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Use of Lamprey Passage Structures at Bonneville and John Day Dams

2016 Annual Report

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On the cover: *Cascades Island fishway entrance (dewatered for maintenance) and Lamprey Passage Structure at Bonneville Dam. Bollards have been attached to the concrete to create heterogeneous flow and lead lamprey to the LPS entrance. The variable width weir can be seen in front of the bulkhead. It is designed to cause reduced water velocities, to help lamprey enter lower in the water column, and maintain salmon attraction velocities higher in the water column.*

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Abstract

To improve adult Pacific Lamprey (*Entosphenus tridentatus*) upstream passage at Bonneville Dam, we operated the Washington auxiliary water supply, the Cascades Island downstream entrance, and the Bradford Island auxiliary water supply, lamprey passage structures. Our 2016 objectives were to 1) operate the lamprey passage structures, 2) enumerate and validate lamprey passage at these structures, and 3) evaluate performance of these structures during the migration season.

The total corrected passage estimate for the lamprey passage structures at Bonneville Dam during the 2016 monitoring season (April – October) was 56,846, a 9% increase from 2015 (52,127). Of the total corrected passage estimate for lamprey passage structures at Bonneville Dam during 2016, Washington auxiliary water supply, Cascades Island downstream entrance, and the Bradford Island auxiliary water supply, accounted for 72% and 7% and 21%, respectively. Volitional passage was monitored with mechanical counters. Due to overcounting by mechanical counters in the past, counts were validated one night every two weeks with video, and a correction factor for mechanical count estimates was calculated and applied. The average semi-monthly correction factor for mechanical counts based on video observations at Bradford Island auxiliary water supply, Cascades Island downstream entrance, and Washington auxiliary water supply, lamprey passage structures was 0.46, 0.93, and 0.75 respectively.

From 2014-2016, the earliest a lamprey passed any of the lamprey passage structures was April 21 and the latest a passage event occurred was on October 27. To benefit adult lamprey upstream passage, lamprey passage structures should continue to operate from early-April to the end of October at Bonneville Dam. Due to the lamprey passage structures mechanical count error, our results suggest that it is important to continue validating the mechanical counts with video. We suggest additional active and passive tag studies to assess passage success, overall at Bonneville Dam, and among the different LPSs and ladders. As a result, a direct comparison between lamprey passage structures and ladder passage could be used to assess fishway performance.

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Introduction

Background

Since the 1960's, there has been a steady decline of Pacific Lamprey (*Entosphenus tridentatus*) passing the dams on the Federal Columbia River Power System (USACE 2009). Scientists have attributed the decline to several causes including pollution, habitat loss, irrigation, intentional removal, ocean conditions, and difficulty passing dams. As a result of this decline, there has been significant regional concern regarding the stability of Pacific Lamprey populations in the Columbia Basin. In 1993, Pacific Lamprey were listed as an Oregon State sensitive species. The Tribes have repeatedly voiced concern about the decline of Pacific Lamprey, a culturally important species (Nez Perce, Umatilla, Yakama, and Warm Springs Tribes 2009). On January 28, 2003, the Pacific Lamprey was petitioned for listing under the Federal Endangered Species Act. However, no funds were committed in 2003 or 2004 to make a determination. As a result, "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) between the Federal Columbia River Power System Action Agencies, the 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 addressed actions to protect Pacific Lamprey. 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 (USFWS) 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 USACE dams along the lower Columbia and Snake Rivers. Bonneville Dam is the first hydroelectric dam on the mainstem Columbia River that Pacific Lamprey 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 lamprey that passed / unique lamprey that entered) from 1997-2010 was 0.52 at Bonneville Dam. They contrast this to the 0.95 fishway passage efficiency for adult salmonids at Bonneville Dam.

The swimming capabilities and characteristics of Pacific lamprey are very different from salmonids. Salmon are strong swimmers usually found in the upper water column, and cross the dam during day-light hours.. Conversely, Pacific Lamprey, are relatively weak swimmers, primarily found low in the water column, and tend to pass the dam during the night-time. (Wills and Anglin 2012, Keefer 2013). Adult salmon migrating upstream are attracted to and enter relatively high flows and are unaffected by 90° corners typically found at the fishway entrances. Adult salmonid burst speeds can range from 8 to 26 feet-per-second (fps), with sustained speeds close to five fps, while adult sea lamprey (Petromyzon marinimus) which have similar critical swimming speed to Pacific Lamprey (Clemens et al. 2010), have been measured to burst swim 6-7 fps (Bell 1991). Furthermore, water velocities of approximately 8-10 fps may represent a barrier to many adult Pacific lampreys (Keefer 2010). Once inside fishways, adult salmon are guided and excluded from areas of potential danger by diffuser grates and picketed leads (Clay 1994). The adult lamprey can pass through typical 1 inch diffuser gratings and picketed leads and often are lost in areas migrating fish were not intended to enter.

Several structural and operational changes have been made by the USACE Portland District, including installation of Lamprey Passage Structures (LPS) and modification of fishway entrances at Bonneville and John Day dams to increase lamprey passage. Structural changes include four LPS installations at Bonneville Dam and one at John Day. The LPSs are designed for lamprey passage including sections that are designed for climbing and rest boxes. A keyhole shaped ladder entrance was also installed at Cascades Island and John Day North to reduce velocity near the bottom of the water column for bottom oriented lamprey while maintaining higher velocitites near the top for salmond 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 in the Powerhouse 2 ladders to provide lower velocities for passing lamprey. There is also an effort to refine techniques for counting lamprey that pass USACE dams. Counts of Pacific Lamprey 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. A further description of all the improvements are described in USACE (2009).

Life History of the Pacific Lamprey (Entosphenus tridentatus)

Pacific Lamprey migrate up the Columbia River on their way to spawning areas. Although further research is needed, Yun et al. (2011) suggests that Pacific Lamprey olfactory cues could influence migration, similar to Sea Lamprey (Wagner et al. 2011). The run at Bonneville Dam begins in April, peaks in June-July, and terminates by October. Lamprey overwinter in freshwater before they resume there spawning journey. Adults typically spawn between March and July (USFWS 2008). After spawning the breeding lamprey will die. The fertilized eggs will mature until hatching in 19 days at 59° Fahrenheit. The larval lamprey (ammocoetes) will live in silt/sand substrates for 3-7 years, transform into juveniles (macropthalmia) and migrate to the ocean. Adult Pacific Lamprey live in the ocean for one to three years before returning to spawn (Figure 1).

