Use of Adult Pacific Lamprey Passage Structures at Bonneville and John Day Dams
2019 Annual Report

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On the cover: The Bradford Island Lamprey Passage Structure exit slide with the new aluminum cover fabricated by Bonneville Project. The cover was added to inhibit algal growth on the grooved ultra-high molecular weight (UHMW) density plastic. In addition to the cover, the UHMW plastic grooves were deepened from 1/8” to 1/4". These modifications are to prevent lamprey attachment when exiting the structure.

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Executive Summary

The Columbia Basin Tribes have raised repeated concerns about the decline of the Pacific Lamprey (*Entosphenus tridentatus*) populations and their low passage rates at U.S. Army Corps of Engineers' dams on the Columbia and Snake rivers. In response to these concerns, several operational and structural changes have been implemented. These changes focus on improving passage efficiencies by installing lamprey passage structures (LPSs) at Bonneville and John Day dams. These LPS fishways accommodate lampreys' attachment behavior and provide them an alternative route past higher velocities, dead ends, and serpentine weirs found in the fishways designed for salmonids. Our monitoring goals were to operate the LPSs, improve passage estimates using video validation, and report the number of lampreys passed during the 2019 migration season in relation to previous years.

There are five lamprey-specific fishways at Bonneville Dam and one at John Day Dam. We monitored the four LPSs at Bonneville Dam, University of Idaho monitored the lamprey flume structure (LFS), and Columbia River Inter-Tribal Fish Commission (CRITFC) technicians operated traps at Bonneville and John Day dams for the lamprey translocation program.

The total lamprey escapement at Bonneville Dam was estimated at 70,877 by the end of 2019. Bonneville LPSs passed 21,132 lampreys, or 30% of the total passage at Bonneville during April through October. The proportion of LPS use was 65% at Washington shore fish ladder's auxiliary water supply (WA-AWS) LPS, followed by 31% at Bradford Island fish ladder's auxiliary water supply (BI-AWS) LPS, and 4% at Cascades Island fishway entrance (CI-ENT) LPS. The University of Idaho collected 40 lampreys from the Washington shore LFS from May to September. CRITFC technicians collected three lampreys from the John Day North Entrance LPS trap during July to September, the fewest fish to date.

We reviewed 560 hours of video which were used to validate the accuracy of the LPS mechanical count systems. Corrections were applied to overcounting (negative percent difference) and undercounting (positive percent difference). Percent difference varied by location from (-0.2%) at Washington shore upstream migrant tunnel junction (WA-UMTJ) LPS, (-0.3%) at BI-AWS, (-8.9%) at WA-AWS, and (-10.1%) at CI-ENT. The overall count for all LPSs combined was adjusted down by 6.5%, indicating that there is room for improvement to the mechanical systems.

Although proportional use of LPSs has reduced from 46% to 30% of total Bonneville passage (2018 vs 2019), these structures still prove their importance by passing a third of the lampreys that passed this season. Albeit imperfect, the mechanical counters used on the LPSs are lower in cost than direct live counts and monitor passage during all hours of the day. At the end of the 2019 monitoring season, we installed four optic sensor counters at the WA-AWS LPS exit side. These new optic counters will not be evaluated until next season, but will help meet the goals of the USACE Pacific Lamprey Passage Improvements Implementation Plan by developing new techniques for counting lampreys. Managers depend on timely, accurate counts at Bonneville Dam to set goals for the tribal translocation program and as an indication of the health of the Columbia River Basin's lamprey population.

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Introduction

Background

The Pacific Lamprey (*Entosphenus tridentatus*) is an anadromous fish species that spends a large proportion of their lifecycle in the Columbia River Basin, where they are an important resource yet are declining in abundance. Lampreys are an essential source of food for many fish, birds, and mammals. They also hold cultural significance to Tribes of the Columbia River Basin. Moreover, the Tribes of the Columbia River Basin were the first to voice concern about the decline of lampreys and developed their own recovery plan (CRITFC, 2011; Close et al. 2002). The U.S. Army Corps of Engineers' (USACE) fish counting program is the primary source for monitoring Pacific Lamprey populations in the Columbia River Basin. The program began in 1938 at Bonneville Dam and has been used as evidence for the population level decline. Scientists have attributed the decline to several causes including: spawning and rearing habitat loss from hydroelectric dam inundation, the difficulty lampreys have passing dams, irrigation diversions that strand juveniles, and poor ocean conditions leading to decreased prey availability (Close et al. 2002; Keefer et al. 2013; Murauskas et al. 2013).

One important aspect in the recovery of Pacific Lamprey populations has been improving their passage at USACE dams along the Columbia and Snake rivers. The first dam on the mainstem Columbia River that lamprey encounter during their migration is Bonneville Dam. The traditional fishways at Bonneville Dam are designed to attract adult salmonids (*Oncorhyncus* spp.). Salmon are strong swimmers, attracted by high water velocities as they migrate upriver, and are unaffected by sharp turns commonly found in fishways. In contrast, the high velocities, turbulence, and 90^o corners at Bonneville Dam fishways often exceed Pacific Lamprey swimming capacity (Clay, 1994; Johnson el al. 2012). However, several structural and operational changes have been made in the USACE fishways, including installation of Lamprey Passage Structures (LPSs) inside the ladders 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. These structures have lower velocities and volumes of water when compared to salmonid fishways. These structures are advantageous to lampreys' attachment behavior by incorporating wetted ramps designed for climbing out of the salmonid fishways using their oral disks, rest boxes at the top of ramps, and exits that typically slide downward into the forebay to ease passage. For more information on other structural improvements and operational modifications see the USACE Pacific Lamprey Passage Improvements Implementation Plan: 2008-2018 (2014 update).

Since their implementation, LPSs have been responsible for passing between 30-47% of the total lamprey escapement at Bonneville Dam. Further research is needed to help understand the passage requirements at dams but these structures continue to prove their importance in conserving the species.

Monitoring Goals

1. Perform regular inspections of four lamprey passage structures at Bonneville Dam to ensure functionality and safe passage.
2. Improve passage estimates by validating and correcting for mechanical counters used to monitor these structures.
3. Report the number of lampreys passed by lamprey passage structures, between location and years, and in relation to total dam escapement.

Methods

Study Area and Location of LPSs

During the 2019 lamprey run, we monitored four LPSs at Bonneville Dam located at Bradford Island, Cascades Island, and two at Washington Shore (**Figure 1**). The Bradford Island auxiliary water supply (BI-AWS) LPS has two entrance ramps in the auxiliary water supply channel that parallels the Bradford Island flow control (serpentine weir) section. 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 is inside the Cascades Island fishway entrance, on the north end of the spillway tailrace and the exit is located in the spillway forebay. The Washington shore fish ladder auxiliary water supply (WA-AWS) LPS was modeled after the BI-AWS with two entrance ramps. It provides a passage route from the auxiliary water supply channel to the top of the fishway, bypassing the flow control (serpentine weir) section. The Washington shore upstream migrant tunnel junction (WA-UMTJ) LPS has two additional LPS entrance ramps connected to the existing WA-AWS via aluminum irrigation pipe. Once lampreys traverse the pipe, they eventually descend and trigger a paddle counter before connecting back to the original WA-AWS LPS. They continue to the WA-AWS LPS exit and are counted again. Thus the sums of both counters is not additive, but is indicative to which entrance ramps were used.

