events viewed, followed by sources of error (attaching, pulse, or bounce), and the resulting under or over count. Units are counts.

LPS Location	Events Viewed	Lamprey Attaching	Water Pulse	Paddle Bounce	Over-count	Under-count
WA-AWS	279	8	0	0	12	149
WA-UMTJ	87	0	0	13	27	8
CI-ENT	8	2	0	0	2	0
BI-AWS	96	113	34	2	149	6

Daily lamprey passage fluctuated greatly at each of the LPSs with most fish passing in June and July (Figure 7 and Figure 8). The WA-AWS, CI-ENT, and BI-AWS LPSs accounted for 74.0%, 2.4% and 23.6% of total passage, respectively. The LFS passed 51 fish, or less than 1% of total passage. At most LPSs the highest daily passage occurred during the end of June and early July with a pulse of fish in late August (Figure 7 and Figure 8).

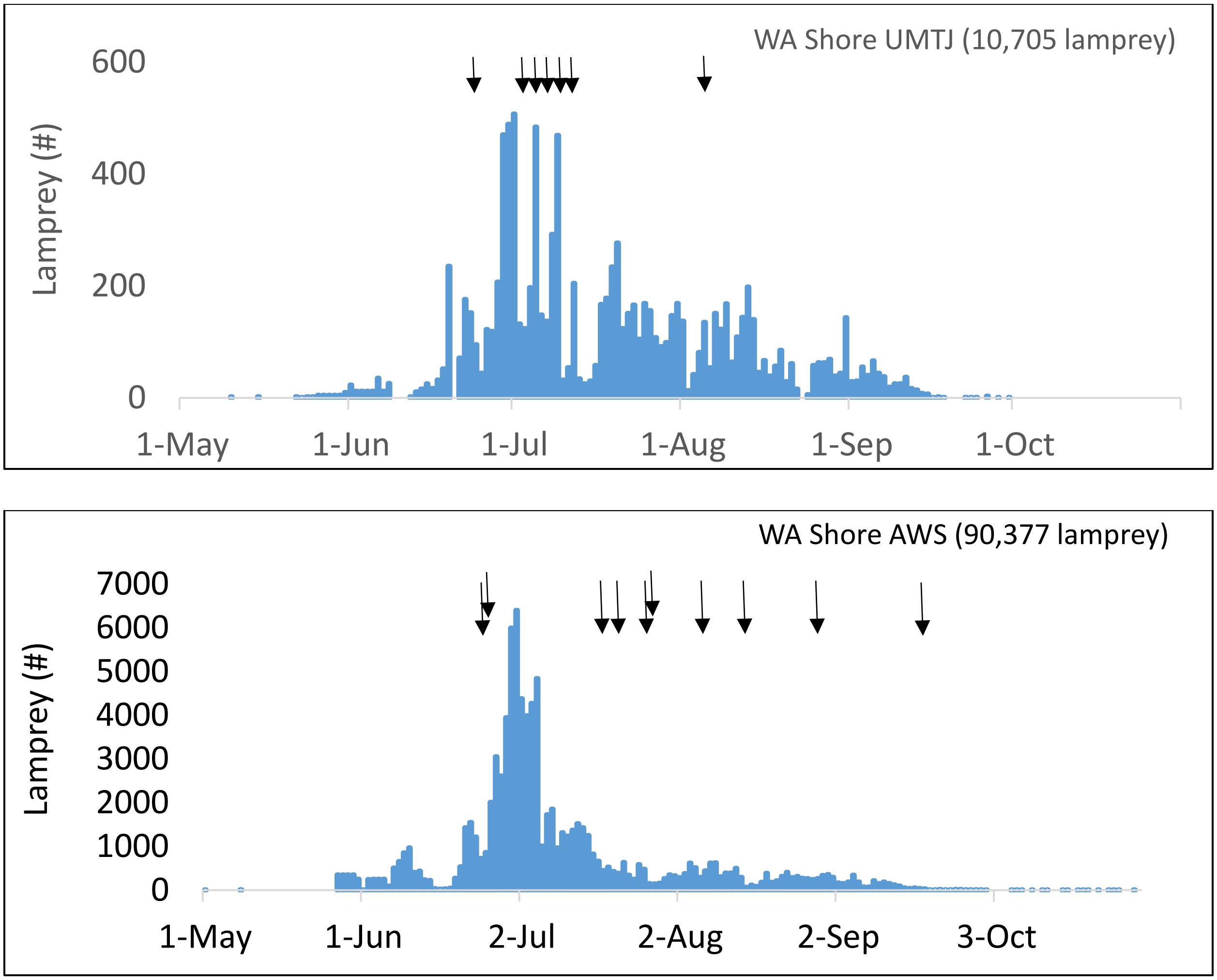

Figure 7. Daily lamprey passage estimate (corrected) at the Washington Shore UMT Junction LPS (top) which feeds into the Washington shore auxiliary water supply (WA AWS, bottom). The WA UMTJ lampreys do not add to the passage total. Arrows indicate when lamprey mortalities were found in the LPSs or on the grating nearby (e.g. jumped out). **Note changing y-axis**.

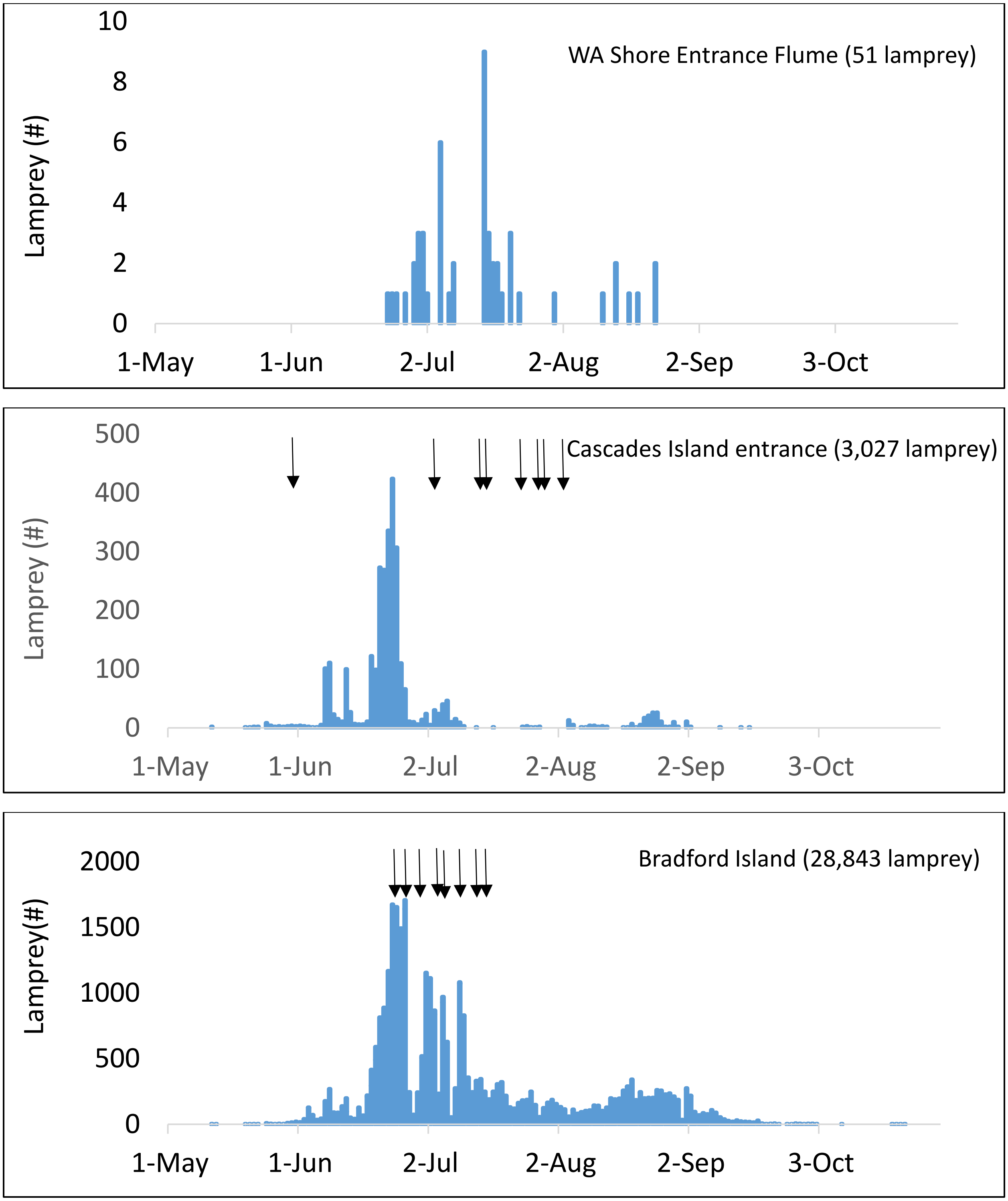

Figure 8. Daily lamprey passage at the Lamprey Flume System (LFS counts), Cascades Island entrance (CI ENT LPS estimate), and Bradford Island auxiliary water supply (BI AWS LPS estimate). Arrows indicate when lamprey mortalities were found in the LPSs or on the grating nearby (e.g. jumped out). The LFS operated from 22 June to 24 August, 2017, no mortalities were found. **Note changing y-axis.**

In total, 41 lamprey mortalities were found in/near the Bonneville LPSs in 2017. Thirteen mortalities were found in the BI AWS (0.05% of passage), 10 in the CI ENT (0.33% of passage), 10 in the WA AWS (0.01% of passage), and 8 (0.07% of passage) in the WA UMTJ (Figure 7). No PIT tags were detected in any of the lamprey mortalities and no mortalities were found in the LFS (see Appendix C for location of mortalities, fish length, and other data).