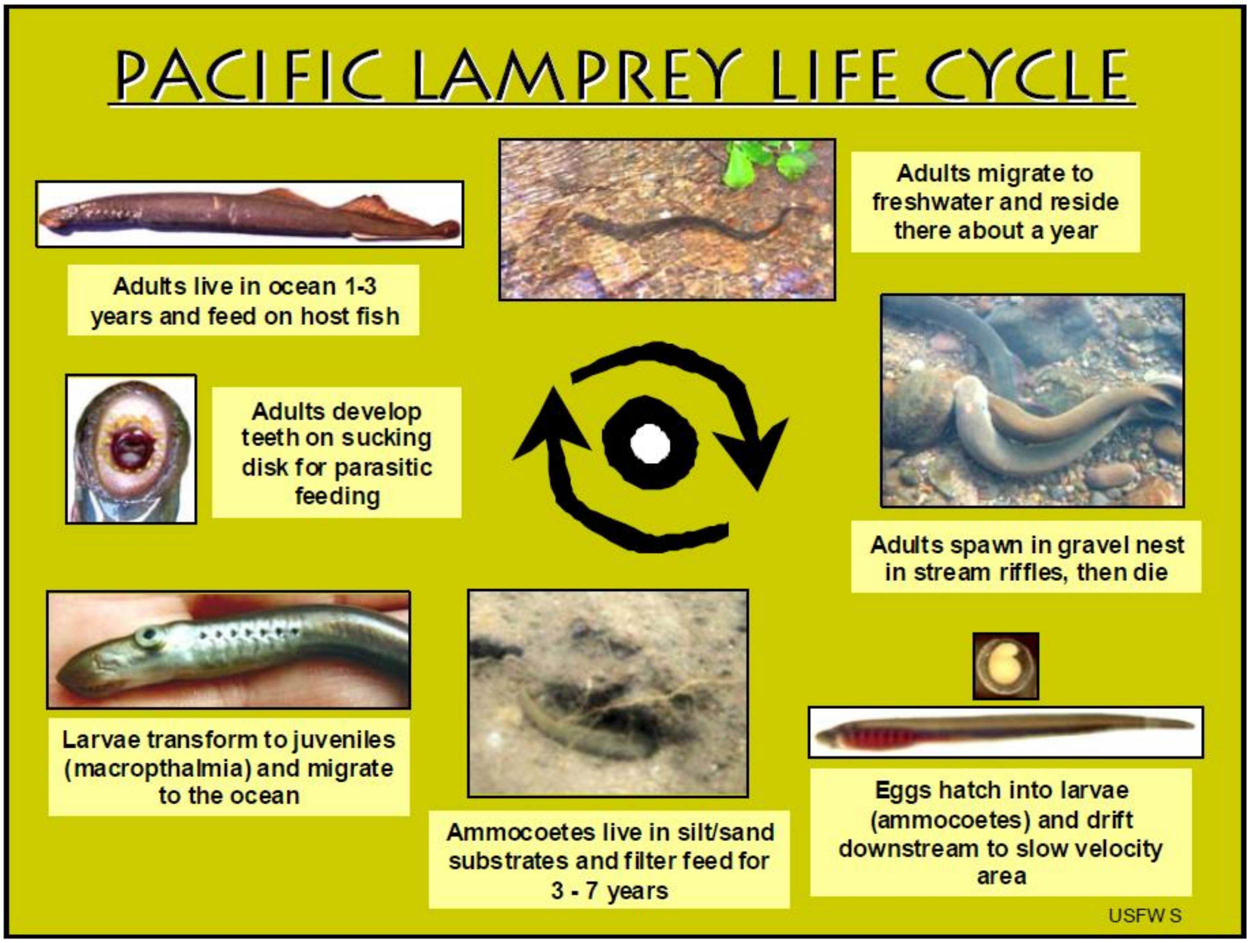

Figure 1. Pacific Lamprey Life Cycle (US Fish and Wildlife Service 2008).

Objectives

The 2016 objectives of the USACE Fisheries Field Unit are:

1) Operate and inspect the LPSs at Bonneville Dam
2) Enumerate and validate lamprey passage through LPSs
3) Evaluate LPS performance

The LPS at John Day Dam was not operated during 2016 due to mechanical failure of the elevator used to access the LPS, without which trap-and-haul operations are virtually impossible. Therefore, the John Day LPS is not included in this report. Further information on lamprey passage through the traditional adult salmonid ladders at Bonneville Dam and John Day Dams can be found in the Annual Fish Passage Report (USACE 2017).

Study Area

Bonneville Dam is located on the Columbia River at river mile (rm) 146. Lamprey can use multiple passage routes through Bonneville Dam including the fish ladders which were designed for salmonid passage and LPSs that were designed for lamprey passage. During 2016, we focused our study on three of the four LPS's at Bonneville Dam, located at Bradford Island, Cascades Island and Washington Shore (Figure 2). The LPS at Washington Shore Fish Ladder's north downstream entrance (WA-NDE) was not operated during 2016 and therefore is not included in this report. A missing access hatch door near the flume entrance was repaired in November 2016.

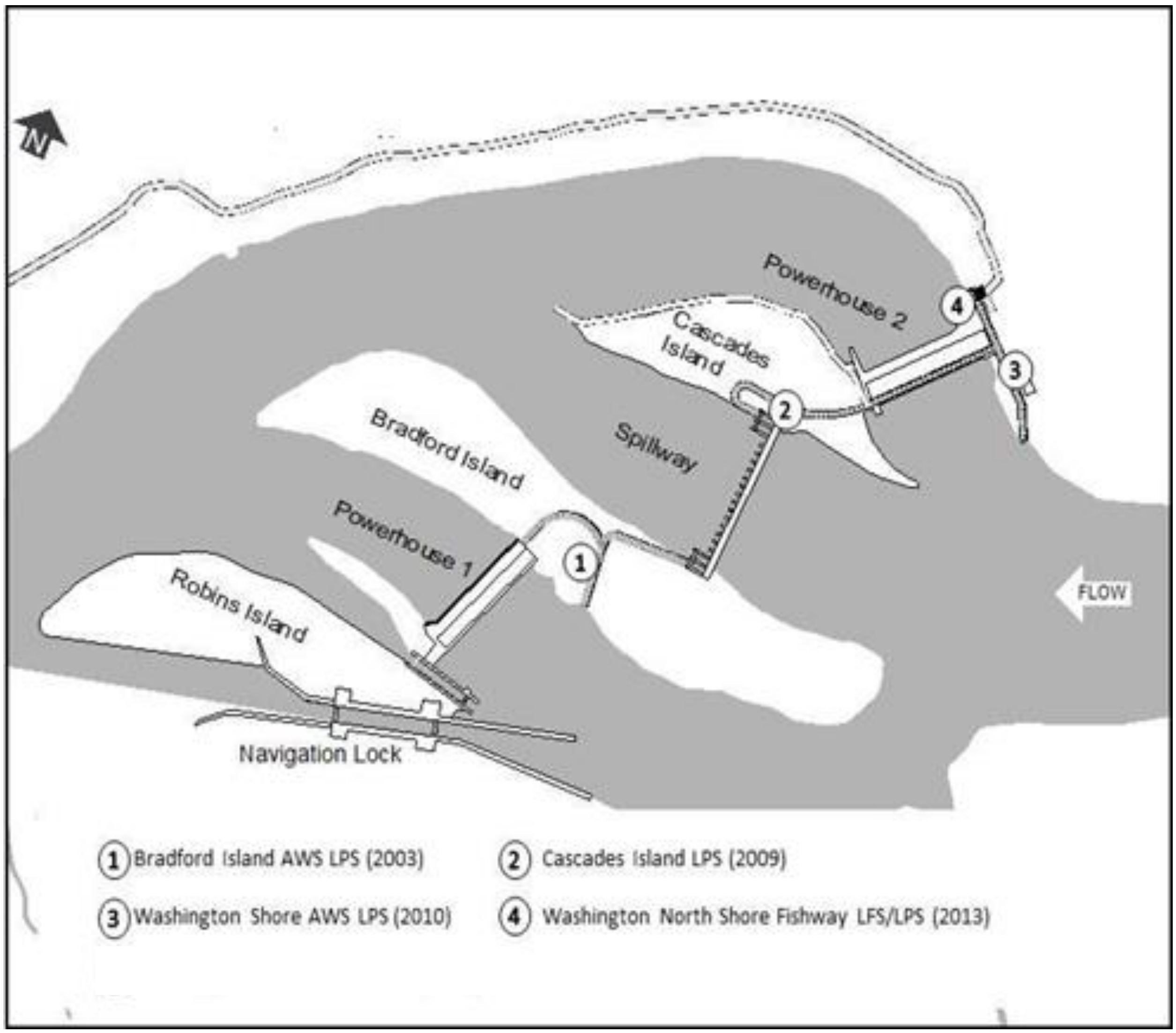

Figure 2. Lamprey Passage Structure locations at Bonneville Dam.