The University of Idaho monitored the lamprey flume structure (LFS) located at Washington shore's north downstream fishway entrance. The flume structure has upper and lower entrances that span the entire fishway entrance. It was designed to allow approaching lampreys an alternative route bypassing known dead ends in the Washington shore fish ladder. The LFS ends in a trap from which lampreys are collected and typically transported upstream. If proven effective, the next step would be to convert it to a volitional passage system by extending it to the forebay.

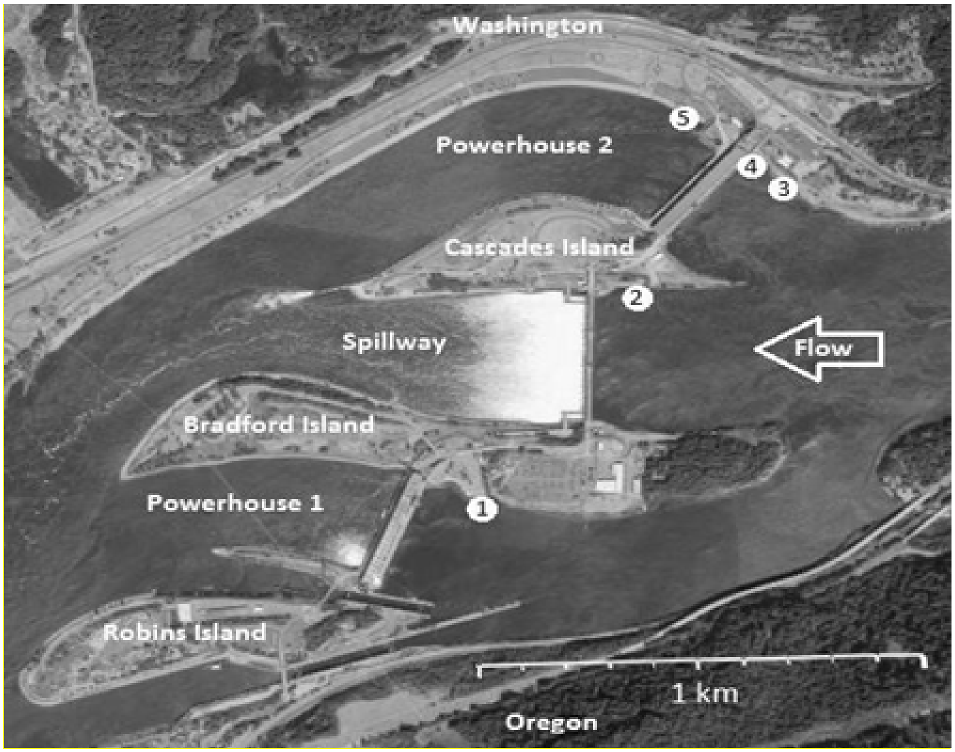

Figure 1. Lamprey passage structures (LPSs) locations at Bonneville Dam. (1) Bradford Island AWS LPS (2) Cascades Island ENT LPS (3) Washington shore AWS LPS (4) Washington shore UMTJ LPS (5) Washington shore Lamprey flume structure.

For a more complete description of all LPSs at Bonneville Dam pertaining to their dimensions, year of installation, modification history, and photos of LPSs see the methods section of Zorich et al. (2019) and Moser et al. (2010). For a complete description of the John Day North Entrance LPS see part 1 of the manual prepared by Budwig et al. (2014).

Operation and Inspection - Methods

The LPSs were operated from mid-April to the end of October, extending beyond the typical adult lamprey passage season (May to September) at Bonneville Dam. Inspections occurred three times a week to ensure the mechanical count systems and video collection were operational and water was flowing properly. Any issues with the count system such as counter sensitivity or video visibility were addressed when detected.

Bonneville Project Biologists performed regular inspections of the LPSs, monitoring flow, recording water temperature, and removing fish that died to prevent obstructions or alarm cues (pheromones) from stopping migration (Wagner et al. 2011).

Passage Validation and Estimates – Methods

Lamprey Passage Structures

The mechanical counting systems at Bonneville Dam are very similar in design. The newer paddle and proximity switch at the BI AWS and WA Shore LPSs, were designed by Portland District engineers. It uses a proximity detector to monitor a ferrous tab attached to the paddle's axle as an indicator of passage. As lampreys pass the exit, they move the paddle and the attached ferrous tab. This movement is detected by the proximity detector and it sends a voltage pulse. This voltage pulse is tallied by the counter and recorded by the data logger. The data logger totals the number of pulses at intervals of 60 seconds and writes the data to a computer file. The CI-ENT LPS uses the original perforated in-line paddle that is attached to the arm of a limit switch. The switch sends a signal to the same type of counter and data logger used at the other sites. Refer to Zorich et al. (2019) methods section for specific brand and model numbers along with photos of mechanical counting components for each LPS site.

During LPS inspections, tests were conducted to ensure the counting systems were functioning properly, logging systems were checked, and data were 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. If there were any issues noted, the mechanical counters were adjusted to improve the accuracy. Passage data from the new data loggers were automatically written to a laptop three times a day as text files and downloaded for transfer to the office network when LPSs were inspected. Occasionally, power outages and other glitches led to gaps in the lamprey counts. The counts for these days were either taken directly from the counter displays, when available, or interpolated from data records on either side of the gap.

The four mechanical counters associated with the LPSs have been found to over and undercount passing lampreys. The counts require video validation and correction before they can be used. To collect video at the LPSs an IP camera with infrared lights was mounted above the paddle counters and connected to a digital video recorder (DVR) at all sites. For photos of camera positioning and specific brand and model numbers of equipment, refer to the methods section of Zorich et al. (2019). Video recordings were used to validate the data reported by the mechanical counting systems and to calculate correction factors. One night of recording was reviewed every other week, starting at 20:00 to 06:00 - typical peak hours for lamprey passage.

A correction factor was calculated and applied to the raw mechanical counts to increase the accuracy of the LPS passage estimate. The difference between the mechanical and corrected counts was quantified using percent difference. 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 (Equation 1).

Equation 1. $$Correction\ Factor = \frac{Video\ Count}{Mechanical\ Count}$$

Daily counts were multiplied by correction factors from the nearest biweekly review. To be compatible with early reports we followed the methods of Gallion et al. (2017) to calculate percent difference (Equation 2).

