Adult Pacific Lamprey Passage Structures: Use and Development at Bonneville Dam and John Day Dam South Fishway, 2014

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Report of research by

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Executive Summary

In 2014, we continued a multi-year study to evaluate and improve adult Pacific lamprey passage at Columbia River Dams with the following objectives:

1) Determine lamprey use of Bonneville Dam lamprey passage structures (LPSs) located at the auxiliary water supply channels.
2) Assess the effects of providing refuge areas at auxiliary water supply channels and fishways.
3) Determine lamprey use of the Bonneville Dam LPS located at the Cascades Island fishway entrance.
4) Develop methods to collect lamprey from the makeup water supply channel at Cascades Island.
5) Develop methods to enumerate lamprey entering a newly-installed trap at the south fishway of John Day Dam.
6) Design, build, and test lamprey use of an experimental wetted wall at Bonneville Dam.

To achieve these monitoring objectives, we used two approaches. First, we estimated individual lamprey passage in the existing structures. For these estimates, we used lamprey-activated counters in the Washington Shore, Bradford Island, and Cascades Island AWS structures.

Second, we marked lamprey with passive integrated transponder (PIT) tags and monitored their movements within the LPSs. In 2014, we tagged 1,497 adult lamprey with a PIT tag (599 of which were also tagged with a radio transmitter). Antennas to detect PIT tags were integrated into all of the lamprey passage structures, and antennas were also operated at the top of the Bradford Island, Washington Shore, and Cascades Island fishways to identify lamprey passage routes and rates of movement.

Throughout the 2014 Pacific lamprey migration, the picketed leads at the entrances to the Washington Shore and Bradford Island auxiliary water supply channels were raised by 3.8 and 2.5 cm, respectively, in an effort to increase lamprey access to the passages structure. Lamprey use of the Washington Shore and Bradford Island AWS LPSs was higher in 2014 relative to other years of operation. At the Washington Shore AWS, LPS passage efficiency for all PIT-tagged lamprey was 91%. At the Bradford Island AWS, LPS passage efficiency was 100%. In 2014, 18% of the 1,198 PIT-tagged lamprey released downstream from Bonneville Dam used one of these structures to pass the dam.

Two lamprey refuges were operated in the Washington Shore auxiliary water supply channel from 15 May to 30 October. A total of 174 PIT-tagged lamprey (15% of the lamprey released downstream from Bonneville) were detected in the refuges in 2014. The mean residence time was 29.9 h. More than half (61%) of these fish were subsequently detected in the Washington Shore LPS. In fact, of the 364 lamprey detected exiting the Washington Shore LPS or fishway, 33% had used a refuge, indicating that lamprey were able to find and take advantage of these relatively small refuge areas.

Two lamprey refuges were also operated in the Washington Shore fishway proper near the terminus of the Upstream Migrant Tunnel in 2014. However no assessment of lamprey use of these refuges was gained from PIT detections due to problems with the detection systems that could not be resolved in-season.

In 2013, the LPS located at the Cascades Island fishway entrance was extended to allow for volitional lamprey passage from tailrace to forebay. In 2014, modifications were made to improve LPS exit passage efficiency, passage estimation, and accessibility to closed portions of the LPS. In 2014, the LPS was operated from 14 May to 30 October and during that period 2,832 lamprey were counted exiting to the forebay. Results from a period of video validation of the mechanical exit counter provided a corrected range of estimated passage values of 2,548 to 2,889 lamprey.

Lamprey use of the Cascades Island LPS was substantially higher in 2014 than in 2013 (n = 155), and the highest since its first year of operation in 2009. In addition to 1 tagged in 2013, 7 PIT-tagged fish released downstream from Bonneville Dam in 2014 (0.6%) volitionally entered and were detected in the LPS. All fish detected at the LPS were also detected exiting the structure; passage efficiency was 100%. For these fish, median travel time from the first antenna to the exit slide was 2.9 h.

In past years adult lamprey have been detected and observed accumulating in the Cascades Island makeup water supply channel, a structure that has no direct access to the forebay. In 2014, we deployed 2 cylindrical traps within the upper portion of this channel. Between 19 May and 30 October, 1,512 lamprey were captured in the traps and released untagged upstream from the dam.

As in past years, we continued to monitor PIT-tagged lamprey use of this area. In 2014, 5%, of the PIT-tagged lamprey released downstream from Bonneville Dam were detected at this location. These results were consistent with those from past years and indicate that high numbers of adult lamprey occupy this area. These lamprey should be precluded from entering the makeup water supply channel, provided with an outlet to the forebay, or actively trapped in the channel and transported upstream.

In 2013, a lamprey trap was installed at the John Day Dam south fishway. A PIT antenna installed in the trap collector detected 28 PIT-tagged fish, 7 of which had been tagged in 2013. In 2014, the trap was fished by tribal personnel on 50 nights between 12 June and 26 September, and 52 adult lamprey were captured. During periods when the trap was operated in pass-through mode, a digital video camera recorded lamprey passage. Of the 21 lamprey tagged in 2014 and detected at the trap collector, 16 (76%) were detected again as they exited the top of the south fishway exit. Median residence at the collector for PIT-tagged fish was 17.2 h, and median passage time from the collector to the ladder exit was 6.4 h.

In 2014, we built an experimental wetted wall designed to attract and pass lamprey without impacting co-occurring salmonid species. To test Pacific lamprey climbing ability in relation to flow, the wall was outfitted with three regulated water delivery mechanisms. We installed the wall in an experimental raceway and conducted trials using experimental lamprey. These fish were introduced to the raceway and their passage success was evaluated and behaviors were documented. All experimental lamprey used the wetted wall during these trials, indicating that the device could be a useful component of new or exisiting aids to lamprey passage.

Contents

Introduction

Pioneering research has shown that adult Pacific Lamprey passage at dams can be facilitated with lamprey-specific fishways. These lamprey passage structures (LPSs) are designed to take advantage of lamprey swimming and climbing performance while minimizing searching and fallback behavior (Reinhardt et al. 2008; Kemp et al. 2009; Keefer et al. 2011; Moser et al. 2011). In traditional fishways, many Pacific lamprey make multiple entrances and repeatedly fall back and mill about in difficult passage areas (Moser et al. 2002a; Keefer et al. 2013). Successful LPS design reduces downstream movement of lampreys and facilitates rapid ascents over short horizontal distances (Moser et al. 2011).

Lamprey Passage Structure Development, 2004-2013

We initially developed the LPS at Bonneville Dam, the first mainstem dam that lamprey encounter when migrating up the Columbia River (rkm 235; Figure 1). Here adult lamprey have difficulty entering fishways, and those that successfully enter are often obstructed or delayed near the top of the fishway (Moser et al. 2002b; Johnson et al. 2009a, 2009b; Keefer et al. 2013). In these areas, vertical slot weirs (‘serpentine’ weirs) present an obstacle to upstream movement. Consequently, lamprey routinely aggregate in auxiliary water supply (AWS) channels, which are adjacent to the tops of these fishways (Moser et al. 2005).

Figure 1. Aerial photo showing configuration of Bonneville Dam with approximate location of fishways at: (a) Washington Shore, (b) Cascades Island, and (c) Bradford Island.

Lamprey enter AWS channels through connecting trash racks or via picketed leads downstream from fish count stations. Historically there has been no readily passable outlet from AWS channels to the dam forebay. Prior to LPS development, radiotelemetry studies indicated that lamprey resided in AWS channels for 4 d on average and then typically moved back downstream (Moser et al. 2005). Although the AWSs present a difficult passage area for lamprey, they provide "salmon-free" channels; locations where *in situ* experiments to develop lamprey passage can be conducted without affecting adult salmon passage (Moser et al. 2011).

The first LPS was installed in 2004 at the AWS channel near the top of the Bradford Island fishway (Figure 2). Lamprey entered the structure via one of two collector ramps and then passed through a series of wetted aluminum ramps, rest boxes, and horizontal flumes that led upward and to an exit slide at elevation 7.9 m. The overall

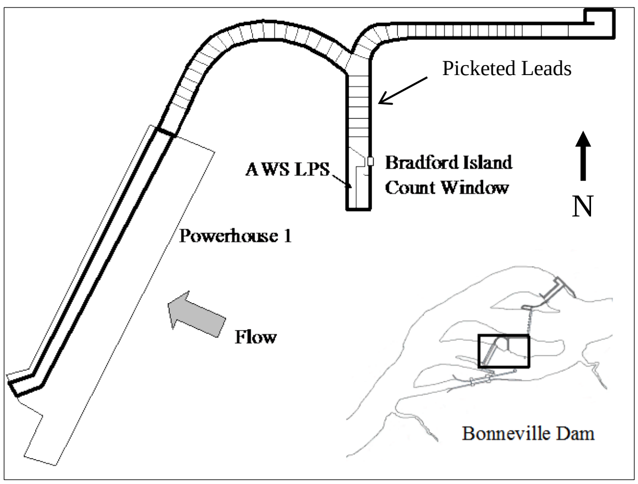

Figure 2. Schematic drawing of the Bradford Island fishway system at Bonneville Dam with locations of the auxiliary water supply LPS (AWS LPS) and count window.

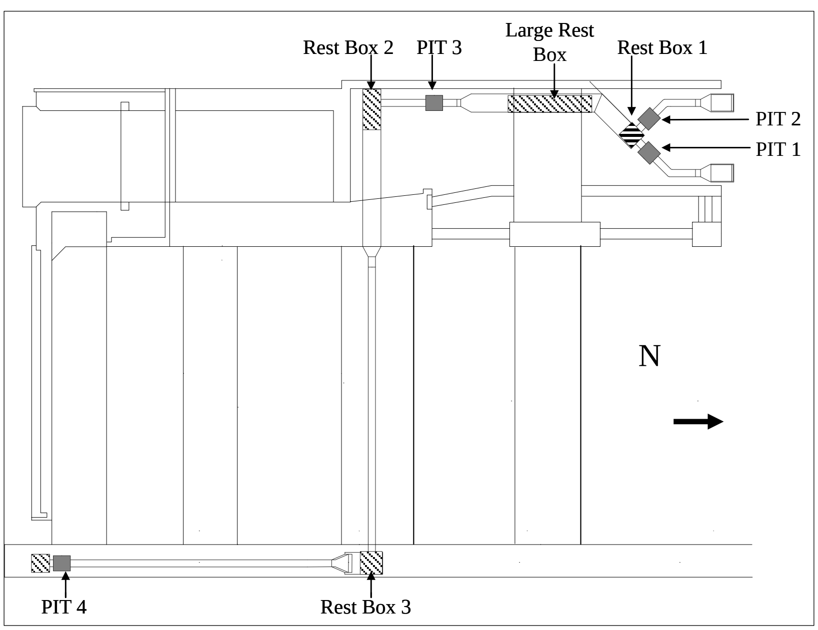

Figure 3. Top view of the Bradford Island LPS with locations of half-duplex PIT-tag detection antennas (PIT 1-4) and rest boxes indicated.

horizontal distance was 35.6 m (Figure 3). Lamprey exited from the LPS into the forebay of Powerhouse 1 immediately upstream from the Bradford Island fishway exit (Figure 2).

Columbia River water was supplied to the top of the Bradford Island LPS via a 10.2-cm-diameter PVC pipe fed by two 3-hp submersible pumps in the forebay. Flow was regulated by pumping water into an upwelling trap box at the top of the LPS. Pumps were operated to maintain a depth of 3 cm on the ramps and approximately 10 cm in the closed flumes. Lamprey actuated a limit switch as they exited the LPS into the forebay, and these exit data were used annually to evaluate lamprey use of the structure.

To monitor passage of PIT-tagged lamprey, the LPS was constructed with a series of four half-duplex PIT-tag detection antennas (Figure 3). Antennas were integrated into the LPS using a rectangular PVC sleeve, which prevented the aluminum from attenuating the PIT signal. Sleeves were inserted seamlessly into the chutes leading to Rest Boxes 1, 2, and 4. Each reader was comprised of a loop antenna of 10-gauge multistrand wire wrapped around the PVC insert, and each insert had an outer aluminum housing to shield the antenna. Each antenna was connected to a transceiver, which synchronized multiple antennas and recorded and transmitted the time and date of each detection.

We defined passage efficiency as the number of lamprey detected at the LPS exit divided by total number detected entering the LPS. From 2004 to 2008, passage efficiency of PIT-tagged lamprey was 90-100%, and their median passage time was less than 1 h (Moser et al. 2011). The success of the Bradford Island LPS prompted further development, and we installed an entrance collector at the Washington Shore fishway in 2005 to assess the collection potential of this location (Figure 4; Moser et al. 2008). We selected this location and installed a full LPS at the Washington Shore AWS channel in 2007 (Figure 5; Moser et al. 2011).

While the Washington Shore AWS LPS was in many respects similar to the Bradford Island LPS, it incorporated some unique features. Similar to the Bradford Island LPS, it was fabricated of aluminum, with 51-cm wide ramps that terminated in rest boxes. Rest boxes for both LPSs were fitted with a plastic mesh fyke, which allowed lamprey to exit only in an upstream direction, preventing them from moving back downstream.

However, due to the width of the fishway entrance ramps, fykes for this structure were wider than those at the Bradford Island LPS. Ramp grades in the Washington Shore and Bradford Island AWS LPSs were similar (45°), as were the water supply systems and lamprey counters at the exit slide. The Washington Shore LPS featured a “switchback” design (Figure 5) with broad crests at the top of each ramp to facilitate lamprey progress.

The overall length of the Washington Shore AWS LPS was approximately 19 m, with an elevation gain of 9.1 m (Figure 5).

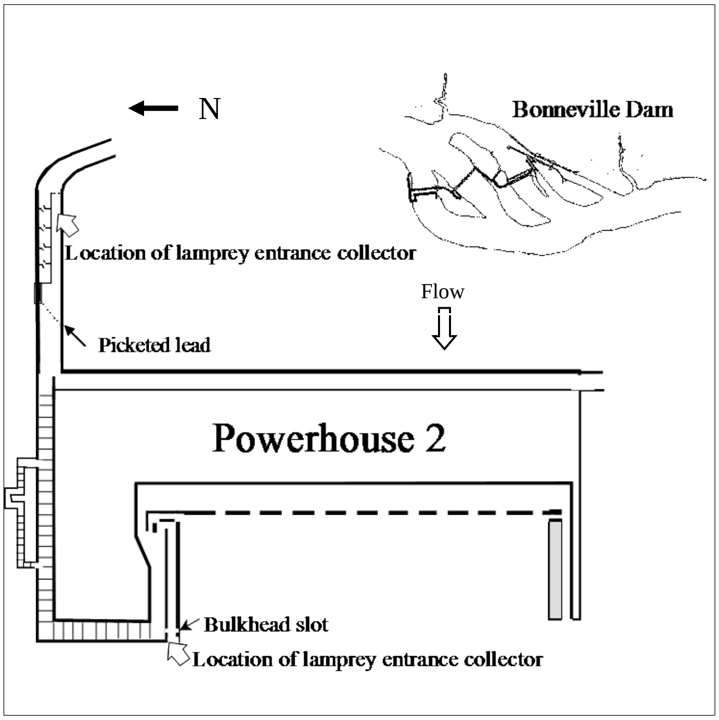

Figure 4. Plan view of Bonneville Powerhouse 2 showing location of lamprey structures at the Washington Shore fishway.

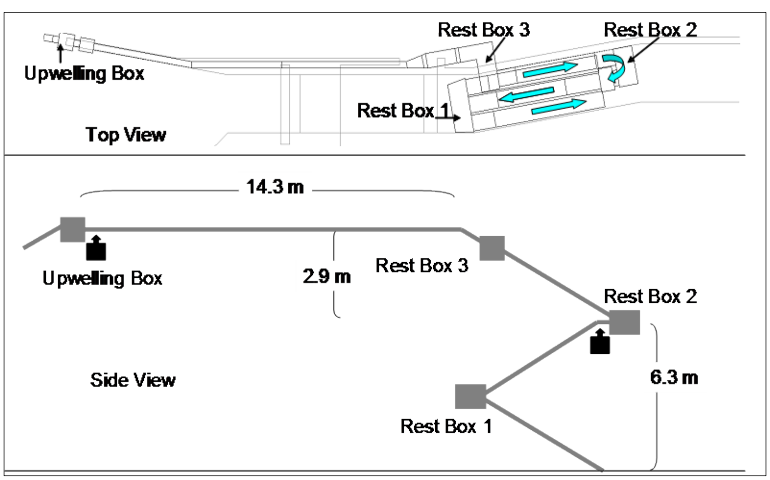

Figure 5. Upper panel shows plan view of the Washington Shore AWS LPS. Shaded arrows indicate the direction of water flow on the switchback ramps. Lower panel show side view of the same structure. Black boxes indicate the position of half-duplex PIT antennas.

While initial passage efficiency at the Washington-shore AWS LPS was 90-100%, it has dropped to 71-86% in recent years (Moser et al. 2012). Nevertheless, most lamprey that were able to pass through the structure did so quickly (median passage time < 0.5 h; Moser et al. 2012).

The greatest limitation to lamprey use of these structures was poor collection efficiency (Moser et al. 2011). Lamprey collection has been limited both by lamprey access to and retention in the AWS channels. To address this, some operational and structural modifications were implemented in 2011 and 2012. Lamprey access to the AWS channels was increased by slightly raising picketed leads at the AWS channel entrances (Figures 2 and 4).

Structural changes were also made at the Washington Shore fishway in 2011 and 2012 to improve lamprey access to the AWS channel. Pickets that help prevent lamprey from entering the areas behind the count station were narrowed to force more lamprey to use the AWS channel. Simultaneously, a ramp was installed along the base of the picketed lead to bridge the channel lip and improve lamprey guidance under the leads and into the channel. To improve lamprey retention in the channel, two refuges were installed to provide dark and calm holding areas during the day.

A third LPS was installed in 2009 at the Cascades Island fishway entrance (Figure 6). This ambitious structure allowed lamprey to ascend from the tailrace level to an elevation of 27 m (the full height of the dam). It incorporated many of the design features from the AWS structures, but was much longer (92.4 m; Figure 6).

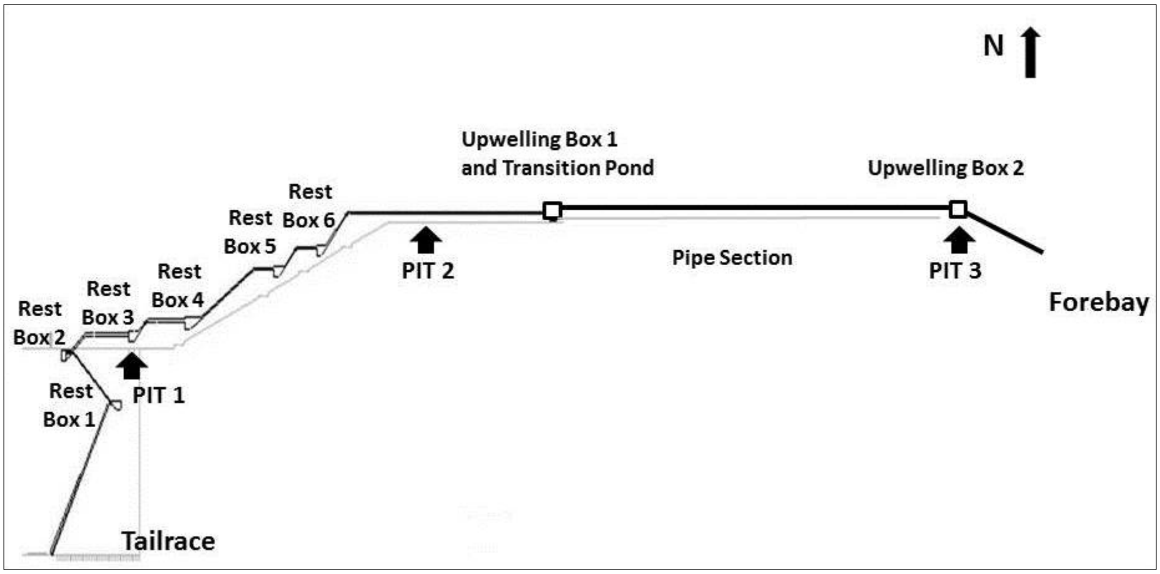

Figure 6. The Cascades Island entrance LPS collector in 2014 (side view), showing locations of rest boxes, the upwelling box and transition pond, and PIT monitoring antennas.

At Cascades Island, Rest Boxes 1 and 2 could not be accessed from the deck and were fitted with remotely operated valves to de-water them. Otherwise, the original ramps and rest boxes were similar to those at the Washington Shore AWS LPS, with 0.51-m wide ramps emptying into the rest boxes through plastic mesh cones (Moser et al. 2012). The Cascades Island LPS was fitted with two HD-PIT antennas to monitor passage of PIT-tagged lamprey (Figure 6).

Modifications for the 2014 Lamprey Migration Season

In 2014, the picketed leads at the Washington Shore and Bradford Island AWS channels were raised to 3.8 and 2.5 cm above the fishway floor, respectively, for the entire season. As in 2013, two lamprey refuges were operated downstream from the Washington Shore AWS channel near its confluence with the upstream migrant tunnel (UMT). Two additional refuges were operated in the AWS channel downstream from the LPS entrance (Corbett et al. 2014).

Unfortunately, at the two refuges downstream from the LPS entrance, PIT monitoring was precluded by problems with the power supply in this area. Previous years of operation indicated high lamprey use of refuge areas and an improvement in lamprey access to the AWS channels when picketed leads were raised (Moser et al. 2012; Corbett et al. 2013). Monitoring of PIT-tagged fish that used the AWS LPSs and/or refuges allowed evaluation of their efficacy.

Modifications to the Bradford Island AWS LPS in 2014 included the installation of a redesigned exit slide to improve lamprey exit behavior and count system functionality. Additionally, a ramp was installed at the sill downstream from AWS picket leads to improve access to the LPS. A new picketed lead with reduced spacing was also installed to exclude lamprey from the area behind the count station crowder.

Modifications to the Washington Shore AWS LPS in 2014 included the installation of a redesigned exit slide to improve lamprey exit behavior and count-system functionality. Additionally, as an alternative to the mechanical lamprey-activated counters used in recent years, an electrical impedance counter (Smith-Root, SR-1100 Fish Counter) was simultaneously used on an experimental basis at this LPS exit.

In past years, adult lamprey have been detected and observed accumulating in the Cascades Island makeup water supply channel, a structure that has no direct access to the forebay. Lamprey trap-and-haul operations at this location were successful in 2012 and 2013 (Corbett et al. 2013, 2014), and likely contributed to the migration success of lamprey that otherwise would have been blocked from or delayed in movements upstream. Therefore, in 2014 we allocated significant time and resources to continue trap-and-haul operations in the Cascades Island makeup water channel.

In 2013, we monitored a newly installed lamprey trap at the John Day Dam south fishway. The trap is operated in the AWS channel adjacent to the count station for periodic collection of lamprey by tribal groups. The trap operates in two modes: one in which lampreys enter and are collected, and one in which lamprey enter and are able to pass through and continue upstream. The trap is deployed and recovered via a jib crane, and collected lamprey are moved directly, either to a tank truck or to an on-site holding tank for transport at a later time.

This collection structure provides a passage point at which lamprey can be enumerated. In 2014, we applied methods that were developed and refined in 2013 to monitor lamprey passage at the John Day south fishway trap. Monitoring was initiated to produce a more reliable estimate of lamprey passage at this site, particularly when operated in pass-through mode.

In addition to being designed for lamprey, lamprey-specific passage structures must not impact co-occurring species in fishways (primarily salmonids). In 2014, we designed an experimental wetted wall climbing structure intended to collect and pass lamprey without impacting migrating salmonids. To test Pacific lamprey vertical climbing ability in relation to flow, the apparatus was outfitted with three regulated water delivery mechanisms and installed in an experimental raceway.

Experimental lamprey were introduced to the raceway, and their passage success and behaviors were documented via video and direct observation. Lamprey climbing success from these trials showed that a vertical wetted wall could be a useful addition to existing structures or provide future aids to Pacific lamprey passage. Wetted walls could be used to collect lamprey and direct them into alternative routes, to provide passage over small barriers, or to provide access to larger lamprey passage systems in locations with structural or space constraints.

2014 Study Objectives

Our objectives in 2014 were to:

1) Determine lamprey use of Bonneville Dam lamprey passage structures (LPSs) located at the auxiliary water supply (AWS) channels.
2) Assess the effects of providing refuge areas at AWS channels and fishways.
3) Examine lamprey use of the Bonneville Dam LPS located at the Cascades Island fishway entrance.
4) Develop methods to collect lamprey from the make up water supply (MUWS) channel at Cascades Island.
5) Develop methods to enumerate lamprey entering a newly installed trap at the south fishway of John Day Dam.
6) Design, build, and test lamprey use of an experimental wetted wall at Bonneville Dam.

To achieve the monitoring objectives, we used two approaches. First, we assessed LPS use based on estimates from lamprey-activated counters at the Washington Shore, Bradford Island and Cascades Island LPS exit slides. We also monitored lamprey passage at the John Day south fishway lamprey trap using an underwater camera to augment tribal lamprey collection records at the trap.

Second, we tagged adult Pacific lamprey with passive integrated transponder (PIT) tags, released them downstream from Bonneville Dam, and recorded passage events using PIT-tag antennas installed at the LPS exits, at other locations within the LPSs, and at other locations within the fishways. We calculated LPS collection efficiency, passage efficiency, and lamprey passage rate at each structure using detections of PIT-tagged lamprey. PIT detections were also used to evaluate lamprey use of the Bonneville refuges and the trap at John Day Dam.

Third, we designed and constructed a prototype wetted wall and tested its functionality using lamprey collected at Bonneville Dam.

OBJECTIVE 1: Determine use of lamprey passage structures at Bonneville Dam auxiliary water supply channels

Evaluations Based on Passage Estimates and Video Imagery

Methods

Modifications to the Bradford Island AWS (BI) LPS in 2014 included installation of a redesigned exit slide to improve lamprey exit behavior and count-system functionality (Figure 7). Additionally, a ramp was installed at the sill downstream from the AWS picket leads to improve access to the LPS (Figure 8). A new picketed lead with reduced spacing was also installed to exclude lamprey from the area behind the count-station crowder (Figure 8).

Physical and video validations have shown that systems that record lamprey passage at LPS exits are occasionally subject to double counting, particularly at the Washington Shore LPS (Corbett et al. 2014). As an alternative to the mechanical, lamprey-activated counters currently in use, we employed an electrical impedance counter (Smith Root SR 1100) on an experimental basis during 2014. This technology measures changes in water conductivity created by a passing fish and counts these changes as passage events (Liscom and Volz, 1975).

Modifications to the Washington Shore AWS (WA) LPS in 2014 included installation of a redesigned exit slide to improve lamprey exit behavior and count system functionality (Figure 9). An electrical impedance counter (Smith-Root, SR-1100 Fish Counter) was also used on an experimental basis at this LPS exit (Figure 10). Prior to the migration season, two impedance detection coils were built into the base of the Washington Shore AWS LPS exit slide (Figure 10) and connected to the impedance counter.

Impedance counter trials were conducted over one day during afternoon hours to limit interference with volitional LPS passage. For these trials, lamprey were captured at Washington-shore fishway traps and transported to the Washington-shore AWS LPS exit. Lamprey were individually introduced to the Washington-shore AWS LPS at the farthest-upstream upwelling box, which enters the exit slide.