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 lamprey that swim into the auxiliary water supply channel from the main fish ladder. There are two entrance ramps that parallel the Bradford Island serpentine weir section. It has a total length of 118.1 feet and height of 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 (CI) LPS was installed in the winter of 2008-09. The CI LPS is unique because of its length and location. The entrance to the LPS is just inside the Cascades Island salmonid fish ladder entrance in the tailrace and the exit was extended into the spillway forebay in 2013. It has a total length of 532.8 feet and height of 88.6 feet the longest and highest climb of all USACE LPSs (Zobott et al. 2015 Table 1).

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 68.2 feet and height of 30.2 feet (Zobott et al. 2015, Table 1). For a more complete description of the BI-AWS and WA-AWS LPSs see the report by Moser et al. 2011.

Methods

Operation and Inspection

The LPSs are operated to encompass the adult lamprey passage season at Bonneville Dam. In 2016, the LPSs were in operation from early April through late October. The LPSs were inspected weekly during April, twice per week during May and October, and daily from Monday through Friday during the peak passage months of June through September to ensure they were operating properly. Inspections were conducted and focused on monitoring proper water flow, amount of sediment, and removing and documenting any lamprey mortalities.

During inspections, personnel would confirm that there was sufficient water flow in the LPSs using an index point where the height of the water was measured with a ruler. This measurement would allow us to determine if the water level had changed between inspections. If the water level had changed noticeably, then the inspector would further investigate to determine what caused the water level change. Any malfunctioning parts of the LPS would be addressed or reported to USACE Bonneville project biologists who would coordinate repairs.

Accessible LPS rest boxes were inspected to look for the buildup of sediment. If a buildup of sediment was observed, the inspector would flush the excess sediment through a drain valve located in the lower section of the rest box or holding tank. Rest boxes would not be flushed if there were lamprey present since there is a possibility that they could be flushed out with the sediment. The first two rest boxes in the lower section of CI-DE are not accessible during regular inspections. These rest boxes require a crane and man-basket to access and are checked annually unless 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.

During inspections each rest box was visually inspected to look for the presence of lamprey. The number of lamprey present was recorded. Lamprey that appeared moribund and did not respond to stimuli were removed *via* a dip net and further inspected to confirm mortality. Lamprey mortalities were removed from the LPS rest boxes as literature suggests that lamprey may avoid pheromones produced by dead or dying conspecifics (Wagner et al. 2011), suggesting that mortalities in the LPS may affect lamprey passage. Lamprey mortalities were measured, scanned for a Passive Integrated Transponder (PIT) tag, photographed, and placed in a freezer for later analysis. Mortality information was submitted to USACE Bonneville project biologists. The project biologists 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.

After the 2016 passage season was complete we used the corrected daily passage estimates for each LPS to calculate the first passage event, 10% passage completion, 50% passage completion, 90% passage completion, and the last passage event. To further assess operational timing, these numbers were also calculated for 2014 and 2015. Similar methods were used from 2014-2016 to correct mechanical counts. Examining these metrics across several years provides more perspective on operational timing.

Passage Enumeration and Validation

Volitional lamprey passage events were recorded at BI-AWS, CI-DE, and WA-AWS from 5 April, 2016 (8 April at CI-DE) through 27 October 2016. The counting system consisted of an eight inch diameter, light weight perforated plastic paddle at the terminus of an eight inch PVC exit pipe, limit switch (Honeywell Heavy Duty Limit Switch model numbers: LSA1A-4M & LSA1A), a data recorder (T&D Corporation RTR-505 Wireless Data Recorder), and a network base station (T&D Corporation RTR-500NW) (Figure 3). As lamprey exited the LPS the paddle was physically triggered and the limit switch connected to the paddle completed a voltage circuit. This voltage pulse was recorded by the wireless data recorder, which reported the time and date at pre-set intervals (60 seconds) along with the number of pulses (passage events) during that interval.

During LPS inspections, tests were conducted to ensure the counting system was functioning properly. 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 in a log book so they could be removed from the data set before analysis. The 3.6 volt batteries of the wireless data recorder were also monitored and replaced as necessary (about once a month). Finally, passage data was downloaded bi-weekly from the base station via a USB connection to a laptop computer and T&D RTR 500W software.

Figure 3. Mechanical counter components used to enumerate lamprey passage including the limit switch attached to exit paddle and cushion, wireless data recorder, and network base station (from left to right).

To validate the data from these counting systems we used video recording equipment to archive and subsequently review lamprey passage events. Video reviews were conducted biweekly from mid-May through September but did not start at CI LPS or BI LPS until June due to fewer passage events. Video was recorded from 20:00 on Tuesday nights to 06:00 on Wednesday mornings (typical peak hours for lamprey passage). Video recording equipment was housed outside in a waterproof enclosure or inside a building. At the WA-AWS LPS we used a GANZ digital video recorder (DVR) (model number: DR4HD-2TD) connected to an externally mounted camera, manufactured by ARM. At the CI LPS we used a Pelco DX4708HD (DVR) connected to a Pelco Sarix IMP319-1ERS camera mounted above the in-line paddle counter (Figure 4). At BI LPS we used a Sony handheld video camera that was focused on the paddle at the end of the LPS exit pipe. Incandescent outdoor lights were used during filming hours so that the exit pipe was viewable overnight.

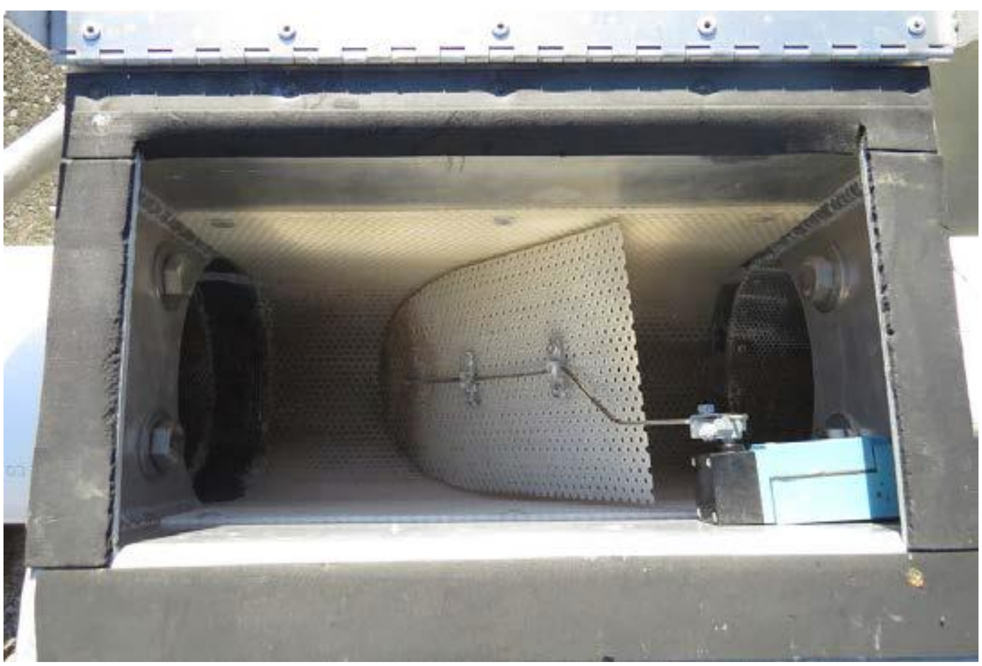

Figure 4. The inline paddle and limit switch that make up the mechanical counter at Cascades Island downstream entrance lamprey passage structure.