Equation 2. $$Difference\ (\%) = \left(\frac{Corrected\ Estimate - Mechanical\ Count}{Mechancial\ Count}\right) * 100$$

For data analysis an R script (R version 3.5.1 R Core Team 2018) was used to stitch together raw count files, remove paddle tests, sum daily passage, and produce linear regression models. Microsoft Excel 2013 was used to apply correction factors, report counts to the region, and generate graphics.

Evaluation of Performance – Methods

Lamprey Passage Structure performance was evaluated using the number of lampreys passed at each LPS relative to total dam passage. A summary of annual LPS passage is presented as a long term record of use in **Appendix A**. Relative use was used to compare between LPS locations and between the years 2015-2019. It was calculated by dividing passage at each LPS by the estimate of total dam passage (total dam passage = day time counts + night time counts+ LPS passage+ trap and haul take).

Similar to previous authors, we used "relative use" to further report LPS performance among LPSs and between years. However, we estimated total passage at Bonneville Dam as the sum of all known passage routes for 2017-2019, or using a linear regression model for 2015 and 2016

(Gallion et al. 2017) rather than multiplying the daytime index (window counts) by three (Corbett et al. 2014 Table 1 and earlier NOAA reports).

Results

Operation and Inspection - Results

The Bonneville LPSs operated between 197 and 204 days in 2019, while the LFS operated for 124 days and the JDA-N ENT LPS operated for 66 days (**Table 1**). The Bonneville LPS count systems were inspected three times a week, while the LFS and JDA-N ENT LPS traps were checked daily.

Table 1. Operation dates of Lamprey Passage Structures and the Lamprey Flume Structure at Bonneville Dam and the John Day North Entrance LPS at John Day Dam.

Location	Start Date	End Date	Days of Operation
Bradford Island AWS	4/18/2019	10/31/2019	197
Cascades Island Entrance	4/16/2019	10/31/2019	199
Washington Shore AWS	4/11/2019	10/31/2019	204
Washington Shore UMTJ	4/11/2019	10/31/2019	204
Washington Shore LFS[¥]	5/13/2019	9/13/2019	124
John Day North Entrance[†]	7/10/2019	9/13/2019	66

[¥]Operated under contract by the University of Idaho. [†]Operated for translocation by CRITFC technicians.

Some lampreys die due to the rigors of freshwater migration. In total, nine lamprey mortalities were found in the Bonneville LPSs in 2019 by Project Biologists. Eight of these mortalities were in the Washington shore rest boxes, and one was in the Cascades Island pond of the LPS. Of the eight mortalities at WA shore rest boxes, two were measured at 66 centimeters (cm) total length and one was 74 cm total length. The remaining five mortalities at WA shore were not measured. The mortality found at Cascades Islands LPS was 59 cm total length. Additional lamprey mortalities were found in the fishways when inspected by Bonneville Project Biologists. These mortalities are not covered in this report, but can be found on the FPOM website:

http://pweb.crohms.org/tmt/documents/FPOM/2010/

Passage Validation and Estimates - Results

Lamprey Passage Structures - Results

Count validation was performed by comparing 560 hours of video and 2,206 passage events to the associated mechanical counts. Correction factors were calculated from 10 hours of video (one night) reviewed at each site every other week and ranged from 0.99 to 1.00 at WA-UMTJ, 0.69 to 1.00 at WA-AWS, 0.35 to 1.00 at CI-ENT, and 0.95 to 1.01 at BI-AWS (**Table 2**). Video validation could not be performed some days due to equipment failures such as power outages or malfunctioning video recording, resulting in time gaps of up to a day. During July, video review increased to one night every week at each site through the peak of the lamprey run.

Table 2. Correction factors (CF) for Bonneville Dam LPS mechanical counters from video collected 25 April to 24 September, 2019. The mechanical column is the value reported by counter. The video column is the observed count during the same time period.

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	0	0	1.00	0	0	1.00	0	0	1.00	0	0	1.00
2	0	0	1.00	0	0	1.00	0	0	1.00	0	0	1.00
3	0	0	1.00	0	0	1.00	0	3	0.97*	1	1	1.00
4	48	48	1.00	72	70	0.97	177	169	0.95	12	12	1.00
5	212	212	1.00	34	30	0.88	214	205	0.96	45	45	1.00
6	34	34	1.00	20	7	0.35	236	191	0.81	62	62	1.00
7	17	17	1.00	1	1	1.00	289	264	0.91	94	93	0.99
8	68	69	1.01	1	1	1.00	221	201	0.91	96	96	1.00
9	29	29	1.00	1	1	1.00	92	81	0.88	47	47	1.00
10	42	42	1.00	2	2	1.00	30	30	1.00	9	9	1.00
11	57	54	0.95	0	0	1.00	23	22	0.96	3	3	1.00
12	13	13	1.00	0	0	1.00	26	24	0.92	0	0	1.00
13	3	3	1.00	2	2	1.00	13	9	0.69	0	0	1.00
14	2	2	1.00	0	0	1.00	2	2	1.00	0	0	1.00

*correction factor was an average

At the CI-ENT LPS, observation periods five and six (**Table 2**) resulted in overcounts due to lamprey attachment. These large correction factors were due to lampreys attaching upstream of the paddle, hitting it with their tail and causing the paddle to overcount.

The main contributing factor of overcounts at WA-AWS LPS were caused by the high velocity in which the lampreys move out of the upwelling box and down the chute to the paddle. Some lampreys were observed moving rapidly out of the upwelling box. During this movement, it appears that lamprey make contact with the paddle, activating it prior to it fully passing. This error was recorded in both observation periods six and thirteen (**Table 2)**.

Undercounts occur when lampreys pass the paddle without being detected, although less frequent it does occur at all locations. Bradford Island AWS had the fewest occurrences at 2.5%, followed by WA-AWS 3.0%, WA-UMTJ 4.1%, and CI-ENT 4.4% of the total number of lampreys reviewed from the video. For comparison, the percent of overcounts observed during video validation was 2.9% BI-AWS, followed by 4.6% WA-UMTJ, 13.2% WA-AWS, and 21.1% CI-ENT. The effect that undercounts have on the correction factors were masked due to undercounts occurring less frequently than overcounts. The only occurrence of an undercount that caused a correction factor to be larger than 1.0 was during observation period 8 (**Table 2**) at BI-AWS.

Overall, the Bonneville LPS passage estimate during 2019 decreased by 6.5% from 22,598 to 21,132 when corrected for mechanical counting error. Percent difference was used to compare count accuracy at each location and at all sites over the season (**Table 3**). The most accurate counting location (requiring the least corrections) was the WA-UMTJ, followed by the BI-AWS, then WA-AWS, and the count system requiring the most correction was CI-ENT.

Table 3. Corrected estimates for lamprey passage at LPSs during 2019. Difference (%) = ((Corrected Estimate – Mechanical Count) / Mechanical Count) * 100 rounded to the nearest whole value.