Additional lamprey mortalities were found in the fish ladders when inspected by Bonneville Dam project biologists. Those mortalities are not covered in this report, but can be found on the FPOM website (http://www.nwd-wc.usace.army.mil/tmt/documents/FPOM/2010/). Not all lampreys that die during migration are detected, some may simply wash down the fishway back into the river. Mortalities were sometimes associated with high passage rates (e.g. WA UMTJ and BI AWS), but the association was not as strong as in years past at WA-AWS and CI-ENT (see Gallion et al. 2016).

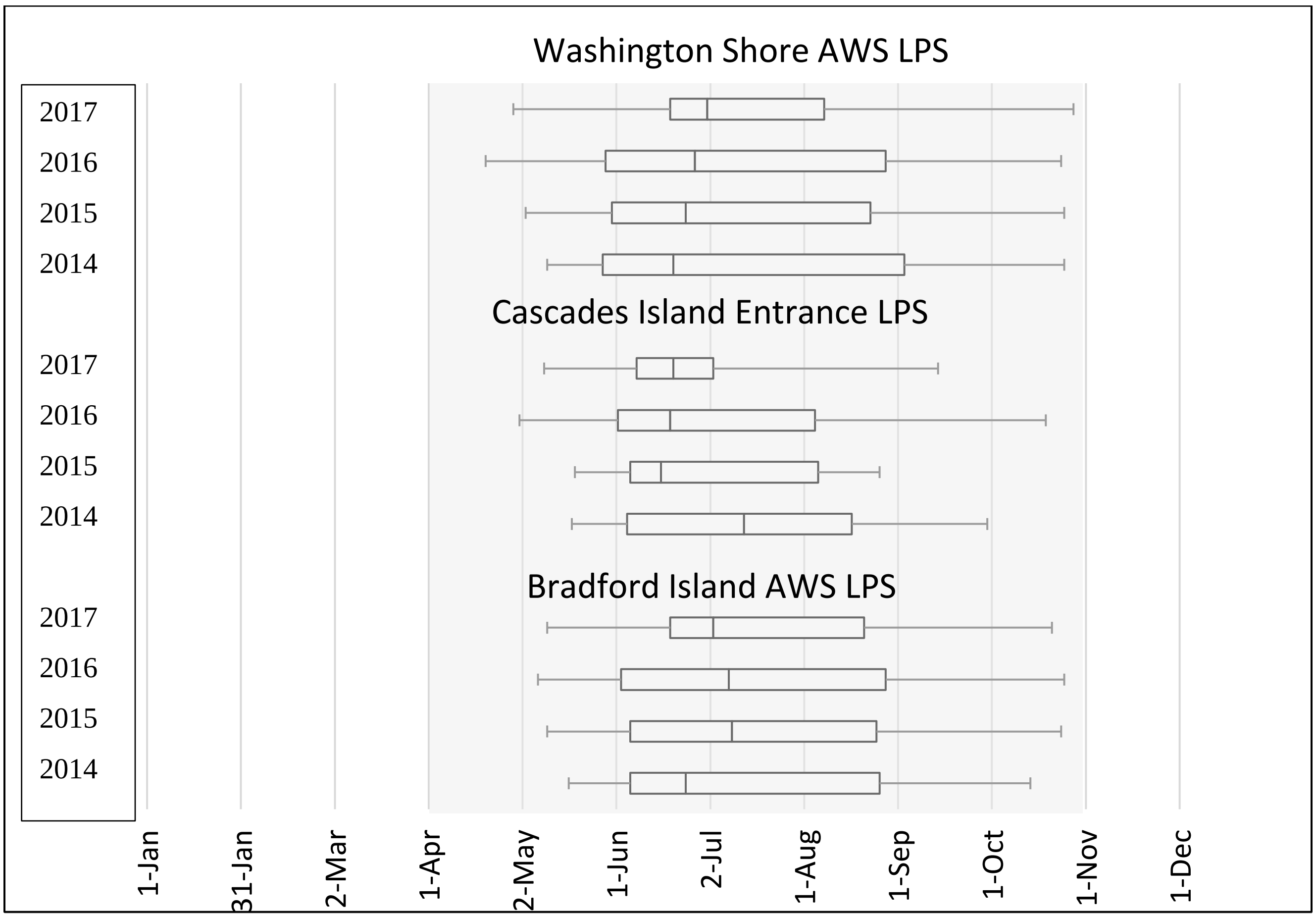

Figure 9. Run timing of Pacific Lampreys passing Bonneville Dam Lamprey Passage Structures during 2014-17. Whiskers are dates of first and last fish passage, boxes show 10%, 50% and 90% run completion dates. Grey box indicates typical dates of LPS operation (1 April to 31 October).

Lamprey run timing through the LPSs was similar to previous years with the exception of the 50th percentile at the CI-ENT LPS which was about four weeks later than previous years (Figure 9). The first lamprey of the season passed through the WA-AWS on 1 May and the last lamprey passed 30 October, one day prior to the LPSs being dewatered and shut down for the season. Diurnal passage through the LPSs is very similar for WA-UMTJ, WA-AWS, and BI-AWS with passage increasing at dusk and throughout the night and decreasing at dawn (Figure 10). However, passage at CI-ENT showed a more gradually decreased after dawn.

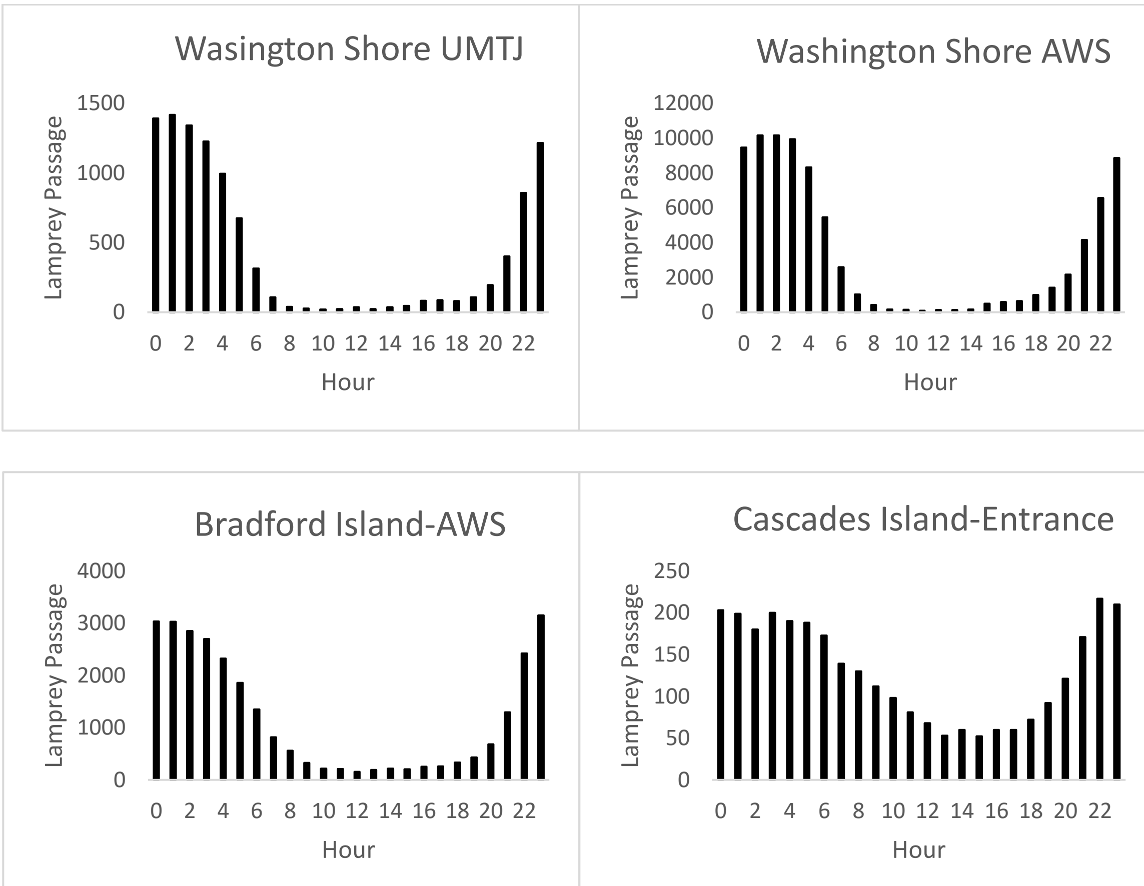

Figure 10. Diurnal distribution of lamprey passage by hour through LPSs at Bonneville Dam 2017. The LFS does not have a mechanical counter or time stamp so is not presented here. Note changing y-axis.