Video recordings for each week were reviewed alongside the corresponding data produced by the RTR-505 data recorder. During video review we tallied and summed the number of lamprey passing through the system. Because of inconsistencies between the number of lamprey passing and the number of lamprey being recorded by the data recorder we calculated a correction factor to achieve better estimates of lamprey passage for each week.

The correction factor was calculated by dividing the number of lamprey that were observed passing in each video review period by the number of lamprey that were recorded passing by the RTR-505 data recorder for the same period. Correction factors were applied to daily counts for each corresponding week to provide a more accurate estimate of lamprey passage.

Overcounts were enumerated for each review period by subtracting the number of lamprey observed during video analysis from the recorded number of lamprey tallied by the counting system. This provided us with the total number of overcounts for each review period as well as any under counts that had been observed.

Overcounts were classified into one of three categories: hanging lamprey, water pulse, or paddle bounce. Overcount from hanging lamprey were defined as additional counts due to lamprey using their mouths to attach and hang in the LPS and activate the paddle multiple times. Overcount from water pulse was defined as additional counts due to a burst of water during lamprey passage in which hanging lamprey were not visible. Overcount from paddle bounces were defined as additional counts due to paddle bounces after lamprey passage (caused by high exit velocity).

From 5 July to 28 September we classified each overcount using passage event timestamps from the RTR-505 data recorder during video review. Each overcounted lamprey from the RTR-505 was isolated in the recording and classified in order to assess the causation of overcounted lamprey.

During video review we also observed that some lamprey were passing the counting system at the BI LPS without triggering it. Those events were classified as undercounts and were included when calculating correction factors for that site.

Performance Evaluation

A summary of total annual passage since LPS installation is presented as an indicator of relative success, independent of run size. In addition, we visually examine daily lamprey passage estimates relative to mortality removal from the LPS to determine if mortality presence had an effect on passage.

Results

Operation and Inspection

The Bonneville LPSs operated between 202 and 205 days in 2016 (Table 1).

Table 1. Operation dates of Lamprey Passage Structures (LPS) during 2016.

LPS Location	Start Date	End Date	Days of Operation
Bradford Is.-AWS	4/5/2016	10/27/2016	205
Cascades Is.	4/8/2016	10/27/2016	202
Washington-AWS	4/5/2016	10/27/2016	205

The timing and magnitude of lamprey passage through the LPSs are observed in Figure 5.

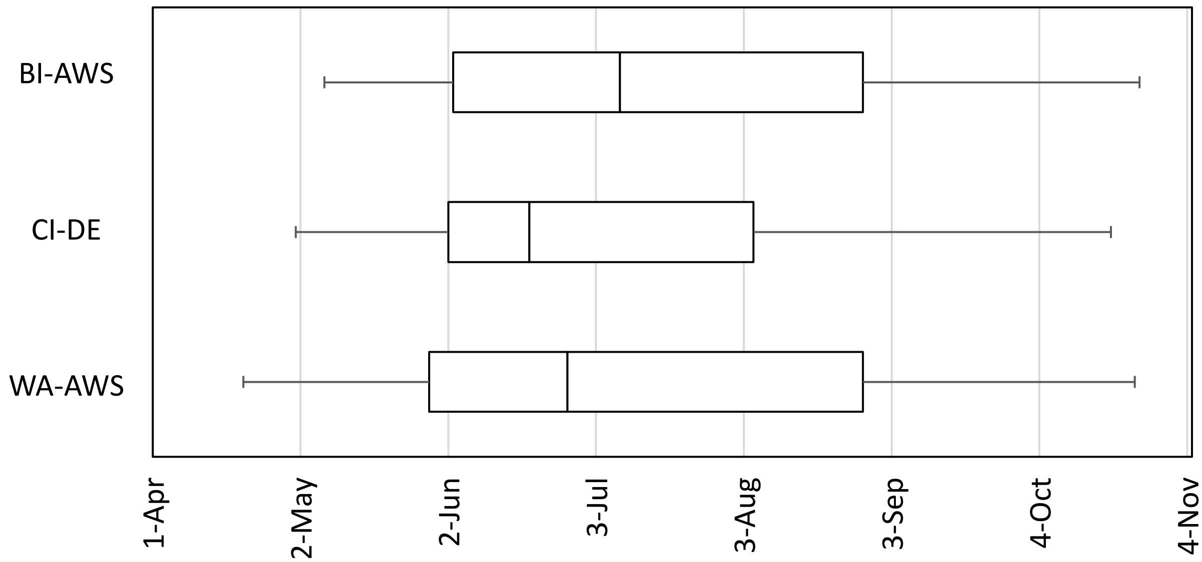

Figure 5. Run timing of Pacific Lamprey passing Bonneville Dam Lamprey Passage Structures during 2016. Whiskers show dates of first and last fish passage, box plot depicts the estimated 10%, 50% and 90% run completion passage dates.

The water flow in the LPSs was found to be sufficient for the entire passage season. On 15 August it was noted that the water level in the BI-AWS LPS had dropped since the last inspection on 12 August; however, this did not interfere with the LPS operations. The issue was reported to Bonneville Project Fisheries and they ordered that the two pumps of the LPS be pulled and inspected by Bonneville staff. It was determined that one of the pumps had stopped working due to electrical problems, but the one operating pump was able to provide sufficient water for the LPS to function. Electricians were able to fix the broken pump and it was put back into service on 17 August.

The amount of sediment observed in the LPSs was not to the level where it affected passage. Flushing sediment helps when conducting inspections so that lamprey in the rest boxes are more readily observed. The CI-DE LPS rest boxes had the most sediment buildup during 2016 and they were flushed regularly. The BI-AWS and WA-AWS LPSs did not experience much sediment buildup and thus rarely needed to be flushed.

In total, 33 lamprey mortalities were found in the Bonneville LPSs in 2016. Of these, four were found in the BI-AWS LPS, 15 in the CI-DE LPS and 14 lamprey mortalities were found in the WA-AWS LPS. No PIT tags were detected in any of the lamprey mortalities.

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/).

Passage Enumeration and Validation

Lamprey passage counted from 280 hours of video was compared with mechanical passage estimates to determine a correction factor (Table 2). Correction factors were calculated from 10 hours of video review at each site every two weeks. Over the ten semi-monthly observation periods, correction factors averaged (with range of min to max) 0.75 (0.58 to 1.00) at WA-AWS LPS, 0.93 (0.77 to 1.00) at CI LPS, and 0.46 (0.35 to 0.77) at BI LPS.

Table 2. Uncorrected daily mechanical counts, video counts and correction factor (CF) for Bonneville Dam LPS from video validation May 17th to September 28th 2016.