LPS Location	Mechanical Count	Corrected Estimate	Difference (%)
Bradford Island AWS	6,561	6,538.4	-0.3
Cascades Island ENT	861	774.4	-10.1
Washington AWS	15,176	13,818.9	-8.9
Washington UMTJ	2,602	2,597.9	-0.2
Total*	22,598	21,131.7	-6.5

*Total does not include Washington UMTJ to prevent double counting. Fish from UMTJ merge into the Washington AWS LPS and are counted again when exiting there.

The WA-AWS, CI-ENT, and BI-AWS LPSs accounted for 65.4%, 3.7%, and 30.9% of total LPSs passage, respectively. Corrected daily lamprey passage fluctuated greatly at each of the LPSs with most fish passing in June and July (**Figure 2**). Cascades Island ENT LPS had the earliest peak passage of all the sites, which occurred at the beginning of June and continued to decrease drastically until it ceased in activity at the start of September. Bradford Island AWS LPS and the nearby window counts had peak passage occur in the middle of June, however, the LPS passage then decreased in comparison. The Washington shore LPSs had peak passage occur roughly a month later than the other sites, with peak passage occurring in the middle of July for both the LPSs and window counts.

The first lamprey of the season passed through Bradford Island AWS LPS on 25 April and the last lamprey passed on 20 October at Washington shore AWS LPS, 11 days prior to the LPSs being dewatered and shut down for the season. No lampreys were collected from the LPSs during dewatering. Refer to **Table 10 in Appendix A** for annual lamprey run timing from 2014 to present.

The current count systems operate on a complicated network requiring communication between the pulse signal (activated by the paddle), counter, data logger, and laptop. These count systems occasionally have power outages or glitches that cause lapses in the counts. Through close inspection of the date-time stamps, breaks in that communication have been identified. The BI-AWS count system had eight breaks in the data records, of five minutes or more, totaling two days or 1% of the 197 days of operational time. The largest single outage was 24 hours. The CI-ENT LPS had 11 breaks in the data records, of five minutes or more, totaling three days or 2% of the 199 days of operational time. The largest single outage was eight hours. The Washington shore data had 12 breaks, of five minutes or more, totaling 6.9 days or 3% of 204 days of operational time. The largest single outage was 22 hours. As previously described in methods, data gaps of more than one night were filled using digital count readings recorded from inspections or using linear interpolation from data on both sides of the break.

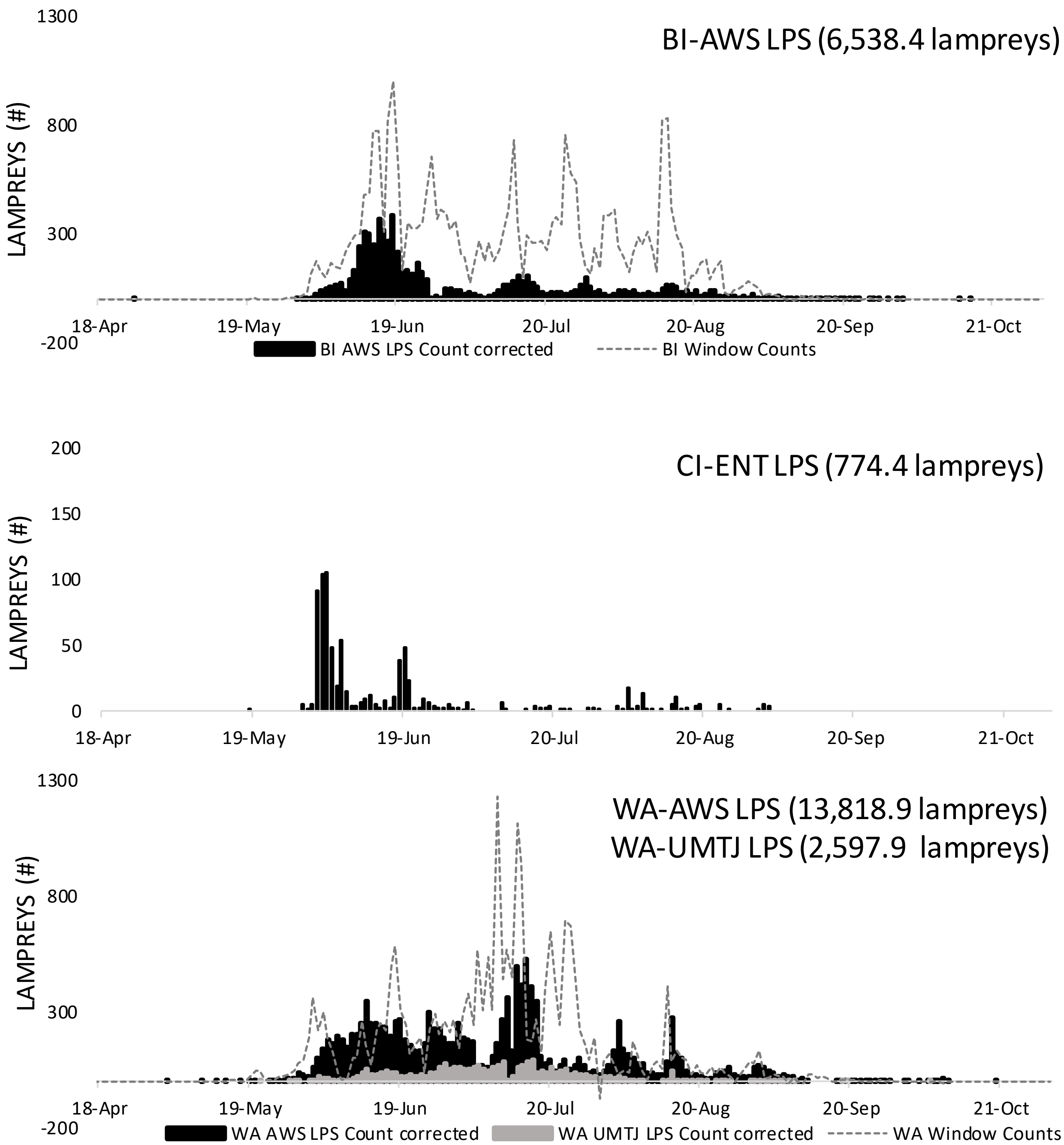

Figure 2. Daily lamprey passage estimates (corrected) at Bonneville Dam LPS sites. The top panel is Bradford Island auxiliary water supply LPS (BI-AWS LPS, black bars) daily passage along with 24 hour window counts represented as a dashed line. The middle panel is solely Cascades Island entrance LPS (CI-ENT LPS) daily passage, as there are no window counts for the time period. The bottom panel is Washington shore daily passage. The Washington shore upstream migrant tunnel junction LPS (WA-UMTJ LPS, grey bars) feeds into the Washington shore auxiliary water supply (WA-AWS, black bars). The WA-UMTJ lampreys do not add to total passage counts. The dashed line represents 24 hour window counts at Washington shore. **Note changing y-axis magnitude for middle panel.**

Lamprey Structures Operated by Others - Results

The lamprey flume structure (LFS) was operated under contract by the University of Idaho. The John Day North Entrance lamprey trap (JDA-N ENT LPS) was operated by CRITFC to collect fish for tribal translocation programs. Both structures are terminal traps where fish are hand counted and typically moved to holding tanks. These counts do not require video validation. In 2019, the LFS collected 40 lampreys in the 124 days of operation (**Table 4**). The University of Idaho is writing a report that will cover daily collection from the LFS as well as results of their passage study using PIT and radio-tagged lamprey (Keefer et al. in prep).