Over time the mechanical counters have been modified to be more dependable, and data loss has decreased over the years. However, the more complicated newly designed counts systems at Washington shore required regular adjustment and still double counted during some paddle testes. At BI-AWS and CI-ENT count data were overwritten due to the Eagle Creek forest fires. Employees were not allowed onto the dam for several days and 18 hours of data were lost on 30-31 August.

At Washington shore when the paddle is moved, a pulse is sent to a counter display, which in turn sends a pulse to a data logger, which writes a text file to a laptop three times a day. Unfortunately, of 183 days of operation there were 24 breaks in the data records due to software glitches and power outages for a total time of 477.6 hours (19.9 days) or 11% of the operational time. Most were 15 minutes or less with the largest break of 186.6 hours (7.78 days) due to a power outage from 17 to 25 October when there was very little passage. Data gaps were filled using linear interpolation or from the counter display data written on inspection sheets.

Prior to the installation of the globe type cameras, external Arm Bullet Color Camera and GANZ DVR were used to record video of the exit pipe at the WA-AWS LPS. While reviewing this video it was determined that some lampreys were grazing the bridge wall as they fell from the LPS. To prevent injury a piece of old submersible traveling screen was fashioned into a cone directing lampreys to the center of the fishway (Figure 11). Additional video confirmed this modification was successful at protecting lampreys from grazing the bridge and fishway wall.

Figure 11. A cone of fish screen material was used to prevent lampreys from grazing the bridge wall or the opposing fishway wall (left image). Fyke that clogged with lampreys was removed from AWS upwelling box to allow fish to exit on 6/21/17 (right image).

On the morning of June 21, 2017 project biologist informed the FFU that several lampreys had spilled out of the final traversing section of the WA-AWS LPS. It was determined that the final fyke had become clogged with lampreys and as more moved into the traversing section behind them water piled up, pushing up the lids on the traversing section and allowing lampreys to spill onto the concrete deck. The fish were rescued and when the fyke was removed they began to rapidly pass. This is the first instance where the capacity of an LPS to pass lampreys has been exceeded.

Lamprey Flume System

A total of 51 lampreys were collected in the LFS holding tank in 2017. The first lamprey was caught on 23 June and the last lamprey was caught 23 August. The highest number of lampreys caught in one day was nine on 15 July. On this day the water temperature was 20 °C, tailwater was 18.6 feet above sea level, and the auxiliary water supply butterfly valve was open 60%. Initially, the auxiliary valve was programmed to change at 15%, 30% and 60% daily to test for optimal attraction. Due to low collection numbers in mid-July the USACE Project Development Team (PDT) requested the valve to be set at 60% continuously (Appendix B). After a week of operating at 60%, lamprey collection was still very low and the decision to rotate at 30%, 45%, and 60% was implemented until it was shut down on 24 August (Figure 12).

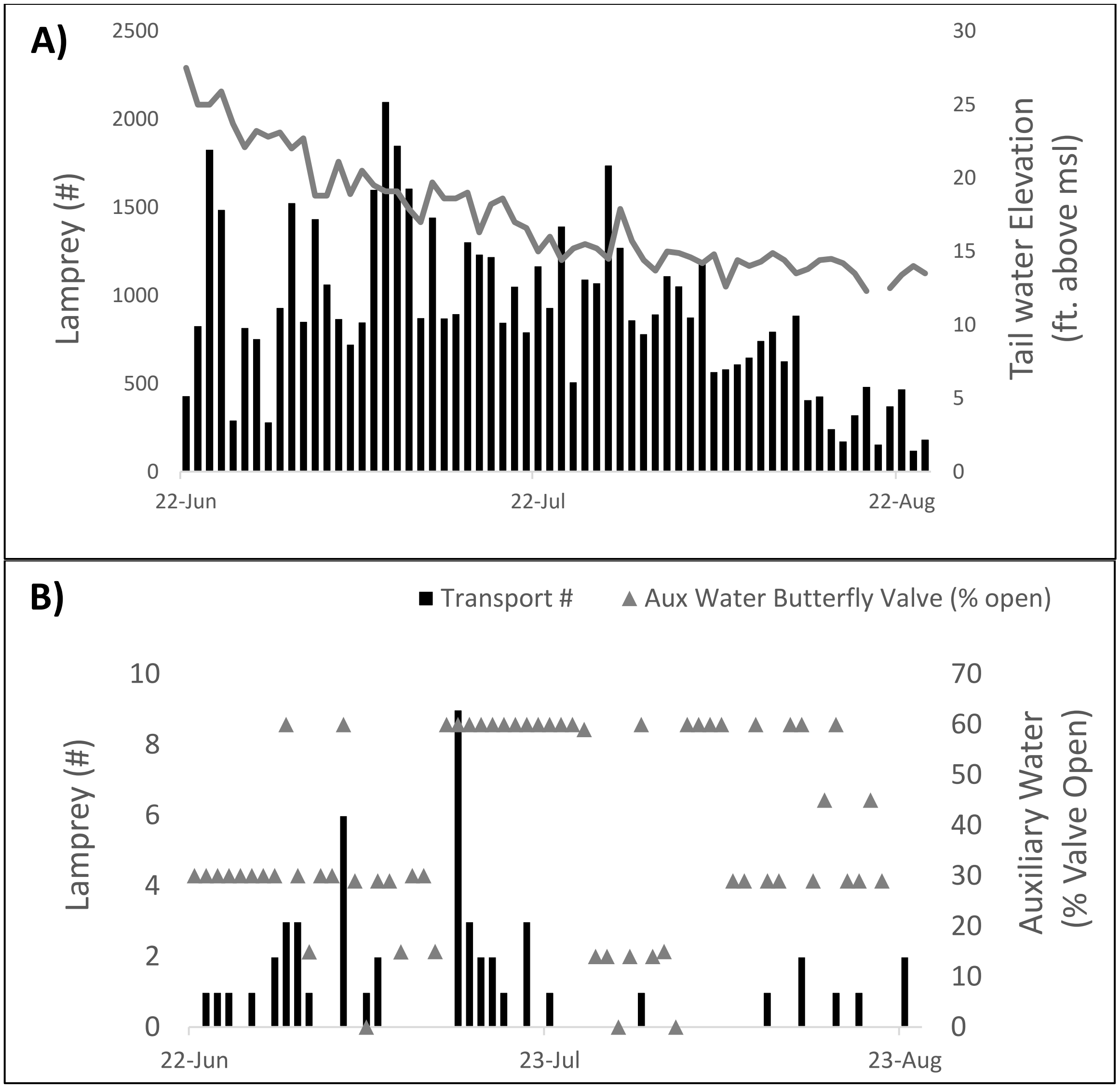

Figure 12. Daily Pacific Lamprey passage in 2017. A) Washington shore counting window, day counts + night counts (black bars) in relation to tail water elevation (grey line). B) Fish collected from the Washington shore Lamprey Flume System (black bars) and attraction water valve opening percent open (triangles on secondary y-axis).

Evaluation of Performance

Lamprey Passage Systems

Total LPS passage this season was reflective of the large lamprey run passing Bonneville Dam and was the greatest to date. Proportional passage (LPS route) was similar to previous years likely following water flow from the dam, and morality remained low. Total LPS passage was 122,247 with WA-AWS LPS increasing from 40,880 in 2016 to 90,377 in 2017. It should be noted that two new entrance ramps were installed during winter 2016-17 below the count slot. These are the WA-UMTJ entrances which feed into the WA-AWS potentially allowing it to pass more fish. Lamprey passage has generally increased at this location since 2010, combined with window counts, 2017 recorded the highest passage since installation of LPSs (Figure 13). In its first year of use the two new entrances of the WA-UMTJ LPS collected 10,705 lampreys that then swam past the counter and into rest box three of the WA-AWS LPS. Lamprey passage at BI-AWS more than doubled from 12,115 in 2016 to 28,843 in 2017(138%). Surprisingly passage decreased at CI-ENT by 24% from 3,851 in 2016 to 3,027 in 2017. However, 2017 is the second highest at CI-ENT and the highest lamprey passage recorded since installation of BI-AWS (Figure 13).