Study fish were observed as they descended the LPS exit slide and were recaptured before they entered the fishway. We noted whether or not each individual lamprey was detected by the counter as it passed over the impedance coils. During these trials, a Smith-Root engineer was on site to make adjustments to the equipment to enhance performance. Immediately following the trials, all study fish were released upstream from Bonneville Dam at the Stevenson Boat Ramp, Stevenson, WA.

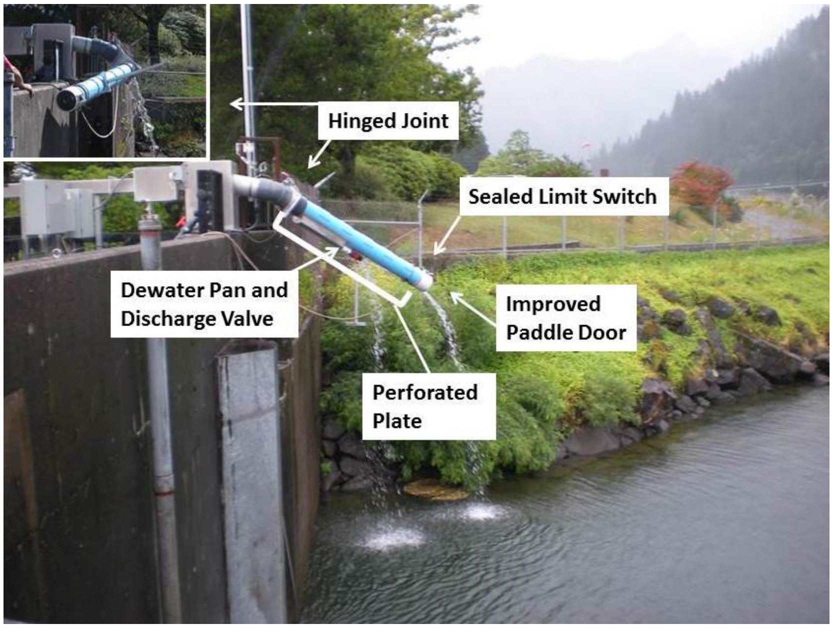

Figure 7. Photograph of redesigned exit slide at Bradford Island AWS LPS with features labeled.

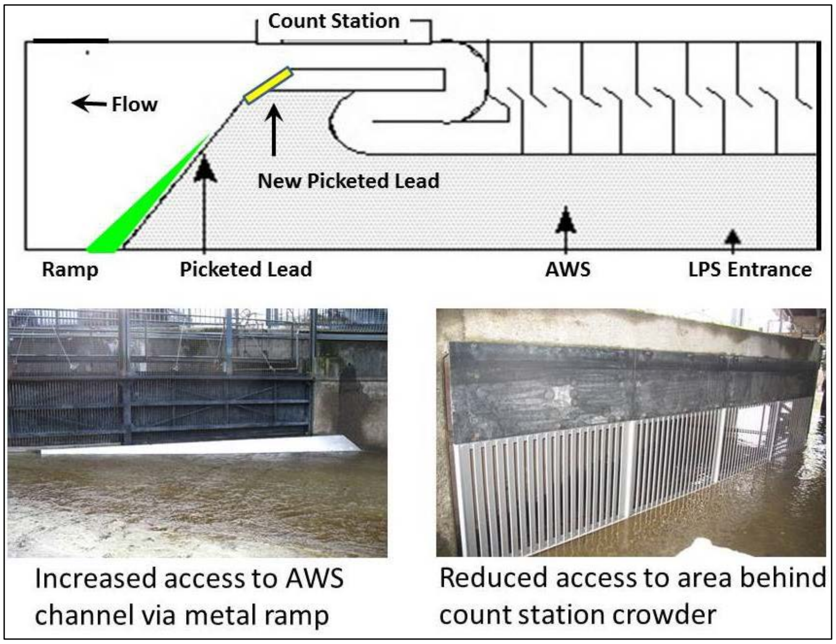

Figure 8. Upper panel diagram shows location of newly installed ramp and picketed lead at Bradford Island fishway. Lower panel photos (L-R) show ramp and picketed lead.

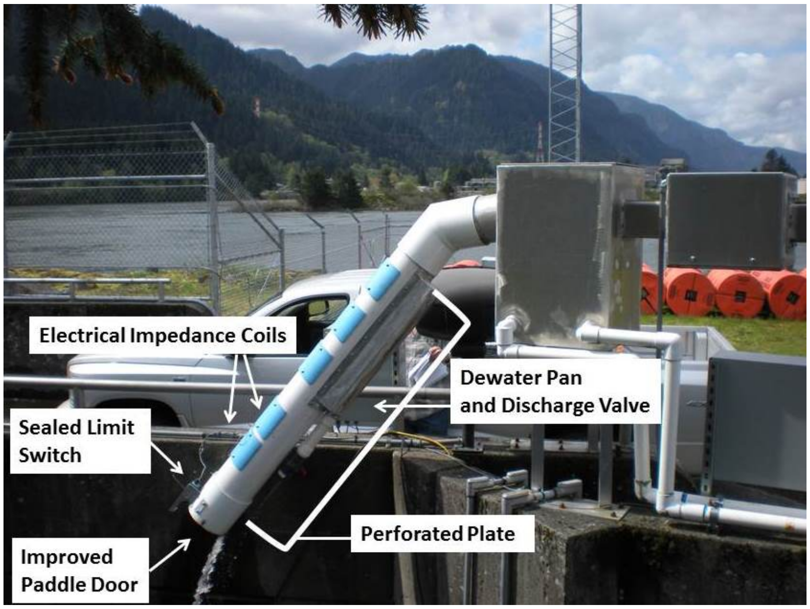

Figure 9. Photograph of redesigned exit slide at Washington Shore AWS LPS with features labeled.

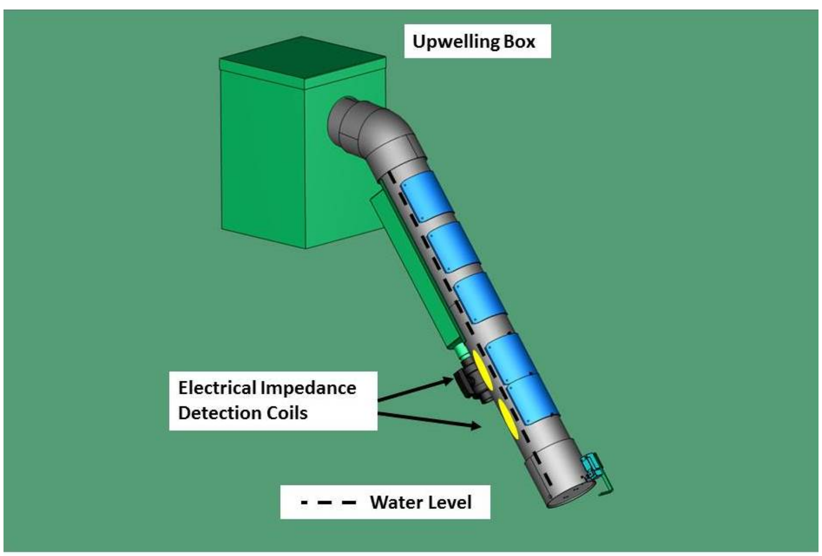

Figure 10. Diagram of exit slide at Washington Shore AWS LPS showing the upwelling box where lamprey were introduced, electrical impedance detection coils, and water level in the exit slide.

Results

In 2014, The Bradford Island LPS was operated between 23 April and 20 October, and passage events were estimated from 8 May to 20 October. The Washington Shore LPS was operated between 1 April and 29 October, and passage events were estimated from 8 May to 29 October. There were gaps in the Washington Shore LPS count record on 22 and 23 July due to exit-slide modifications and on 7 and 8 September due to internal battery failure.

Video recording data obtained from the USACE Fisheries Field Unit suggested that lamprey counts at both the Washington Shore and Bradford Island AWS LPSs were overestimates for at least some of the season. These overestimates were caused by lamprey that attached at the exit door and activated the counter limit switch more than once during a passage event. To account for periods of possible overcounting, Fisheries Field Unit personnel applied a correction factor to the Bradford Island and Washington Shore LPS counts, which adjusted passage estimates for all dates of operation (N. Zorich, personal communication).

At the Bradford Island AWS LPS, the total lamprey count was 24,188, and the adjusted count was 18,487 (Figure 11) in 2014. At the Washington Shore AWS LPS, the total lamprey count was 37,617 and the adjusted count was 29,765 (Figure 12).

We evaluated the efficacy of modifications made in 2014 by comparing both inter- and intra-annual estimated collection efficiencies at both AWS LPSs. Interannual collection efficiency was estimated by first estimating total lamprey abundance at the top of each ladder. This estimate was calculated by tripling the count station counts at each ladder in each year. The AWS LPS count was then divided by the total lamprey abundance estimate to calculate collection efficiency (Table 1). These were conservative estimates based on extrapolation of daytime counts: approximately two-thirds of migrating lamprey typically pass count stations at night (Moser and Close 2003).

This method by no means provided an exact measure of abundance, and it did augment the known variance originating from window counts (Clabough et al. 2012). However, it provided a standard means of comparing annual numbers, including early study years. Nighttime video counts of lamprey have been conducted at Bonneville Dam by the U.S. Army Corps of Engineers since 2009. However, these counts are conducted only from 15 June to 30 September each year; they do not encompass the entirety of the lamprey migration.

Bradford Island Fishway

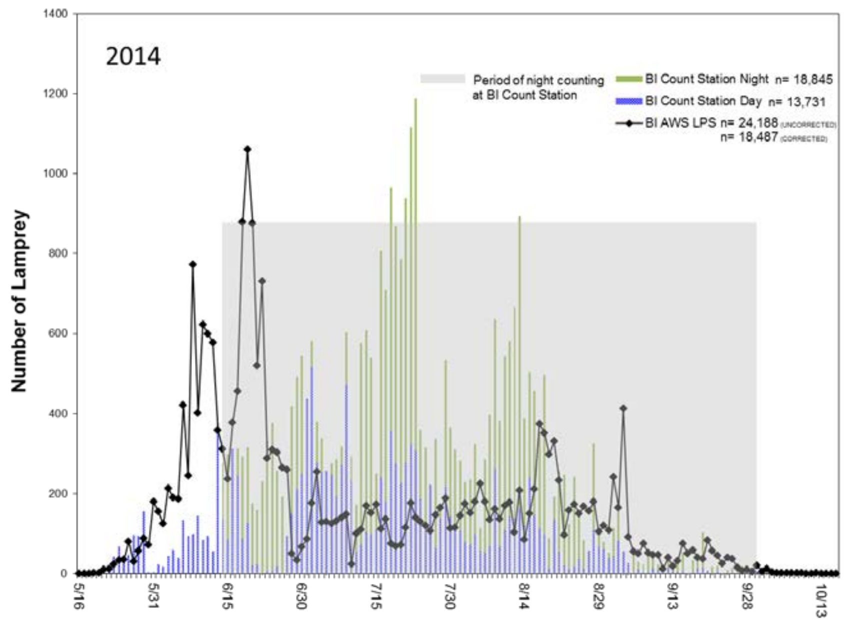

Figure 11. Number of lamprey counted at the Bradford Island count station during the day (blue) and night (green) and at the AWS LPS exit slide (closed diamonds) during the periods of LPS operation in 2014. Total values reported for the count station and LPS.

Washington Shore Fishway

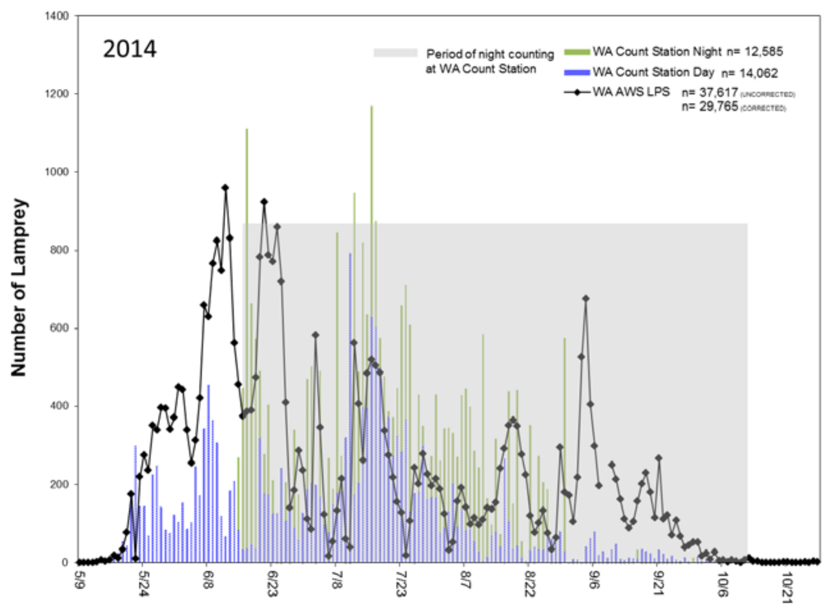

Figure 12. Number of lamprey counted at the Washington Shore count station during the day (blue) and night (green) and at the AWS LPS exit (closed diamonds) during periods of LPS operation in 2014. Total values reported for the count station and LPS.

Table 1. Results from LPS counts and collection efficiency calculations ((LPS count/(daytime window count × 3)) × 100) as reported at each structure, 2007-2014. In-season collection efficiency values are also given for 2011 when pickets were raised (1-29 June) and when they were lowered to prevent salmonids from entering (1-30 July). Counts include only days when LPS counters were operational (i.e., outage days are not included). Adjusted counts are shown for the Washington Shore AWS LPS in 2013 and 2014 and for the Bradford Island AWS LPS in 2014.

	Bradford Island		Washington Shore	
	LPS count (n)	Collection efficiency (%)	LPS count (n)	Collection efficiency (%)
2004	7,490	21		
2005	9,242	30		
2006	14,975	34		
2007	7,387	38	2,517	11
2008	6,441	40	1,985	12
2009	3,302	50	1,199	10
2010	1,933	39	2,961	29
2011	7,476	34	6,345	26
1-29 Jun 2011	241	30	934	41
1-30 Jul 2011	3,160	32	1,707	16
2012	4,392	18	5,686	12
2013	13,066	44	18,329	48
2014	18,487	45	29,765	71

Figures 11 and 12 include count station counts at each ladder, but we focus on the extrapolated counts in these analyses to maintain continuity across study years and to cover the entire migration season. In 2014, adjusted counts were used for estimates of collection efficiency at both the Bradford Island and Washington Shore LPSs. These estimates indicated that overall collection efficiency was 45% at the Bradford Island and 71% at the Washington Shore AWS LPS (Table 1).

Of the experimental lamprey introduced to the upwelling box leading to the Washington Shore AWS LPS exit slide, 70% were not recorded passing by the impedance counter as they exited. We observed that non-detected lamprey failed to contact the electrodes due to swimming behavior and the steep slope of the exit slide.

Evaluations Based on Monitoring of Tagged Lamprey

Methods

Lamprey were collected for tagging at the Bonneville Dam Adult Fish Facility and from the Cascades Island AWS channel. We deployed one portable trap and two fixed traps at weirs in the adult facility fishway; all traps were set each night from approximately 2100 to 0700 PST. Each morning, trapped lamprey were transferred to a holding tank with running Columbia River water.

After anaesthetizing lamprey using 60-ppm eugenol, we measured each fish for weight (nearest g), total length (nearest 0.5 cm), and girth (nearest 0.1 cm) at the insertion of the anterior dorsal fin (nearest mm). For fish tagged with only a PIT tag, we made a 4-mm incision just off the ventral midline at a location even with the insertion of the anterior dorsal fin. A disinfected half-duplex (HD) PIT tag (3 × 32 mm) was inserted into the body cavity. Fish were allowed to recover for at least 6 h and released in the evening.

For lamprey implanted with both a PIT and radio tag, we followed the method of Keefer et al. (2014). For these double-tagged fish, a larger incision was made, and the PIT tag was inserted first. These fish were also allowed to recover for at least 6 h and then released in the evening.

For lamprey with a PIT-tag only, downstream releases were approximately 3 km below Bonneville Dam at the Hamilton Island boat ramp, while upstream releases were made at the Stevenson boat ramp (rkm 235.1). Double-tagged lamprey were released downstream from the dam at both the Hamilton Island boat ramp and at Tanner Creek.

Results

In 2014, 898 lamprey were tagged with only a PIT tag. Of these, 599 were released downstream and 299 released upstream from Bonneville Dam (Table 2). These fish were tagged between 15 May and 23 September 2014 (mean date 2 July), but the upstream release group was tagged only during the first half of the run. Mean length of PIT-only lamprey was 67.0 cm (range 39.5-81.5 cm).

An additional 599 lamprey were tagged with both a PIT tag and radio transmitter (Keefer et al. *in review*). All 599 were released downstream from Bonneville Dam (Table 2). These fish were tagged between 23 May and 12 September 2014 (mean date 5 July), and their mean length was 67.5 cm (range 53.0-79.0cm).

Table 2. Number of lamprey tagged in 2014 with only a PIT tag, or with a PIT tag and radio transmitter, and their release locations relative to Bonneville Dam.

Tag treatment and release location relative to Bonneville Dam	Number released (n)
PIT-only	
Released downstream	599
Released to LPS	0
Released upstream	299
PIT + radio tag	
Released downstream	599
Released to LPS	0
Released upstream	0
Total PIT tagged	1,497

Bradford Island—Of the 599 PIT-only fish released below Bonneville Dam, 24 (4%) were detected at the Bradford Island AWS LPS. Similarly, 15 (3%) of the 599 double-tagged fish released below the dam were detected at this structure (Table 3). These percentages were similar even though double-tagged fish were released at both Hamilton Island and Tanner Creek, while PIT-only lamprey were released only at the Hamilton Island boat ramp. One fish double-tagged in 2013 (PIT + JSATS transmitter) was detected in this structure in 2014. A total of 5.6% of all fish detected at Bonneville Dam (n = 699) used this LPS (Table 4).

In 2014, 39 of the 39 PIT tagged fish detected at the top of a Bradford Island LPS collector ramp were subsequently detected at the exit slide (i.e., passage efficiency through the Bradford Island AWS LPS was 100%). Similarly, in 2012 and 2013, most fish detected in the Bradford Island AWS LPS were detected at the exit slide (i.e., passage efficiency was 98% in both years).

In 2014, for all PIT-tagged fish, median passage time from a Bradford Island collector to the exit slide was 0.69 h (range 0.42-1.53 h). Median passage time from a collector to the exit slide was 0.69 h (range 0.42-1.53 h) for PIT-only fish and 0.73 h (range 0.47-1.29 h) for double-tagged fish. Some PIT-tagged fish were detected using the Bradford Island fishway exit, either in addition to or instead of the LPS.

Table 3. Number of PIT-tagged fish detected in the LPSs in the Bradford Island and Washington Shore auxiliary water supply (AWS) channels in 2007-2014. Values as a percentage of all PIT-tagged fish released downstream from Bonneville Dam are given in parenthesis. Note that PIT-only fish were released at the Hamilton Island boat ramp, while double-tagged fish were released at both Hamilton Island and Tanner Creek.

	Tagged lamprey detected in an LPS after release							
	Bradford Island AWS				Washington Shore AWS			
	PIT only		PIT + JSATS/radio		PIT only		PIT + JSATS/radio	
	n	(%)	n	(%)	n	(%)	n	(%)
2007	31	4	--	--	26	3	--	--
2008	55	9	14	5	16	3	0	0
2009	26	7	10	3	10	3	5	2
2010	0	0	10	3	5	38	17	5
2011	60	8	0	0	59	7	3	13
2012	40	5	5	3	56	7	6	4
2013	35	4	8	4	199	23	28	14
2014	24	4	15	3	134	22	61	10

Table 4. Number of PIT-tagged lamprey released downstream from Bonneville Dam and subsequently detected at a Bonneville Dam LPS in 2014.

	Detections of tagged lamprey				Percent of total
Detection location (LPS)	PIT only (n)	Double tag (n)	Total (n)	Total detected at a Bonneville LPS (n = 699) (%)	released below Bonneville (n = 1,198) (%)
Bradford Island AWS	24	15	38	5.6	3.3
Washington Shore AWS	134	61	195	27.9	16.3
Cascades Island	6	1	7	1.0	0.6

In 2014, 78 PIT-tagged fish (7% of those released downstream) were detected at the fishway exit but not detected in the Bradford Island LPS. Of the 39 fish that were detected in this LPS during 2014, 4 (10%) were subsequently detected after having fallen back into the fishway exit; all four were subsequently detected at upstream dams. In comparison, 66 PIT-tagged fish (6% of those released downstream) were detected at the fishway exit but not detected in the LPS in 2013. Of the 43 fish detected in the LPS during 2013, 6 (12%) were subsequently detected at the fishway exit; none of these fish were detected at upstream dams.

Some lamprey that exited the Bradford Island LPS or fishway were later detected upstream. In 2014, 18 (45%) of the fish that used the Bradford Island LPS were detected at upstream sites. This proportion was similar to those observed in 2013 (49%) and 2012 (58%). In 2014, 40 (51%) of the fish detected exiting the Bradford Island fishway without using the LPS were detected at upstream sites. In previous years, the percentages detected at upstream sites were 80% in 2009, 57% in 2010, 74% in 2011, 72% in 2012, and 73% in 2013.

Washington Shore—Of the 599 PIT-only fish released downstream from Bonneville Dam, 134 (22%) were detected at the Washington Shore LPS. Of the 599 double-tagged fish released below the dam, 61 (10%) were detected using this structure in 2014 (Table 3). Eight lamprey tagged in 2013 (5 PIT-only and 3 double-tag) were detected at the Washington Shore AWS LPS in 2014.

At the Washington Shore LPS, no lamprey were detected only on the upper PIT antenna (i.e., were missed by the lower antenna). Therefore, detection efficiency of the lower antenna was 100% in 2014 (Figure 5). Of the 134 PIT-only lamprey known to have entered this LPS, 14 were not detected on the upper antenna near the exit slide. Thus, the minimum estimate of LPS passage efficiency was 90% (120/134). Passage efficiency was 93% (57/61) for the double-tagged fish. Median travel time from the first antenna to the exit slide was 0.5 h (range 0.24-2.64 h) for PIT-only fish and 0.47 h (range 0.24-2.72 h) for double-tagged fish.

The Washington Shore LPS empties into the Washington Shore fishway downstream from the fishway exit. In 2014, 130 PIT-tagged fish that had not been detected in the LPS were detected at the Washington Shore fishway exit. Of the 195 fish that used the LPS in 2014, 117 (60%) were detected as they migrated upstream and passed through the fishway exit; of the remaining 78 fish, 39 were detected at upstream dams, indicating low detection efficiency at the Washington Shore fishway exit antenna.

After passing Bonneville Dam, many PIT-tagged lamprey were detected upstream. In 2014, 90 of 195 (46%) fish that used the Washington Shore LPS were detected at upstream sites, while 75 of 130 (58%) fish detected using only the traditional fishway exit were detected at upstream sites (Table 5).

Table 5. Number and proportion of PIT-only and double-tagged lamprey released downstream from Bonneville Dam, detected at the Washington Shore AWS LPS, and subsequently detected at sites upstream from the dam, 2007-2014. Also shown are upstream detections of fish that did not use the LPS. Note PIT-only fish were released at Hamilton Island, while double-tagged fish were released at both Hamilton Island and Tanner Creek.

	Number detected at Washington Shore AWS LPS				Detected upstream from Bonneville Dam			
	PIT-only		Double-tagged (PIT + JSATS/radio)		After exiting Washington Shore LPS		Exited Washington Shore without using LPS	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
2007	26	3	--	--	--	--	--	--
2008	16	3	0	0	--	--	--	--
2009	10	3	5	2	3	20	53	41
2010	5	38	17	5	7	32	17	30
2011	59	7	3	13	27	44	85	63
2012	56	7	6	4	22	35	84	60
2013	199	23	28	14	139	61	81	66
2014	134	22	61	10	90	46	75	58

Cascades Island—Of the 1,198 total fish PIT-tagged and released downstream from Bonneville Dam, 62 (5%) were detected at the entrance to the Cascades Island makeup water supply channel. These included 45 of the 599 PIT-only fish (8%) and 17 of the 599 double-tagged fish (3%; Table 6). One PIT-only fish tagged in 2013 was detected at the makeup water channel in 2014. Of the 62 lamprey detected at the Cascades Island flow-control area, 22 (35%) were subsequently detected at upriver sites (Table 6).

Of the 62 PIT-tagged lamprey detected at the entrance to the Cascades Island makeup water channel, some were subsequently detected at other Bonneville Dam structures. For example, 22 of these 62 fish (35%) were detected exiting the Washington-shore LPS and/or fishway; 2 (3%) were detected at the Washington-shore LPS, but not exiting; 1 (2%) was detected exiting the Bradford Island fishway; and 1

(2%) was detected exiting the Cascades Island LPS. Four (7%) were subsequently detected at an upstream location, indicating that they passed Bonneville Dam without detection at LPS or top-of-ladder sites.

Of the 599 PIT-only lamprey released below Bonneville Dam, 3 (1%) were recaptured in makeup water supply traps at Cascades Island subsequent to being detected at the antenna downstream. This is likely an underestimate since not every lamprey captured in a makeup water supply trap was scanned for a PIT tag. For these 3 lamprey, time from detection to recapture at a trap upstream lamprey was 1.8, 992.8 and 1,234.2 h, indicating that lamprey can occupy this area for extended periods.

Table 6. Number of PIT-only and double-tagged lamprey released below Bonneville Dam and subsequently detected at the Cascades Island make up water supply channel and at sites upstream from Bonneville Dam, 2007-2014. Note that PIT-only fish were released at Hamilton Island, while double-tagged fish were released at both Hamilton Island and Tanner Creek.

	Detected at Cascades Island makeup water supply channel						Subsequently detected upstream	
	PIT-only		Double-tagged (PIT + JSATS/radio)		PIT-only and double-tagged		PIT-only and double-tagged	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
2007	64	8	NA	NA	64	8	23	36
2008	51	8	8	3	59	6	19	32
2009	27	7	10	3	37	6	6	16
2010	0	0	7	2	7	2	1	14
2011	61	8	1	4	62	8	23	37
2012	85	10	11	7	96	10	37	39
2013	72	8	9	5	81	8	30	37
2014	45	8	17	3	62	5	22	35

Discussion

In 2014, lamprey counts at Bonneville Dam were the highest since 2006 (CBR 2015), and numbers of lamprey passing via each of the three LPS structures were the highest since they were installed. Counts indicated that LPSs were used most frequently (as a proportion of the season total) early and late in the migration season. This suggests that either the structures do not have sufficient capacity to accommodate large numbers of lamprey or the passage count is underestimated during the peak lamprey run.

For lamprey PIT tagged and released downstream from Bonneville Dam, similar percentages were detected at each Bonneville Dam LPS in 2013 and 2014 (Corbett et al. 2014). As in 2013, LPS collection efficiencies were high: collection efficiency in 2014 was amongst the highest observed at the Bradford Island LPS and by far the highest recorded at the Washington Shore LPS. Given the abundant lamprey run, LPSs passed far more lamprey than in previous years. The Washington Shore LPS saw proportionally more use by tagged fish than the Bradford Island LPS, though overall use by lamprey was 32% higher in the Washington Shore fishway than in the Bradford Island fishway based on window counts, explaining a portion of this difference.