Table 4. Annual lamprey collection at Bonneville Dam's Washington shore Lamprey Flume Structure.

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
2018	10 April – 14 September	157	591
2019†	13 May – 13 September	124	40

*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 which left an opening in the upstream flume section which lamprey could exit. †The missing hatch was discovered in September 2015 when tailwater dropped to about 11' (msl). Thus it may have impacted collection efficiency in 2015 as well. In October 2019, the same middle access hatch was discovered missing and may have impacted collection.

The John Day North Entrance LPS collected three fish in the 66 days of operation in 2019. The three lampreys were each collected on July 11, 19, and 21st by CRITFC, far fewer than previous years (**Table 5**).

Table 5. Annual lamprey collection at the John Day Dam North Entrance LPS which ends in a terminal trap box. It was not operated in 2016 or 2017 due to a broken access elevator.

Year	Dates Operated	Days (#)	Lampreys Collected
2014	25 June - 30 September	97	1,228
2015	5 May - 17 September	70	419
2018	21 June - 22 August	63	1,873
2019	9 June – 14 September	67	3

Evaluation of Performance – Results

Lamprey Passage Structures – Results

Along with total lamprey passage, use of Bonneville LPSs generally increased from 2010 to 2017 with declines seen in the last two years (**Figure 3**). This year's total LPS passage decreased to 21,132, with WA-AWS LPS accounting for the majority of lampreys 13,819 (65.4%), BI-AWS passing 6,538 (30.9%), and CI-ENT passing 774 (3.7%) of fish that used LPSs. The WA-UMTJ LPS collected 2,598 lampreys which then swam into the WA-AWS LPS and are counted again as they exit there.

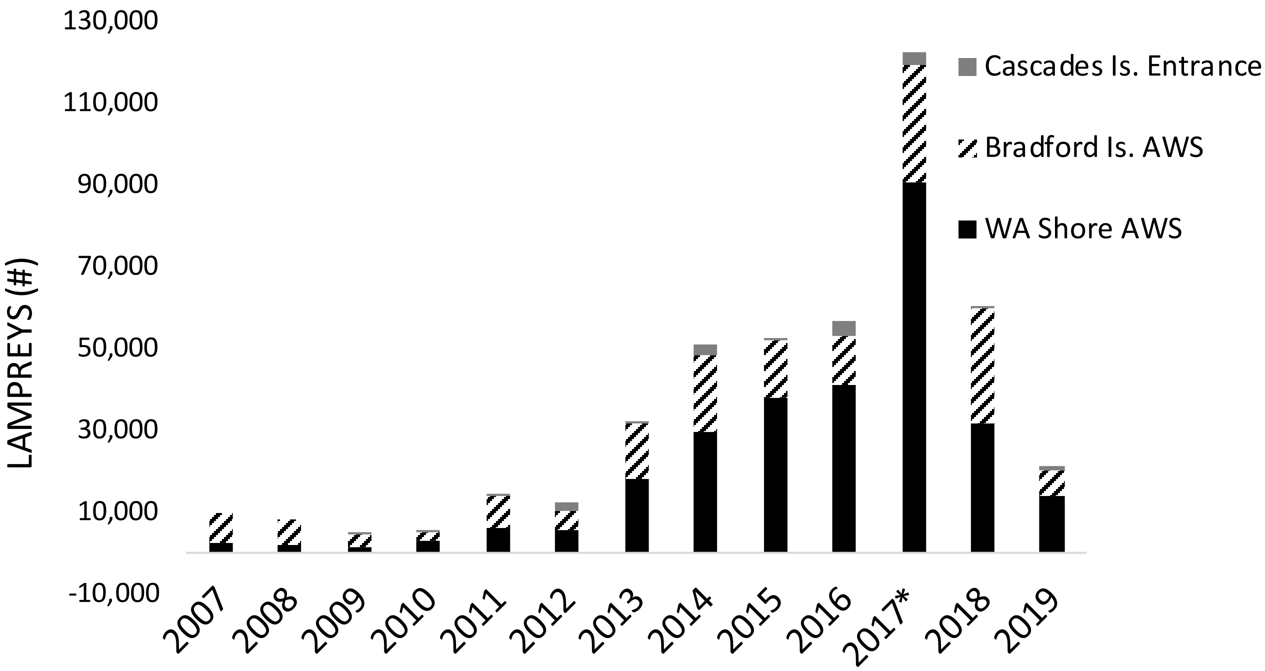

Figure 3. Annual lamprey passage estimates for Washington shore AWS (black), Bradford Island AWS (pattern), and Cascades Island entrance (gray) LPSs during 2007-2019. *Two more entrance ramps were added to the WA Shore AWS LPS in 2017.

When migrating lampreys reach Bonneville Dam, they must choose between three tailraces with varying flows dependent on powerhouse priority and spill (Powerhouse 1, spillway, or Powerhouse 2). This degree of the attraction between varying flows and conditions can impact which LPS entrances are available to them. **Table 6** provides an overview of LPS proportional passage (the number of fish passing an LPS as a percent of total dam passage) in recent years.

Table 6. 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
2019	70,877	13,819 (20)	774 (1)	6538 (9)	21,132 (30)
2018	131,765	31,432 (24)	882 (0.6)	28,105 (21)	60,420 (46)
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).

The proportional use of LPSs was lower than previous years, 30% vs. 40-47% (2019 vs. 2015-18) largely due to the declines at the WA-AWS LPS and BI-AWS LPS (**Table 6**). Lamprey passage decreased by 4% at WA-AWS and decreased by 12% at BI-AWS from 2018, however BI-AWS passage this season was similar to 2015-17.

To provide bookends to our lamprey passage estimate (summation) and develop a realistic passage estimate for Bonneville Dam when counts are net negative (i.e. 2015 and 2016), we developed a linear regression model using lamprey counts at The Dalles Dam (upstream) to predict Bonneville Dam passage (see **Appendix B** for details). Using the 2019 daytime window counts at The Dalles Dam of 4,221, the model estimated 51,853 (36,198 - 67,508 lower and upper 95% confidence interval) passed Bonneville Dam which is lower than our summation estimate of 70,877. Of note, our estimate of 70,877 is higher than the upper 95% CI (67,508) calculated for this model.