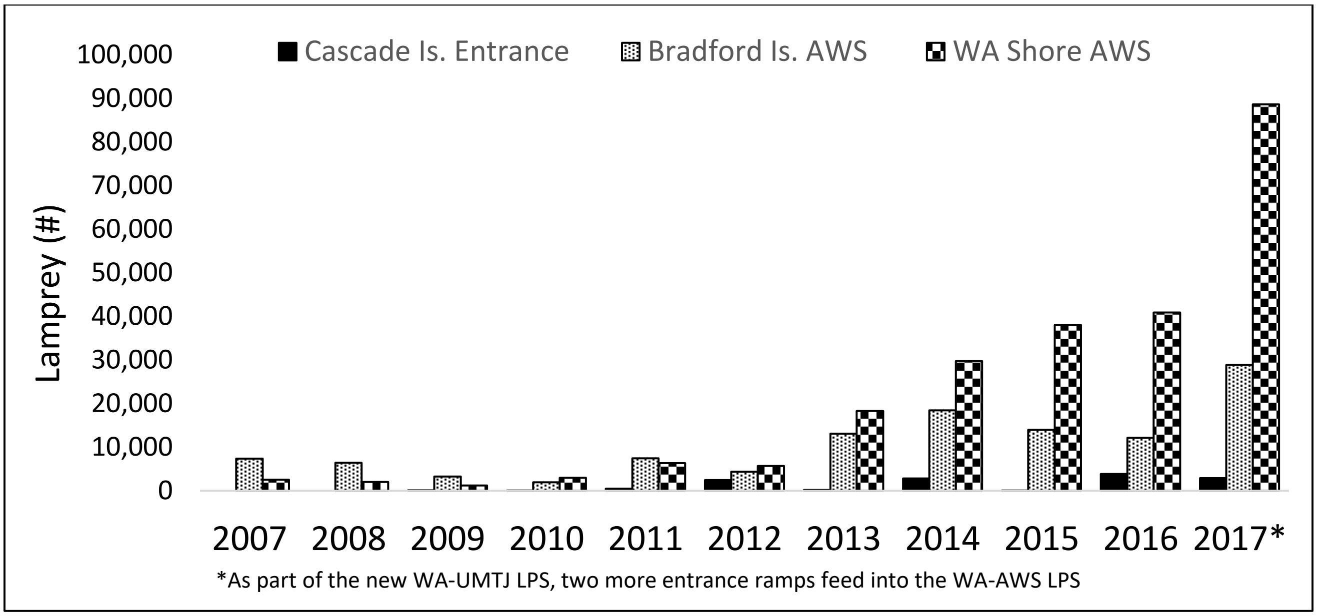

Figure 13. Annual lamprey passage estimates shown for CI-ENT, BI-AWS, WA-AWS lamprey passage structures from 2007-2017. CI-ENT was operational in 2009.

Total dam passage has fluctuated through the years, which means the number of lamprey available to use any passage route changes each year. As various modifications to improve LPS passage have taken place, year to year changes in lamprey abundance confounds performance evaluations. To control for run size we looked at proportional routes of passage, as percent of lamprey using each LPS, to see if they are changing over time or if they are effected by improvements such as additional ramps. As Figure 14 shows, through time an increasing proportion of lamprey are choosing the WA-AWS LPS, the number choosing the BI-AWS LPS has been reduced, and the proportion choosing the CI-ENT LPS is typically small.

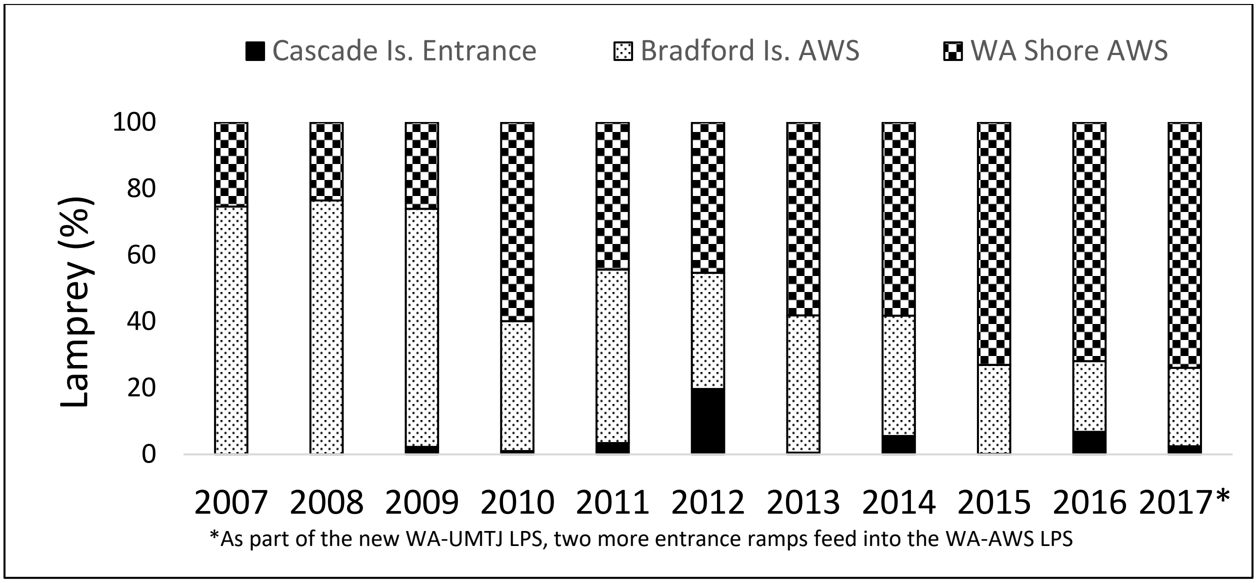

Figure 14. Proportional routes for LPS passed fish 2007-17. CI-ENT was first installed in 2009 as was the lamprey friendly keyhole entrance slot and bollards that were part of the same entrance modification.

Similar to previous authors we used relative use to further evaluate LPS performance among LPSs and between years. However we estimated total passage at Bonneville Dam as the sum of all known passage routes (2017) or using a linear regression model for 2015 and 2016 (Gallion et al. 2017) rather than multiplying the daytime index by three (Corbett et al. 2016 Table 1 and earlier reports). While not all LPS entrances were available for all lamprey Table 5 provides a broad look at recent LPS proportional passage (the number of fish passing an LPS as a percent of total dam passage).

Table 5. Use of LPSs relative to estimated lamprey passage at Bonneville Dam. Units are passage number with (percent of estimated dam passage).

Year	Bonneville Dam Estimated Passage	WA-AWS LPS	CI-ENT LPS	BI-AWS LPS	Total LPS
2017	292,411	90,377 (31)	3,027 (1)	28,843 (10)	122,247 (42)
2016*	121,850	40,880 (34)	3,851 (3)	12,115 (10)	56,864 (47)
2015*	130,332	38,069 (29)	72 (0.1)	13,986 (11)	52,127 (40)

* LPS passage numbers for 2015-16 from Gallion et al. 2017 tables 5-7. LPS passage numbers for 2017 from this report.

It should be noted that the CI-ENT LPS is uniquely located and has the potential to pass smaller lampreys, as measured by total length, which might not make it to other LPSs higher in the fish ladder (Kirk et al. 2015). Several years of radio telemetry studies, show that large fish make it further up fishways and further up the fishway and further up the river system (Keefer et al. 2013).

At Washington shore the night time window counts can be highly negative (downstream movement) resulting in an unrealistic overall negative lamprey passage index. For example in 2015 the overall index was negative (daytime index 20,252 and night time index of (-122,914)) with slightly positive index in 2016 (daytime index 28,091 and night time index (-26,123)). Similar to the negative results from night time video in 2008 by previous researchers (Clabough et al. 2012) and the difficulties of video review experienced in the 1990's by Aaron Jackson CTUIR (pers. comm 2016). Possible reasons for this are recycling of lampreys within the adult ladders at the count station. Lamprey may move downstream past the count slot after exiting the LPS upstream, or other unknown issues. Similarly, Bradford Island counts were negative during night time hourly counts, however overall the passage index was positive at this location in both 2015 and 2016 leading to questions of count accuracy.