Almost half of the PIT-tagged lamprey that used an LPS were subsequently detected upstream from Bonneville Dam (45% of Bradford Island fish and 46% of Washington Shore fish). Hence, lamprey using both of these LPS structures showed similar migration success to upstream sites. In contrast, 58% of lamprey detected at the top of the Washington Shore fishway that had not used an LPS were detected upstream. Lopez-Johnston (2014) reported that upstream migration of radio-tagged lamprey was not negatively affected by LPS use. However, that study also reported a diminished rate of PIT detection for lamprey that had used the LPS as they moved farther upstream in the Columbia Basin.

It is possible that LPS users represent fish that are less successful in traditional fishways, and therefore have lower passage success at fishways upstream from Bonneville Dam. For example, lamprey detected at the Cascades Island makeup water supply antenna provide an additional comparison. These fish represent a subset of the PIT-tagged lamprey that may be detected passing upstream. Because they are detected lower in the fishway system, the percentage that reach sites upstream from Bonneville Dam (35%) is lower than that of both LPS users and fish detected at traditional fishway exits. Regardless, results at all three locations indicate that LPS routes pass a portion of the population not passing the serpentine weirs. These passage routes can potentially increase the diversity of traits (size, motivation, etc.) for lamprey spawning in tributaries above the dam.

We strive to provide accurate in-season estimates of lamprey passage each year, making modifications to improve accuracy and availability of count information (Moser et al. 2012; Corbett et al. 2013, 2014). While improvements have been made, several factors have negatively affected the precision of lamprey count information. Each exit slide has been lined with rolled plastic or aluminum perforated plate, as these materials hinder the ability of lamprey to attach by oral disc to LPS surfaces. As evidenced by video validations in 2014, gaps in coverage of the perforated plate have provided areas for lamprey to attach and thereby affect the accuracy of passage estimates.

Unfortunately, due to the design of LPS exit slides, these gaps were located in close upstream proximity to the count paddle. Some lamprey were able to attach upstream from the count paddle while 50-70% of its body passed under the paddle. In subsequent attempts to back-climb, the count paddle was lifted and the limit switch engaged multiple times. This behavior created multiple counts for a single lamprey passage event. The PVC coupling at the terminus of the exit slide allows mounting of the count paddle system. This area was not lined with perforated plate in 2014, and it provided an ~8-inch smooth surface where lamprey could attach (Figure 13). These areas should be lined with perforated plate to improve LPS passage estimation accuracy.

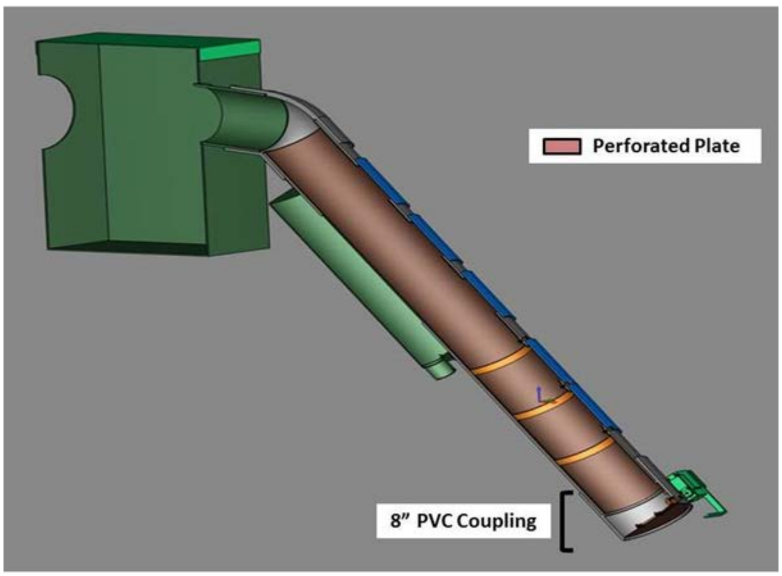

Figure 13. Cross section drawing of Bradford Island AWS LPS and Washington Shore AWS exit slides showing area that is lined with perforated plate and location of PVC coupling.

During our test of the impedance counter, only 30% of experimental lamprey were detected, and the impedance counter was deemed an ineffective method to estimate LPS passage. To improve detection efficiency of the impedance counting system, the engineer on site for the trials recommended: 1) modifying the counter with a new auto balance switch, 2) redesigning the counter output circuit specific to the lamprey swimming style, 3) reducing the angle of the exit slide, and 4) increasing the volume of water that flows out of the exit slide.

A significant problem was that over 50% of the lamprey body length was above the water level as they passed over one or both of the detection coils. As a result, lamprey did not create a large enough change in conductivity to be detected by the impedance counter.

The slope of the exit slide at Washington Shore is roughly 51 degrees and is the steepest of any LPS exit slide at Bonneville Dam. Although tests showed that the impedance counter is unusable at Washington-shore AWS LPS in its current configuration, it is possible that such a counter could be used at a different LPS exit slide with slope that is positioned at a lesser angle. To further assess this method of counting, continued testing with an experimental LPS exit slide would be necessary. Such an experimental exit slide would need to be equipped with variable slope settings as well as modifications to the counting equipment.

The Cascades Island makeup water supply channel is a known dead-end for migrating lamprey. Many fish detected at the downstream end of the channel subsequently passed the dam by other routes. However, scanning of lamprey obtained in salvage trapping efforts revealed that residence times could be quite long (>51 days) in the makeup water supply channel. Effort should be made to reduce lamprey entry into and/or residence in this area.

OBJECTIVE 2: Assess the effects of providing refuge areas in auxiliary water supply channels and fishways

Introduction

Research has shown that lamprey species seek refuge from light during daylight hours (Binder and McDonald 2007). Results from radiotelemetry studies indicate that upstream-migrating lamprey fall back downstream through AWS channels and fishways at Bonneville Dam, and that fallbacks in this area rarely are followed by reascensions (Keefer et al. 2013). In an effort to retain lamprey in the AWS channel and Washington Shore fishway during daylight, we designed and installed refuges that provide low-light areas where lamprey could hold.

Design and Installation of Refuges

Lamprey refuges were constructed of aluminum (Figure 14) and positioned on the fishway bottom and along fishway walls to allow ease of access. As in previous years, two lamprey refuges were positioned along the north and south walls of the Washington Shore AWS channel upstream from the picketed lead (Figure 15). Both of these refuges were operated throughout the 2014 lamprey migration period.

Prior to the 2013 migration period, two additional refuges were installed in the Washington Shore fishway downstream from the AWS channel. These refuges were positioned along the north and south walls of the fishway below its junction with the upstream migrant tunnel (Figure 16; Corbett et al. 2014). A PIT antenna was integrated into each refuge to allow detection of tagged lamprey (Figure 17).

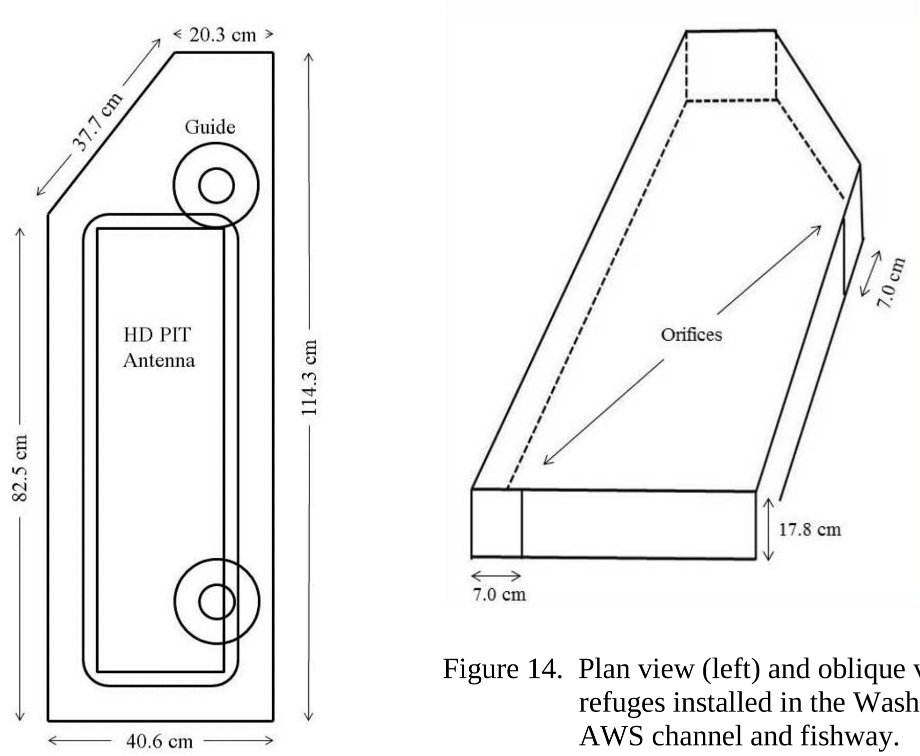

Figure 14. Plan view (left) and oblique view (above) of refuges installed in the Washington Shore AWS channel and fishway.

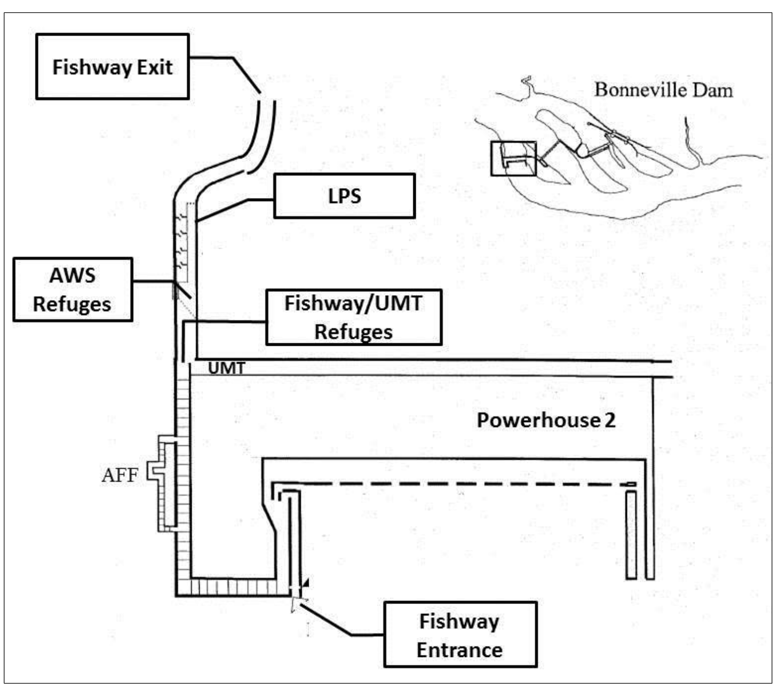

Figure 15. Location of refuges in the Washington Shore AWS channel and fishway at Bonneville Dam.

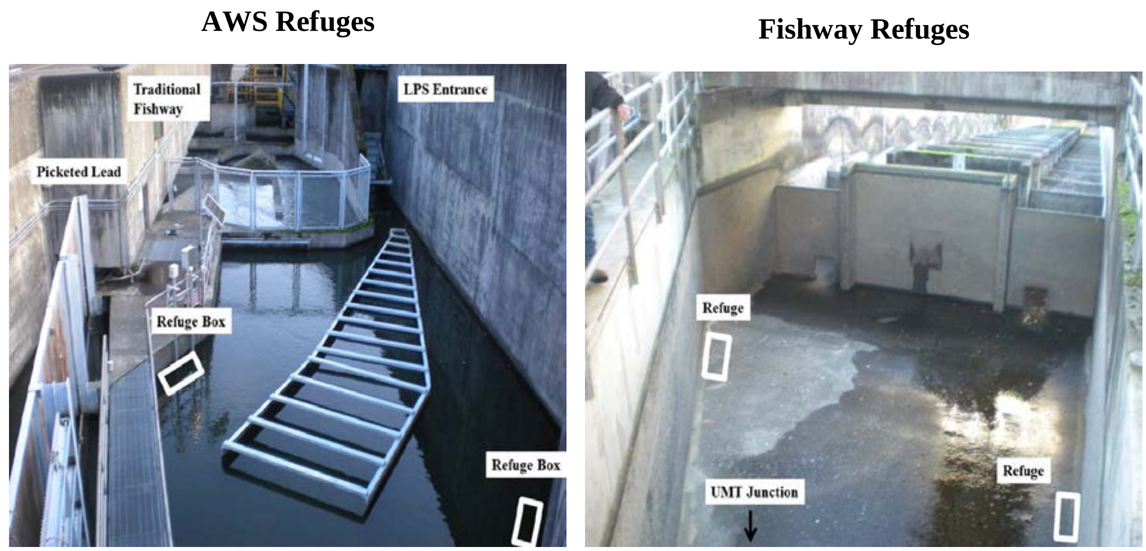

Figure 16. Location of refuges in the Washington Shore AWS channel and fishway at Bonneville Dam.

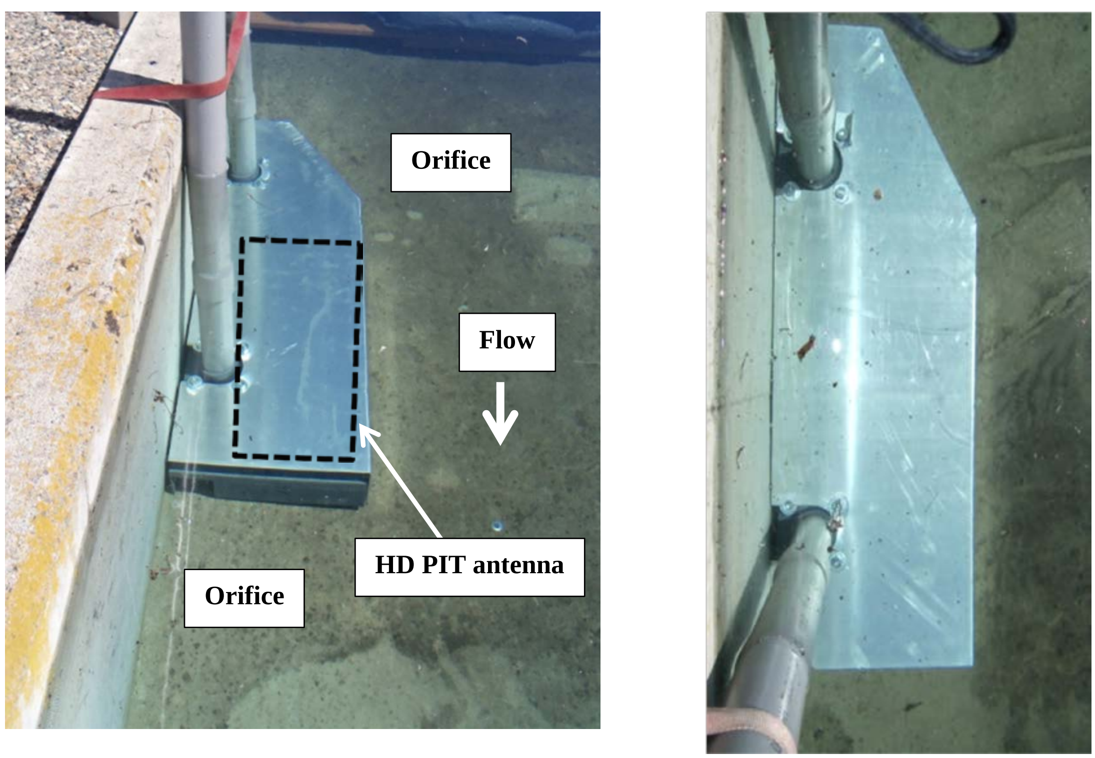

Figure17. Photographs of refuge design and placement.

Monitoring of Tagged Lamprey

Methods

The two refuges in the Washington Shore AWS channel were in place prior to the lamprey migration in 2014, and their use PIT-tagged lamprey was monitored continuously throughout the migration season. Patterns of refuge entry and exit timing were analyzed using a circular analysis of variance. The two refuges in the Washington Shore fishway were also in place prior to the start of lamprey migration, but these refuges could not be monitored due to detection system problems that could not be resolved during the migration season.

For each AWS refuge, we enumerated detections of PIT-tagged lamprey and calculated the percentage of these individuals subsequently detected in the Washington Shore LPS. We determined the fate of fish that used refuges by screening detections on the LPS and fishway exits. Residence times for individual PIT-tagged lamprey in the refuges was calculated by subtracting time of first detection from time of last detection on a refuge antenna.

Some lamprey that used a refuge were tagged with both a PIT and radio tag. An extensive array of radio-telemetry receivers in the Washington-shore fishway allowed us to monitor these fish as they entered the refuge study area (Johnson et al. in review; Figure 18, HBO and KBO receivers).

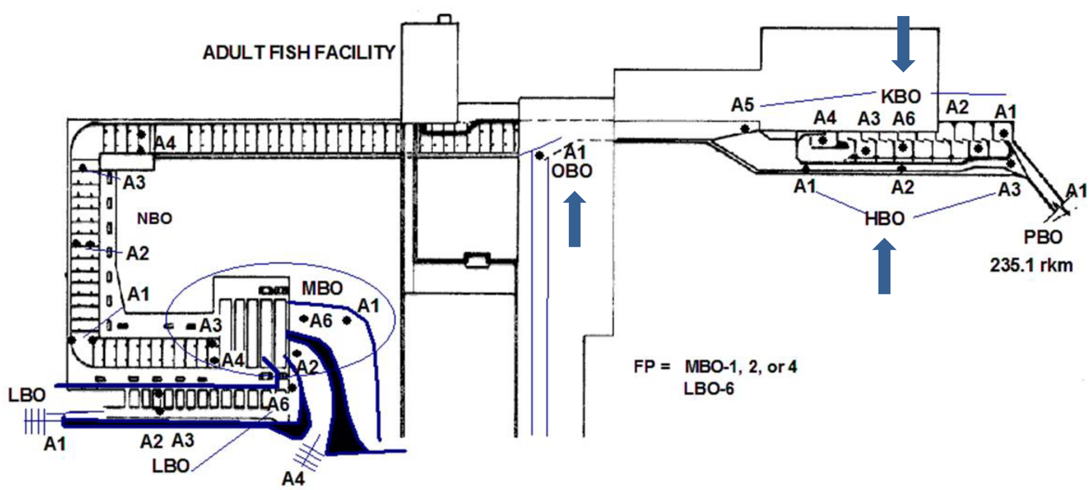

Figure 18. Radio antenna array at the Washington-shore fishway at Bonneville Dam in 2014 (from Johnson et al. in review). Blue arrows point to receivers near the refuge study area (antenna complexes HBO, KBO and OBO).

For lamprey detected on either the HBO or KBO telemetry receivers, sites of last detection were classified as 1) last detection at or downstream from Bonneville Dam (below BO), 2) in the Bonneville Dam pool (top BO to TD), or 3) upstream from The Dalles Dam (above TD).

Results

Lamprey refuges were operated in the Washington Shore AWS channel from 15 May to 30 October 2014. Of the 1,198 lamprey PIT-tagged and released downstream from Bonneville Dam, 174 (15%) were detected in AWS refuges. Of the 174 lamprey detected in a refuge, 106 (61%) were subsequently detected at the AWS LPS, and 120 (69%) were subsequently detected at the LPS or fishway exit.

Sixty-one of the 174 PIT-tagged lamprey (35%) detected at an AWS refuge were subsequently detected upstream from Bonneville Dam. Of the 364 PIT-tagged lamprey detected exiting either the Washington Shore AWS LPS or fishway, 120 (33%) had previously been detected at an AWS refuge. Median residence time of PIT-tagged lamprey within an AWS refuge was 14.2 h (± 48.5 h, range <1 min to 336.7 h).

In the refuge at the south wall of the Washington Shore fishway, the PIT detection system failed due to a faulty transceiver. To restore detection ability at this refuge, the manufacturer will need to troubleshoot the transceiver on-site or it will need to be replaced. In the refuge at the north wall of the fishway, a PIT tag is trapped within the refuge and is impeding detection of other tags. To restore detection ability at this refuge, the tag will need to be located and removed when the ladder is de-watered. The remote, submerged position and arrangement of these refuges precludes the ability to test the antennas prior to the migration season.

Of the radio-tagged lamprey that entered the study area, 63 were detected using an AWS refuge and 154 were not detected at the refuge antennas. Refuge users passed upstream from Bonneville Dam at a slightly lower rate (68.3%, 43/63) than non-users (72.1%, 111/154) (Figure 19, middle and right pairs of columns). In addition, a higher percentage of refuge users than non-users were last detected in the Bonneville pool, but fewer refuge users had a last detection upstream from The Dalles Dam (Figure 19).

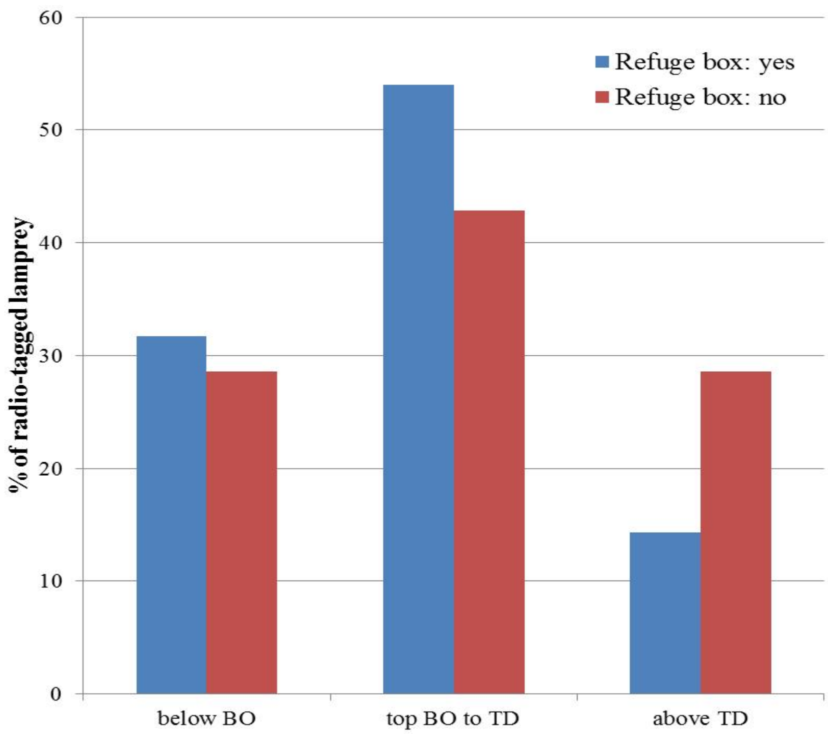

Figure 19. Percentages of radio-tagged lamprey last detected at or downstream from Bonneville Dam (below BO), in the Bonneville pool (top BO to TD), or upstream from The Dalles Dam (above TD). Blue bars indicate lamprey that used an AWS refuge and red bars indicate those that did not.

Discussion

Lamprey were clearly attracted to and resided in the refuges we tested. A total of 217 radio-tagged lamprey entered either the AWS channel or the serpentine section at the top of the Washington Shore fishway. Of these fish, 29% used a refuge in spite of the relatively small access area for these structures. The width of the AWS channel where these refuges were deployed is 7.3 m. Consequently, the refuge footprint represents just 11% of the cross-sectional floor area at this location, and it is unlikely that many of these lamprey entered the AWS channel where the refuges were positioned.

Nevertheless, of the combined PIT-only and double-tagged lamprey detected exiting a Washington-shore LPS or fishway, 33% had visited an AWS refuge. It is likely that use of the fishway refuges was similarly high, as was the case in 2013 (Corbett et al. 2014).

Total numbers of lamprey detected exiting the Washington shore fishway and also detected in a refuge have been substantial each year since these structures were installed (Corbett et al. 2013; 2014). These numbers are likely underestimates due to the high probability of PIT-tag collision on refuge antennas. In some cases, a PIT-tagged lamprey resided in a refuge for several weeks. During this period, any other PIT tags entering the refuge would potentially be missed due to tag collision.

Tag collisions occur when two or more PIT-tag signals are transmitted simultaneously and neither is read correctly. Video monitoring could be used to further evaluate lamprey behavior in and near the refuges, but despite potential underestimates, the PIT data clearly indicated that lamprey were seeking out these relatively small refuges in the AWS channel.

Mean lamprey residence time in the AWS refuges was 29.9 h in 2014 and 57.2 h in 2013 (Corbett et al. 2014). However, lamprey were detected in the refuges for periods ranging from several seconds to several weeks. Tagged lamprey were regularly detected in refuges during the day and for periods in excess of 8 h, suggesting that the refuges functioned to retain lamprey that might otherwise have moved back downstream within the fishway.

An analysis of the lamprey entry and exit timing for the AWS refuges was conducted using pooled PIT detection data from 2013 (Corbett et al. 2014) and 2014. Only lamprey that used the refuges for more than 1 h were included in this analysis. Lamprey entered refuges more often at night, particularly in the hours immediately preceding sunrise, and they exited refuges in the late evening hours (Figure 20). The distributions of entry and exit times were significantly different (High concentration F-test, $P < 0.001$). Comparisons between north and south refuges for both entry and exit timing showed no statistically significant differences ($P = 0.236$ in both cases).

Over one-third of tagged lamprey that used a refuge were subsequently detected upstream from Bonneville Dam. Radiotelemetry provided a higher rate of detection (68%) of refuge users and greater resolution of the distribution for both refuge users and lamprey that exited at the Washington-shore fishway but had not used a refuge (Figure 19). Radio-tagged lamprey that used a refuge were less likely to be detected at radio receiver sites that were upstream from The Dalles Dam than radio-tagged lamprey that did not use a refuge.

It is possible that extended residence times in the refuges resulted in lamprey overwintering in lower portions of the Columbia River drainage. Alternatively, use of lamprey refuges may have been associated with traits affecting total migration distance (e.g. Hess et al. 2014) including motivation, though this remains speculative and whether refuges alter the composition of the adults passing Bonneville Dam remains unknown.

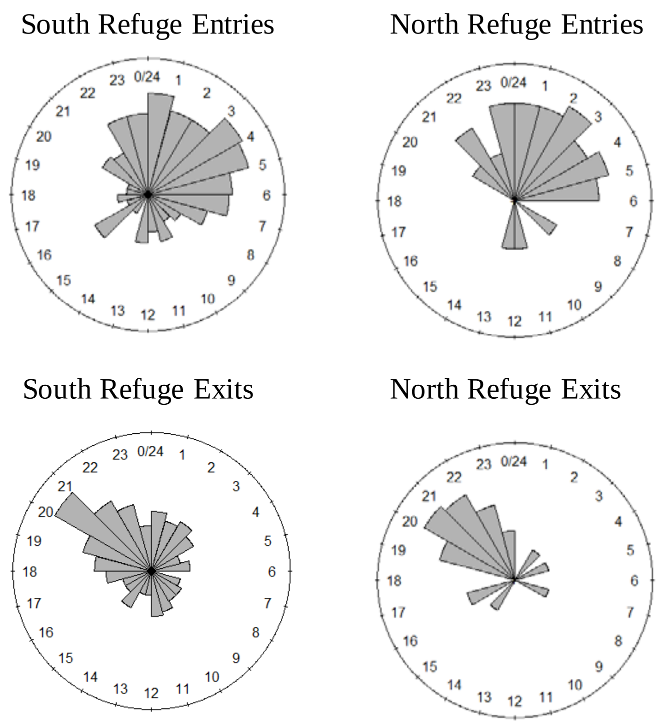

Figure 20. Rose plots of Washington-shore AWS refuge entries and exits by PIT-tagged lamprey for a 24-hour clock.