Last season's video review found that lampreys were attaching to Bradford Island exit slide for as long as 75 minutes (Zorich et al. 2019). This year, the grooved ultra-high molecular weight plastic slide was deepened from 1/8" to 1/4" and an aluminum cover was added to prevent algal growth. We collected two nights of video to determine if lampreys were still attaching to the exit slide with the new modifications. We evaluated 127 passage events from the video recorded. Only three lampreys were able to attach, or 2% of 127 and released after three seconds without reattaching. All attachment locations observed were on the uncovered portion of the LPS exit slide with the most algal growth. It appears that the lack of algal growth due to the aluminum covers fabricated by Bonneville Project are preventing most lampreys from attaching to the exit slide. We recommend that the top of the slide is scrubbed each week and that the remaining covered section is power washed at the end of the season.

Lamprey Structures Operated by Others - Results

Both the Bonneville LFS and the JDA-N ENT LPS were successful in collecting lampreys this season, but both collected far fewer than in previous years (**Table 4** and **Table 5**). While an evaluation of their performance is beyond the scope of this report, we provide tables of fish collection and effort (days operated) to be consistent with previous years and have the information on lamprey passage available in one report. For more information about the Bonneville LFS performance refer to the report from the University of Idaho (Keefer et al. in prep.).

The lamprey flume structure captured 40 fish in 124 days of operation in 2019. Fewer than 2018 (591 fish) and similar to 2013 (29 fish) and 2017 (51 fish) (**Table 4**). The years with low capture numbers of lampreys are likely due to the structure being in need of repair. In the 2013 season, the LFS was shut down for several days due to in-season repairs and had the lowest collection year since operation began. A missing access hatch on the structure prevented operation in 2016, and in 2017 caused low capture numbers. The missing hatch was repaired prior to the 2018 season, which caught the highest amount of lampreys collected to date. During the 2019 operation, the LFS passed a low amount of fish indicating that an issue with the hatch may need additional repairs. At the end of the 2019 season, the USACE Dive team conducted an ROV (remotely operated vehicle) inspection of the LFS. The ROV inspection again found the middle access hatch missing, which appeared to also have a broken hinge (FPOM MFR, 31/OCT/2019).

The JDA-N ENT LPS trap only collected three fish despite in-season efforts to increase trapping efficiency (**Table 5**). The John Day project biologists and CRITFC staff made several attempts to improve collection: including removing any potential negative smells by flushing the rest boxes, removing a section of new pipe attached to the upwelling box, and changing the water supply line with a rubber flexi hose. Furthermore, to prevent any changes to flow, they also removed a small amount of silicone around the terminal of the flume (E. Grosvenor, personal communication, 01/07/2020). It is still unknown why so few lampreys were collected this season.

Conclusions

Operation and Inspection – Conclusions

The time frame for LPS operation, frequency of inspection, and low mortality rates were adequate to provide safe passage for the 2019 lamprey run. Window counts show that 5% of the run passed Bonneville Dam by 5 June and the run was 95% complete by 17 August. These dates were encompassed by LPS operations and we recommend continuing to operate LPSs surrounding this time frame to provide additional routes of passage for early and later migrants. There are still concerns of the additional energy and stress lampreys experience when attempting to climb back into the plunge box added to the WA-AWS exit. One potential solution is to return the slide to the original 55° angle rather than the current 45° angle. This should result in safe passage for lampreys as they drop into the middle of the fishway. Video monitoring would be required to ensure they drop without grazing the walls of the fishway, the initial reason the plunge box was installed.

Passage Validation and Estimates – Conclusions

We successfully used video to validate the mechanical counters, then calculated and applied correction factors to the mechanical counts. Correction factors varied by site and through the season, supporting the need for frequent video validation to capture changing circumstances that influence them. Through re-design and several small improvements, the difference from mechanical to corrected passage estimates has decreased overall, but improvement to mechanical counts should continue to help provide more accurate estimates of lamprey passage (**Table 6**).

Table 6. Difference (%) between mechanical and corrected lamprey passage by LPS site from 2015-19.

LPS Location	2015	2016	2017	2018	2019
BI AWS	(-33)	(-48)	(-65)	33	(-0.3)
CI ENT	4	(-5)	(-26)	(-6)	(-10.1)
WA AWS	(-32)	(-24)	92	5	(-8.9)
WA UMTJ	Not installed	Not installed	(-19)	(-3)	(-0.2)
All	(-32)	(-30)	(-9)	16	(-6.5)

The BI-AWS LPS had the greatest improvement in corrected passage from 33% difference last season down to (-0.3%) this year. This improvement in the passage estimate is accredited to several modifications between the seasons, such as increasing the length of the shock absorber (Zorich et al. 2019), along with adjusting the metal tab that indicates paddle position during count system manual checks. The combination of previous modifications and early detection of issues this season increased the accuracy. However, a correction factor not equal to one indicates the system can be improved further.

The CI-ENT LPS had the largest seasonal percent difference between mechanical and corrected counts. An overcount was caused by lampreys attaching upstream of the paddle, allowing their tail to activate the paddle prior to actual passage. This attachment behavior occurred during observation periods four through six (**Table 2**) at the peak of this site's passage (middle panel, **Figure 2**). Because these errors occurred during a passage boom and Cascades Island has relatively low passage numbers, this behavior greatly impacted the accuracy at this site for the entire season. While this has been observed in previous years, its impact had been minimal. One potential way to prevent attachment is similar to the approach used for the BI-AWS exit slide: lining the bottom of the camera box section with ultra-high molecular weight plastic with grooves cut 1/4" by 1/4".

The WA-AWS and WA-UMTJ LPS counting systems had a seasonal correction difference of (-8.9%) and (-0.2%) respectively (**Tables 3** and **6**). The WA-AWS count system had overcounts throughout the season causing the correction factors to range from 0.69 to 1.00 (**Table 2**). The cause of error observed during video validation was from the fish's rapid body movements which activated the paddle multiple times prior to passing. To prevent this error in the future it would likely require a redesign of the passage structure. The WA-UMTJ count system also experienced this behavior, thus impacting a single correction factor in observation period seven (**Table 2)**. However, WA-UMTJ was the most accurate count system this year with only one observation period requiring correction to the mechanical counts.

The highly variable nature of lamprey passage during the season, and the many moving parts of the current mechanical counter design, continues to make it difficult to improve the accuracy of the true mechanical count. If the count system or video system has issues during a passage boom, it will impact accuracy at that site for the entire season. We recommend installing redundant counters (mechanical, optical, electromagnetic, direct proximity detection etc.) at one site so they can all be compared to video collected at that site and with each other. At the end of 2019, four optic sensor counters were installed at the WA-AWS exit slide. Their evaluation will have to wait until next lamprey passage season.