To develop a realistic passage estimate for Bonneville Dam when counts are net negative, we looked for other lamprey counting locations that are highly correlated to Bonneville Dam in previous years. We used linear regression to model total passage at Bonneville during 2015 and 2016. We compared Bonneville Dam total passage index to The Dalles Dam day passage index from 2009 to 2014. We used only day time counts from The Dalles Dam because there were only two years of night counts available (2013 and 2014). Night counts at Bonneville Dam were not reported prior to 2009. Annual passage at Bonneville Dam from 2009-2014 ranged from 17,299-114,746 and averaged 64,120. We used this same model (see Appendix B) as a way of checking our estimate, which is not only one of the largest ever but also was heavily adjusted using video validation.

Applying the same formula to daytime window counts at The Dalles Dam in 2017 results in an estimate of 314,411 (492,866 – 135,957 upper and lower 95% CI) at Bonneville Dam. This is greater than our reported estimate of 292,441 derived from daytime window counts + night time window counts + LPS passage + LFS trap and haul + other fish trapped an release upstream of Bonneville for research or tribal translocation programs. However our point estimate using summation is with the 95 % CI of the linear regression model and is 7.5 % lower.

Lamprey Flume System

The Lamprey Flume System passed 51 fish in 64 days of operation in 2017 similar to 2013 and 2015, but less than in 2014 (545 fish, 113 days) see Table 6. Due to low capture of lampreys in previous seasons, the test of randomizing attraction water settings was foregone in favor of operating more days at higher levels (e.g. 60% open) which may confound the comparison. Catch per unit of effort (CPUE) of each valve opening was calculated as, the number of lampreys caught in the LFS during each treatment divided by the number of nights of each treatment (auxiliary butterfly valve was open a given percent). There were four conditions during this season: 15% (n= 8 nights, CPUE= 0.125), 30% (n= 24 nights, CPUE= 0.542), 45% (n= 4 nights, CPUE= 0), and 60% (n= 25 nights, CPUE=1.44).

Table 6. Annual lamprey collection at the Washington shore LFS during 2014-2015, and 2017.

Year	Dates Operated	Days (#)	Lampreys collected (#)
2013*	4 June – 20 August	45	29
2014*	20 May – 10 September	113	545
2015	5 May - 31 August	107	69
2017	22 June - 24 August	64	51

*Values from Kirk et al. 2015. In 2013 the LFS was shut down for 16 days due to in-season repairs, thus the date range is greater than 45 days. In 2016 the LFS was not operated due to a missing access hatch.

The 15% (n=8) and 45% (n=4) treatments had low sample sizes and non-homogeneous variance, preventing the use of the Kruskall-Wallis test of the four treatments, and were excluded. We used the Shaprio-Wilk test for normality to test the null hypothesis: The data is normally distributed. Results for 30% open (W = 0.65482, p-value = 3.83e-^{06}) and 60% (W = 0.70808, p-value = 6.854e-^{06}) lead to rejection of the null hypothesis. We then used the non-parametric Wilcoxon ranked sums test was used to compare CPUE (lampreys/night) at the 30% and 60% valve open treatments.

It should be noted that the treatments were not randomly applied during the passage season and so results may be confounded by other variables such as water temperature (increasing swim scope) and dropping tail water level (more distance to climb, potential for salmonid ladder flows to wash out of LFS attraction flows as tail water drops).

The 30% and 60% valve open treatments were not significantly different (W = 215, p-value = 0.064). Although lacking statistically significance, lampreys were almost 3 times as likely to be collected when the auxiliary butterfly valve was open 60% ($\bar{X}$=1.46, SD= 2.16, n= 26) compared to 30% open ($\bar{X}$=0.48, SD=0.83, n=23). A larger sample size is needed to improve the statistical power of these comparisons and randomization of treatment application to prevent confounding results due to non-measured variable.

Conclusions

Operation and Inspection

The time frame for LPS operation (April or May-October) and frequency of inspections were adequate to provide safe passage for the 2017 lamprey run. The window counts report the first lamprey passed Bonneville Dam on 4 May and by 15 August the run was 95% complete. These dates were captured by LPS operations and we recommend continuing to operate LPSs during this time frame. Every other day inspections allowed us to notice that a pump had failed and get it running before any mortality occurred.

Operation of the LFS has typically been scheduled to start 1 June, after the lamprey run is in full swing, ending 31 August. This season, there was an issue with connecting power to the pumps leading to a three week delay and a shorter operating window, 64 days from 22 June to 24 August.

This likely reduced the number of lampreys collected. To maximize potential collection next season we recommend starting the LFS by 1 May (see Evaluation of Performance below).

Passage Validation and Estimates

The automated counting mechanisms used on the LPSs offer the potential of lower cost monitoring of lamprey passage when compared to live counters, but are inaccurate and video review to determining correction factors adds to their cost. In previous seasons, the counting mechanisms versions using limit switches were found to be inaccurate and had some down time due to battery failure, where no data logging occurred. The newly designed counters installed at the WA-AWS & WA-UMTJ LPSs had neither been bench nor field tested and required constant monitoring and field adjustment to have comparable accuracy to the previous counters. Determining correction factors for each location results in 440 hours of video to review, (10 hours per session x 11 sessions x 4 sites). During low passage times the video could be reviewed at 2x to 4x speed, any faster risks missing a passage event. During times of high passage, it may take slightly more than one hour of review for one hour of video recorded as it takes more time to collect the data – especially when performing a detailed review to determine the cause of counting error. Finding, installing, and testing more accurate counting mechanisms could reduce or eliminate the need for video validation saving effort and money.

Surveying lamprey passage and counting systems elsewhere we found agencies and researchers have used similar approaches to monitor lamprey passage at low-head dams. The Umatilla Tribe uses paddle activated limit switches (similar to BI-AWS and CI-ENT), the Yakama Nation is using a wetted climbing wall with trap box, U.S. Fish and Wildlife Service tested several structures to pass lampreys at the low-head Cape Horn Dam located on the Eel River in California, and the Great Lakes Fishery Commission uses trap boxes. Monitoring of the wetted climbing walls at the Yakima River's Prosser Diversion Dam was accomplished using video for behavioral information and then hand counting of lampreys as they were removed from a trap (Lampman pers. comm. to Zorich on 17 January 2018). The evaluation at Cape Horn Dam trapped and PIT tagged lampreys to evaluate their passage structures (Goodman & Reid 2017) and used a motion detection camera with DVR to count non-tagged fish passage. Trap boxes are used in the Great Lakes region to control and remove invasive Sea Lampreys and capture about 40% of the population (Great Lakes Fishery Commission 2018). There are plans for a large lamprey passage evaluation at Bonneville Dam using both PIT and acoustically tagged fish in 2018 and a wetted wall has been installed at the Bradford Island fishway.

Novel counting approaches include proximity detectors, photoelectric counters, and advanced digital camera technologies. Next season we will investigate using proximity detectors and/or photoelectric counters at the Washington shore AWS exit shoot. Moving fish will be detected by ultrasound or trip an infrared light tallying a count. Another option found in the commercial aquaculture industry would be a pipe fish counter using digital camera technology. One such system, the AquaScan Fish Counter claims to be 98% accurate for fish weighing 2 grams to 7 Kg (Water Management Technologies 2017). However, the design of the AquaScan counter may not be compatible with lampreys if they are able to attach to the camera while sliding past it. The AquaScan and similar devices may require a clear view of the fish, so bar screen used to prevent lamprey attachment may be discordant with these types of devices. Moreover, these technologies may be cost prohibitive (~$30K vs. $10 to $100 photoelectric counters). However, the cost of an accurate counter may balance the current method of time consuming video review to determine correction factors.

Our estimates of total lamprey passage at Bonneville Dam and of LPS passage during 2017 are some of the highest reported since counting began in 1938. However, the amount of correction was large and some observation periods had a low number of events to base a correction factor on. Caution is warranted given the large amount of both positive (+ 93% at WA AWS) and negative (-65% at BI AWS) adjustments made after video validation was complete (Table 3). Also, at the CI ENT LPS the bulk of fish passed from mid-June to early July (Figure 8) and passage events outside that window were low. There was one observation period (number 5) where no lamprey were recorded passing, and two other where only one fish passed, so we are depending on a very small number of events to validate passage and calculate a correction factor. If possible, it would be more robust to observe a minimum number of passage events so that the variability of the correction factor has a chance to level out (e.g. 30 events).