Observation Period	Washington AWS			Cascades Island DE			Bradford Island AWS		
	Mechanical	Video	CF	Mechanical	Video	CF	Mechanical	Video	CF
1	35	35	1.00	NA	NA	NA	NA	NA	NA
2	1183	1041	0.88	120	113	0.94	544	370	0.68
3	1188	937	0.79	13	13	1.00	164	77	0.47
4	571	402	0.70	10	10	1.00	263	146	0.56
5	127	96	0.76	2	2	1.00	121	44	0.36
6	570	338	0.59	5	4	0.80	272	95	0.35
7	666	388	0.58	2	2	1.00	182	70	0.38
8	248	173	0.70	13	10	0.77	75	58	0.77
9	51	46	0.90	1	1	1.00	53	24	0.45
10	16	16	1.00	0	0	1.00	11	6	0.55

The majority of count error was due to overcounting. Overcounts identified in video review periods were summed and classified as either due to hanging lamprey, water pulse, or paddle bounce (Table 3). A total of 70 hours of video was reviewed semi-monthly at each site over the course of fourteen weeks. In this period there were a total of 614 overcounts at WA-AWS LPS which were classified as being 95.1% due to hanging lamprey, 0% due to water pulse, and 4.9% due to paddle bounce. At CI-DE LPS a total of 4 overcounts were recorded and were classified as 100% due to hanging lamprey. There were a total of 424 overcounts at the BI-AWS LPS of which 94.6% were classified as due to hanging lamprey, 5.2% due to water pulses, and <0.01% due to paddle bounce. Across all sites there were 1042 overcounts of which 989 (94.9%) were classified as due to hanging lamprey, 22 (2.1%) due to water pulse, and 31 (3.0%) due to paddle bounce.

Table 3. Classification of overcounts from video reviews every two weeks during 5 July to 28 Septemer 2016 at WA-AWS, CI-DE, and BI-AWS LPSs.

Observation period	Washington AWS			Cascades Island DE			Bradford Island AWS		
	Hanging	Water	Bounce	Hanging	Water	Bounce	Hanging	Water	Bounce
1	NA	NA	NA	0	0	0	113	4	0
2	18	0	2	0	0	0	74	4	1
3	215	0	17	1	0	0	173	7	0
4	273	0	5	0	0	0	108	5	0
5	69	0	6	3	0	0	18	0	0
6	9	0	0	0	0	0	23	6	0
7	0	0	0	NA	NA	NA	5	0	0
Total	584	0	30	4	0	0	401	22	1
	Total overcount		614	Total overcount		4	Total overcount		424

Under counts were recorded in the same semi-monthly video review as overcounts. A total of 24 under counts were recorded exclusively at BI-AWS LPS and accounted for <.01% of total passage.

Overall, the Bonneville LPS passage estimate during 2016 was reduced by 30% from 81,587 to 56,846 when corrected for mechanical counting error (Table 4).

Table 4. Estimated lamprey passage at Bonneville Dam Lamprey Passage Structures during 2016, corrected for mechanical counting error and the resulting difference for the entire passage season.

LPS Location	Mechanical Count	Corrected Estimate	Difference (%)
Washington AWS	54,043	40,880	-24%
Cascades Island	4,073	3,851	-5%
Bradford AWS	23,471	12,115	-48%
Total	81,587	56,846	-30%

Daily lamprey passage fluctuated greatly at each of the LPSs (Figure 6). The WA-AWS, CI-DE and BI-AWS LPSs accounted for 72%, 7% and 21% of total passage, respectively.

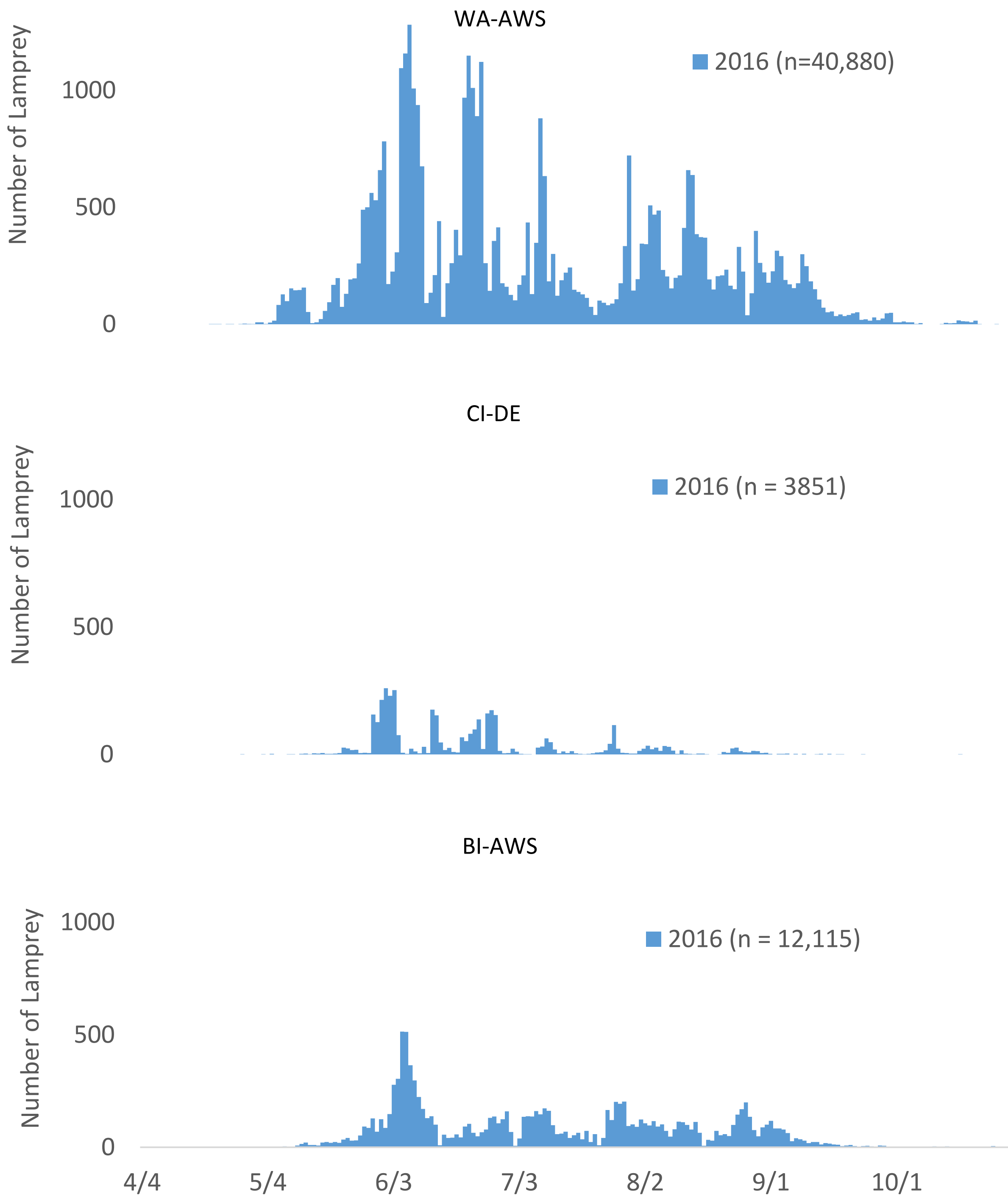

Figure 6. Daily lamprey passage estimate (corrected) at the Bonneville Dam Washington auxiliary water supply (WA-AWS, top), Cascades Island (CI-DE, middle) downstream entrance and Bradford Island auxiliary water supply (BI-AWS, bottom) Lamprey Passage Structures during 2016.

Performance Evaluation

Lamprey passage at WA-AWS LPS increased from 38,069 in 2015 to 40,880 in 2016, or +7%. Lamprey passage during 2016 was the highest recorded since installation. (Table 5).

Table 5. Annual lamprey passage estimates at Washington auxiliary water supply lamprey passage structure during 2007-2014 (Corbett et al. 2015) and 2015-2016 (Gallion et al. 2016).

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]

1: Corrected for mechanical count error

A total of 14 lamprey mortalities were removed from WA-AWS LPS. Passage was relatively high ($n \geq 244$) on six days when mortalities were removed (Figure 7, red arrows), and passage was relatively low ($n \leq 232$) on eight days when mortalities were removed (Figure 7, black arrows).