Evaluation of Performance – Conclusions

LPS passage at Bonneville Dam during the 2019 monitoring season (April – October) was 21,132 or 30% of estimated total lamprey escapement which was 70,877 by the end of 2019. Use of LPSs is lower than previous years, when passage at these structures was between 41-47% of the run (**Table 6**). Of the lampreys that used LPSs, they favored the WA-AWS (65% of LPS passage), BI-AWS LPS (31%), and CI-ENT LPS (4%). It is uncertain why the proportion of LPS use was less than recent years. Some potential reasons include: lampreys are dying in the system, releasing an alarm pheromone and reducing passage for a day or more, or the new parts and equipment added to improve the LPSs have not had time to season (Wagner et al. 2011). Although LPS passage was lower at Bonneville Dam than previous years, these structures provide additional routes for lampreys and continue to prove how important these systems are by moving nearly a third of all lampreys that passed Bonneville Dam.

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References

Budwig, R., C. Syms, B. Basham, S. Lee, and C. Caudill. 2014. Operations and Maintenance Manual for the John Day North Fishway Entrance Lamprey Passage Structure. Prepared for USACE.

Clabough, T. S., M.L. Keefer, C.C. Caudill, E.L Johnson, and C.A. Peery. 2012. Use of Night Video to Enumerate Adult Pacific Lamprey Passage at Hydroelectric Dams: Challenges and Opportunities to Improve Escapement Estimates. *North American Journal of Fisheries Management*, Vol. 32, Issue 4, 687-695.

Clay, C. H. 1994. *Design of fishways and other fish facilities*. CRC Press Publisher, Boca Raton, FL, USA.

Close, D. A., Fitzpatrick, M.S., & Li, H.W. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific lamprey. *Fisheries*, *27*(7), 19-25.

Corbett, S. C., K. E. Frick, M. L. Moser, B. Wassard, M. L. Keefer, and C. C. Caudill. 2014. Adult Pacific Lamprey Passage Structures: Use and Development at Bonneville Dam and John Day Dam South Fishway, 2013. Annual report to the U.S. Army Corps of Engineers, Portland District.

Corbett, S. C., K. E. Frick, M. L. Moser, B. Wassard, M. L. Keefer, and C. C. Caudill. 2015. Adult Pacific Lamprey Passage Structures: Use and Development at Bonneville Dam and John Day Dam South Fishway, 2014. Annual report to the U.S. Army Corps of Engineers, Portland District.

CRITFC (Columbia River Inter-Tribal Commission). 2011. Tribal Pacific Lamprey Restoration Plan for the Columbia River Basin, CRITFC. Portland, Oregon.

FPOM (Fish Passage Operation & Maintenance). 2019. Memorandum for the record MFR PH 2 LFS ROV Inspection 19BON63 October 2019. Accessed on December 23, 2019 URL:

https://pweb.crohms.org/tmt/documents/FPOM/2010/NWP%20Memos%20of%20Coordination%20and%20Notification/BON%20MOC%20and%20MFR/19BON63%20MFR%20PH2%20LFS%20ROV%20inspection.pdf

Gallion, D. G., P.L. Madson, K.M. Gibbons, J.L. Mejia, G.S. Robertson, and N.A. Zorich. 2016. Use of Lamprey Passage Structures at Bonneville and John Day Dams, 2015 Annual Report. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR.

Gallion, D. G., T.H. Van Hevelingen, and B.K. van der Leeuw. 2017. Use of Lamprey Passage Structures at Bonneville and John Day Dams, 2016 Annual Report. U.S. Army Corps of Engineers, Portland District Fisheries Field Unit. Cascade Locks, OR.

Johnson, E. L., Caudill, C. C., Keefer, M. L., Clabough, T. S., Peery, C. A., Jepson, M. A., & Moser, M. L. (2012). Movement of radio-tagged adult Pacific lampreys during a large-scale fishway velocity experiment. *Transactions of the American Fisheries Society*, *141*(3), 571-579.

Keefer, M. L., Caudill, C.C., Clabough, T.S., Jepson, M.A., Johnson, E.L., Peery, C.A., Higgs M.D., & Moser, M.L. 2013. Fishway passage bottleneck identification and prioritization: a case study of Pacific lamprey at Bonneville Dam. *Canadian Journal of Fisheries and Aquatic Sciences*, *70*(10), 1551-1565.

Kirk M. A., C.C. Caudill, C.J. Noyes, E.L. Johnson, S.R. Lee, M.L. Keefer, H. Zobott, J.C. Syms, R. Budwig, and D. Tonina. 2015. Use of Passage Structures at Bonneville and John Day Dams by Pacific Lamprey, 2013 AND 2014. Technical Report to USACE 2015-11.

Moser, M. L., M.L. Keefer, H.T. Pennington, D.A. Ogden, and J.E. Simonson. 2010. Development of Pacific lamprey fishways at a hydropower dam. *Fisheries Management and Ecology*. 18. 190 - 200.

Murauskas, J. G., Orlov, A.M., & Siwicke, K.A. 2013. Relationships between the abundance of Pacific Lamprey in the Columbia River and their common hosts in the marine environment. *Transactions of the American Fisheries Society*, *142*(1), 143-155.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/ (October 2019).

USACE (U.S. Army Corps of Engineers). 2014. Pacific Lamprey passage improvements implementation plan: 2008-2018 204 Revision. USACE, Northwest Divison, Portland, Oregon. Accessed on February 3, 2020 URL:

http://pweb.crohms.org/tmt/documents/FPOM/2010/Task%20Groups/Task%20Group%20Lamprey/10%20Year%20Lamprey%20Plan%20update%20final%202015.pdf

Wagner C. M., Stroud E.M, and Meckley T.D. 2011. A deathly odor suggests a new sustainable tool for controlling a costly invasive species. *Canadian Journal of Fisheries and Aquatic Sciences*, 68(7), 1157-1160.

Zorich, N. A., K.M. Gibbons, and K.N. Bayley. 2019. Use of adult Pacific Lamprey Passage Structures at Bonneville and John Day Dams, 2018 Annual Report. U.S. Army Corps of Engineers, Portland District, Fisheries Field Unit. Cascade Locks, OR.

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 2017-2019.

Year	Dates Operated	# 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[1,2]
2018	25 April – 31 October	189	31,432[1]
2019	11 April – 31 October	204	13,819[1]

1: Corrected for mechanical count error; 2: Two additional entrance ramps were installed near the WA Shore upstream migrant tunnel junction.

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 2017-2019.

Year	Dates Operated	# 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]
2018	8 March – 31 October	237	28,105[5]
2019	18 April – 31 October	197	6,538[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 2017-2019.

Year	Dates Operated	# 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]
2018	25 April – 31 October	186	882[6]
2019	16 April – 31 October	199	774[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.

Table 10. Run timing of Pacific Lampreys passing Bonneville Dam using Lamprey Passage Structures during 2014-2019. Dates show timing of fist and last fish passage and 10%, 50%, and 90% completion of run.