Keefer et al. (2013) identified specific bottlenecks to lamprey passage through fishways at Bonneville Dam. Particularly notable problem areas were in the Washington Shore junction pools and at the tops of both the Washington Shore and Bradford Island fishways. These areas showed high turn-around rates by radio-tagged lamprey. Moreover, fallback from areas at the top of ladders was less likely to be followed by further passage attempts than fallbacks from from lower elevation fishway segments.

Keefer et al. (2014) reported that at both Bradford Island and Washington Shore, improving upstream passage efficiency near the tops of fishways had the potential to increase overall dam passage success more than improvements at any other fishway section. For these reasons, refuge sites must be carefully considered so that lamprey are afforded a daytime haven in areas where turn-arounds without reascension are common.

However, preliminary radiotelemetry results indicated that lamprey that used a refuge were slightly less likely to pass over Bonneville Dam than those that did not, suggesting possible tradeoffs associated with these sites (i.e., they may benefit some fish, but not others). Alternatively, if motivation was associated with use of a refuge, refuges may provide a benefit if use prevents fallback out of the ladder by lamprey nearing a motivational threshold.

Testing of these lamprey refuges near the top of the Washington Shore ladder showed great promise. Lamprey clearly found and used these refuges in spite of their small footprint. Further monitoring is needed to get a more complete count of lamprey use of these structures. Due to the extended residence times in the refuges, PIT collisions probably occur regularly and probably resulted in under-estimation of refuge use. Video monitoring would allow for further evaluation of lamprey behavior in relation to refuges, and provide information on potential effects of lamprey refuges on salmonids and other fishway occupants.

OBJECTIVE 3: Determine use of the lamprey passage structure at the Cascades Island fishway entrance

Introduction

Between 2009 and 2012 the Cascades Island LPS was operated as an experimental passage structure, and lamprey that ascended were collected at a terminal trap (Moser et al. 2012; Corbett et al. 2013). In 2013, prior to the lamprey migration period, the terminal trap was removed and the LPS was extended to the forebay to allow lamprey to volitionally pass from tailrace to forebay (Corbett et al. 2014) (Figure 6).

Results from 2013 (Corbett et al. 2014) led us to use video as a validation of the pulse count system and establish a correction for passage estimation at the Cascades Island LPS in 2014. Modifications made to the LPS exit slide improved count system functionality, but problems still existed. Modifications made in 2014 were aimed at improving structure maintenance, lamprey use, and count accuracy.

Modifications to the Cascades Island Lamprey Passage Structure

In 2013, during video validation of passage estimation at the Cascades Island LPS exit slide, 93% of lamprey passage events recorded by the camera were also recorded by the pulse counter (Corbett et al. 2014). Notable in the camera imagery was the observation that lamprey frequently attempted to attach within the exit slide and back-climb as they activated the exit door. We determined that exiting lamprey were not sufficiently prompted to exit due to the relatively low angle of the terminal exit slide (8°). Additionally, we identified attachment surfaces within the exit slide that allowed lamprey to swim or back-climb within the slide. We also concluded that the LPS pipe section between the transition pond and exit slide could benefit from increased accessibility.

In 2014, modifications were made to improve LPS exit passage efficiency, passage estimation, and accessibility to closed portions of the LPS. To improve lamprey exit behavior the slope of the exit slide was increased by 6° to 14% (Figure 21), and most exposed areas within the exit slide were lined with rolled, perforated plate. Four ports and hatch covers were installed at regular intervals along the length of the LPS pipe section that connects the transition pond and the terminal exit slide to facilitate LPS cleaning and inspection (Figure 22).

Figure 21. Photo and illustration of 2013 position and 2014 modification that increased the slope of the Cascades Island exit slide.

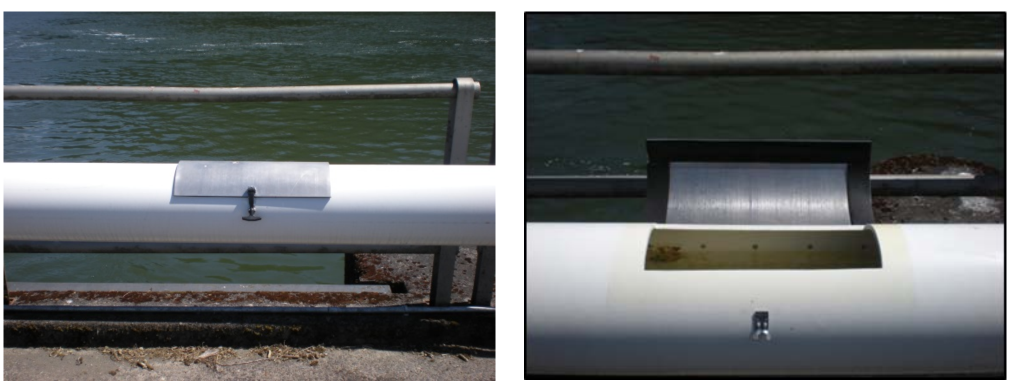

Figure 22. Photos of one of four ports and hatch covers added to the Cascades Island entrance LPS exit extension in 2014 to facilitate inspection and cleaning.

Evaluations Based on Passage Estimates and Camera Observations

Methods

Lamprey use of the Cascades Island LPS was monitored by a lamprey-activated limit switch connected to a wireless pulse-measuring data logger at the exit door (RTR-505, TandD Corporation). The data logger collected and transmitted pulse data to a network base-station at the LPS exit (RTR-500NW, TandD Corporation). The base station communicated by radio uplink to a local area network (LAN) housed in the tailrace south tower (south end of Bonnville Dam spillway; Corbett et al. 2014). Raw pulse count data were delivered twice daily via email at 0500 and 2100.

In 2014, a motion-activated camera (Sony IPELA SNC-CH240) was mounted on the Cascades Island LPS exit slide to provide information on counter performance and passage behavior. Imagery from the camera was archived, and camera records of lamprey passage events were paired with passage events recorded by the pulse counter. The camera was aimed at the lamprey-activated count paddle, where pulse measurements were made. As motion was detected within the field of view, the camera recorded a 7-second time-stamped video clip. We reviewed video clips and compared corresponding time-stamped pulse count measurements.

Results

The Cascades Island LPS was operated for 170 d from 14 May to 30 October 2014. During this period, the pulse counter recorded a total of 2,832 lamprey exiting the LPS to the Bonneville Dam forebay (1,189 day, 1,643 night). Results from video validation indicated that the "correct" range of counts was 2,548-2,889 (i.e., the pulse counter results ranged between an overcount of ~10% and an undercount of ~2%; Figure 23).

Video validation at the Cascades Island LPS exit slide was conducted between 26 July and 12 August (Figure 24). Of the 43 lamprey passage events recorded by the camera, 42 (98%) were also recorded by the pulse counter. For 4 of these 42 passage events (10%), the pulse counter recorded multiple passage events and over counted by 1, 1, 3 and 6 events, totaling 53. There was one instance where the pulse counter recorded a lamprey passage event, but there was no corresponding video observation.

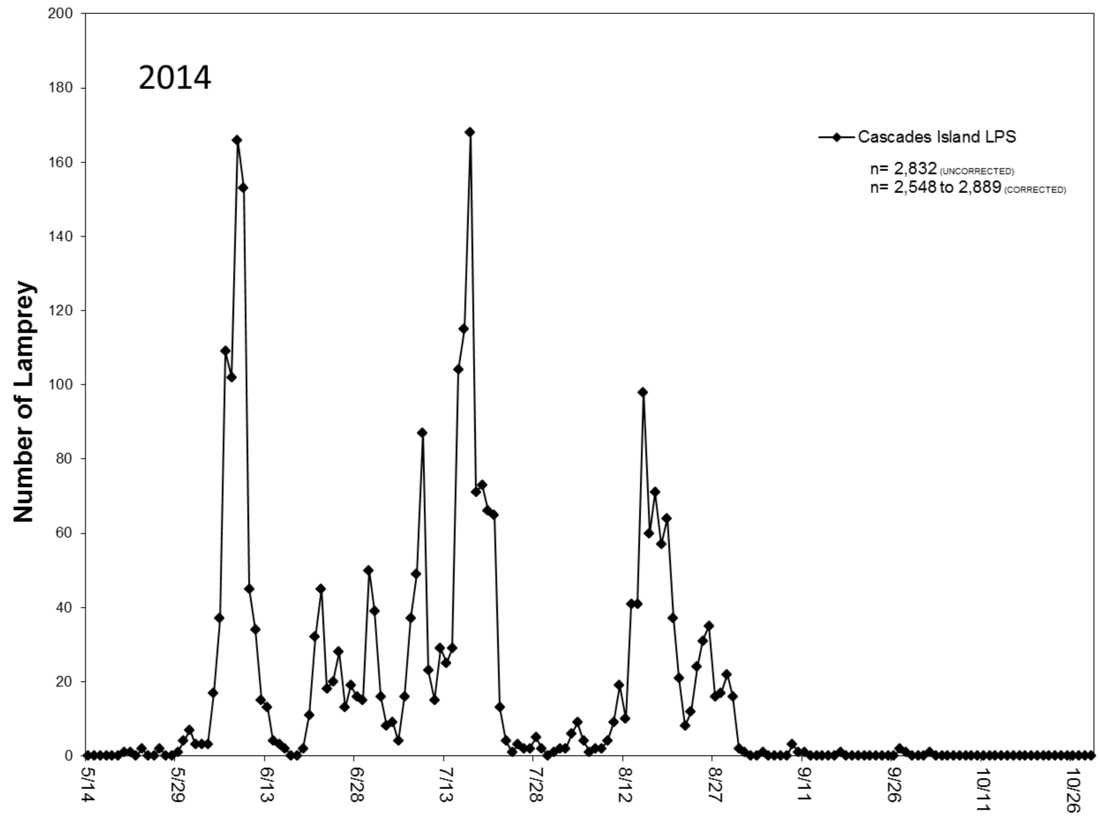

Figure 23. Number of lamprey counted at the Cascades Island LPS exit slide (closed diamonds) during the periods of LPS operation in 2014. Total uncorrected and corrected values are reported for the LPS.

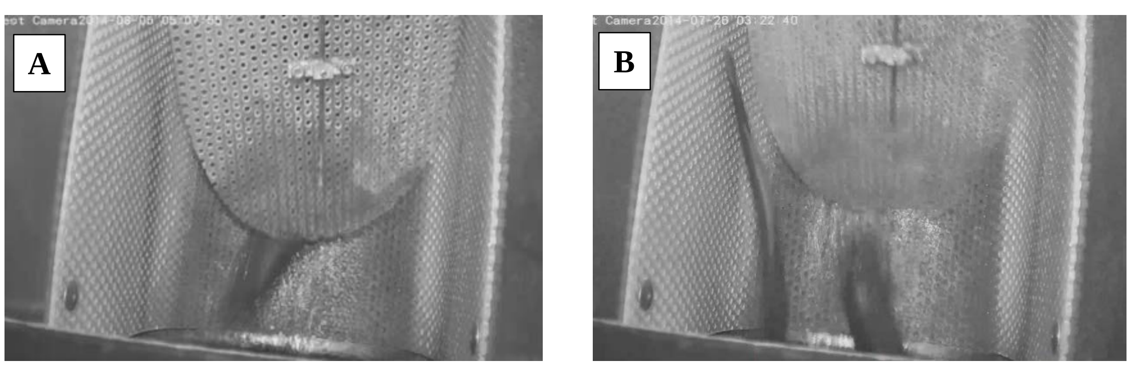

Figure 24. Photos of lamprey passing under the count paddle at the Cascades Island LPS exit: A) head-first orientation, and B) tail-first orientation.

During validations, lamprey were observed passing under the count paddle either in a head-first or tail-first orientation (Figure 24). Instances where lamprey passed in the head-first orientation always resulted in a single event being recorded by the pulse-counter. In each of the 4 instances where the pulse counter recorded multiple counts for a single lamprey passage event, lamprey were observed passing in a tail-first orientation. During these events, the limit switch was activated multiple times by lamprey attempts to back-climb. This resulted in multiple events being recorded by the pulse-counter for a single lamprey passage event.

There were also several instances where lamprey passed in the tail-first orientation, and a single count was recorded by the data logger. Such outcomes were due to lamprey not attempting to back-climb, or to the attempted back-climb not being vigorous enough to re-activate the limit switch. In one instance, a lamprey was observed passing under the count paddle slowly and with very little body movement such that the limit switch was not activated and no corresponding pulse was measured by the pulse counter.

Evaluations Based on Monitoring of Tagged Lamprey

Methods

PIT-tagged fish were detected at three antenna locations within the Cascades Island LPS: just upstream from Rest Box 3, at the transition pond, and just before fish entered the exit slide (Figure 6).

Results

Of the 1,198 lamprey PIT-tagged and released downstream from Bonneville Dam in 2014, 7 (0.6%) were detected in the Cascades Island LPS (6 PIT-only and 1 double-tagged). In addition, one PIT-only lamprey tagged and released below the dam in 2013 was detected in this LPS. For these 8 fish, LPS passage efficiency was 100%, and median travel time from the first antenna to the exit slide was 2.9 h (range 1.7-20.9 h). Of the 8 lamprey detected in the Cascades Island LPS during 2014, 1 (13%) was detected at the makeup water supply channel prior to being detected at the Cascades Island LPS, and 4 (50%) were subsequently detected at sites upstream from Bonneville Dam.

Discussion

Regardless of whether counts were corrected, the number of lamprey counted in the Cascades Island LPS was an order or magnitude higher in 2014 than in 2013 (Table 7). This was likely due to both an additional year of "seasoning" for LPS components, which were newly installed in 2013, and to the relatively larger run size in 2014.

Table 7. Estimated lamprey passage (minus recaptured and experimental lamprey) at the Cascades Island LPS, 2009-2014. Passage methods include collection at terminal trap (2009-2012) and exits from the LPS to the forebay (2013-2014).

Year	Lamprey passage at Cascades Island LPS (n)	Passage method
2009	106	Trap and haul
2010	48	Trap and haul
2011	485	Trap and haul
2012	2,472	Trap and haul
2013	155	Counted exiting to forebay
2014	2,832	Counted exiting to forebay

At the Cascades Island LPS, modification of the exit slide improved count accuracy, but the slope of the exit slide is still shallow enough for lamprey to attempt back-swimming. Therefore, the optimal slope of the exit slide at this LPS remains undetermined. Experimental testing is needed to determine optimal slope for this and other LPS exit slides.

Alternative approaches to prevent back-climbing could include altered size or spacing of perforated lining in the exit slide or use of alternative tubing in the count section (e.g., corrugated tubing). Design of the exit slide should consider both lamprey exit efficiency and the performance of passage estimation systems. By incorporating such findings into current and future LPS designs, common problems associated with delayed exits, potential physical damage to lamprey, and count accuracy could be reduced or eliminated.

Due to its siting, the Cascades Island LPS exit features several design elements that differ from those of other LPSs. The slide entrance is roughly at a 90-degree angle to the LPS, which slows the approach velocity of lamprey (Figure 25 photo A). It appears that as lamprey exit the upwelling box to the elbow section at the slide entrance, they sense a loss in elevation and frequently attempt to attach and back-climb.

A small gap in the perforated plate at a structural joint is suspected to be the site where lamprey gain attachment (Figure 25 photo B); however, this was not validated because the area is beyond the camera field of view. For lamprey that successfully attach at this gap, one-third to one-half of the posterior body length will pass under the count paddle. After attaching and attempting to back-climb, a lamprey will activate the limit switch multiple times. This can result in overcounting of a single passage event by the pulse counter.

For lamprey that attempt, but fail to attach at this location, passage can be slowed by the attempt, and these fish can pass under the count paddle in a tail-first, horseshoe orientation. Video validation showed that most lamprey passed under the count paddle in this orientation, indicating that these fish frequently attempt to attach but are not always able. For lamprey that passed under the count paddle in a head-first orientation, the result was an accurate passage event record reported by the pulse counter.

Figure 25. Photos of the Cascades Island LPS exit (A, yellow outline), the gap in perforated plate (B, yellow outline), and lamprey passing under the counter paddle (C).

These observations suggest that further modification is needed at the Cascades Island LPS exit slide. If possible, the slide angle should be aligned with the LPS axis so that lamprey velocity is not reduced as they enter the slide. Any gaps in perforated plate should be eliminated to reduce lamprey attachment. At present, the slide is positioned at the highest angle possible, given the site characteristics. Nevertheless, other configurations of the exit area should be considered (e.g., raising and lengthening the slide). Such changes should result in a slide angle that forces lamprey to exit rapidly, without injury, and that allows monitoring equipment to produce an accurate count.

OBJECTIVE 4: Develop methods to collect lamprey from the makeup water supply channel at Cascades Island

Introduction

In past years adult lamprey have been observed accumulating in the Cascades Island makeup water supply channel, an area that has no direct access to the forebay. Lamprey trap and haul operations at this location were successful in 2012 and 2013 (Corbett et al. 2013, 2014), and likely contributed to the migration success of lamprey that otherwise would have been blocked from or delayed in movements upstream. Through these efforts, we have been able to document specific areas where lamprey accumulate, and thus identify suitable sites for future LPS collection within the channel. While efforts are underway to limit lamprey access to this area, the need continues for trap-and-haul operations at the makeup water supply channel.

Methods

In 2014, portable traps similar to those at the adult fish facility were deployed at the Cascades Island makeup water supply channel upstream from the picketed lead near the fishway exit (Figure 26). Lamprey have been observed accumulating in this area, and

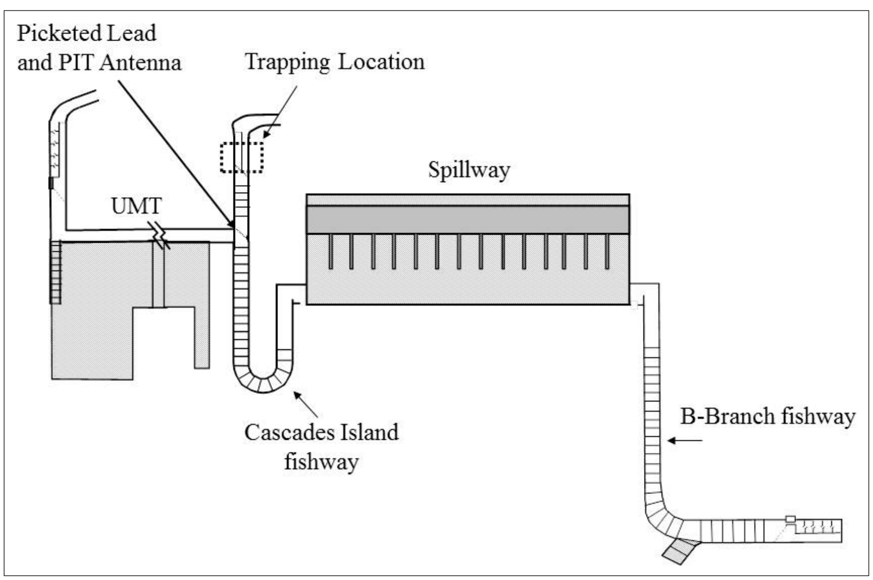

Figure 26. Locations of the HD-PIT antenna at picketed lead and trap deployments at the Cascades Island MUWS channel.

PIT-tagged lamprey have been detected in this channel during all previous years of monitoring. Trapping sites (Figure 27) were selected both to evaluate lamprey use of the channel and to provide information for future siting of an LPS collector. Traps were attached to a weighted, standing wire to allow ease of deployment while ensuring that they remained firmly in place. Collected lamprey were enumerated and then transported and released upstream from Bonneville Dam.

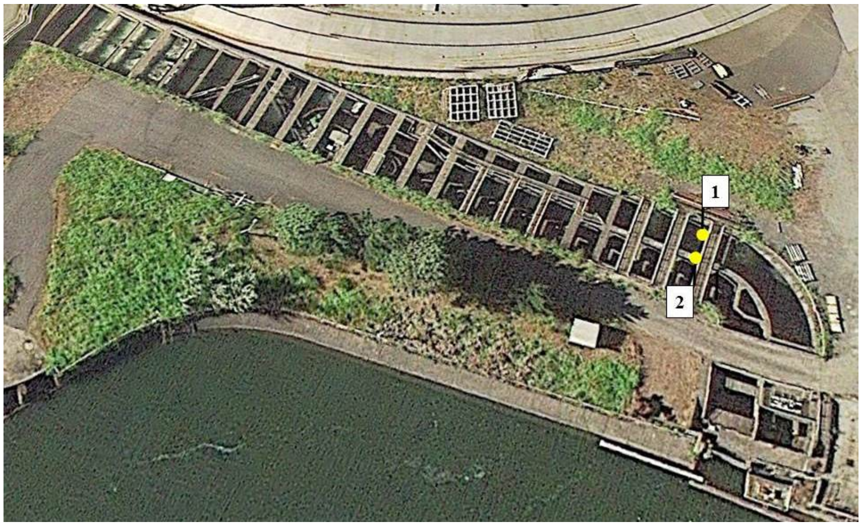

Figure 27. Locations of the two traps (yellow dots) deployed in the Cascades Island makeup water supply channel in 2014.

Results

The two portable traps were deployed between 19 May and 30 October 2014 in the flow-control section upstream from the picketed lead and downstream from the fishway exit (Figure 27). They were recovered 1-2 times per day, checked for lamprey, and re-deployed. A total of 1,512 adult lamprey were captured from the Cascades Island makeup water channel. All of these fish were transported and released approximately 1 km upstream from the dam near Stevenson, WA.

Of these captured lamprey, 81 were used in experimental trials of a wetted wall collector between 22 September and 3 October (Objective 6). All lamprey used in experimental trials were released within 24 h of capture. After 3 July, all captured lamprey were scanned for a PIT tag. Lamprey continued to be collected in this channel after picket lead spacing was reduced in 2014 (Figure 28).

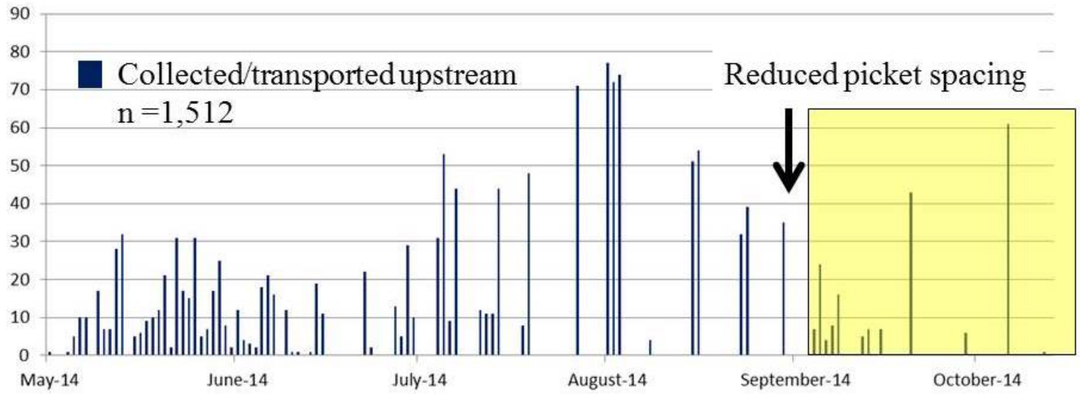

Figure 28. Lamprey captures by date at traps in the Cascades Island makeup water supply channel. Shaded area indicates the period when picket spacing was reduced to discourage lamprey entry into the channel. Those captured during this time may have entered the channel prior to the change or may have passed through the narrower spacing.

Discussion

Collection of lamprey was very successful in 2014 at the Cascades Island makeup water supply channel upstream from the picketed lead (Table 8). Collected lamprey were transported upstream from Bonneville Dam and contributed to lamprey passage, as many likely would not have passed Bonneville Dam otherwise.

Table 8. Date range of trapping effort and number of lamprey trapped at the Cascades Island makeup water supply channel, transported and released upstream from Bonneville Dam 2012-2014.

Study year	Dates of trap operation	Lamprey captured and released upstream from Bonneville Dam (n)
2012	16 Aug-20 Sep	268
2013	9 Jul-23 Oct	625
2014	19 May-30 Oct	1,512

In addition to trapping results from 2012-2013 (Corbett et al. 2013, 2014), detections of PIT-tagged lamprey released downstream from Bonneville Dam between 2007 and 2014 have also indicated that high numbers of migrating lamprey accumulate in the makeup water supply channel (Table 6). Further evidence of lamprey accumulation in this area was provided by the observation of both live and dead lamprey in the serpentine weir section of the Cascades Island ladder, which has water but is not operated for fish passage.

Initial attempts to reduce lamprey access to the makeup water supply were not completely successful: lamprey continued to enter the channel and become trapped long after the picketed lead spacing was reduced to prevent access (Figure 28). These entries of lamprey may have been caused by discontinuities between the fishway floor and bottom of the new picket or by an insufficient reduction in spacing of the picketed lead. Further modifications to eliminate lamprey access to this area were completed during the in water work period in 2015, after these assessments were completed.

To improve lamprey passage at Bonneville Dam, fish that access this makeup water supply should be provided with an outlet to the forebay via a lamprey passage structure. Without a volitional passage route from this area, lamprey can spend long periods of time in the makeup water supply channel. Also, lamprey captured from this area were observed to be exceptionally large, potentially representing a select subset of the migrating population that could be passed with a route from this area.

Alternatively, lamprey should be actively trapped and transported upstream throughout the migration period. However, trapping results and visual observations indicate that lamprey passage could best be improved by placement of an LPS at this AWS. Based on locations of collected lamprey, LPS entrance collectors should be located along the north and south walls of the makeup water supply at the approximate locations of trap sites 1 and 2 (Figure 27). These entrance collectors can be connected to the forebay using a structure similar in design to that of existing AWS LPSs.

OBJECTIVE 5: Develop methods to enumerate lamprey entering a newly installed trap in the south-shore fishway at John Day Dam

Introduction

Prior to the 2013 migration season, a trap was installed at the John Day Dam south fishway count area. The purpose of this trap was to collect Pacific lamprey for tribal broodstock and to enumerate lamprey passage through this area (Figure 29, Corbett et al. 2014). The trap was designed to operate in two modes: a capture mode in which lamprey enter and are collected, and a pass-through mode in which lamprey enter and are able to pass through and continue upstream (Figure 30 and 31). A camera system was installed to record numbers of lamprey entering the trap in either mode.