Evaluation of Performance

Passage rates for the LPS is best illustrated by investigating the routes of passage and relative collection efficiency (Figure 14 and Table 5). The two additional entrance ramps in the Washington shore fishway (WA-UMTJ) moved a little under 10% of WA-AWS passage, which doubled 2016's estimate. However, passage at BI-AWS also doubled and no changes were made there suggesting that lampreys collected by WA-UMTJ's new ramps were compensatory rather than additive this year. In addition Figure 14 shows that proportional passage was similar in 2015 and 2016 prior to the installation of the new ramps. Next year's proportional passage may be more instructive after the WA-UMTJ LPS has had a year to season its performance could increase. Whether WA-UMTJ passage is additive or compensatory, the individual fish that use it can avoid the energy expended attempting to pass the serpentine weirs or fighting the high velocities in the AWS to reach the WA-AWS LPS. Previous research shows the count slot and serpentine weirs are a major turnaround point, that fish make several attempts to pass them, and that passing more fish near the top of the fish ladder increase upstream passage as well (Keefer et al. 2013).

The LFS collected the fewest fish of the four years it has operated despite the large lamprey run, and we are concerned it has some blockage, such as the sedimentation, which is suspected to have prevented the operation of the PH2 NDE weir nearby. Alternatively, explanations for the low utilization could include: late operation that missed the bulk of the migrating fish or insufficient to attractant flow due to the operational limit of 60% open butterfly valve setting.

It is difficult to evaluate the performance of the LFS as it has never been ran at its full attraction water volume due to concerns that entrained air from the auxiliary attraction water might cause a bubble curtain and dissuade or delay adult salmon from entering the fishway (Appendix C FPOM minutes June 2014). Starting the LFS by 1 May would take advantage of higher tailwater at that time, thus a shorter climb for lamprey using this passage route. Operating at a higher tailwater may also avoid obscuring the LFS attraction flows which can be negated by counter current coming from the adult fishway and could recreate the conditions that occurred in 2014 when 545 lampreys were collected (Kirk et al. 2015). We further recommend inspection of the LFS entrance using a remotely operated vehicle (ROV) or human divers to determine if it is clogged with sediment or the entrance has become dislodged and is not functioning within design criteria.

There was no significant difference in CPUE when auxiliary water was operated at the 30% or 60% open levels, however larger sample sizes would increase statistical power. For the 2018 evaluation we recommend operating the attraction water (butterfly valve) at 30% and 60% open, on alternating days for the entire season. Only by holding to a schedule of experimental attraction flows can the data be analyzed to suggest best future operations. The time, energy, and funding used to install this system requires learning more about why so few lampreys are using it in recent years when it passaged more fish previously.

As LPSs continue to pass more fish it is important to integrate these counts into the daytime passage index. In 2017 LPSs passed 122,247 lampreys or 42% of our estimated escapement (292,411). The LPS passed fish make up a large part of total passage but are not currently posted to the web alongside the U.S. Army Corps day and night time fish passage index (http://www.fpc.org/environment/home.asp).

We recommend continued operation of LPSs at Bonneville Dam and continued research to determine if the LFS needs to be repaired or could be operated a different way to capture more lampreys. Managers depend on timely, accurate counts at Bonneville Dam as an indication of the health of the Columbia Basin’s lamprey population. The automated counting mechanisms used on the LPSs offer low cost, around the clock monitoring of passage, but are imperfect. To increase count accuracy (called for in the Columbia Basin Fish Accords MOA as reiterated in the USACE 10 year Plan) we suggest trials of innovative counters such as proximity or photoelectric counters placed in line with the current paddle counters for comparison. Finally, as LPSs continue to pass a large proportion of all lampreys passing Bonneville Dam, these counts need to be integrated with the current on-line day and night window counts to better reflect actual lamprey passage at the dam. Changes in the lamprey population can be recognized through accurate and dependable monitoring and reporting.

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Appendix A. Annual lamprey passage tables for Bonneville Dam LPSs.

Table 7. Annual lamprey passage estimates at Washington auxiliary water supply lamprey passage structure during 2007-2014 (Corbett et al. 2015), 2015-2016 (Gallion et al. 2016), and 2017.

Year	Operation period	# days	Estimated Passage
2007	25 June – 22 October	119	2,517
2008	13 May - 28 October	168	1,985

2009	26 May – 2 November	160	1,199
2010	8 June – 25 October	139	2,961
2011	26 May – 9 November	167	6,345
2012	2 June – 11 November	162	5,686
2013	16 May – 16 October	153	18,329
2014	8 May – 29 October	174	29,756[1]
2015	30 March – 28 October	212	38,069[1]
2016	5 April – 27 October	202	40,880[1]
2017	1 May – 31 October	184	90,377[1]

1: Corrected for mechanical count error

Table 8. Annual lamprey passage estimates at Bradford Island auxiliary water supply lamprey passage structure during 2007-2015 (Corbett et al. 2015), 2015-2016 (Gallion et al. 2016), and 2017.

Year	Operation period	# days	Estimated Passage
2004	Unknown	NA	7,490
2005	Unknown	NA	9,242
2006	Unknown	NA	14,975
2007	8 May – 22 October	167	7,387
2008	13 May – 28 October	168	6,441
2009	26 May – 2 November	160	3,302
2010	4 June – 25 October	143	1,933
2011	26 May – 9 November[1]	154	7,476
2012	2 June – 9 November[2]	144	4,392
2013	16 May – 16 October[3]	141	13,066
2014	8 May – 20 October	165	17,587[5]
2015	30 March – 28 October	212	13,986[5]
2016	5 April – 27 October[4]	205	12,115[5]
2017	5 April– 31 October	210	28,843[5]

1: 13 days of data gaps; 2: 16 days of data gaps; 3: 12 days of data gaps; 4: 2 days of data gaps; 5: Corrected for mechanical count error. In 2006 a second collection ramp was added to the east side of the AWS.

Table 9. Annual lamprey passage estimates at Cascades Island entrance lamprey passage structure during 2007-2014 (Corbett et al. 2015), 2015-2016 (Gallion et al. 2016), and 2017.

Year	Operation (days)	# days	Estimated Passage
2009	26 May – 3 September[1]	73	106
2010	31 May – 10 September[2]	75	48
2011	6 June – 15 September[3]	94	485
2012	23 May – 20 September[3]	113	2,472
2013	24 June – 4 October[3,4]	95	155
2014	14 May - 30 October[5]	167	2,832

2015	6 April – 30 September	177	72[6]
2016	8 April – 27 October	202	3,851[6]
2017	5 April– 31 October	210	3,027[6]

1: Experimental flow testing was conducted; system was operated weekdays only; 5 days of data gaps; 2: LPS was operated weekdays only; 3: 7 days of data gaps; 4: CI LPS was extended to the forebay using mostly PVC pipe prior to 2013 operation; 5: two days of data gaps; 6: corrected for mechanical count error.

Appendix B. Bonneville Dam lamprey passage estimate using a linear regression model

Adult Pacific lamprey can pass Bonneville Dam by several routes. Through the traditional salmonid fish ladder, they are visually counted through a window when passing count slots (Washington shore, Bradford Island, and occasionally Cascades Island). They are mechanically counted when using Lamprey Passage Structures (LPS) as described in this report, and could be captured in traps and released upstream of the dam for research or the tribal translocation program.

Visual lamprey counting, especially from night time video, is extremely difficult to perform accurately. Additionally, lamprey are seen passing underneath the fish crowder brushes and squeezing through the fish crowder picket leads suggesting they may still use this route to avoid the count slot after the picket lead spacing was reduced to ¾ inches. The serpentine weirs, or flow control section, upstream of the count slots at Bonneville Dam are a known turn around point for lamprey. They will repeatedly move back and forth through the count slot, attach to the window for long periods of time, and generally move in a less directed way than salmonids do. These varied behaviors result in dynamic movements of lamprey which makes them difficult to track in the window. An additional complication is they may be able to move upstream behind the count slot, behind the crowder for example, and are only counted when they float downstream through the slot in the mid-water column.

At Washington shore the night time window counts can be highly negative (downstream movement) resulting in an unrealistic overall negative lamprey passage index for 2015 (daytime index 20,252 and night time index of (-122,914) with slightly positive index in 2016 (daytime index 28,091 and night time index (-26,123). Similar to the negative results from night time video in 2008 by previous researchers (Clabough et al. 2012) and the difficulties of video review experienced in the 1990's by Aaron Jackson CTUIR (pers. comm 2016). Possible reasons for this are recycling of lampreys within the adult ladders at the count station. Lamprey may move downstream past the count slot after exiting the LPS upstream, or other unknown issues. Similarly, Bradford Island counts were negative during night time hourly counts, however overall the passage index was positive at this location in both 2015 and 2016 leading to questions of count accuracy.