Location	Year	1st Fish	10%	50%	90%	Last Fish
BI-AWS	2014	19-May	8-Jun	26-Jun	28-Aug	16-Oct
	2015	12-May	8-Jun	11-Jul	27-Aug	26-Oct
	2016	8-May	4-Jun	9-Jul	29-Aug	26-Oct
	2017	12-May	21-Jun	5-Jul	23-Aug	23-Oct
	2018	1-Jun	16-Jun	25-Jun	30-Jul	29-Oct
	2019	25-Apr	11-Jun	20-Jun	13-Aug	16-Oct
CI-ENT	2014	20-May	7-Jun	15-Jul	19-Aug	2-Oct
	2015	21-May	8-Jun	18-Jun	8-Aug	28-Aug
	2016	2-May	3-Jun	20-Jun	6-Aug	20-Oct
	2017	11-May	10-Jun	22-Jun	5-Jul	16-Sep
	2018	30-Apr	25-May	16-Jun	31-Jul	20-Sep
	2019	18-May	1-Jun	6-Jun	4-Aug	2-Sep
WA-AWS	2014	12-May	30-May	22-Jun	5-Sep	27-Oct
	2015	5-May	2-Jun	26-Jun	25-Aug	27-Oct
	2016	21-Apr	30-May	28-Jun	29-Aug	25-Oct
	2017	1-May	21-Jun	3-Jul	10-Aug	30-Oct
	2018	8-May	12-Jun	26-Jun	8-Aug	22-Oct
	2019	2-May	9-Jun	5-Jul	14-Aug	20-Oct

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, lampreys 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, lampreys are seen passing underneath the fish crowder brushes and squeezing through the fish crowder horizontal picket leads. This suggests they may still use this route to avoid the count slot even after the downstream picket lead spacing was reduced to ¾". 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 lampreys 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 lamprey within the adult ladders at the count station. Lampreys 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 for both years 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 2018. 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 total escapment at Bonneville Dam from 2009-2018 ranged from 18,822 to 292,441 and The Dalles daytime passage index ranged from 2,726 to 30,696 (**Table 1**).

Table 1. Pacific Lamprey passage at Bonneville Dam (day and night ladder, LPS, and trapped), and The Dalles Dam (daytime ladder). Data from 2015 and 2016 have been excluded as they indicated a net negative passage at the Washington shore count station, possibly due to recycling of fish.

Year	Bonneville Dam	The Dalles Dam
2018	131,765	10,515
2017	292,441	30,696
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

We used the analysis software R and the lm() function to fit a line to the data in **Table 1** resulting in an $r^2 = 0.97$ and p-value < 0.001. We then used Excel to graph the best fit line and label the year corresponding to each data point (**Figure 1**).

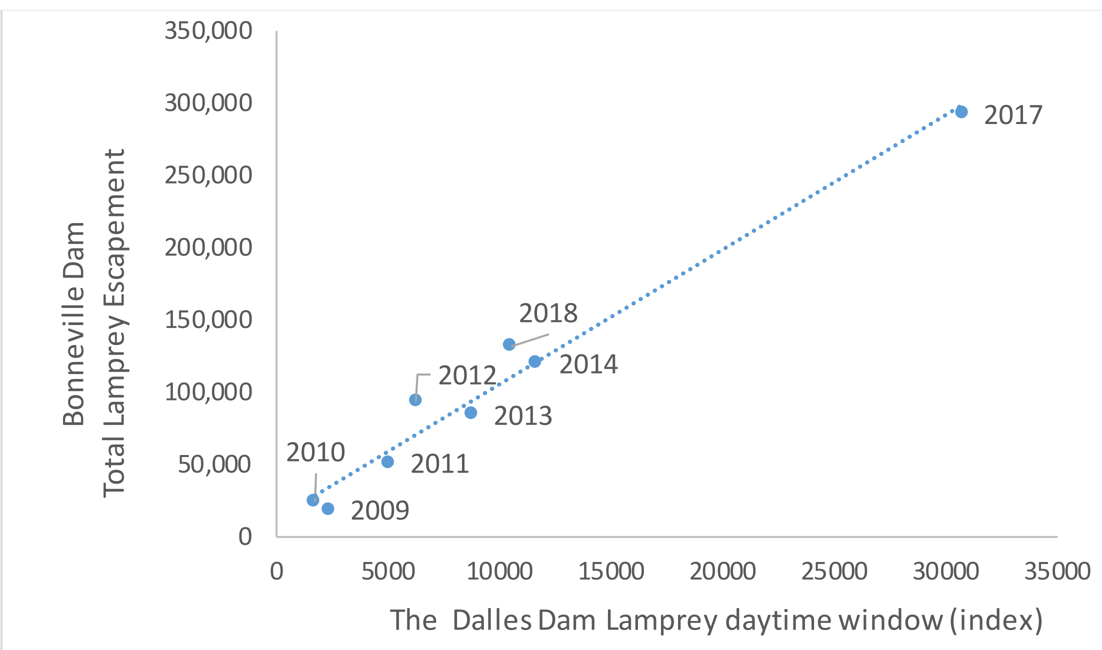

Figure 1. Fitted line and equation from the passage data in Table 1. The x-axis is The Dalles Dam daytime window index. The y-axis includes the Bonneville daytime window index + night time video counts + LPS counts + trapped lamprey release above the dam.

To re-estimate 2015 and 2016 using the most recent data, and to estimate 2019 total lamprey passage we used these formula;

1) Bonneville Dam lamprey passage in 2015 = 12,513 + 9.318 * 12,400

2) Bonneville Dam lamprey passage in 2016 = 12,513 + 9.318 * 11,557

3) Bonneville Dam lamprey passage in 2019 = 12,513 + 9.318 * 4, 221

Where the daytime passage index at The Dalles Dam was 12,400 in 2015, 11,557 in 2016, and 4,221 in 2019. 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.

We estimate 121,850 (209,430 - 34,270 upper and lower 95% CI) lamprey passed Bonneville Dam during 2016.

Finally we estimate 51,853 (67,508 – 36,198 upper and lower 95% CI) lamprey passed Bonneville Dam during 2019 which is lower than the 70,822 lamprey passage estimate made by summing all routes of passage (summation method - this report). This is only the second year that the summation estimate fell outside of the 95% CI calculated using a linear regression model.

R Code for predictive model and 95% CI by Nathan McClain:

```
tda.day <- c(10515, 30696, 11662, 8737, 6241, 5003, 1726, 2318)  #years 2018, 2017, 2014, 2013, 2012,
        2011, 2010, 2009  day window count only

bonn.all <- c(131765, 292441,120100, 84347, 93456, 51201, 24564, 18822)#day window count + night
        window count + LPS count + research released upstream + Tribal tanslocation release upstream

model.a <-lm(bonn.all ~ tda.day)
summary(model.a)

plot(tda.day,bonn.all, xlab="The Dalles Dam daytime window lamprey (index)", ylab="Bonneville Dam
        Escapment (all sources)", main="Lamprey index Correlation")
abline(model.a)

newyear <- data.frame(tda.day=4221) #daytime window count from The Dalles Dam all of 2019
predict(lm(bonn.all~ tda.day), newyear, interval="confidence", level = 0.95)
```