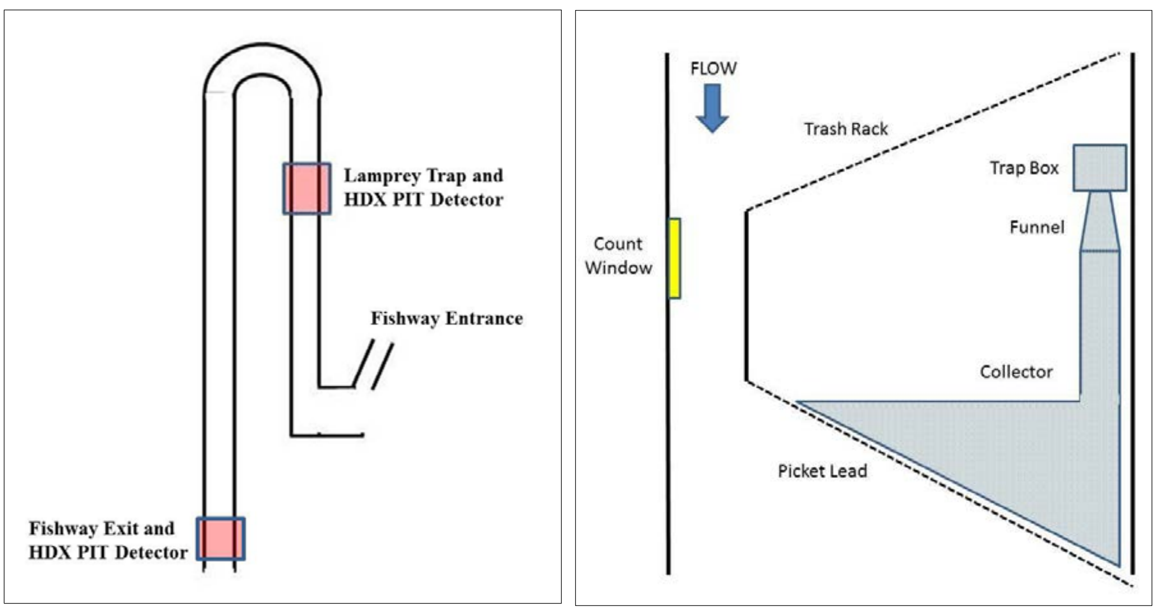

Figure 29. Plan views showing location of the lamprey trap and PIT-tag detectors in the John Day south fishway. Right panel shows location of the trap in relation to other structures within the fiishway.

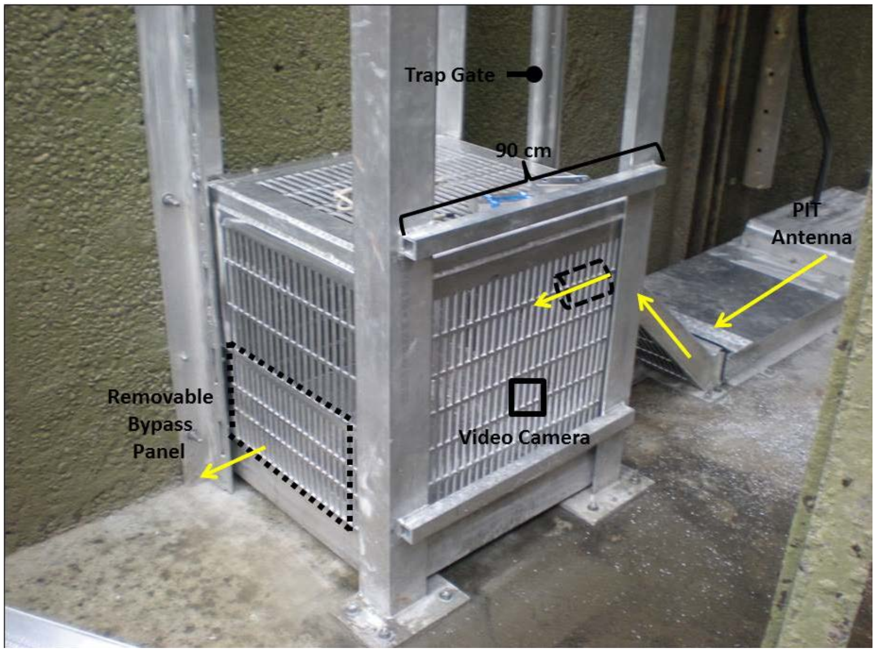

Figure 30. Photo of trap and associated features (labeled) in the south fishway at John Day Dam.

During testing in 2013, the camera system was optimized to ensure that recorded video could be used to enumerate lamprey when the trap was operated in pass-through mode. In addition, a PIT-tag detection antenna was positioned downstream from the trap (Figure 29). During deployment in 2013, the vertical camera infrastructure originally designed for the trap proved faulty (Corbett et al. 2014). However, results from tests of a reconfigured camera showed that high-quality imagery could be captured and recorded at this structure. In 2014 the camera was deployed in the reconfigured (within-trap horizontal) position during the lamprey migration period.

In 2014 the camera system recorded video of lamprey entering the trap. These images will be used to enumerate lamprey use of the trap during operation in the pass-through mode. Modifications to this trap in 2014 included: 1) installation of a solid entrance ramp to improve access, and 2) modification of the trap access door hinge for partial opening. Additionally, a tank was installed to hold lamprey collected for tribal transport.

Methods

To enumerate lamprey entering the trap, we deployed an underwater camera (Speco Technologies 1/3” CCD waterproof). The camera was connected to a digital video recorder system, (HIKvision iVMS-4200 client software) and recorded imagery was played back using viewing software (HIKvision VSplayer V 7.0).

Initial tests of the system in 2013 had been conducted with the camera deployed in a vertical position using a camera tube that had been incorporated into the original trap design. Due to problems with this arrangement (Corbett et al. 2014), an alternate deployment was tested using the same camera mounted horizontally inside the trap box (Figures 30 and 31). In this deployment, the camera lens was pointed towards the 10-cm orifice at the entrance to the trap box (Figure 31).

In 2014 the camera was deployed between June and September. For periods of trap operation in capture mode (bypass panel removed), digital video was surveyed using viewing software (VSPlayer), and lamprey that entered the trap were enumerated.

A monitoring system was also located at the collector immediately downstream from the trap funnel to detect any PIT-tagged lamprey that entered the trap (Figures 29 and 30).

Results

Between 12 June and 26 September 2014, 78 lamprey were collected at the trap during 50 trapping periods (approximately 1,200 h). Collected lamprey were transported for tribal restoration purposes (A. Jackson, Confederated Tribes of the Umatilla Indian Reservation, personal communication). On the PIT-tag monitor at the trap collector, we detected 28 PIT-tagged fish that had been released at downstream locations in 2013 and 2014.

From the 288 h of video footage recorded during 16-30 July, when the trap was operated in pass-through mode, we observed an additional 66 lamprey swimming through the structure. An additional 432 h of digital video was recorded when the trap was operated in pass-through mode (18 trapping periods from 31 July to 19 August). This imagery will be reviewed and the results reported. By comparison, a total of 16,461 lamprey were counted during day and night visual counts at the John Day south count window between 1 June and 30 September (Figure 32).

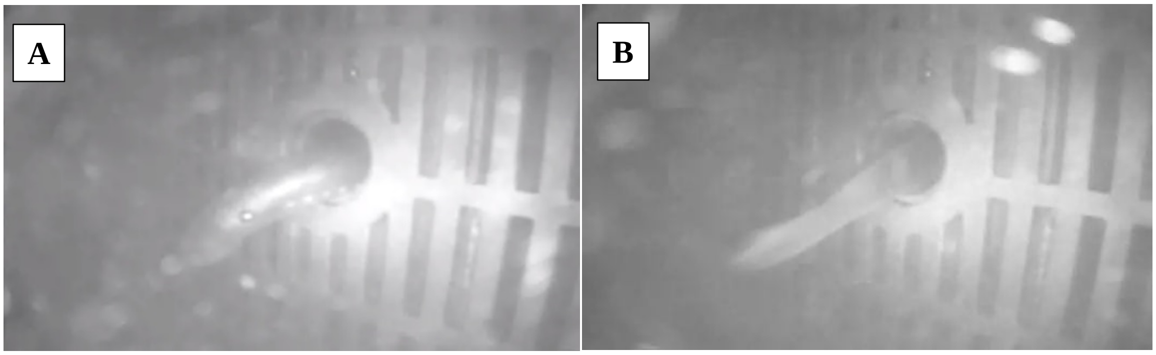

Figure 31. Still imagery extracted from recorded video displaying examples of: A) lamprey only partially entering the trap box via the entrance port, and B) lamprey exiting the trap box via the entrance port.

Some interesting lamprey interactions with the trap have been observed during video reviews. Many individuals showed hesitation upon entering the trap box from the entrance port. Frequently a lamprey would extend one third to one half of its body length into the trap box (Figure 31A) and appear to search for a surface to attach to before retracting from the entrance port. Additionally, one lamprey that had previously fully entered the trap box was observed exiting the trap box head-first through the entrance port (Figure 31B).

A total of 28 PIT-tagged lamprey were detected at the trap antenna. Of those detected, 21 had been tagged and released downstream from Bonneville Dam in 2014 (16 PIT-only and 5 double-tagged). The remaining seven had been tagged and released in 2013, including six PIT-only fish released downstream from Bonneville Dam and one double-tagged (JSAT and PIT) fish released upstream from the dam.

Of the 21 lamprey tagged in 2014 and detected at the trap collector, 16 (76%) were subsequently detected at the south fishway exit, and 7 of these 16 (44%) were subsequently detected upstream. Five lamprey were detected at the trap collector but not subsequently detected either at fishway exits or at an upstream dam. This suggests that these five lamprey fell out of the south fishway and did not pass John Day Dam by any route.

Of the lamprey PIT-tagged in 2014 and detected at both the trap collector and south fishway exit, median occupation time at the trap collector was 17.2 h (range 0.6-365.1 h). Median travel time from the trap collector to the south fishway exit for these fish was 6.4 h (range 4.3-63.4 h).

Discussion

Data from trap captures, digital video, and PIT detections indicated that lamprey successfully entered the south fishway trap box at John Day Dam in 2014. It is important for trap operators to note that when operating this structure in pass-through mode, the entrance gate to the trap box must be open and the bypass panel (Figure 30) removed. Otherwise lamprey will fall back and be delayed at this site.

Data from PIT detections indicated that lamprey were occupying the collector for extended periods, but and not quickly passing through to the trap box. The shape and design of this collector is similar to that of the refuges installed at the AWS channel and fishway at Bonneville Dam. Periods of occupation (time at first detection to time of last detection) were similar to those observed at the refuges at Bonneville Dam, suggesting that this trap collector functioned as a refuge. It is also possible that behaviors change between locations because of differing physiology and environmental conditions.

While the modified video camera position improved our ability to utilize video in assessing lamprey behavior and use of the trap box, the video monitoring itself had some pitfalls. For example, because the camera is now mounted horizontally within the trap box, lamprey were observed making contact with it. In addition, the camera coaxial cable was accidentally severed during one instance of trap deployment and recovery, resulting in a period of camera outage. If a camera system is to be deployed going forward, it would benefit from an upgrade to a wireless system, considering the frequency with which the trap box is deployed and recovered. In the vertical position, camera system operation is completely independent of the trap box, but the imagery is unusable.

When the south fishway trap was operated in pass-through mode, there was a large discrepancy in the magnitude of lamprey passage based on window counts vs. numbers of trapped lamprey and video review of the trap structure. Video recorded in 2014 provided valuable insight into lamprey interaction with the trap itself and offers some possible explanation for the large difference between daily trap catches and fishway window counts (Figure 32). Structural modifications may improve lamprey access to the trap box and thereby increase catch rates. Providing an attachment surface immediately inside the entrance port may reduce entrance hesitation and retraction from the trap box.

Video evidence of the lamprey that exited head-first through the entrance port indicates that captured lamprey are able to escape the trap box, and this ability to escape may account for some of the low catch rates. Modifying the entrance port with a one-way valve or fyke could help retain lamprey that enter the trap box.

Low numbers of lamprey in the south fishway trap may also relate to broader issues with the structure. Modifications in 2014 could have reset the seasoning timeline, essentially creating another new year; we may see improvements in future years as seasoning of the structure continues. Alternatively, there may be vibration or velocity attributes of the trap and collection structures that deter lamprey from this structure.

Lamprey interactions with the downstream portions of the trap (funnel, conduit, transition grating) are currently unknown. However, PIT detections have shown that some lamprey occupy the downstream portions of the structure for extended periods before entering the trap box. Video monitoring of these portions could help identify areas that are impeding lamprey passage.

Camera systems deployed at structures at hydroelectric dams have proven to be valuable lamprey passage monitoring tools (Clabough et al. 2012; Negrea et al. 2014). Further refinement and optimization of the camera system should allow for accurate enumeration of lamprey that migrate upstream through the structure when the trap is operated in pass-through mode.

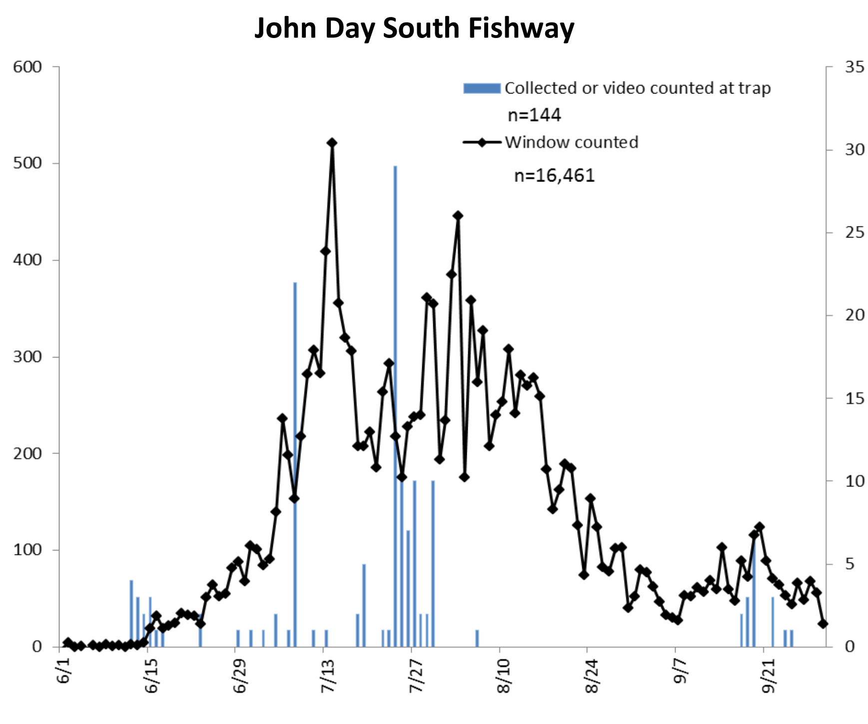

Figure 32. Number of lamprey counted at the John Day south count station (closed diamonds, primary axis) and either collected from the trap or video counted entering the trap (bars, secondary axis) during dates it was operated in pass-through mode in 2014. Total values reported for the count station and trap.

OBJECTIVE 6: Design, build, and test lamprey use of an experimental wetted wall at Bonneville Dam.

Introduction

Lamprey that reach the serpentine weir sections at the top of Bonneville Dam fishways cannot access an LPS without moving back downstream. Such downstream movement may induce ladder fallback with no subsequent passage attempt. A high percentage of lamprey that fall back fail to re-ascend and pass Bonneville Dam (Keefer et al. 2013).

Serpentine weir sections of fishways are not well-suited to installation of a typical LPS because of both space constraints and potential negative interactions with salmonids. A novel "climbing wall" concept was originally conceived in the laboratory (Kemp et al. 2009; Moser et al. 2012) and pioneered in the field at Winchester Dam on the Umpqua River, Oregon. The design takes advantage of Pacific lamprey vertical climbing ability (Figure 33).

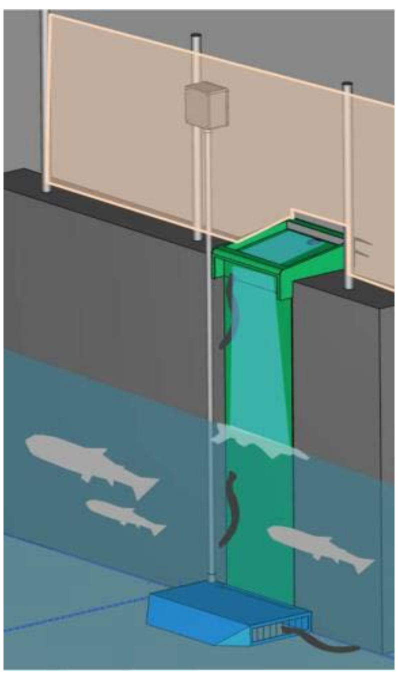

Figure 33. Schematic diagram of theoretical wetted wall. Conduit pipe is located adjacent to the climbing surface on the upstream side of the wall, and a refuge box is placed on the fishway floor below the climbing surface. These features encourage exploration of the passage option provided.

We designed and built a device that allows lamprey to pass from the serpentine weir section of a fishway into an adjacent AWS, thereby providing access to an existing LPS (Moser et al. 2011). While the vertical climbing ability of Pacific lamprey is well documented (i.e. Kemp et al. 2009), we found no studies exploring the impact of flow on climbing ability.

Minimizing flow into a fishway while still allowing for successful lamprey passage will reduce the potential for negative interactions with co-occurring salmonids. We designed an experimental wetted wall and conducted trials to test lamprey vertical climbing success in response to differing water delivery mechanisms and flow levels.

Methods

Using a block design, we tested three water supply mechanisms (sidewell, upwell, and overflow) at three flow levels each (1.7-47.5 gal/min) for at least 10 lamprey per treatment. We recorded the time required by each lamprey to first touch the wall, then crest the vertical component of the structure, and finally exit the structure. The number of climbing attempts made in a 2.5-h trial was also recorded. Experiments were conducted between 22 September and 3 October 2014.

Table 9. Experimental flow levels as measured by cascading volume (gal/min) used for each water delivery mechanism for an experimental wetted wall installation in the Fingerling Experimental Research Laboratory at Bonneville Dam.

Flow level	Overflow	Sidewell	Upwell
Low	3.8	6.0	1.7
Medium	24.0	19.8	3.9
High	47.5	27.4	8.2

We fabricated a vertical aluminum wall (5.4 ft high, 18 in wide) with a 6-in radius crest that lead into a shallow 18-in pan. The pan narrowed to a 4-in exit, and the entire structure was installed in the Fisheries Engineering Research Laboratory at Bonneville Dam. Columbia River water was pumped from a raceway in the lab to upper reservoirs by two submersible pumps rated to deliver 28 gpm at a 5-ft head level. Water was supplied to the experimental structure via three different mechanisms: sidewelling, upwelling, and overflow.

Water flowed down the climbing surface and through the exit, cascading over the weir into the lower raceway and out the exit into a separate reservoir (Figure 34). Water temperature remained relatively constant through the study, ranging 18.2-20.2°C (64.8-68.4°F). Temperature was monitored using a temperature/alarm data logger (HOBO Pendant, 64K-UA-001-64, Onset Computer Corporation). Overhead fluorescent lighting provided illumination.

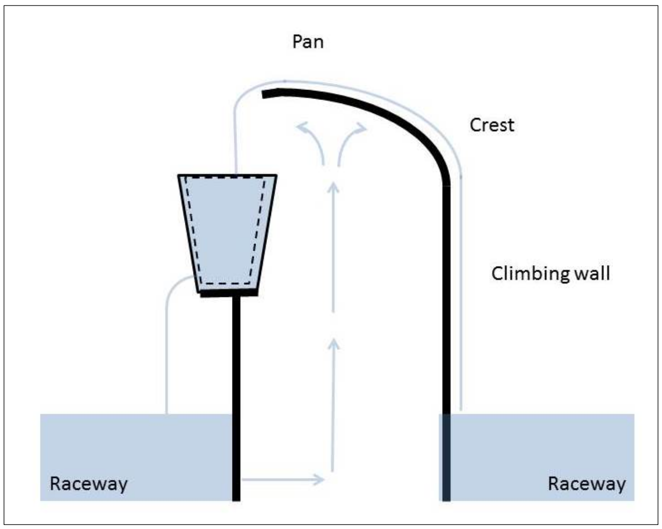

Figure 34. Schematic diagram (side view) of experimental wetted wall collector with features labeled.

Experimental lamprey were collected from traps deployed at the Cascades Island makeup water supply channel. Following capture, lamprey were transported to a holding tank, marked, weighed, and immediately transported to the raceway at the base of the wetted wall. All experimental lamprey were handled without anesthetic. To uniquely mark experimental lamprey, individuals were marked with 1-2 1-in colored anchor tags (Floy T-Bar) attached to the first dorsal fin (Figure 35).

Test fish were introduced to the raceway containing the wetted wall at previously set experimental conditions (Figure 36), and observed throughout the length of the trial. Data were recorded for lamprey that interacted with the wetted wall within 2.5 h. Some lamprey that did not ascend within the trial period were left unobserved in the raceway overnight to evaluate climbing success outside of the experimental timeframe.

Following trials, all experimental lamprey were transported and released upstream from Bonneville Dam. Tags were removed before fish were released to the river.

Figure 35. Photos of experimental wetted wall collector show lamprey ascending during a trial.

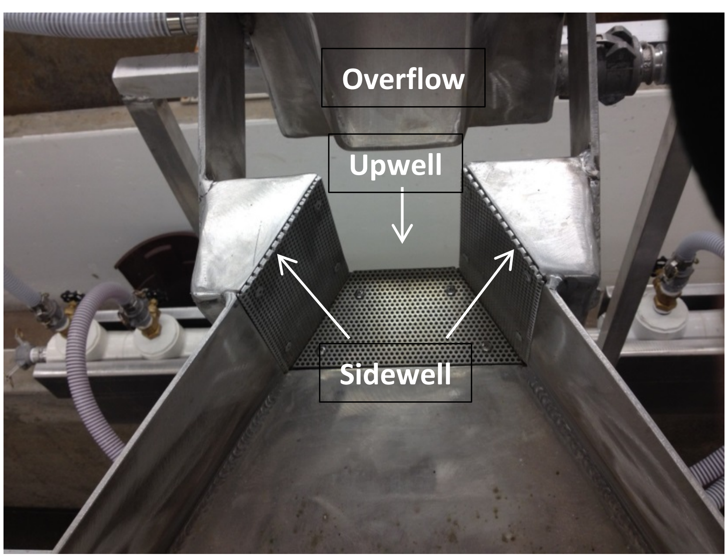

Figure 36. Photo of wetted wall collector pan exit with three water delivery system inputs labeled.

Results

All lamprey that interacted with the wetted wall were ultimately successful in climbing it. A subset (7.1%) attached to the wall but did not ascend within the 2.5-h experimental block. However, even these fish passed over the wall when left overnight. Most lamprey navigated the structure on their first attempt, although one attempted six times prior to passing. The average number of climbing attempts ranged 1.0-1.8, depending on water supply and flow treatment (Table 10). Supplying the structure with water via the overflow method resulted in the fewest attempts per fish, regardless of flow treatment.

Lamprey climbed the experimental wetted wall and successfully exited at all of the flow levels tested. Passage times were consistently fast, regardless of the experimental flow. Average time from first interaction with the structure to exit ranged 9-36 min between the low-flow overflow supply treatment and the high-flow upwelling supply treatment (Table 10). Passage time was consistent across flow treatments; lamprey showed the most variable passage time in response to the upwelling water supply, with the only significant difference within any treatment being between the medium and high flows for the upwelling supply (Figure 37).

Table 10. Average time taken by lamprey to find, climb, and exit the experimental wetted wall climbing structure at different flow levels (high medium, and low). Results are given for each water delivery treatment (overflow, sidewell, and upwell).

			Time (min:second)				
	Test fish (n)	Attempts (n)	First touch to crest	Final touch to crest	First crest to exit	First touch to exit	Final touch to exit
Overflow							
High	10	1.1	14:30	14:18	12:06	26:36	26:24
Medium	10	1.0	14:30	14:30	13:24	27:54	27:54
Low	12	1.1	9:10	8:25	17:15	26:25	25:40
Sidewell							
High	11	1.3	15:22	14:05	3:42	19:42	19:06
Medium	12	1.3	16:15	13:20	7:50	24:05	21:10
Low	12	1.6	30:05	8:38	10:55	41:00	19:33
Upwell							
High	11	1.3	36:42	27:18	10:12	46:54	37:30
Medium	14	1.3	17:00	11:09	5:55	22:55	17:05
Low	13	1.8	23:11	14:05	9:30	34:00	24:00

Time to pass was divided between vertical climbing and time in the pan (the horizontal area between the climbing crest and the exit). Passage time for the vertical component was consistent across flow treatments and water supply mechanisms (Figure 37). We used a Kruskal-Wallis one-way ANOVA on ranks; results showed no difference in the median values among all treatment groups ($P = 0.091$).

Within water supply types we found only two differences. First, time on the wall was longer for the high-flow vs. the medium-flow treatment with the upwelling water supply (Dunn's Method $Q = 2.395$, $P<0.05$). Second, time in the pan was longer for the low-flow vs. the high flow-treatment with the sidewelling water supply (Dunn's Method $Q = 2.596$, $P<0.05$).

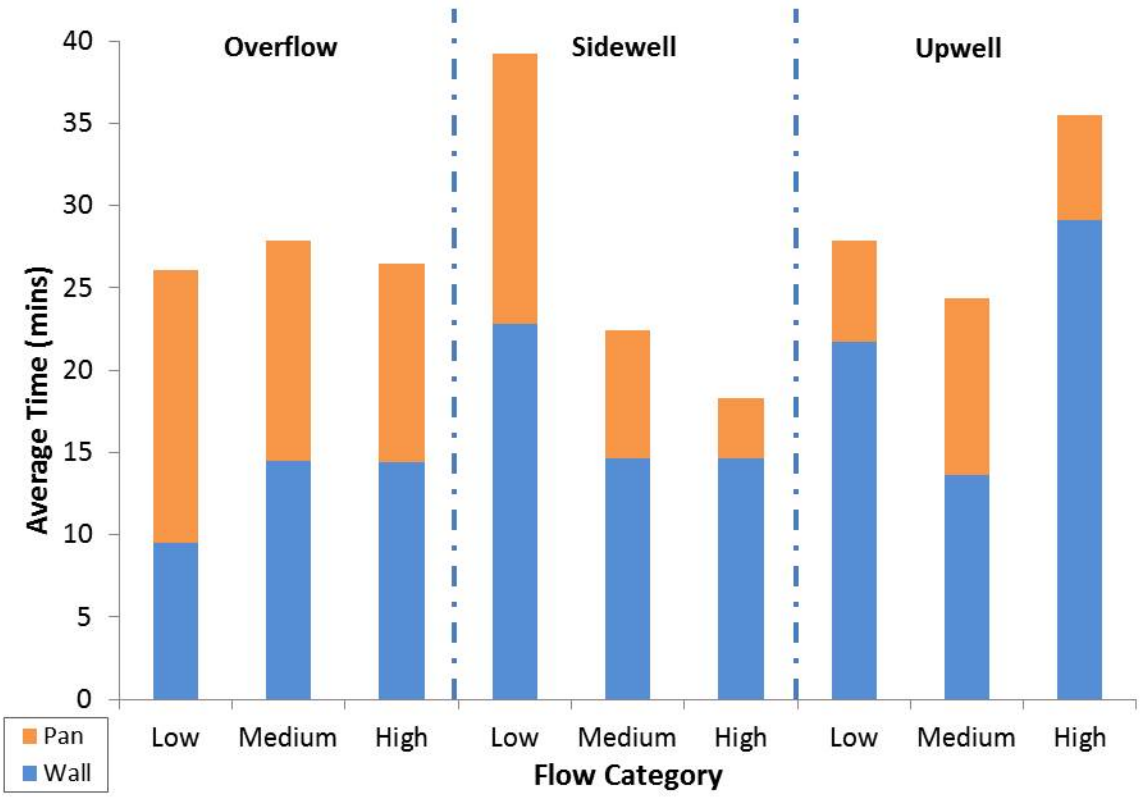

Figure 37. Average time lamprey spent on the vertical wall portion (blue) and upper pan section (orange) of the experimental wetted wall for each water supply type.