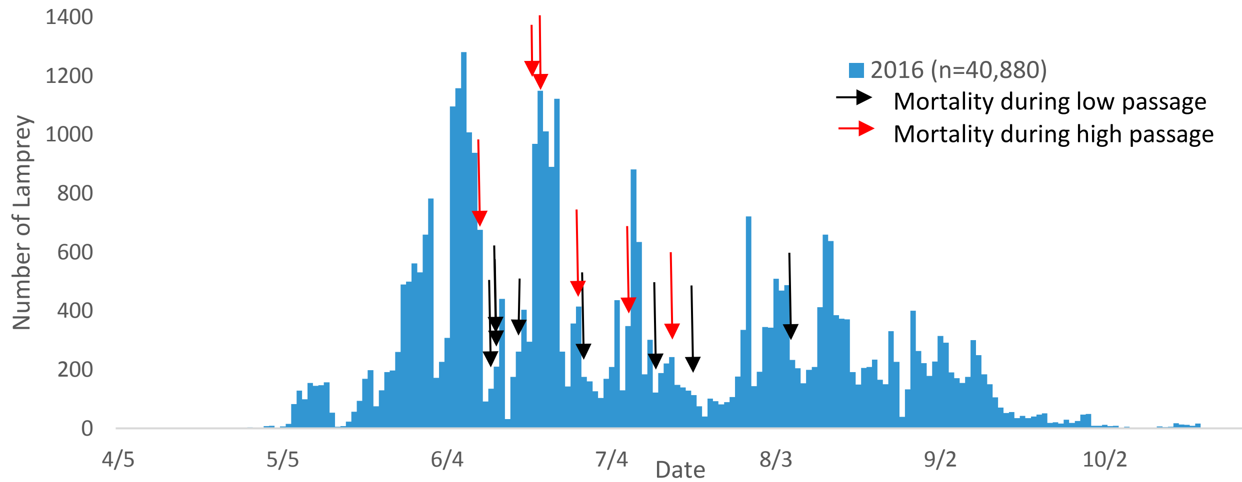

Figure 7. Corrected daily lamprey passage counts at Bonneville Dam Washington auxiliary water supply lamprey passage structure during 2016. Arrows indicate when lamprey mortalities were found in the structure or near the structures entrance.

Lamprey passage at BI-AWS LPS decreased from 13,986 in 2015 to 12,115 in 2016, or -13%. Lamprey passage during 2016 was the 5th highest recorded since installation (Table 6).

Table 6. Annual lamprey passage estimates at Bradford Island auxiliary water supply lamprey passage structure during 2007-2015 (Corbett et al. 2015) and 2015-2016 (Gallion et al. 2016).

Year	Operation period	# days	Estimated Passage
2004	NA	NA	7,490
2005	NA	NA	9,242
2006	NA	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]

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

A total of four lamprey mortalities were removed from BI-AWS LPS (Figure 8). Passage at this location was relatively high (n ≥ 108) on all three days when mortalities were removed.

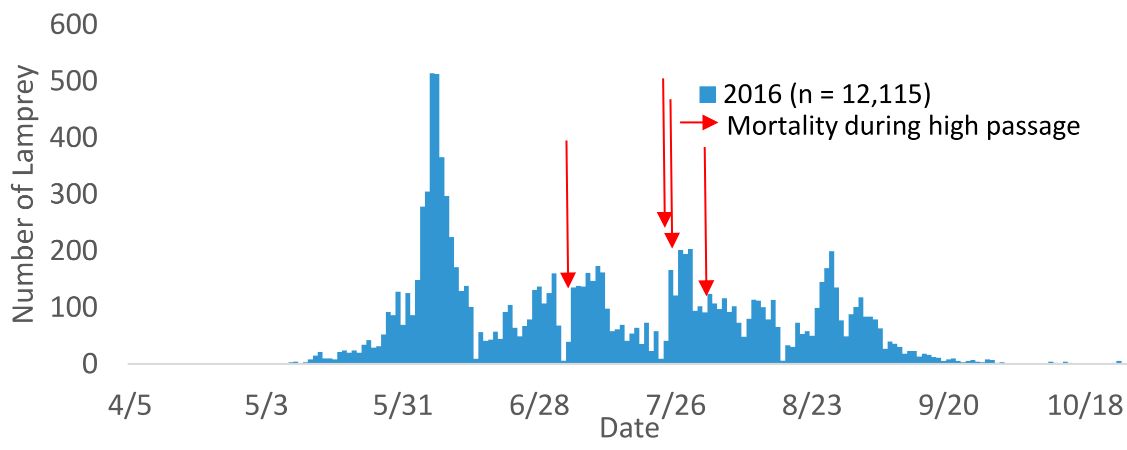

Figure 8. Corrected daily lamprey passage counts at Bonneville Dam Bradford Island auxiliary water supply lamprey passage structure during 2016. Arrows indicate when lamprey mortalities were found in the structure or near the structures entrance.

Lamprey passage at CI-DE LPS increased from 72 in 2015 to 3,851 in 2016or +5,349%. Lamprey passage during 2016 was the highest recorded since installation. (Table 7)

Table 7. Annual lamprey passage estimates at Cascades Island downstream entrance lamprey passage structure during 2009-2016.

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
2016	8 April – 27 October	202	3,851

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 into Bonneville Dam forebay prior to operation during 2013; 5: 2 days of data gaps

A total of 15 lamprey mortalities were removed from CI-DE LPS (Figure 9). Passage was relatively high (n ≥ 68) on 3 days when mortalities were removed, indicated by red arrows. Passage was relatively low (n ≤ 26) on 10 days when mortalities were removed, indicated by black arrows.

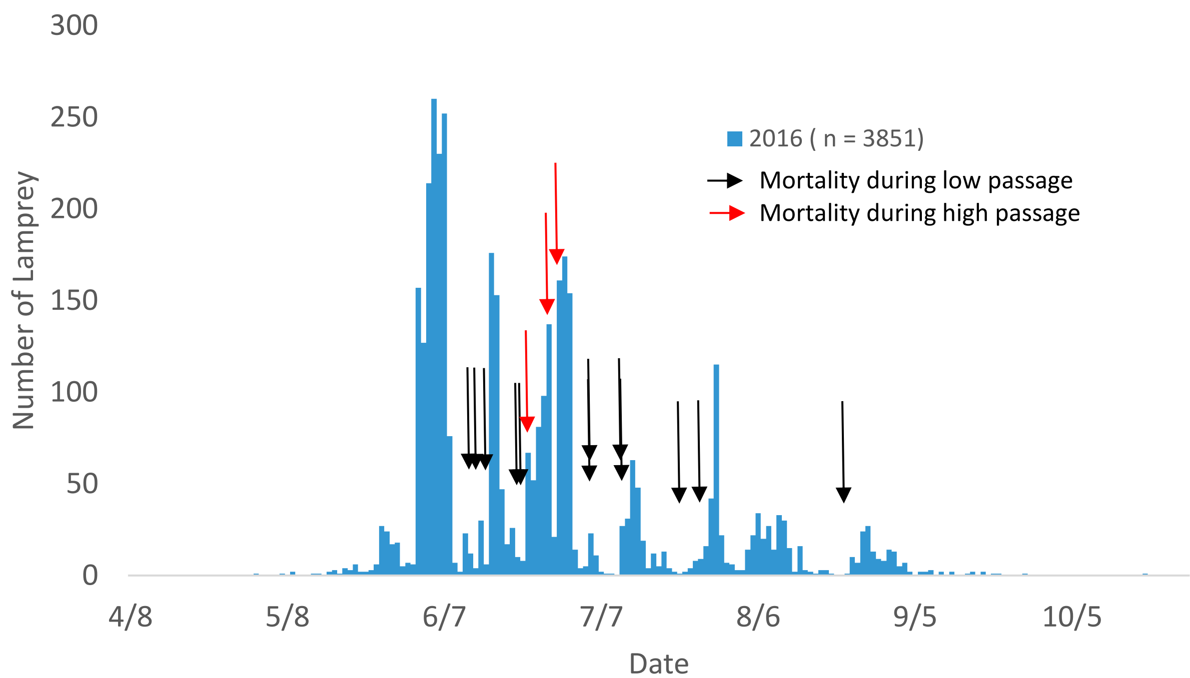

Figure 9. Corrected daily lamprey passage counts at Bonneville Dam Cascades Island downstream entrance lamprey passage structure during 2016. Arrows indicate when lamprey mortalities were found in the structure.