To develop a realistic passage estimate for Bonneville Dam when counts are net negative, we looked for other lamprey counting locations that are highly correlated to Bonneville Dam in previous years. We used linear regression to model total passage at Bonneville during 2015 and 2016. We compared Bonneville Dam total passage index to The Dalles Dam day passage index from 2009 to 2014. We used only day time counts from The Dalles Dam because there were only two years of night counts available (2013 and 2014). Night counts at Bonneville Dam were not reported prior to 2009. Annual passage at Bonneville Dam from 2009-2014 ranged from 17,299-114,746 and averaged 64,120 (Table 1).

Table 10. Pacific lamprey passage at Bonneville Dam (Ladder, LPS and trapped), and The Dalles Dam (daytime ladder).

Year	Bonneville Dam	The Dalles Dam
2014	120,100†	11,662
2013	84,347†	8,737
2012	93,456†	6,241
2011	51,201†	5,003†
2010	24,564†	1,726
2009	18,822†	2,318

† Values have been updated from our 2015 report to use the best available data and incorporate corrections. Most adjustments resulted in less than a 6% change. However, an error was found in the Annual Fish Passage Report Table 24b. In 2010 night counts were only reported for Bradford Island (4,155), here we have included Washington Shore (9,276).

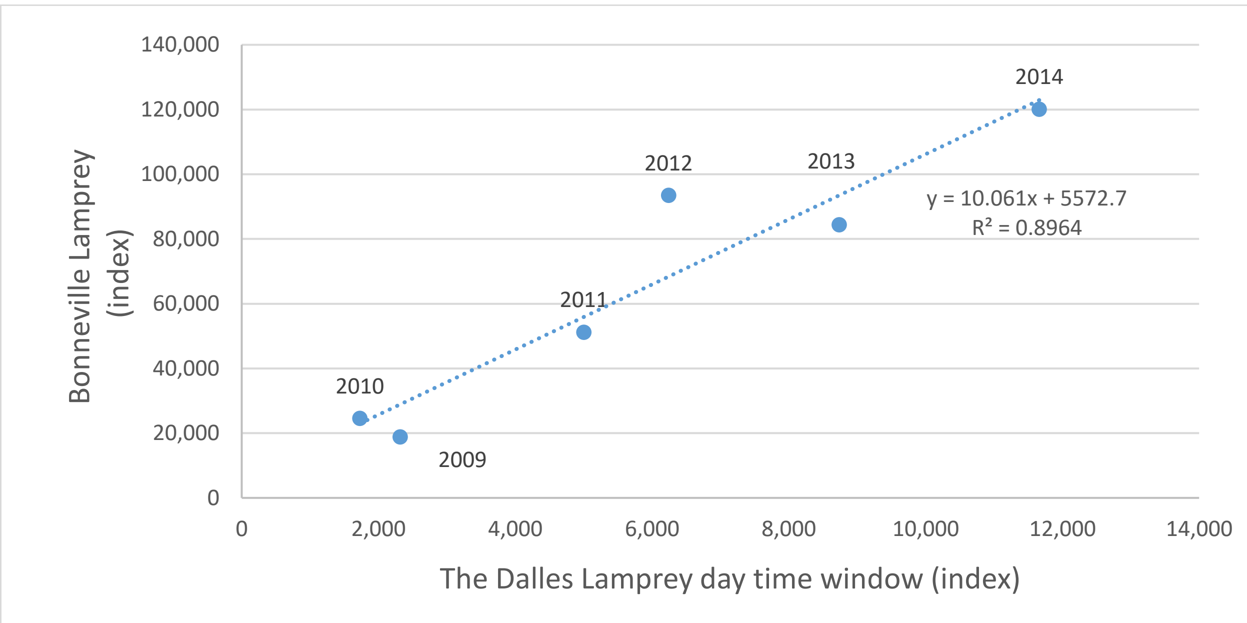

Figure 15. Fitted line and equation from passage data. The x-axis is The Dalles daytime window index. The y-axis includes the Bonneville daytime window index + night time video counts + LPS counts + trapped lamprey release above the dam.

The line fitted to these data had an $r^2 = 0.90$ with a p-value = 0.0004. To re-estimate 2015 and to estimate 2016 total lamprey passage we used these formula;

1) Bonneville Dam lamprey passage in 2015 = 5572.7 +10.061 * 12,400
2) Bonneville Dam lamprey passage in 2016 = 5572.7 +10.061 * 11,557
3) Bonneville Dam lamprey passage in 2017 = 5572.7 +10.061 * 30,696

Where 12,400 was the daytime index at The Dalles Dam during 2015 and 11,557 was the daytime index in 2016, and 30,696 was the index in 2017. As a result, we estimate 130,332 (221,914 – 38,749 upper and lower 95% CI) lamprey passed Bonneville Dam during 2015, which is adjusted up from 127,956 initially reported.

Further, we estimate 121,850 (209,430 - 34,270 upper and lower 95% CI) lamprey passed Bonneville Dam during 2016. Applying the same formula to daytime window counts at The Dalles Dam in 2017 results in an estimate of 314, 411 (492,866 – 135,957 upper and lower 95% CI) at Bonneville Dam. This is greater than our reported estimate of 292,411 derived from daytime window counts + night time window counts + LPS passage + LFS trap and haul + other fish trapped an release upstream of Bonneville for research or tribal translocation programs.

You will notice our point estimates (130,332 or 121,850 or 314,405) are outside the range of our existing data (Table 1). They are some of the highest passage estimates since lamprey counting resumed in 1997 and are based on some of the highest window counts at The Dalles Dam and therefore should be used with caution.

Appendix C. Data from lamprey mortalities removed form LPS at Bonneville Dam.

Table 11. Pacific Lamprey mortalities found in the Lamprey Passage Systems (LPS) at Bonneville Dam.

Date	Time	Site	Location	Length (cm)	Inter-dorsal (cm)
2-Jul	1145	BI	LPS grating	59	2
2-Jul	1145	BI	LPS grating	55	2.3
2-Jul	1145	BI	LPS grating	62.4	2.4
26-Jun	1051	BI	LPS grating	65.5	3.9
24-Jun	845	BI	LPS grating	22	UNK
4-Jul	855	BI	RB 1	58.5	2
8-Jul	1030	BI	RB 1	59.5	2.5
30-Jun	1117	BI	RB 1	58	3.1
10-Jul	1050	BI	RB 1	67.7	3.5
4-Jul	900	BI	RB 2	62	3
8-Jul	1030	BI	RB 2	65	3
4-Jul	900	BI	RB 2	68.9	4.8
12-Jul	1000	BI	Road	UNK	UNK
10-Jul	1200	CI	POND	56.3	2
10-Jul	1200	CI	POND	67.7	2.1
30-May	1600	CI	POND	72	3.7
23-Jul	945	CI	RB 4	60.2	1.9
2-Jul	1117	CI	RB 4	60	2
2-Jul	1117	CI	RB 4	58.5	2.3
12-Jul	930	CI	RB 4	69	3.3
20-Jul	845	CI	RB 4	65.5	4
22-Jul	935	CI	RB 4	UNK	UNK
1-Aug	1100	CI	RB 4	62.1	UNK
8-Sep	1609	WA AWS	RB 1	66.5	2.5
6-Aug	1011	WA AWS	RB 1	63.5	3.2
18-Aug	1130	WA AWS	RB 1	73	4
30-Jul	1030	WA AWS	RB 2	65.9	2.8
16-Jul	1136	WA AWS	RB 2	73.5	3.5
16-Jul	1136	WA AWS	RB 2	60.5	3.5
11-Jul	1045	WA AWS	RB 2	68.7	4.1
9-Jul	900	WA AWS	RB 2	59	5.5
21-Jun	700	WA AWS	Upwelling	59	UNK
21-Jun	700	WA AWS	Upwelling	69	UNK
10-Jul	1020	WA UMTJ	RB 1	67.6	3
26-Jun	837	WA UMTJ	RB 1	77.7	3.4

8-Jul	930	WA UMTJ	RB 2	71	3.5
4-Jul	1126	WA UMTJ	RB 2	63	4.2
4-Jul	1126	WA UMTJ	RB 2	72.4	5.4
2-Jul	1044	WA UMTJ	RB 2	73	UNK
6-Jul	800	WA UMTJ	RB 2	66	UNK
4-Aug	900	WA UMTJ	RB 2	UNK	UNK

Table 12. Summary statistics of Pacific Lamprey measurements from mortalities removed from Lamprey Passage Systems (LPS) at Bonneville Dam.