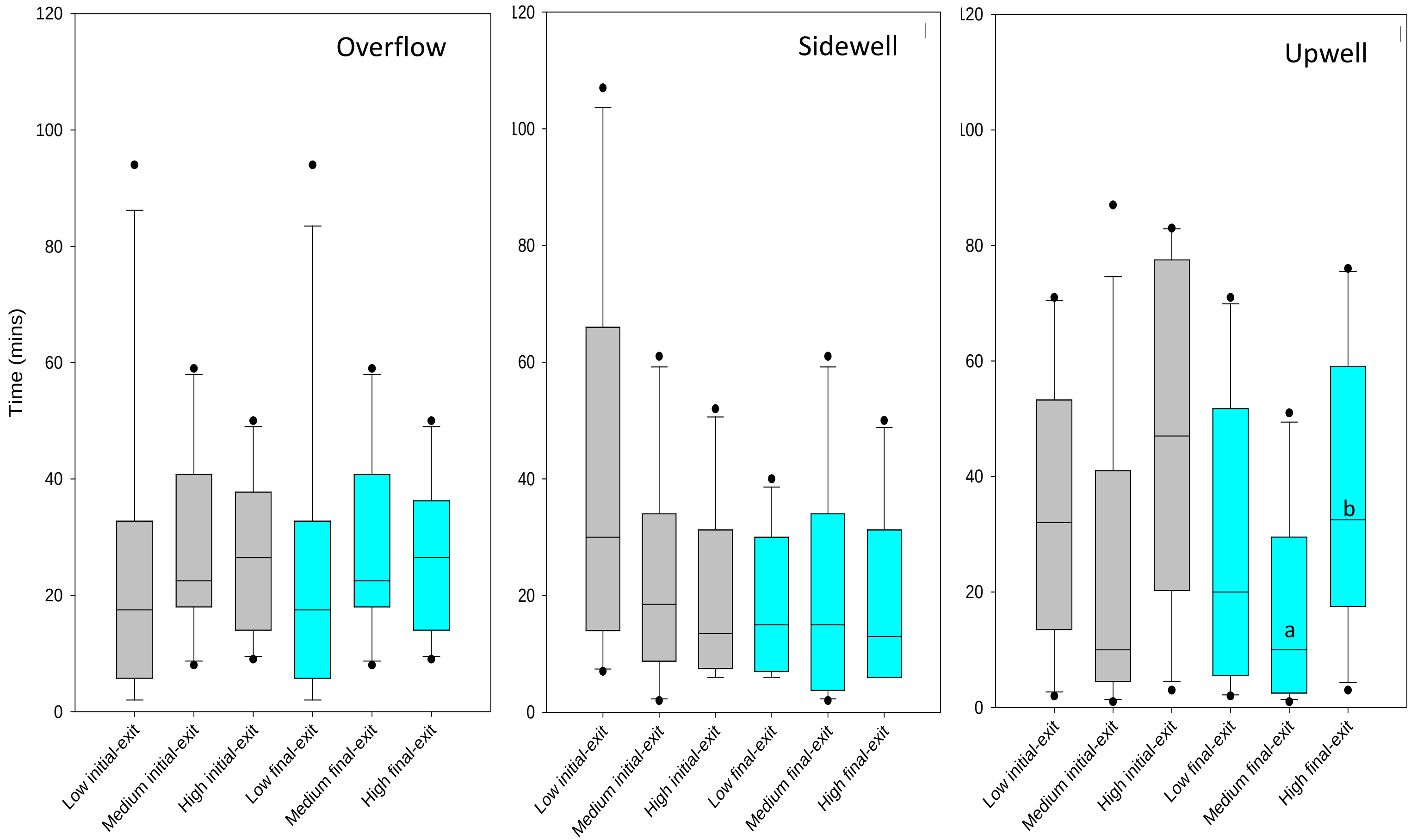

Figure 38. Passage time (min) as a function of water supply type. Reported times are from initial attachment on the climbing structure to final exit (initial-exit) or from final attachment to final exit (final-exit) for low, medium, and high flow treatments. Boxes indicate quartiles, lines indicate median, whiskers indicate 10^{th} and 90^{th} percentiles, and dots (●) indicate 5^{th} and 95^{th} percentiles. Single instance of a significant difference between flow treatments for final attachment to exit within a water supply category is indicated (upwelling).

Discussion

The experimental wetted wall structure was successful at passing lamprey, and its design shows great potential for field applications. Lamprey did not show a strong preference for any flow level or water supply orientation: passage rates and times on the experimental structure were similar amongst treatments. These results indicate that field applications of this structure would likely be successful over a range of potential operational discharges.

Our behavioral observations can be used to inform design improvements. For example, among the conditions tested, we found that a sidewelling water supply of 6-20 gpm (cascading volume) produced the lowest levels of stress response (i.e. thrashing in upper pan, multiple attempts). We recommend this configuration for field testing, as lamprey were quickly attracted to the structure by these flow levels, and passage times were consistently short.

Minor changes to the structural design are recommended. Removal of the perforated plate used for upwelling flows will allow lamprey to attach to the exit point. Repeated reattachment after attempting to traverse the perforated area slowed passage for many individuals across treatments. A longer pan at the crest would improve ease of passage by allowing more of the lamprey body to be immersed for swimming, particularly for larger fish. Removal of the perforated plate would also extend the solid pan surface, as would additional length in construction. Another minor modification would be to extend the dry walls flanking the pan area to prevent accidental exits as fish thrash to begin swimming or attach to the sides in the climbs (we had no such exits, but it was close in some instances).

Fishway installation will require additional modifications to the experimental structure. The prototype wetted wall included a conduit pipe attached at the upstream underwater edge of the vertical surface. This pipe was placed to encourage lamprey to explore the area vertically; such impediments cause upward searching behavior where they exist in fishways elsewhere (M. Moser, personal communication). However, while the underwater conduit may help direct lamprey, it also creates a dead-end climbing avenue when extended above the water surface. Such features should be minimized in future installations.

Additionally, a cover will be needed for the pan area to protect migrating lamprey from bird predation and to create a darker, more welcoming environment. A PIT-tag detection and video monitoring system would be necessary for estimating passage counts and evaluating behavior, respectively, at a wetted wall structure.

Lamprey climbing success from these trials shows that a vertical wetted wall can be a useful component of systems to improve passage for Pacific lamprey. These structures can be used to collect lamprey, particularly from constrained areas, and direct them to alternative passage routes. They may also be useful in guiding lamprey over small barriers or into larger passage systems.

Conclusions and Recommendations

1. At Bradford Island AWS LPS, as in previous years, a significant number of PIT-tagged lamprey detected using the LPS were subsequently detected falling back downstream into the Bradford Island fish ladder exit. This was likely due to configuration of the exit slide, where lamprey enter the forebay only a few meters from the fish ladder exit. Lamprey may be dropped over 2 m from the end of this slide before entering the water at low forebay elevations. To remedy these problems, the exit slide should be extended.

2. Of the PIT-only lamprey released downstream from Bonneville Dam between 2011 and 2014, significant percentages (5-10%) have been detected at the Cascades Island flow-control area. In addition, relatively low proportions (<40%) of these fish have been detected upstream, indicating poor passage success.

   Therefore, we recommend installation of an LPS at the top of the Cascades Island fishway to provide a passage route through the flow-control area, which is presently a dead-end for migrating lamprey. Alternatively, lamprey can be excluded from this channel and forced to find alternate passage routes.

3. Overall, lamprey that use both AWS LPSs are detected at sites upstream from Bonneville Dam in lower percentages than those that use a traditional fishway. Lamprey that pass using an LPS tend to be smaller than those that pass via a traditional fishway, so they represent a different subset of the population.

   The LPS may provide a feasible route of passage for small fish that would otherwise have been unsuccessful in passing the dam, though it remains unknown if LPS use increases or decreases fitness. However, there may be a fitness cost to lamprey use of the LPS. Further research is needed to ensure that LPS use does not incur any loss in reproductive potential for lamprey that choose this passage route.

4. Improvements to the design of mechanical exit tubes and doors could reduce periods of counter outage and over-counting, particularly at LPSs that pass high numbers of lamprey. Tests of an electrical impedance counter alternative for monitoring lamprey passage were not promising. This leaves labor-intensive video monitoring as an alternative that could be accurate and avoid the mechanical problems of the counter system, which are subject to damage during lamprey passage.

Digital video systems could be used to periodically observe behavior at LPS exits and to validate passage estimation by mechanical pulse counting systems. Use of weatherproof digital video systems that have adequate data storage capacity and are powered by reliable sources will be required to record LPS exits throughout the migration season.

5. Experimental testing is needed to determine the optimal angle and material for LPS exit slides. Improvements to these exit slides would increase lamprey exit efficiency and the performance of passage estimation systems. Findings could be incorporated to current and future LPS design criteria.

6. Within exit slides, 100% of the surface should be lined with rolled, perforated plate to remove surfaces to which lamprey can attach.

7. If electrical impedance is to be pursued as a method for LPS passage estimation, trials should be conducted using an experimental LPS exit slide that has variable angle settings. The manufacturer should be consulted to customize counting and detection equipment specifically for Pacific lamprey. Designs incorporating high slope exit and lower slope counting sections could be considered.

8. We recommend that LPS count systems be powered by consistent sources of AC power.

9. The capacity of present LPS designs is unknown. If lamprey abundance increases, the number of lamprey using LPSs will put new demands on these systems, particularly the counting systems. Future research should be directed towards determining the maximum capacity of an LPS and the potential need for multiple lamprey-specific passage routes in areas where these fish concentrate in large numbers.

10. Pilot testing of lamprey refuges near the top of the Washington Shore ladder showed great promise. Lamprey clearly found and used these refuges in spite of their small footprint. Additional testing using fish tagged with both radio and PIT tags could improve our understanding of the relative passage metrics of lamprey that use fishway refuges vs. those that do not.

    In addition, video monitoring is needed to establish the actual number of lamprey that enter refuges and whether refuge entry is density dependent. Video monitoring could also provide information on potential effects of lamprey refuges on salmonids and other fishway occupants.

11. In addition to trapping results from 2012 and 2013, detections of PIT-tagged lamprey released downstream from Bonneville Dam between 2007 and 2013 have indicated that high numbers of migrating lamprey accumulate at the Cascades Island makeup water supply channel. Despite efforts to inhibit movement into this channel, high numbers of lamprey were trapped there in 2014, and efforts to determine the route of continued entry to this channel are warranted.

    To improve lamprey passage at Bonneville Dam, we recommend that either further steps be taken to exclude fish from the makeup water supply channel or that an LPS be provided to create an outlet to the forebay for fish that access this channel.

    Alternatively, lamprey should be actively trapped and transported upstream throughout the migration period. Trap-and-haul operations should be conducted from May to October. Modifications made during the 2014-2015 dewatering period may have addressed this issue, but trapping effort is needed to provide upstream passage for any trapped lamprey.

12. For the trap operators at John Day Dam, it is important to note that when the trap is operated in pass-through mode, the entrance gate to the trap box must be open and the bypass panel must be removed. Otherwise lamprey will fall back and be delayed.

    When video evaluations are in progress, operators at this trap must also remember to untether the cable from the camera before recovering the trap box, and to restore the cable before re-deploying the trap box. To prevent this problem, the camera system should be upgraded to a wireless system.

13. The lamprey trap in the John Day south fishway should be modified to improve retention and passage of fish when operated in pass-through mode. Provision of an attachment surface may encourage lamprey to enter the trap with less hesitation. A one way flange-type valve may prevent lamprey from exiting the trap downstream through the entrance port.

14. Experiments with a wetted wall showed that lamprey will climb a vertical wall and exit successfully at any of the flow sources or levels tested. Of the conditions we tested, a sidewelling water supply of 6-20 gpm (low-medium) is recommended for field testing based on behavioral observations in addition to passage-time results. A prototype wetted wall with monitoring capability should be designed and tested at a fishway-to-AWS junction at Bonneville Dam.

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Appendix: Operation Manuals for Bonneville Lamprey Passage Structures

Lamprey Passage Structure (LPS) Operations Manual

Washington Shore Auxiliary Water Supply Channel (AWS) Bonneville Dam

Provided by

Northwest Fisheries Science Center, National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East, Seattle, WA 98112

for

Portland District, U.S. Army Corps of Engineers
P.O. Box 2946, Portland, OR, 97020
Contract E96950021

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Contents

Overview

Pacific lamprey *Entosphenus tridentatus* exhibit relatively low passage efficiency through traditional fishways at Bonneville Dam (Keefer et al. 2013). Lamprey-specific fishways were designed to provide separate passage routes suited to lamprey climbing capabilities (Moser et al. 2011). These structures are operated independently from traditional fishways. This manual is intended to provide information on the background, location, schematics, operation, and maintenance of the lamprey passage structure (LPS) at the Washington Shore auxiliary water supply channel (AWS) at Bonneville Dam.

Washington Shore LPS Configuration

The Washington Shore AWS LPS was installed at Bonneville Dam in 2007 (Moser et al., 2010). Its entrance is located in the upstream end of the auxiliary water supply (AWS) channel at the top of the Washington Shore fishway (Figure 1) to afford a passage route out of this dead-end channel where lamprey congregate.

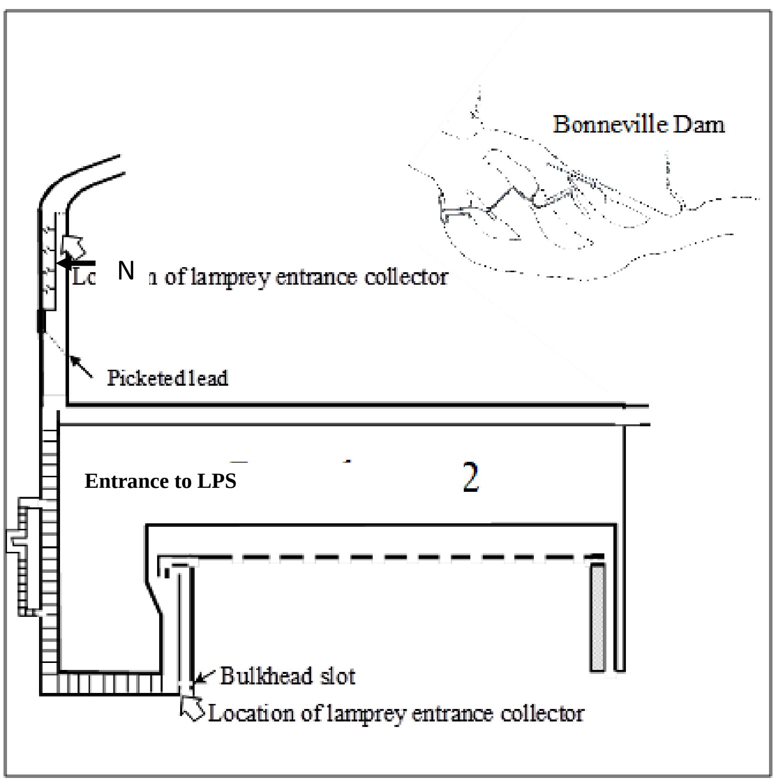

Figure 1. Schematic drawing of Washington Shore fishway at Bonneville Dam. Location of the Washington Shore AWS LPS is indicated by the white arrow.

This LPS consists of two pumps that deliver water to the structure, the structure itself, and an automated counter that records lamprey passage events. All ramps in the Washington Shore LPS are 51 cm wide and have a slope of 45 degrees. The structure is generally operated from 1 May to 15 September each year and is relatively maintenance-free.

Overall length of the LPS is approximately 19 m, with an elevation gain of 9.1 m. The Washington Shore LPS features a switchback design to provide greater elevation gain in a smaller area (Figure 2), with a broad crest at the top of each ramp. The structure is accessed via two 51-cm-wide collector ramps that converge at Rest Box 1 (Figure 3). The climbing ramps ascend in switchback fashion to Rest Boxes 2 and 3, with a PIT antenna (PIT 1) located just downstream from Rest Box 2. The entrance into each rest box is fitted with a one-way plastic mesh fyke to prevent lamprey from moving back downstream within the LPS.

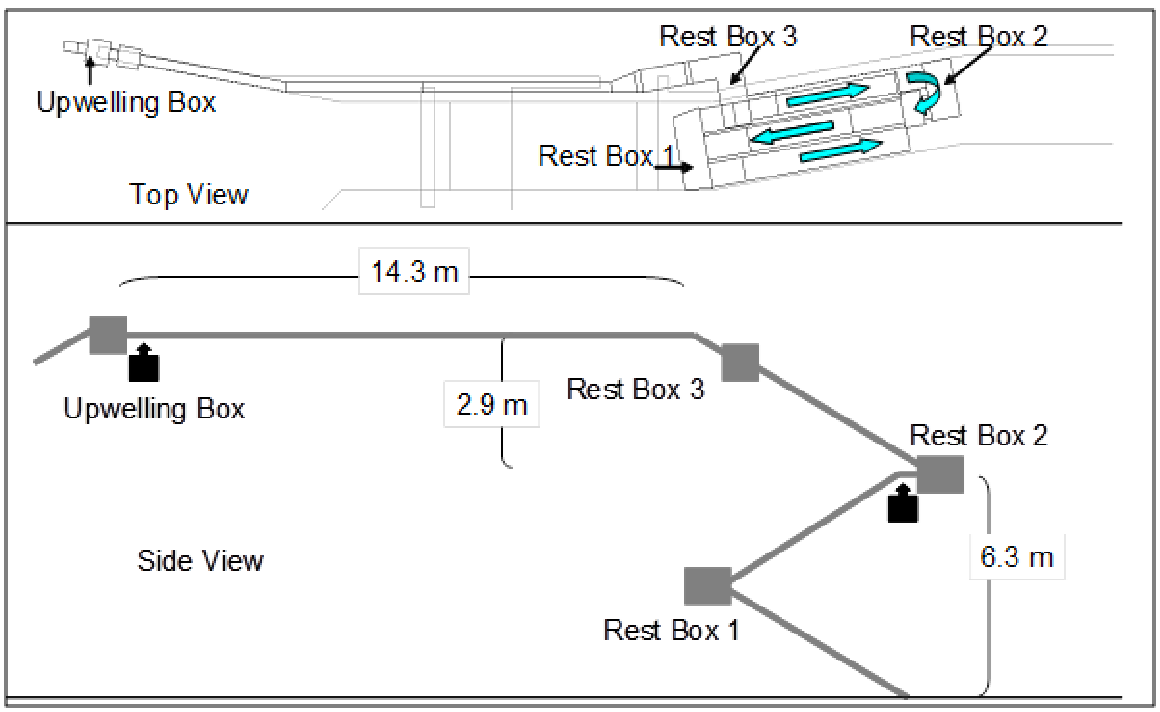

Figure 2. Upper panel shows top view and lower panel side view of lamprey passage structure in the Washington Shore AWS. Shaded arrows indicate direction of flow on switchback ramps. Black boxes indicate positions of half-duplex PIT antennas.

Finally, a long, horizontal flume (20.3 cm wide) outfitted with a PIT antenna (PIT 2) leads to an upwelling box fitted with a PVC exit slide (Figure 3f). The exit slide deposits lamprey down a steep chute (51°) into the Washington Shore fishway approximately 50 m downstream from the fishway exit. The exit slide terminus is outfitted with a fish-activated paddle to count lamprey passing via this route. Detail on dimensions for all components of this LPS are reported by Zobott et al. (in press).

Figure A3. Photos of Washington Shore lamprey passage structure showing ramps converging at Rest Box 1 (a), Rest Box 1 (b), switchback at Rest Box 2 (c), Rest Box 3 (d), upwelling box (e), and exit slide (f).

Lamprey use of the LPS is monitored using lamprey tagged with passive integrated transponder (PIT) tags. Two half-duplex PIT-monitoring antennas are integrated into the structure (Figure 2). To accommodate antennas, a rectangular PVC sleeve was seamlessly inserted into the chutes leading to Rest Box 2 and the terminal upwelling box. The PVC sleeve was needed to prevent the aluminum chute from attenuating PIT signals. Each antenna is comprised of a loop of 10-gauge, multistrand wire wrapped around the PVC sleeve and an outer aluminum housing that acts as a Faraday cage to shield the antenna. This antenna can be connected to a half-duplex PIT transceiver.

Columbia River water is supplied at the top of the LPS via a 10.2-cm-diameter PVC pipe from two, 3-hp submersible pumps. Flow is regulated by an upwelling box at the top of the LPS. This design stimulates lamprey to move onto the exit slide, even though water is passing down the slide. Pump intakes are located in the Washington Shore AWS channel immediately downstream from the Tainter gate. Flow into the upwelling box is regulated to maintain a depth of 3 cm on the ramps and approximately 10 cm in the closed flumes.

Detailed below are instructions for start-up, in-season maintenance, and winter shut down of the LPS and counter. A specification list of parts for the structure and counter system is provided in Table A1, and an electrical wiring diagram of the overall system is shown in Figure A7.

Operations Checklist

Start-Up

1. Visual inspection

   a. Examine LPS for structural integrity and evidence of weakness. Remove debris. Check turns, joints, connections to walls, plastic fyke integrity in rest boxes, cracking in PVC piping. Replace components as necessary.

   b. Pressure wash and scrub algae off of exposed ramp sections. Use no detergent.

2. Close discharge valves at all upwelling and rest boxes

Mostly PVC ball valves, white with orange/red handles (Figure A4).

3. Clean and service pumps and intake screens

See Table A1 for part and system specifications

4. Make sure pump components are connected and pump intakes are submerged

5. Power up pumps and ensure appropriate water levels

   a. Ramp water level: 3 cm

   b. Flume water level: 10 cm

   c. Upwelling box water level: until fyke is at least partially submerged

   d. Exit slide water level: 2 cm. Adjust with valve beneath exit slide (Figure A5)

   e. If water level is insufficient in system, make sure both pumps are operating, check intake screens to make sure they are not plugged, check for cracks in hosing/pipe

6. Count system initiation

   a. Download current version of RTR-500 for Windows software to a laptop computer (http://www.tandd.com/product/rtr500/support.html)

   b. Plug in power supply from gray electrical box at LPS exit (Figure A6) to nearby AC outlet. Turn on power strip switch.

   c. Ensure green light is on for network base station (RTR500-NW; Figure A6), indicating it is powered

   d. Replace battery at wireless data recorder (RTR-505P; special order tubed lithium battery LS14250), ensure that digital display is visible (Figure A6b)

   e. Physically engage the paddle door. Check that wireless data recorder advances by the number of times the paddle was engaged. Adjust paddle arm tension if necessary.

   f. Conduct test download of network base station

Figure A4. Discharge valve at Washington Shore AWS LPS upwelling box.

Figure A5. Discharge valve at exit slide of Washington Shore AWS LPS.

In-Season Maintenance

All in-season maintenance and system manipulations should be conducted during daylight hours when lamprey are less active.

1. **Visual inspection (daily)**
   a. Check rest boxes and flumes for dead lamprey and debris
      The Washington Shore LPS has more mortalities than other structures due to high lamprey use. It is critical that mortality checks be conducted daily.
   b. Check water level and flow
      When adjusting flow for system functionality, pay careful attention to water levels in the exit slide. A constant water level through the exit slide is required to ensure accurate counts (2 cm).

2. **Count system operation and maintenance**
   a. Daily: ensure that system is powered as GFI gets tripped frequently. Check power to base station and check for visible LCD on remote pulse recorder (Figure A6).
   b. Daily: visually check connection between exit paddle and limit switch (Figure A5).
   c. Weekly: count validation (more frequently if needed to investigate count problems)
      Physically deflect the counter arm, and note time and number of intended deflections. Remove validation records from the reported lamprey count.
   d. Daily: download pulse counter data
      i. Open RTR-500 for Windows software on laptop
      ii. Select RTR-500 for Windows icon
      iii. Connect laptop to network base station via USB cable
      iv. From *Communication* tab, select *Download data* (USB)
      v. Name file with LPS name and date/time of download. File extension should be *trz*
   e. Daily: view pulse counter data
      i. Open RTR-500 for Windows software
      ii. Select *multi-scale graph* icon
      iii. From *file* tab, select *open*
      iv. Select *.trz file that you want to view
      v. Examine file for detections across the expected period of operation. Verify presence of validation events. Confirm that count meets approximate expectation for number of lamprey based on timing within the migration season. NOTE: if count is low elative to expectations, re-examine LPS and count system.
      vi. Collected pulse data is viewed in graph and table form using the manufacturer's software (RTR-500 for Windows). A total passage estimate, minus validation events, is reported for the daytime (0500-2100) and nighttime (2100-0500) periods of each date, as per USACE reporting convention.

In-Season Maintenance (continued)

3. Exit slide maintenance (as needed)

a. Because of the steepness of the Washington Shore LPS exit slide and the large number of lamprey using this passage route, daily inspection and maintenance of the exit slide and count system is critical. Maintenance can be done from the forebay deck.

b. Discharge valve. Open discharge valve to decrease water level in exit slide; close valve to increase water level in exit slide.

c. Limit switch-to-paddle connection. Troubleshoot. Common possibilities: replace limit switch, adjust arm tension, reposition paddle.

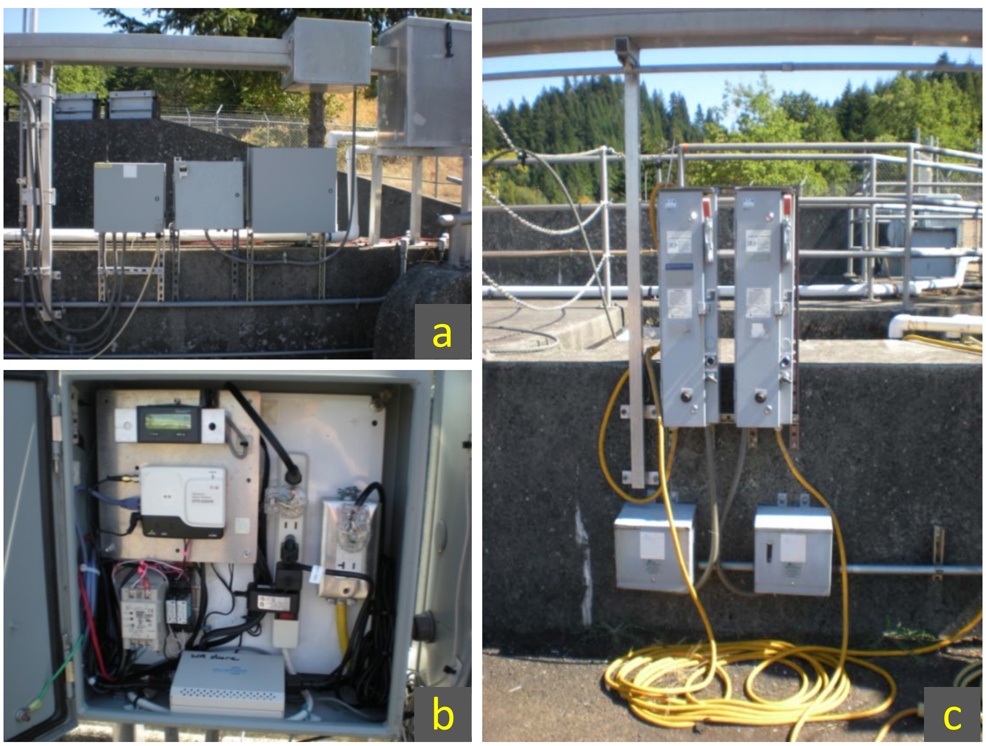

Figure A6. System controls at electrical box (a-b) and pump panels (c) for Washington Shore AWS LPS.