Conclusions

Operation and Inspection

From 2014-2016, the LPSs were started during March (2015), April (2016), and May (2014), and operated through late October. Similar correction methods were used to adjust LPS counts during 2014-2016. During that time, the earliest a lamprey passed any of the LPSs was April 21, 2016 at WA-AWS. The latest passage event occurred on October 27 during both 2014 and 2015. The inspection schedule followed during 2016, and operation of the LPSs beginning in early April and running through the end of October provided passage opportunity to the earliest and latest migrants (Figure 10). From 2014-2016, the earliest upstream migration at any of the adult fish ladders (non-LPS routes) at Bonneville Dam was 6 April (http://www.fpc.org/environment/home.asp).

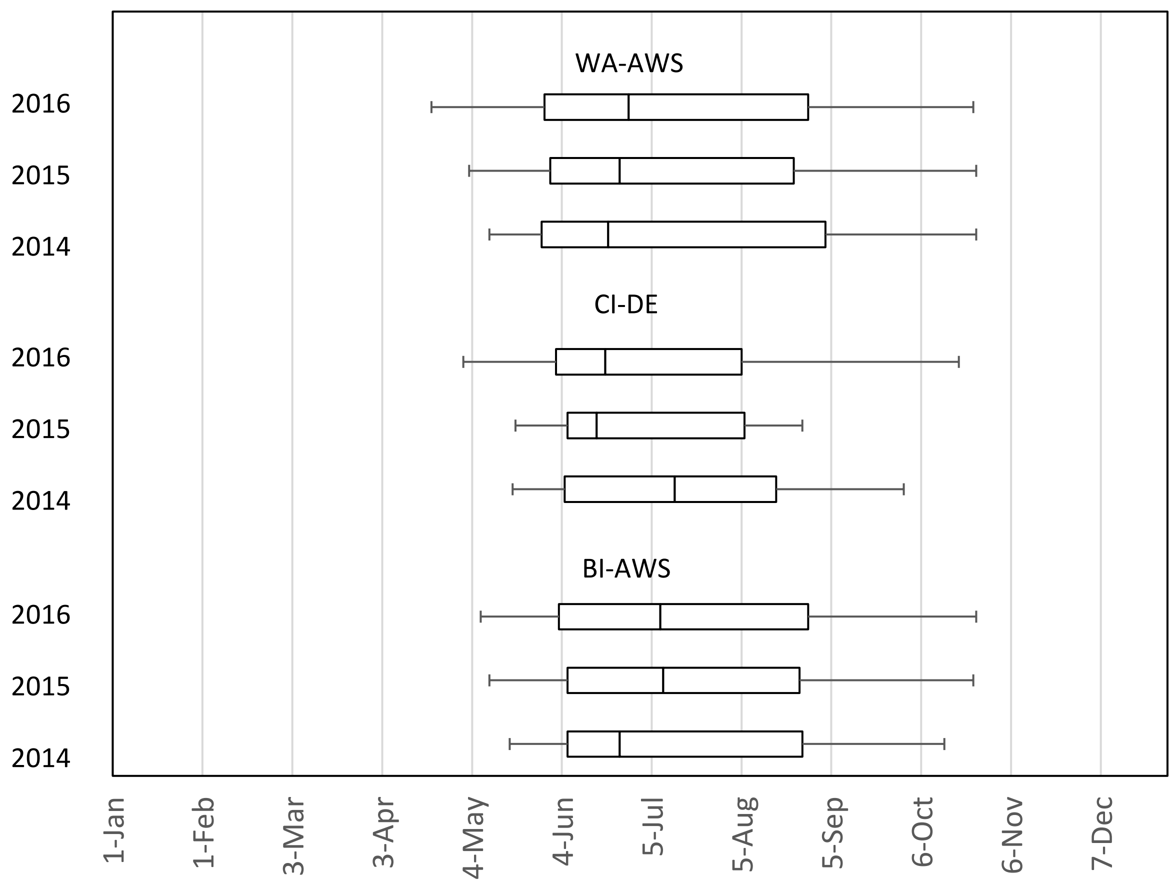

Figure 10. Run timing of Lamprey passing Bonneville Dam Lamprey Passage Structures from 2014-2016. Whiskers show dates of first and last fish passage, box plot quartiles depict the 10%, 50% and 90% passage dates.

Passage Enumeration and Validation

Lamprey passage through the LPSs was successfully enumerated and validated during 2016 but the counting systems could be improved. The BI LPS counting system was the least accurate compared to WA-AWS LPS and CI-DE LPS. The the CI-DE LPS was the most accurate on average but also had the lowest passage volume during review. The counting system at CI-DE LPS is unique in that it features an in-line paddle within the exit pipe. We believe the least amount of correction at this site was largely due to the in-line design. The paddle often straddled hanging lamprey and did not completely close which reduced the error caused by hanging lamprey. The BI LPS and WA-AWS LPS counting systems are similar in that they are triggered by a limit switch connected to a paddle at the end of the LPS exit pipes. Previous research has suggested that the angles of the exit pipes may affect the potential for hanging lamprey and the associated counting error (Gallion et al. 2016). The lower 24° angle of the exit pipe at the BI LPS exit pipe may be more conducive to overcounts from hanging lamprey than the 51° angle of the exit pipe at WA-AWS LPS.

Overcounts were predominately due to hanging lamprey at all three sites. Lamprey exiting the LPSs would frequently hang at the end of, or just inside, the exit pipes, and activate the paddle counter multiple times resulting in inaccurate mechanical counts. Any efforts to modify these counting systems to prevent lamprey from hanging and creating overcounts could increase their accuracy by up to 65% (Table 3).

Overcounts due to water pulses were only recorded at the BI LPS and were only responsible for 5% of overcounts at that site. These overcounts were generally attributed to lamprey further up the exit pipe out of the view of the video camera that were temporarily blocking the flow in a way that created pulses of water large enough to trigger the counting system. The absence of these overcounts at the other two sites may be due to different flow volumes and angles of the pipes in the counting systems.

Overcounts due to paddle bounce were only recorded at WA-AWS LPS with one exception during week 2 of overcount review at BI LPS. Paddle bounces were attributed to lamprey exiting the LPS with a velocity high enough to cause the paddle to bounce and trigger the counting system additional times after the lamprey had passed. A reduction in the angle of the exit pipe at WA-AWS would likely limit the velocity of exiting lamprey and reduce the potential for overcount from paddle bounce. However, too great a reduction could potentially increase the incidence of hanging lamprey as discussed above.

A new counter has been designed and is planned for installation at WA-AWS during 2017. Ideally, future improvements in the counting mechanism will reduce the count error and the frequent need for validation. If there continues to be a significant difference between mechanical and video enumeration, a power analysis or other relevant statistical test may lend insight into the necessary sampling required to achieve a particular (e.g. 95%) count accuracy.