	N	Total Length (cm)			Inter-dorsal Length (cm)		
Location		Average	Minimum	Maximum	Average	Minimum	Maximum
Bradford Island AWS	**13**	**58.6**	**22.0**	**68.9**	**3.0**	**2.0**	**4.8**
LPS grating	5	52.8	22.0	65.5	2.7	2.0	3.9
RB 1	4	60.9	58.0	67.7	2.8	2.0	3.5
RB 2	3	65.3	62.0	68.9	3.6	3.0	4.8
Cascades Island Entrance	**10**	**63.5**	**56.3**	**72.0**	**2.7**	**1.9**	**4.0**
Pond	3	65.3	56.3	72.0	2.6	2.0	3.7
RB 4	7	62.6	58.5	69.0	2.7	1.9	4.0
Washington Shore AWS	**10**	**65.9**	**59.0**	**73.5**	**3.6**	**2.5**	**5.5**
RB 1	3	67.7	63.5	73.0	3.2	2.5	4.0
RB 2	5	65.5	59.0	73.5	3.9	2.8	5.5
Upwelling	2	64.0	59.0	69.0	Not Taken	Not Taken	Not Taken
Washington Shore UMTJ	**8**	**70.1**	**63.0**	**77.7**	**4.0**	**3.0**	**5.4**
RB 1	2	72.7	67.6	77.7	3.2	3.0	3.4
RB 2	6	69.1	63.0	73.0	4.8	3.5	5.4
Grand Total	41	63.8	22.0	77.7	3.2	1.9	5.5

Appendix D. Lamprey Flume System Trip Report

TRIP REPORT

Date: 14 July 2017
From: Sean Tackley, USACE Portland District (CENWP-PM-EF)
Subject: Bonneville Washington Shore Lamprey Flume System (LFS) Operations Testing

Attendance: Sean Tackley (USACE), Brian McIlraith (CRITFC), Gary Fredricks (NOAA), Brian Bissell (USACE).
Purpose: Visually assess entrained air discharge from the LFS upper entrance, located at North Downstream Entrance (NDE) of the Washington Shore Fish Ladder, under various operational settings to identify acceptable range of operations.
Background: Collection of lamprey from the LFS holding tank continues to be minimal. As of 11 July, only 22 lamprey had been collected in 2017 (in approx. 18 days of operation). A butterfly valve controls flows into the LFS and can deliver up to 71 cfs when fully opened. The design discharge for the LFS is 52 cfs, which corresponds to a 60% butterfly valve opening. Due to a history of entrained air issues that have raised concerns about a possible "bubble curtain" emanating from the upper entrance of the LFS under higher flow conditions, LFS operations have been constrained. One operational solution to reducing discharge of entrained air from the upper entrance has been to partially close a closure gate that joins the upper entrance to the rest of the flume. This 4.5 ft tall closure gate is located on the south (tailrace) side of the thimble that passes through the south monolith, and can be manually opened or closed. Testing in 2015 showed that partially closing the gate reduces discharge of entrained air from the upper entrance, presumably because air gets trapped behind the gate and is forced to exit the system further upstream. Since 2015, based on regional coordination and previous visual assessments, operation of the LFS at design discharge (60% valve opening) has only been allowed when the closure gate is in a 1 ft open position. Per **Table 1** below (estimated discharge and velocities from Steve Schlenker, 2015), this operation results in attraction velocities of ~0.8 fps at the upper entrance and ~3.8 fps at the lower entrance. In 2017, the Fisheries Field Unit (FFU) has operated the system with a 1 ft closure gate opening and in an alternating pattern of 14-15%, 30% and 60% butterfly valve position. There is some evidence that the 60% open valve position may attract and collect more lamprey, as the highest number collected in 2017 to date was six fish, corresponding to the 60% setting. Given that few fish have been collected in 2017 (despite the largest lamprey run since the early 2000s) and given that some structural modifications were made during the 2016-17 IWW period to reduce air entrainment in the LFS, it was decided to evaluate larger closure gate openings (2.25 ft, 4.5 ft) and higher flow settings to see if the Corps could expand the upper limits on closure gate opening and/or butterfly valve settings. **Table 1** below summarizes observations regarding settings that were visually assessed.
Key Findings: At design discharge (60% valve opening) and at a tailwater elevation of 18.6 ft, no entrained air could be seen emanating from the LFS upper entrance until the upper entrance closure gate was opened to 4 ft. At a 4.5 ft gate/60% valve setting, a

somewhat intermittent but steady stream of bubbles and small boils emanated from vicinity of the south side of the upper entrance (the south wall of the NDE), consistent with previous settings that were found to be acceptable by NOAA and the Corps. At both 4.5 ft gate/80% valve and 4.5ft gate/70% valve settings, the boils and plume of bubbles became much more pronounced and Fredricks found this operation unacceptable without an evaluation of adult salmon behavior in this area. The 70% and 80% butterfly valve openings also resulted in noticeably more turbulent boils along the main section of the LFS and caused water to spray from LFS gaps and hatches in the climbing section of the structure, prompting concerns about lamprey passage conditions within the LFS under higher flow conditions.

The group agreed that the LFS may be operated at up to 60% valve opening when the upper entrance closure gate is in the fully open position (4.5 ft). Fredricks and Bissell deferred to Tackley on McIlraith on the recommended operation for the remainder of 2017. All agreed that tailwater elevation may change conditions, so periodic monitoring is necessary if the system is operated at this higher setting.

The group discussed capitalizing on the planned 2018-19 lamprey radio-telemetry study and the possible concurrent adult salmon (spring Chinook) study in 2018 to evaluate effects of higher and lower LFS butterfly valve settings on salmon and lamprey behavior in the vicinity of the NDE.

Recommendations:

1. Tackley and McIlraith recommend operating the system at the 4.5 ft (fully open) closure gate/60% butterfly valve setting at all times for the remainder of the season, with periodic monitoring by the FFU, Tackley and BON Fisheries to ensure that the entrained air plume does not get more pronounced as tailwater elevation drops.

2. Tackley will work with Ricardo Walker – in coordination with SRWG - on outlining specific 2018 study objectives related to this topic. Two primary research questions:
    a. Does operating the LFS at higher flow settings (i.e. butterfly valve opening of 80% or similar) delay spring Chinook salmon passage at NDE, thereby exposing them to higher predation risk (vs. 60% or lower setting) during the sea lion predation season (early Spring-June 1)?
    b. Does operating the LFS at higher flow settings (i.e. butterfly valve opening of 80% or similar) result in a greater number of lamprey collected in the LFS LPS collection box (vs. 60% or lower setting)?

3. If LFS efficacy improves substantially in 2017 or 2018, the Corps should consider using fish passage study results and visual observations to develop a schedule of LFS operations that is tailwater elevation dependent. This table could be integrated in to the annual Fish Passage Plan.

Table 1. Summary of conditions and observations from 14 July 2017 visual assessment of entrained air response to various BON WA Shore Lamprey Flume System (LFS) operations. Estimated discharges and velocities were from a table developed by Steve Schlenker (USACE Portland District, Hydraulic Design) in 2015. Tailwater elevation for all scenarios was 18.6 ft.

Test	Butterfly Valve % open	Total Discharge (cfs)	Closure Gate Setting (ft)	Est. Lower LFS Entr. Velocity (ft/s)	Est. Upper LFS Entr. Velocity (ft/s)	Acceptable to NOAA?	Notes
1	60%	52	1.0	3.8	0.8	Yes	No visible bubbles d/s of NDE. Moderate boils along main LFS. No major concerns.
2	60%	52	2.25	3.3	1.4	Yes	No visible bubbles d/s of NDE. Moderate boils along main LFS. No major concerns.
3	60%	52	4.0	TBD	TBD	Yes	Bubbles/light boil plume d/s of NDE visible but intermittent and weak. Plume comes from south inside wall of fishway and does not move laterally across fishway entrance. Moderate boils along main LFS; air/water coming out of gaps in water supply hatches and other gaps. No major concerns.
4	60%	52	4.5	2.3	2.7	Yes	Steady bubbles/light boil plume d/s of NDE visible but boils intermittent and weak. Plume comes from south inside wall of fishway and does not move laterally across fishway entrance. Moderate boils along main LFS; air/water coming out of gaps in water supply hatches and other gaps. No major concerns.
5	80%	68	4.5	3.0	3.5	No	Steady bubble/boil plume d/s of NDE visible. Steady plume from south inside wall of fishway. Slight lateral movement or expansion of plume ~20 ft downstream of entrance. Larger boils along main LFS; water spraying out of lamprey-bearing climbing section of flume. Fredricks concerned about salmon; Tackley/McIlraith concerned about lamprey passage within flume.
6	70%	TBD	4.5	TBD	TBD	No	Steady bubble/boil plume d/s of NDE visible. Steady plume from south inside wall of fishway. Slight lateral movement or expansion of plume ~20 ft downstream of entrance. Larger boils along main LFS; water spraying out of lamprey-bearing climbing section of flume. Concerns about salmon at NDE; lamprey passage within flume.