Shut Down

1. Inspect system for lamprey. Remove fish before proceeding.

2. Power off pumps. Winterize pumps if end of season.

3. Open discharge valves at all upwelling and rest boxes (1 upwelling box, 3 rest boxes at Washington Shore LPS)

4. Download count equipment. Turn off power strip switch. Unplug power cord for count systems.

Parts List

Table A1. Description of parts for lamprey count system and lamprey passage structure (LPS) with details relevant to passage estimation and operation.

Lamprey Passage Count Estimate System			
Item (quantity)	Description	Manufacturer	Model/part no.
Pulse counting data logger (1)	Wireless, remote unit	TandD Corp.	RTR-505P
Network base station (1)	Wireless with network relay	TandD Corp.	RTR-500NW
Limit switch (1)	Enclosed, SPDT (single pole double throw), adjustable rod	Honeywell	PK80112
	Corrosion-resistant	McMaster-Carr	65785K15
Count system communication software (1)	RTR-500 for Windows	TandD Corp.	16607060014

Lamprey Passage Structure			
Item (quantity)	Description	Manufacturer	Model/part no.
Junction box (1)	Two 480-V, 30-amp circuits	Crouse-Hinds	
Receptacle assembly	30-amp, 600-V connecting plug and receptacle for pumps (2)	Crouse-Hinds	AR342 or similar
Plug and receptacle	2-plug connector	Daniel Woodhead	28W76 or 29W76
Transition pond sump pump (1)	120-V, 9.5-amp	McMaster-Carr	42935K15
Submersible pump motor (2)	3-hp, 230-V, 3-phasep FLA 10.9 #75GS30	Goulds	M30432
Submersible pump (2)	3-hp, 75-GPM	Goulds	75GS30
Pump panel (2)	NEMA size1, motor-circuit protector (HMCP), 240-V, 3-phase	Cutler-Hammer	ECN5512BAE-E14
Heater (1)	3-pack with overload relay	Cutler-Hammer	H2011B-3
Transformer for pump (2)	6-KVA, 3-phase, 480/240-V	Acme	T-2A-53329-1S
Water-resistant cord (1)	10/4 SEOW	Grainger	2TYJ9

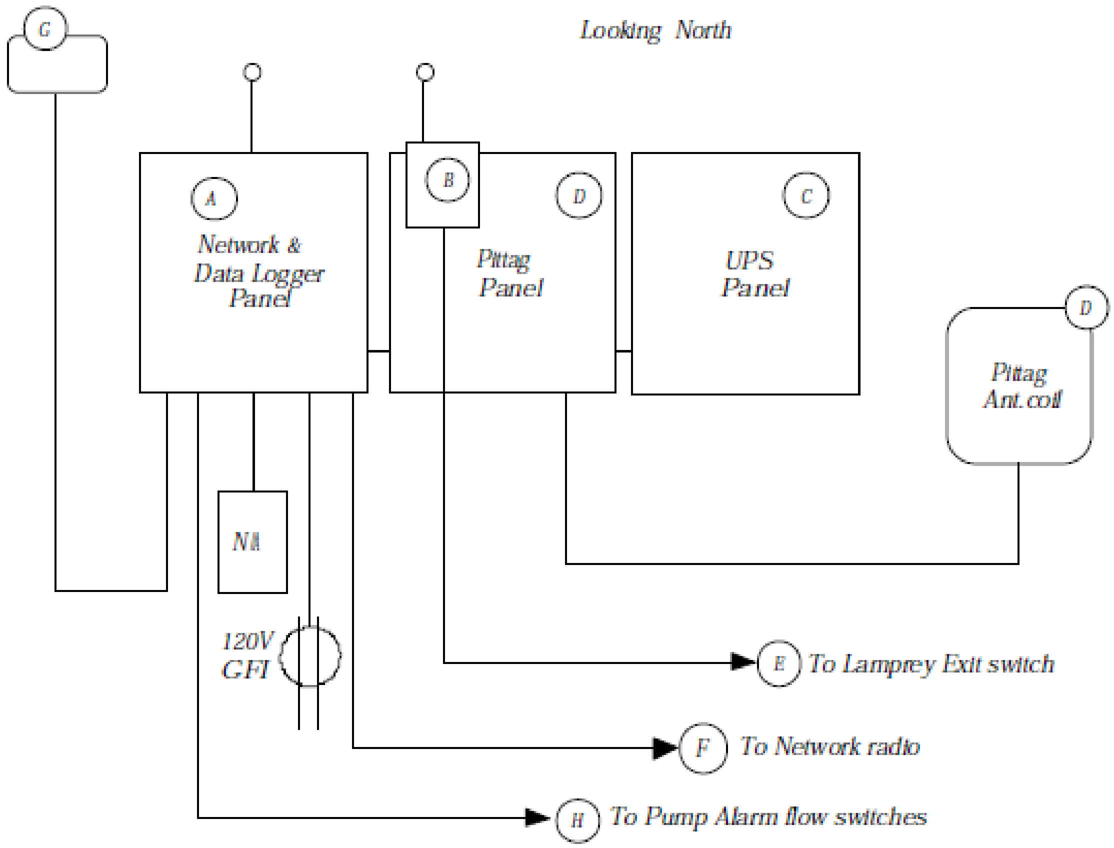

Figure A7. Wiring diagram showing electrical panels for lamprey passage structure (LPS) at the Washington Shore auxiliary water supply channel (AWS) at Bonneville Dam. See Figure 6a for photo of electrical box.

Lamprey Passage Structure (LPS) Operations Manual

Bradford Island Auxiliary Water Supply Channel
Bonneville Dam

Provided by

Northwest Fisheries Science Center, National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East, Seattle, WA 98112

for

Portland District, U.S. Army Corps of Engineers
P.O. Box 2946, Portland OR 97020
Contract E96950021

September 2015

Contents

Overview

Pacific lamprey *Entosphenus tridentatus* exhibit relatively low passage efficiency through traditional fishways at Bonneville Dam (Keefer et al. 2013). Lamprey-specific passage structures were designed to provide separate passage routes suited to lamprey climbing capabilities (Moser et al. 2011). These structures are operated independently from traditional fishways. This manual is intended to provide information on the background, location, schematics, operation, and maintenance of the lamprey passage structure (LPS) in the auxiliary water supply channel at Bradford Island.

Bradford Island LPS Configuration

Installed in 2004, the Bradford Island LPS was the first lamprey-specific passage structure at Bonneville Dam (Moser et al. 2006). Its entrance is located at the upstream end of the auxiliary water supply (AWS) channel at the top of the Bradford Island fishway (Figure B1). This location affords passage from an otherwise dead-end channel where lampreys have been observed to congregate (Figure B2).

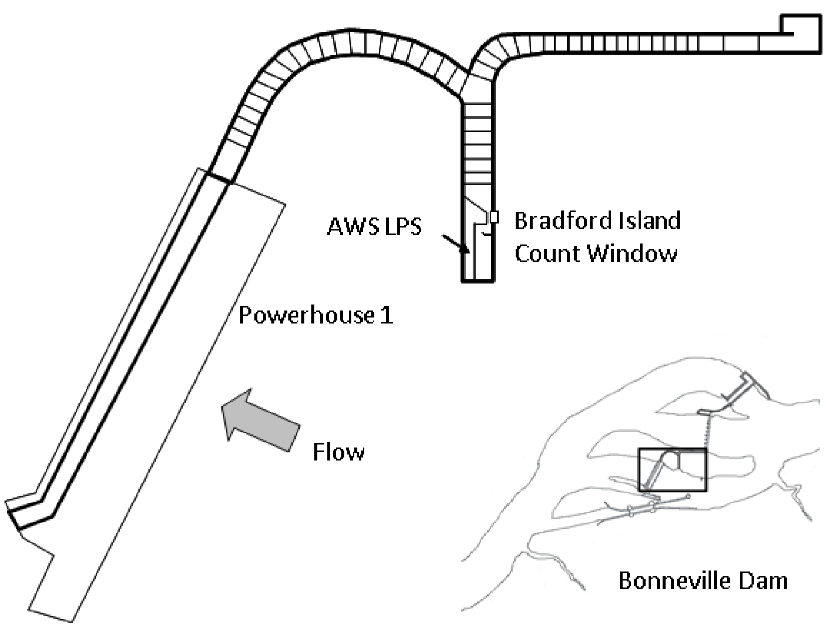

Figure B1. Schematic drawing of Bradford Island fishway system at Bonneville Dam. The location of the Bradford Island AWS is indicated by the black arrow.

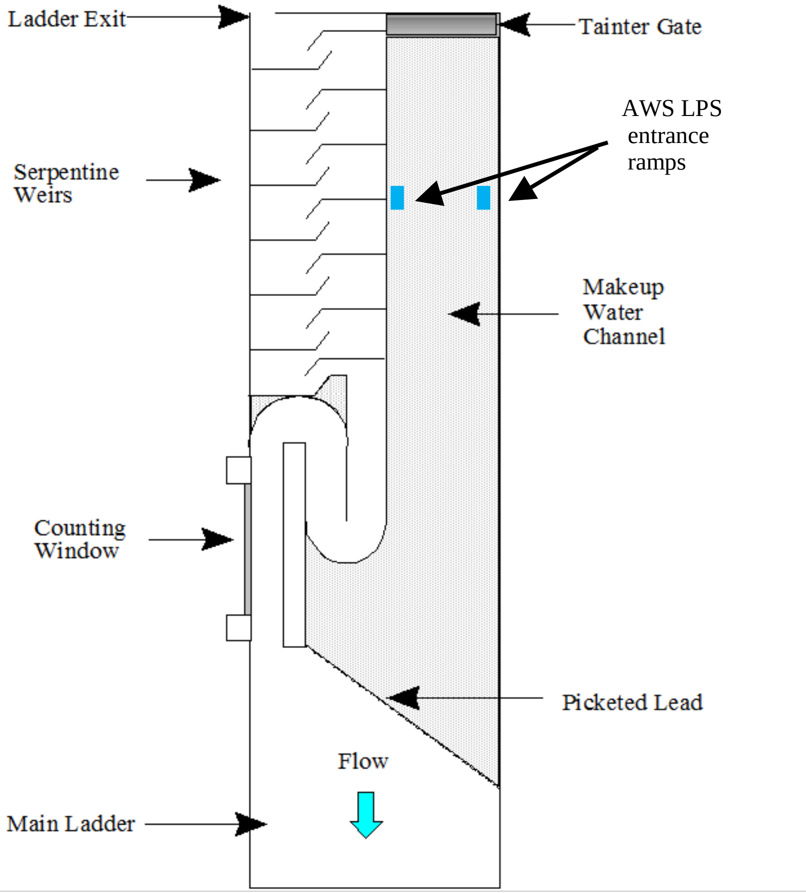

Figure B2. Overhead schematic drawing of the Bradford Island fishway and location of AWS LPS entrances.

The Bradford Island LPS consists of two pumps that deliver water to the structure, the structure itself, and an automated counter that records lamprey passage events. The structure is typically operated from 15 May to 15 September each year and is relatively maintenance-free.

Overall horizontal distance of the LPS is approximately 35.6 m, and elevation gain is 7.9 m. Lamprey access the structure via two 51-cm wide collector ramps, and each ramp is monitored by passive integrated transponder (PIT) detection antenna (PIT 1 and PIT 2). The two collector ramps converge at Rest Box 1 (Figure B3a-b). A short ramp with a broad-crested weir ascends to Rest Box 2, a large rest box (Figure B3c). The structure then progresses up another short ramp monitored by a third PIT antenna (PIT 3) just downstream from Rest Box 3. A shallow ramp and a long horizontal flume (20.3 cm wide) connect to Rest Box 3 to Rest Box 4 (Figure B4).

Figure B3. Photos of LPS installation in the Bradford Island AWS channel: a) dual collection ramps, b) access platform, and c) short ramp leading to large second rest box.

The entrance into each rest box is fitted with a one-way plastic mesh fyke to prevent lamprey within the structure from moving back downstream. The final leg of the Bradford Island LPS includes a short ramp and a long horizontal flume monitored with a final PIT antenna (PIT 4; Figure B5). At the LPS terminus, lamprey enter an upwelling box fitted with a PVC exit slide, which releases them into the Powerhouse 1 forebay approximately 10 m upstream from the Bradford Island fishway exit. The terminus of the exit slide is outfitted with a fish-activated paddle to count lamprey passing via this route. Complete details on all physical components of the Bradford Island LPS were reported by Moser et al. (2006).

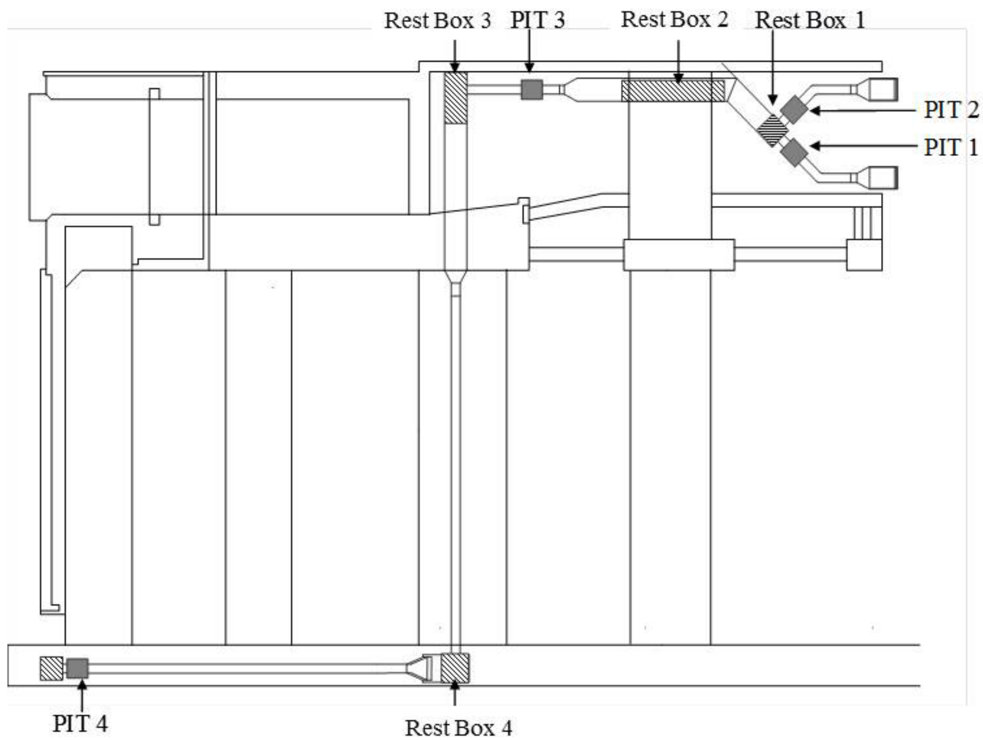

Figure B4. Schematic overhead view of Bradford Island AWS LPS with rest boxes and PIT detector locations indicated.

Use of the LPS by tagged lamprey is monitored with a series of four half-duplex PIT antennas integrated into the design (Figure B4). At each antenna location, a rectangular PVC sleeve is seamlessly inserted into the chute leading to the rest box. The PVC sleeves are needed to prevent the aluminum chute from attenuating PIT signals. Each antenna is comprised of a loop of 10-gauge multistrand wire wrapped around the PVC sleeve with an outer aluminum housing that acts as a Faraday cage to shield the antenna. This antenna can be connected to a half-duplex PIT transceiver.

Columbia River water is supplied to the top of the LPS via a 10.2-cm-diameter PVC pipe from two, 3-hp submersible pumps. Flow is regulated from an upwelling box at the top of the LPS. This design stimulates lamprey to move onto the exit slide, even though water is passing down the slide. Pump intakes are located in the dam forebay approximately 5 m downstream from the Bradford Island fishway exit. Flow into the upwelling box is regulated to maintain depths of 3 cm on the ramps and approximately 10 cm in the closed flumes.

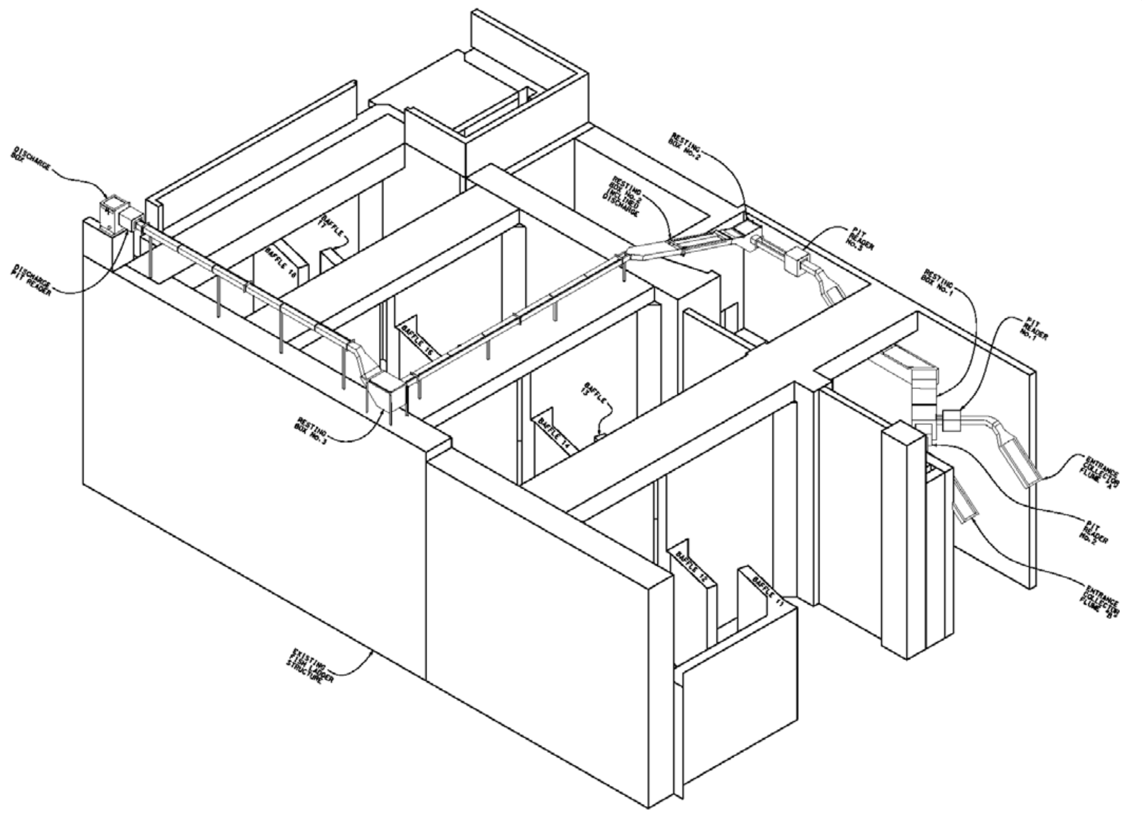

Figure B5. Schematic drawing of the Bradford Island AWS LPS (three dimensional view created by Michael Crump, U.S. Army Corps of Engineers).

In the following sections, we provide procedural instructions and for start-up, in-season maintenance, and winter shut down of the Bradford Island lamprey passage structure and counter system. Specifications for all components of the pump and counter are provided in Table B1, and a wiring diagram for the entire system is shown in Figure B11.

Operations Checklist

Start up

1. **Visual inspection**

   a. Examine LPS for structural integrity and evidence of weakness. Remove debris. Check turns, joints, connections to walls, plastic fyke integrity in rest boxes, cracking in PVC piping. Replace components as necessary.

   b. Pressure wash and scrub algae off of exposed ramp sections. Use no detergent.

2. **Close discharge valves at upwelling box and all rest boxes**

   Mostly PVC ball valves, white with orange/red handles (Figures B6-B7).

3. **Clean and service pumps and intake screens**

   See Table B1 for system parts specifications

4. **Make sure pump components are connected and pump intakes are submerged**

5. **Power up pumps and ensure appropriate water levels**

   a. Ramp water level: 3 cm

   b. Flume water level: 10 cm

   c. Upwelling box water level: until fyke is at least partially submerged

   d. Exit slide water level: 2 cm, adjust with valve beneath exit slide (Figure B7)

   e. If water level is insufficient, ensure both pumps are operating, check that intake screens are not plugged, check for cracks in hosing/pipe

6. **Count system initiation**

   a. Download current version of RTR-500 for Windows software to a laptop computer (http://www.tandd.com/product/rtr500/support.html)

   b. Plug in power supply from gray electrical box (Figures B8-B9) at LPS exit to nearby AC outlet. Turn on power strip switch.

   c. Ensure green light is on for network base station (RTR500-NW; Figure B8), indicating it is powered

   d. Replace battery at wireless data recorder (RTR-505P; special order tubed lithium battery LS14250), ensure that digital display is visible (Figure B9)

   e. Physically engage paddle door. Check that wireless data recorder advances by the number of times the paddle was engaged. Adjust paddle arm tension if necessary.

   f. Conduct test download of network base station.

Figure B6. Example of a discharge valve at a rest box.

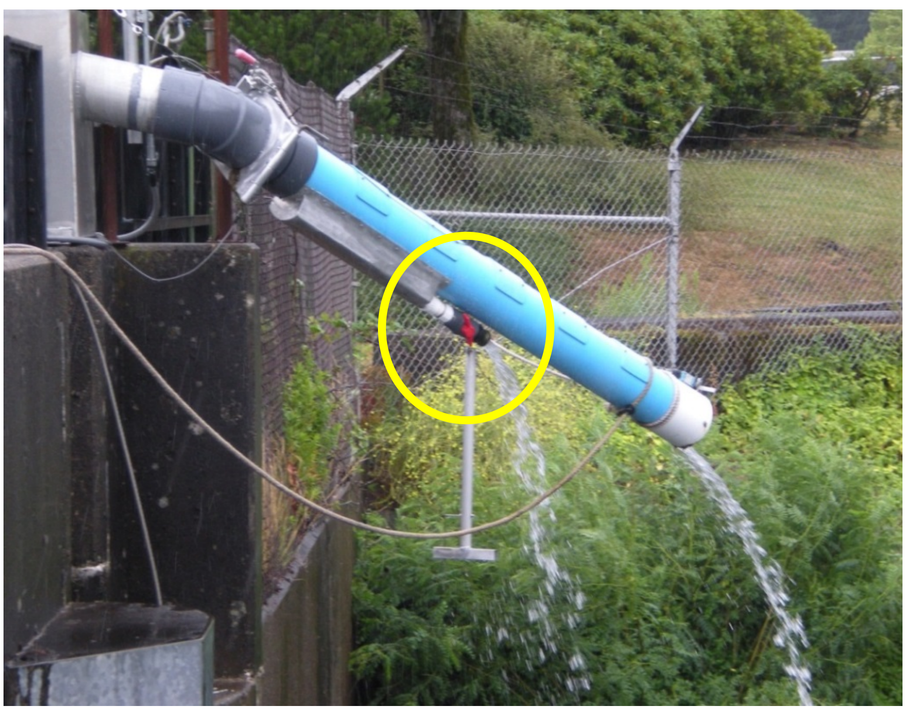

Figure B7. Discharge valve at Bradford Island LPS exit slide.

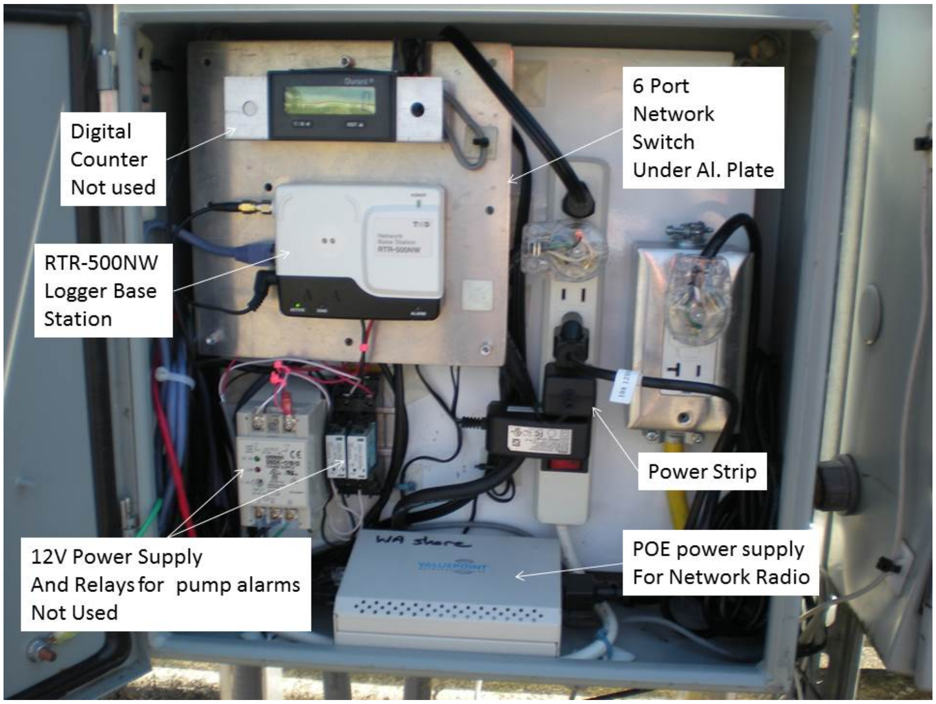

Figure B8. Electrical box with components labeled.

Figure B9. Wireless data recorder, RTR-500.

In-Season Maintenance

All in-season maintenance and system manipulations should be conducted during daylight hours when lamprey are less active.

1. Visual inspection (daily)

a. Check rest boxes and flumes for dead lamprey and debris

b. Check water level and flow
Pump intake screens of Bradford Island LPS are particularly susceptible to clogging during times of high run-off. Regular screen maintenance is critical. Whenever flow is adjusted, check water levels in the exit slide. Accurate counting relies on a constant water level through the exit slide (2 cm).

2. Count system operation and maintenance

a. Daily: ensure system is powered, as GFI gets tripped frequently. Check power to base station and check for visible LCD on remote pulse recorder (Figure B8).

b. Daily: visually check for intact connection between exit paddle and limit switch (Figure B10).

c. Weekly: count validation (more frequently if needed to investigate count problems) Physically deflect the counter arm and note time and number of intended deflections. Remove validation records from the reported lamprey count.

d. Download pulse counter data (daily)

i. Open RTR-500 for Windows software on laptop

ii. Select RTR-500 for Windows icon

iii. Connect laptop to the network base station via USB cable

iv. From *Communication* tab, select *Download data* (USB)

v. Name file with LPS name and date/time of download. File extension should be .trz

e. View pulse counter data (daily)

i. Open RTR-500 for Windows software

ii. Select multi-scale graph icon

iii. From *File* tab, select *Open*

iv. Select *.trz file that you want to view

v. Examine file for detections across the expected period of operation. Verify presence of validation events. Confirm that count meets approximate expectation for number of lamprey based on timing within the migration season. NOTE: If count is low relative to expectations, re-examine the LPS and count system.

vi. Collected pulse data is viewed in graph and table form using the manufacturer's software (RTR-500 for Windows). A total passage estimate, minus validation events, is reported for the daytime (0500-2100) and nighttime (2100-0500) periods of each date, as per USACE reporting convention.