Performance Evaluation

Total corrected LPS passage at Bonneville Dam in 2016 was 56,846 lamprey, which was a 9% increase from the 52,127 during 2015. During 2016, the WA-AWS passed the most lamprey (40,880) of the LPSs, and the most since installation (Table 3, Table 6).

Operations at Bonneville Dam during 2015 and 2016 may have attracted more lamprey to the Washington Shore Fish Ladder and associated WA-AWS LPS. Research suggests, during their upstream migration, lampreys are attracted to flow, and decreases in flow or lentic conditions and not conducive to upstream migrations (Orlov and Beamish 2016). During the period May-September, when most lamprey pass the LPSs, total average discharge was lower during 2015 (132.70 kcfs) and 2016 (155.11 kcfs) in comparison to 2014 (232.51 kcfs) (Table 8). Although total discharge was lower, Powerhouse 2 is the priority powerhouse for power generation at the dam and discharge was proportionally higher during 2015 (0.39) and 2016 (0.41) than 2014 (0.37) and may have attracted more fish to the WA-AWS.

In addition, the Washington Shore Fish Ladder includes fish entering the Cascades Island fish ladder (Figure 1). Due to adult salmonid fall back at the spillway during spill, the Cascades Island Fish Ladder exit was closed in 1982 with the completion of Powerhouse 2. Currently, fish are routed to the upstream migrant transportation channel, which crosses Powerhouse 2 and enters the Washington Shore Fish Ladder. Therefore, lamprey that did not enter the CI-DE LPS at the Cascades Island Fish Ladder entrance would be diverted to Washington Shore Fish Ladder and could enter the WA-AWS LPS. Lastly, project personnel closed gaps in the picket leads at Cascades Island Fish ladder in the winter of 2014, which likely resulted in more lamprey transiting from Cascades Island Fish Ladder to the WA Shore Fish Ladder via the upstream migrant tunnel during 2015 and 2016. Dam operations (ie discharge) and changes to picket leads could, at least in part, explain why Lamprey Passage at WA-AWS increased 28% from 2014 to 2015 and 7% from 2015 to 2016.

Table 8. Total discharge at Bonneville Dam during May through September 2014-2016 including proportion of total discharge for Powerhouse 2 (PH2), Powerhouse 1 (PH1) and Spillway.

Year (May-September)	Total Average Discharge (kcfs)	PH2	PH1	Spillway
2014	232.51	0.37	0.23	0.40
2015	132.70	0.39	0.08	0.53
2016	156.71	0.41	0.10	0.49
Average	173.97	0.39	0.14	0.47

The BI-AWS LPS passed 12,115 lamprey during 2016, which is the fifth highest lamprey passage on record (out of 13 years) since installation (Table 6). Fish can enter the Bradford Island Fish Ladder from the south side of the spillway (B Branch), from the north side of Powerhouse 1 (A Branch) and from the south side of Powerhouse 1. It serves as the passage path for fish migrating upstream along the Oregon shore at Bonneville Dam. On average, the ratio of lamprey passage at

WA-AWS LPS (0.71) to BI-AWS LPS (0.29) was approximately 2.5 to 1 (Table 9). Similarly, the ratio of adult salmonid passage at Washington Shore Ladder (0.65) and Bradford Island Ladder (0.35) was approximately 1.9 to 1. Proportionally higher passage at the WA-AWS LPS and Washington Shore Ladder may be related to attraction flow resulting from operations at Bonneville Dam. The ratio of discharge at PH2 (0.39) to PH1 (0.14) is approximately 2.8 to 1 (Table 8). Furthermore, lamprey passage at BI-AWS decreased during 2014-2016 (Table 9). The lower proportional discharge at Powerhouse 1 during 2015 (0.08) and 2016 (0.10) in comparison to 2014 (0.23) may have attracted fewer lamprey to the BI-AWS LPS (Table 8).

Table 9. Adult lamprey and salmonid passage at WA-AWS and BI-AWS LPSs and the corresponding Washington Shore and Bradford Island fish ladders during May through September.

Year	Lamprey				Salmonid			
	WA-AWS LPS		BI-AWS LPS		Washington Shore		Bradford Island	
2014	29,576	(0.63)	17,587	(0.37)	2,551,137	(0.64)	1,438,012	(0.36)
2015	38,069	(0.73)	13,986	(0.27)	2,187,072	(0.63)	1,269,857	(0.37)
2016	40,880	(0.77)	12,115	(0.23)	1,485,126	(0.68)	698,431	(0.32)
Average	36,175	(0.71)	14,563	(0.29)	2,074,445	(0.65)	1,135,433	(0.35)

The CI-DE LPS passed 3,851 lamprey during 2016 (Table 7). Passage increased from 2009-2016 except in 2013 when the LPS was extended into the forebay and the operating season was limited to 102 days (Corbett et al. 2015, 2013; Moser et al. 2012) and 2015 when passage may have been impeded by an obstructed fyke (Gallion et al. 2016). Of the overall discharge at Bonneville Dam, spillway discharge was proportionally higher during 2015 (0.53) and 2016 (0.49) than 2014 (0.40), which potentially would have attracted more fish to the Cascades Island Fish Ladder and LPS (Table 8). During Fishway inspections of CI-DE LPS on 19 June, 2015 a layer of algae was discovered around the fyke in rest box 5. During 2015, It is possible more lamprey entered the Cascades Island Fish Ladder due to the higher proportional attraction flow (Table 8) and eventually passed, via the upstream migrant tunnel, through the WA Shore Fish Ladder and WA-AWS, but fewer fish passed the CI-DE LPS due to the fyke obstruction. Lamprey passage at CI-DE during 2016 was the highest on record since installation in 2009 and 36% higher than the second highest passage year.

The amount of lamprey mortalities was highly variable when compared to overall passage at each LPS. The BI-AWS LPS passed an estimated 12,115 lamprey in 2016 and had four lamprey mortalities. The WA-AWS LPS passed an estimated 40,880 lamprey and had 14 lamprey mortalities. In contrast, the CI-DE LPS had 15 mortalities, but only an estimated 3,851 lamprey passed via this LPS. The CI-DE LPS is a much different structure than the other two LPSs at Bonneville. It spans the entire fishway at Cascades Island starting at tailwater and ending in the forebay. It is possible the higher proportional number of mortalities removed from the CI-DE LPS could be a result of the longer and more difficult ascension. Overall, the number of mortalities relative to total passage at CI-DE LPS was 0.3%.

Gallion et al. (2016) noted that passage was relatively low when mortalities were found in the rest boxes during the 2015 passage season, suggesting that the pheromones given off by dead or dying lamprey may result in reduced passage events. However, lamprey mortalities found in the LPSs during 2016 did not have a clear negative effect on passage (Figures 6, 7, and 8), indicating there could be other causes for fluctuations in daily passage such as natural variability. There may be too many confounding factors to determine the direct effect of dead lamprey on LPS passage. Wagner et al. (2011) stated that the timing of the death pheromone released from Sea Lamprey is unknown. Also, the existing counting system does not enumerate within the LPSs, so lamprey upstream of the mortality presumably would not be affected and would pass normally. In addition, inspections for mortalities were not conducted on weekends, so mortalities found on Mondays may have died over the weekend. Lastly, the biological drive of lamprey to migrate upstream likely is different among individuals passing Bonneville Dam and possibly, at different times of the year. Certain individuals or during particular times of year, the innate drive by lamprey to migrate upstream could be stronger than the need to avoid dead or dying lamprey. Although there was no clear negative affect on passage in 2016, we still feel that the prompt removal of dead lamprey from the LPSs is prudent, because of the known pheromone release and observed decreases in passage when some mortalities were present.

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