In-Season Maintenance (continued)

3. Exit slide maintenance (as needed)

a. The Bradford Island LPS exit slide is built with a retractable hinged mechanism that allows the terminal region to be accessed from the forebay deck (Figure 10) for in-season inspection and maintenance of the paddle, door, and limit switch.

i. Disconnect hinge lock (Figure 10b). Pull ropes to bring exit slide to deck.

ii. Stabilize structure before conducting work

iii. Reverse procedure to replace

b. Discharge valve. Open to decrease water level in exit slide; close to increase water level in exit slide.

c. Limit switch-to-paddle connection. Troubleshoot. Common possibilities: replace limit switch, adjust arm tension, reposition paddle.

Figure B10. Retractable exit slide of Bradford Island LPS showing slide deployed (a), hinge closed (b), hinge open (c), and slide retracted (d).

Shut Down

1. **Inspect system for lamprey**

   Remove fish before proceeding.

2. **Power off pumps**

   Winterize pumps if end of season

3. **Open discharge valves at upwelling and rest boxes**

   Bradford Island LPS has 1 upwelling box and 4 rest boxes

4. **Download count equipment**

   Turn off power strip switch. Unplug power cord for count systems.

Parts List

Table B1. Description of parts for lamprey count system and lamprey passage structure (LPS) with details relevant to passage estimation and operation.

Lamprey Passage Count Estimate System			
Item (quantity)	Description	Manufacturer	Model/part no.
Pulse counting data logger (1)	Wireless, remote unit	TandD Corporation	RTR-505P
Network base station (1)	Wireless with network relay	TandD Corporation	RTR-500NW
Limit switch (1)	Enclosed, SPDT (single pole double throw), adjustable rod	Honeywell	PK80112
	Corrosion-resistant	McMaster-Carr	65785K15
Count system communication software (1)	RTR-500 for Windows	TandD Corporation	16607060014

Lamprey Passage Structure			
Item (quantity)	Description	Manufacturer	Model/part no.
Junction box (1)	Two 480-V, 30-amp circuits	Crouse-Hinds	
Receptacle assembly	30-amp, 600-V connecting plug and receptacle for pumps (2)	Crouse-Hinds	AR342 or similar
Plug and receptacle	2-plug connector	Daniel Woodhead	28W76 or 29W76
Transition pond sump pump (1)	120-V, 9.5-amp	McMaster-Carr	42935K15
Submersible pump motor (2)	3-hp, 230-V, 3-phasep FLA 10.9 #75GS30	Goulds	M30432
Submersible pump (2)	3-hp, 75-GPM	Goulds	75GS30
Pump panel (2)	NEMA size1, motor-circuit protector (HMCP), 240-V, 3-phase	Cutler-Hammer	ECN5512BAE-E14
Heater (1)	3-pack with overload relay	Cutler-Hammer	H2011B-3
Transformer for pump (2)	6-KVA, 3-phase, 480/240-V	Acme	T-2A-53329-1S
Water-resistant cord (1)	10/4 SEOW	Grainger	2TYJ9

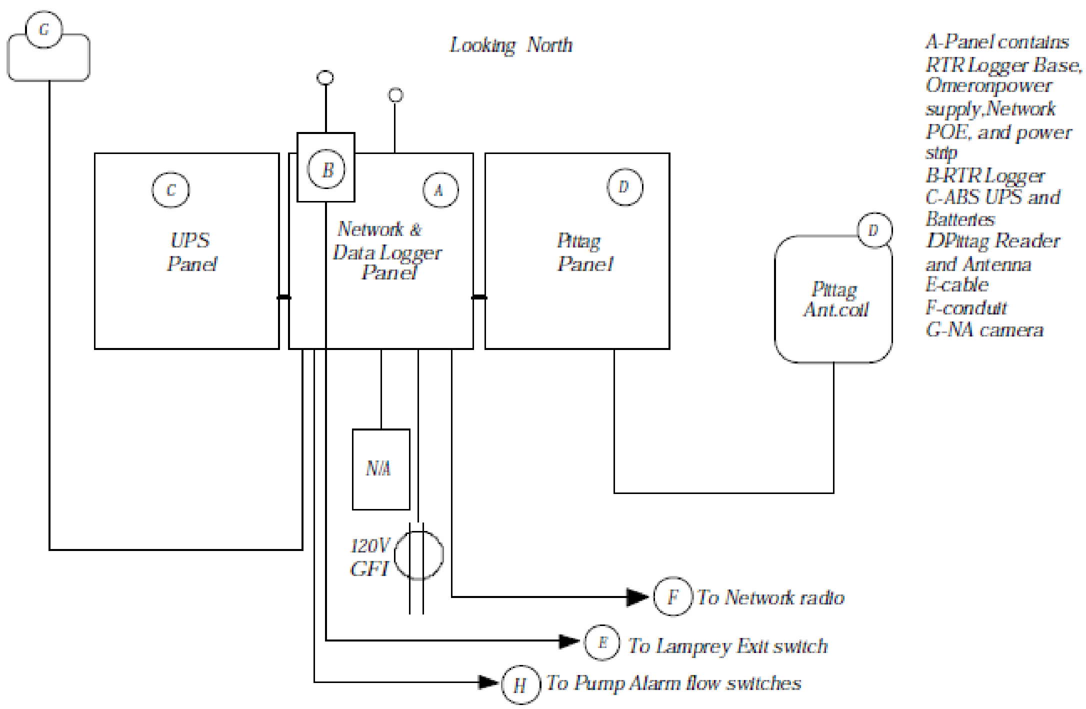

Figure B11. Bradford Island AWS LPS electrical panel.

Lamprey Passage Structure (LPS) Operations Manual

Cascades Island
Bonneville Dam

Provided by

Northwest Fisheries Science Center, National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East, Seattle, WA 98112

for

Portland District, U.S. Army Corps of Engineers
P.O. Box 2946, Portland OR 97020
Contract E96950021

September 2015

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Overview

Pacific lamprey *Entosphenus tridentatus* exhibit relatively low passage efficiency through traditional fishways at Bonneville Dam (Keefer et al. 2013). Lamprey-specific fishways were designed to provide separate passage routes suited to lamprey climbing capabilities (Moser et al. 2011). These structures operate independently from the traditional fishways. This manual is intended to provide information on the background, location, schematics, operation, and maintenance of the lamprey passage structure (LPS) at Cascades Island.

Cascades Island LPS Configuration

The Cascades Island LPS collector was installed at Bonneville Dam in 2009 (Moser et al., 2012) and completed in 2013 with an exit to the Bonneville Dam forebay (Figure C1; Corbett et al. 2014). The LPS entrance is located on the north wall of the Cascades Island fishway just upstream from a bollard field that was designed to lead lamprey from the fishway entrance to the LPS collector (Figure C2).

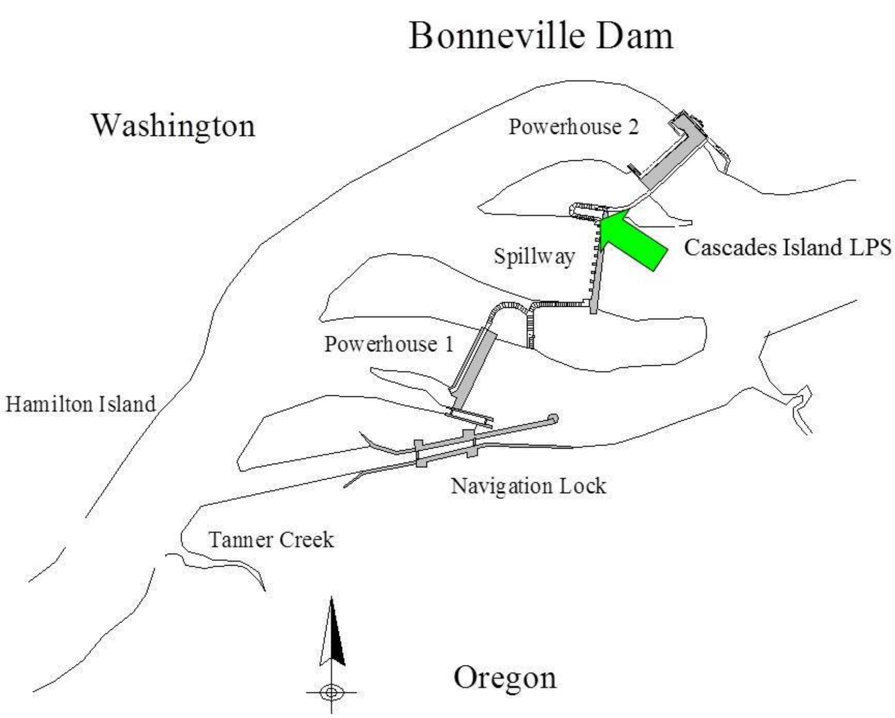

Figure C1. Location of the Cascades Island LPS at Bonneville Dam (green arrow).

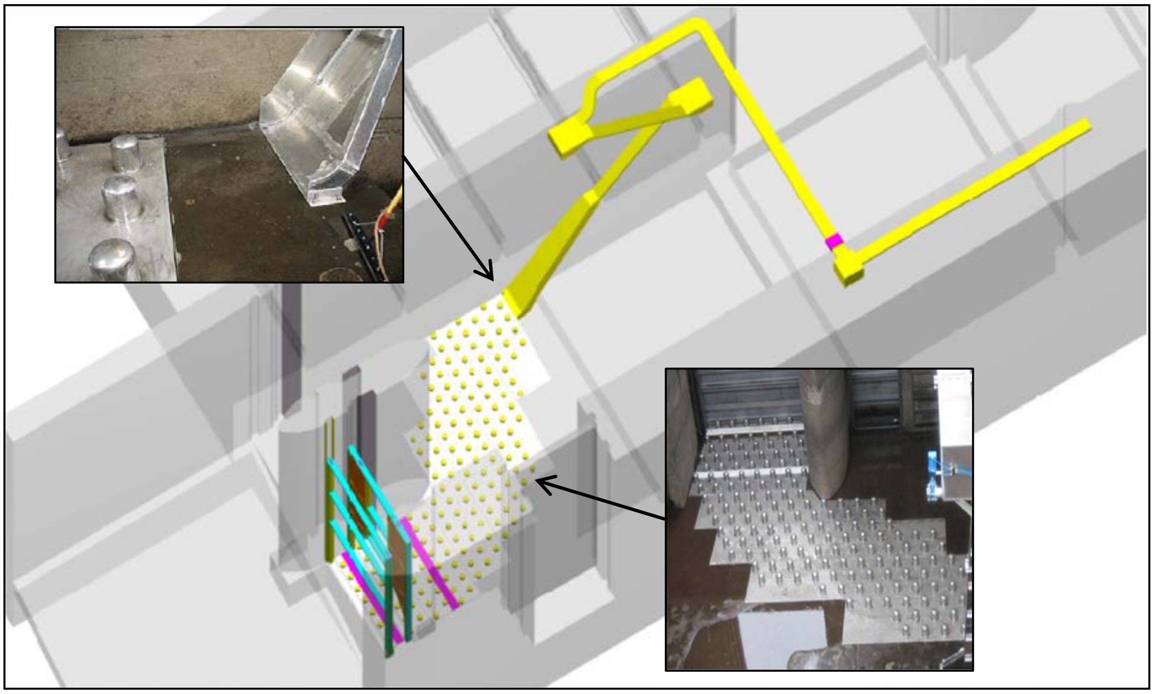

Figure C2. Schematic of Cascades Islands fishway entrance showing velocity-reducing bollard field (inset at lower right) and LPS entrance (inset at upper left). This LPS entrance is located on the north wall of the Cascades Island fishway just upstream of the fishway entrance. Note the collector/entrance ramp is flared at its base width of 1.22 m (4 ft), narrows quickly to a width of 0.61 m (2 ft), and narrows one final time to a width of 0.51 m above the water line. Schematic courtesy of USACE.

The Cascades Island LPS consists of two pumps that deliver water to the structure, the structure itself, and two counters that record lamprey passage events. All ramps in this LPS are 51 cm wide, but the slope of these ramps varies from 30 to 58.6 degrees (Moser et al., 2012). The structure is generally operated from 1 May to 15 September each year and is relatively maintenance-free.

Overall length of the LPS is approximately 172 m, with an elevation gain of 27 m. The Cascades Island structure is composed of a series of ramps, which are wetted to a depth of approximately 3 cm and interspersed with horizontal flumes and rest boxes (Figure 3). The first ramp is 13.79 m long and fabricated of 0.63-cm aluminum. This ramp is supported at 1.8-m intervals by aluminum brackets attached to the fishway wall with wedge anchors. Dimensions of all physical components within the Cascades Island LPS were reported by Corbett et al. (2014).

To improve lamprey collection, the bottom of this first ramp was flared to a width of 1.22 m at its point of contact with the fishway floor. The ramp narrows to a width of 0.61 m over its first 0.61 m of length (Figure C2). At a point 6.7 m up the ramp (normally above the water line), the ramp gradually narrows to a width of 0.51 m. This narrowing allows space for the flanges needed to connect subsequent ramp sections (3.66 m long; Figure 2). After narrowing, the ramp continues upward 7.50 m and empties into Rest Box 1 via a plastic mesh cone. Because Rest Box 1 is not accessible from the deck, it is equipped with a remote drain valve which can be opened to purge lamprey when the structure is shut down.

The second ramp has the same dimensions as the first and connects to Rest Box 2, which is also outfitted with a remote drain valve. The LPS continues upward in a series of ramps and rest boxes (Figure C3). All of these components are accessible from the deck, and each rest box features a hinged lid to allow inspection of the contents. Rest Boxes 2 and 3 can be drained manually and do not require a remotely operated valve. A monitoring antenna for passive integrated transponder (PIT) tags is located just downstream from Rest Box 3. Fyke design varies among these boxes (Figure C4), and all fyke entrances should be inspected to ensure proper functioning (allowing lamprey entrance into each box).

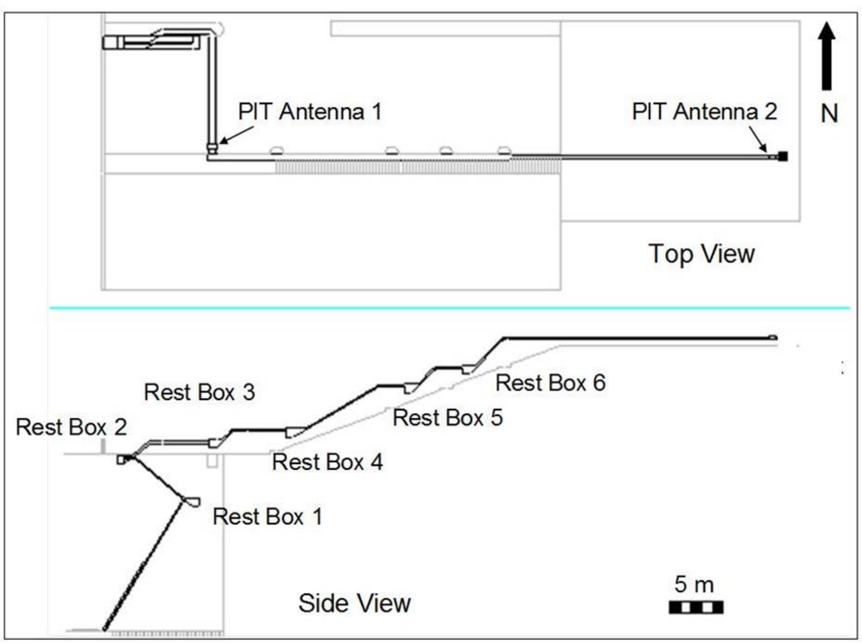

Figure C3. Top (upper panel) and side views of the lower portion of the Cascades Island LPS collector. Locations of PIT monitors are shown in the top view and rest boxes are shown in the plan view.

Figure C4. Examples of different fyke entry designs for rest boxes in the Cascades Island LPS.

From Rest Box 6, a 9-m, 20.3-cm rectangular flume connects the lower sections of the LPS via an upwelling box/slide to a transition “pond” (Figure 5a). A PIT antenna is incorporated into the flume 4 m downstream from the transition pond. The transition pond serves a dual purpose of providing a rest box to migrating lamprey as well as collecting water from the upper LPS. This water is pumped from a collection reservoir into an upwelling box that waters the lower sections of the LPS (insert pump detail). This feature allows the LPS to be operated as a full-elevation, volitional passage structure or as a terminal trap for lamprey collection. Upstream from the pond, a 70 m long, 25.4 cm diameter pipe and 10 m long, 25.4 cm diameter exit slide connect the ascending structure and pond to the forebay (Figure 5b,c).

Columbia River water is supplied to the Cascades Island LPS using two, 3-hp submersible pumps. Pump intakes are located in the upstream end of the Cascades Island makeup water supply (MUWS). A PIT antenna is installed in the terminal flume immediately downstream from the upwelling box that supplies water to the structure. The exit slide deposits lamprey from the upwelling box into the forebay immediately downstream from the log boom that protects the Cascades Island fishway exit. The LPS exit door (activated for lamprey counting) is located at the highest portion of the exit slide (Figure 5c) so that it can be accessed for maintenance from the forebay deck.

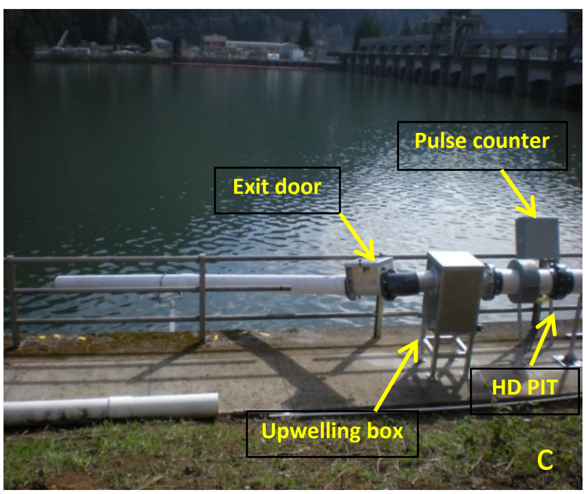

Figure C5. Photos of components for upper portion of Cascades Island LPS collector: transition pond (a), pipe section (b), and exit slide with individual aspects labeled (c).

In the following sections, we provide procedural instructions and for start-up, in-season maintenance, and winter shut down of the lamprey passage structure and counter. Specifications for all components of the pump and counter are provided in Table C1, and a wiring diagram for the entire system is shown in Figure C9.

Operations Checklist

Start-Up

1. **Visual inspection**
   a. Examine structure for structural integrity and evidence of weakness. Remove debris. Check turns, joints, connections to walls, fyke integrity, cracking in PVC piping. Replace components as necessary

   b. Examine PVC pipe section via inspection hatches

2. **Close discharge valves at all upwelling and rest boxes**
   Mostly PVC ball valves at accessible boxes and via remote control for Rest Boxes 1 and 2 (Figure C6). Insert drain plug in pumping reservoir at transition pond (Figure C7).

3. **Clean and service pumps and intake screens**
   Check pumps delivering water to upwelling box and transition pond. See parts list and system specifications in Table C1.

4. **Make sure pump components are connected. Submerge pump intakes.**

5. **Power up pumps.**
   a. Turn on upper pumps (at exit upwelling box)

   b. Once upper section is watered and pumping reservoir at transition pond is full, plug in transition pond pumps to AC power to fill lower section of upwelling box (Figure C7).

   c. Ensure water levels are appropriate.
      i. Ramp level: 3 cm
      ii. Flume level: 10 cm
      iii. Upwelling box level: until fyke at least partially submerged
      iv. Exit slide level: 2 cm (adjust with valve above bottom of slide (Figure C7)
      v. If water level insufficient in system, make sure all pumps are operating, check intake screens to make sure not plugged, check for cracks in hosing/pipe, adjust discharge valve at lower section upwelling box

6. **Count system initiation**
   a. Download current version of RTR-500 for Windows software to a laptop computer (http://www.tandd.com/product/rtr500/support.html)

   b. Plug in power supply from gray electrical box (Figure C9) at LPS exit to nearby AC outlet. Turn on power strip switch.

   c. Ensure green light on network base station is on (RTR500-NW; Figure C9, panel *A*), indicating base station is powered

   d. Replace battery at the wireless data recorder (RTR-505P; special order tubed lithium battery LS14250), ensure that digital display is visible (Figure C9)

   e. Physically engage paddle door. Check that wireless data recorder advances by the number of times the paddle was engaged. Adjust paddle arm tension if necessary.

   f. Conduct test download of network base station.

Figure C6. Discharge valves at rest boxes are mostly PVC ball valves at accessible boxes (a). Remote hydraulic purge valves for Rest Boxes 1 and 2 have controls at the deck (b).

Figure C7. Upstream transition pond showing pumps and unplugged drain in reservoir at Cascades Island LPS.

In-Season Maintenance

All in-season maintenance and system manipulations should be conducted during daylight hours when lamprey are less active.

1. Visual inspection (daily)

a. Check rest boxes and flumes for dead lamprey and debris

b. Check water level and flow
   i. Inspect flexible pump lines and pump position to make sure pumps are untangled and free of debris.
   ii. When flow adjustments are made for system functionality, attention must be paid to exit slide water levels to ensure accurate counting (which relies on a constant water level through the exit slide).

2. Count system operation and maintenance

a. Daily: ensure system is powered as GFI gets tripped frequently. Check power to base station and check that LCD on remote pulse recorder is visible (Figure C5).

b. Daily: visually check for intact connection between exit paddle and limit switch (Figure C8).

c. Weekly: count validation (more frequently if needed to investigate count problems) Physically deflect the counter arm and note time and number of intended deflections. These records must be removed from the reported lamprey count.

d. Daily: download pulse counter data
   i. Open RTR-500 for Windows software on laptop
   ii. Select RTR-500 for Windows icon
   iii. Connect laptop to the network base station via USB cable
   iv. Communication tab. Select Download data (USB)
   v. Name the file with LPS name and date/time of download. File extension should be .trz

e. View pulse counter data (daily)
   i. Open RTR-500 for Windows software
   ii. Select multi-scale graph icon
   iii. File tab. Select Open
   iv. Select .trz file that you want to view
   v. Examine the file for detections across the expected period of operation. Verify presence of validation events. Confirm that count meets approximate expectation for number of lamprey based on timing within the migration season (if especially low relative to expectations, re-examine the LPS and count system).
   vi. The collected pulse data is viewed in graph and table form using the manufacturer's software (RTR-500 for Windows). A total passage estimate minus validation events is reported for each date for both "day" (0500-2100) and "night" (2100-0500) periods, as per USACE convention.

In-Season Maintenance (continued)

3. Exit slide maintenance (as needed)

a. Because of the steepness of the Washington Shore LPS exit slide and the large number of lamprey that use this passage route, daily inspection and maintenance of the exit system is critical. Maintenance at this structure can be done from the forebay deck.

b. Discharge valve. Open to decrease water level in exit slide; close to increase water level in exit slide.

c. Limit switch to paddle connection. Troubleshoot. Common possibilities: replace limit switch, adjust arm tension, reposition paddle.

Figure C8. Cascades Island exit slide passage estimation paddle door, arm, and limit switch.

Shut Down

1. Inspect system for lamprey, including all water reservoirs and pipe sections. Remove fish before proceeding.

2. Unplug transition pond pumps.

3. Immediately purge Rest Boxes 1 and 2 (remotely operated).

4. Power off upper pumps at exit upwelling box. Winterize pumps if end of season.

5 Open discharge valves or drain plugs of all water reservoirs in Cascades Island LPS. These include 2 upwelling boxes, the transition pond, and 6 rest boxes.

6 Download count equipment. Turn off power strip switch. Unplug power cord for count systems.

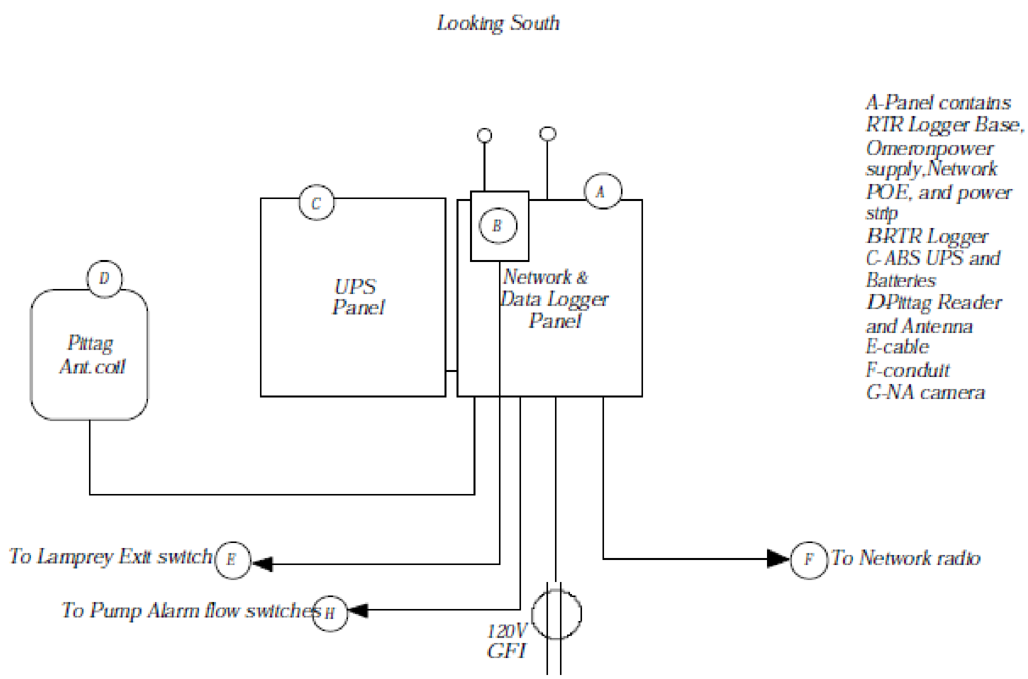

Figure C9. Electrical wiring diagram for Cascades Island LPS electrical panel.

Parts List

Table C1. Description of parts for lamprey count system and lamprey passage structure (LPS) with details relevant to passage estimation and operation.

Lamprey Passage Count Estimate System			
Item (quantity)	Description	Manufacturer	Model/part no.
Pulse counting data logger (1)	Wireless, remote unit	TandD Corporation	RTR-505P
Network base station (1)	Wireless with network relay	TandD Corporation	RTR-500NW
Limit switch (1)	Enclosed, SPDT (single pole double throw), adjustable rod	Honeywell	PK80112
	Corrosion-resistant	McMaster-Carr	65785K15
Count system communication software (1)	RTR-500 for Windows	TandD Corporation	16607060014

Lamprey Passage Structure			
Item (quantity)	Description	Manufacturer	Model/part no.
Junction box (1)	Two 480-V, 30-amp circuits	Crouse-Hinds	
Receptacle assembly	30-amp, 600-V connecting plug and receptacle for pumps (2)	Crouse-Hinds	AR342 or similar
Plug and receptacle	2-plug connector	Daniel Woodhead	28W76 or 29W76
Transition pond sump pump (1)	120-V, 9.5-amp	McMaster-Carr	42935K15
Submersible pump motor (2)	3-hp, 230-V, 3-phasep FLA 10.9 #75GS30	Goulds	M30432
Submersible pump (2)	3-hp, 75-GPM	Goulds	75GS30
Pump panel (2)	NEMA size1, motor-circuit protector (HMCP), 240-V, 3-phase	Cutler-Hammer	ECN5512BAE-E14
Heater (1)	3-pack with overload relay	Cutler-Hammer	H2011B-3
Transformer for pump (2)	6-KVA, 3-phase, 480/240-V	Acme	T-2A-53329-1S
Water-resistant cord (1)	10/4 SEOW	Grainger	2TYJ9