Development of Passage Structures for Adult Pacific Lamprey at Bonneville and John Day Dams, 2013

Steve C. Corbett, Mary L. Moser, Kinsey E. Frick, Bill Wassard,
Matthew L. Keefer,[‡] and Christopher C. Caudill[‡]

Report of research by

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

[‡]Department of Fish and Wildlife Sciences, College of Natural Resources,
University of Idaho, Moscow, ID 83844-1136

for

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

July 2014

Executive Summary

In 2013, 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 (AWS) channels.
2) Assess the effects of providing refuge areas at AWS 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 auxiliary 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.

To achieve the monitoring objectives, we used two approaches. First, we estimated individual lamprey passage in the new and 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 2013, we tagged 1,390 adult lamprey with a PIT tag (400 of which were also tagged with a Juvenile Salmon Acoustic Telemetry System (JSATS) tag and 50 of which were tagged with a radio tag). 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 migration period in 2013, the picketed leads at the entrances to the Washington Shore and Bradford Island AWS channels were raised by 3.8 and 2.5 cm, respectively, in an effort to increase lamprey access to the passages structure during that period. Lamprey use of the Washington Shore AWS channel LPS and the Bradford Island AWS was higher in 2013 relative to other years of operation. At the Washington Shore AWS, LPS passage efficiency was 82%. At the Bradford Island AWS, LPS passage efficiency was 98%. In 2013, 25% of the 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 AWS channel from 27 June to 23 October. A total of 154 PIT-tagged lamprey were detected in the refuges in 2013. The mean residence time was 57.2 h. A large percentage (62%) of these fish were subsequently detected in the Washington Shore LPS. In fact, of the lamprey

detected exiting the LPS or fishway, 28% had used a refuge, indicating that lamprey were able to find and take advantage of these relatively small refuge areas.

Two newly installed lamprey refuges were operated in the Washington Shore fishway proper near the terminus of the Upstream Migrant Tunnel from 3 June to 7 November. A total of 153 PIT-tagged lamprey were detected in these refuges in 2013 (one of which was tagged in 2012). Mean residence time was 52.8 h. A large percentage (33%) of these fish were subsequently detected in the Washington Shore LPS, and of the lamprey detected exiting the LPS or fishway, 20% had used a refuge.

Based on detections of PIT-tagged lamprey at the WA shore LPS and /or the fishway exit and subsequent detections upstream from Bonneville Dam, passage success was similar for tagged lamprey that used a refuge (59%) and those that did not (57%).

In 2013 the LPS at the Cascades Island fishway entrance was extended to allow volitional lamprey passage from tailrace to forebay. The LPS was operated from 24 June to 4 October 2013; 155 lamprey were counted exiting to the forebay. Three PIT-tagged fish released downstream from Bonneville Dam (0.3%) volitionally entered and were detected in the LPS in 2013. Two of these fish ascended the structure, and one fish was detected at all antennas. For this fish, passage time between PIT detectors was 1.6 h. In 2013 we placed 47 PIT-tagged lamprey (25 with a radio tag) into the LPS and found that 79% ascended the LPS and exited to the forebay. Of the radio-tagged individuals that ascended to the forebay, one of 21 was detected falling back downstream from Bonneville Dam. Additionally, we released 25 radio-tagged lamprey to the forebay and none of these was determined to have fallen back downstream of Bonneville Dam.

In past years adult lamprey have been detected and observed accumulating in the Cascades Island auxiliary water supply channel, a structure that has no direct access to the forebay. In 2013 we deployed 1-3 cylindrical traps at 4 different locations within the Cascades Island AWS. Over the 57 d between 9 July and 23 October, 625 lamprey were captured in these traps. As in past years, we continued to monitor PIT-tagged lamprey use of this area. In 2013, 8%, 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 continue to occupy this area and should be provided with an outlet to the forebay or actively trapped and transported upstream.

The newly constructed lamprey trap at the John Day South Fishway was fished by tribal personnel on 18 nights between 24 June and 25 August, and 90 adult lamprey were captured. A PIT antenna in the trap's collector detected 39 PIT-tagged fish, and 26 of these (67%) were detected again as they exited the top of the south fishway exit. Median residence at the collector for PIT-tagged fish was 17.5 h, and median passage time from the collector to the ladder exit was 7.1 h.

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) take advantage of lamprey swimming and climbing performance, while minimizing lamprey searching and fallback behavior (Reinhardt et al. 2008; Kemp et al. 2009; Keefer et al. 2011; Moser et al. 2011). In traditional fishways, 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).

LPS development was initiated at Bonneville Dam, the first mainstem dam 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 (Moser et al. 2002b; Johnson et al. 2009a, 2009b; Keefer et al. 2013). In these areas, 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 locations of the 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 count stations. There is no readily passable outlet from AWS channels to the dam forebay. Radiotelemetry results have indicated that lamprey reside in AWS channels for 4 d on average, and then typically move back downstream (Moser et al. 2005). In addition to being a difficult passage area for lamprey, the AWS is a "salmon-free" fishway channel where *in situ* experiments to develop lamprey passage can be conducted (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 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).

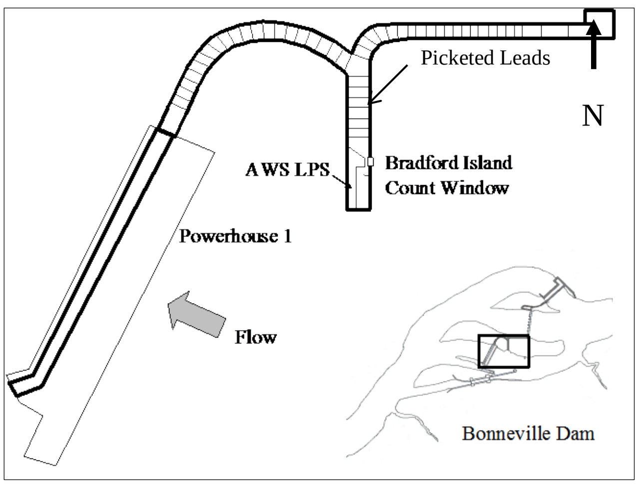


Figure 2. Schematic drawing of the Bradford Island fishway system at Bonneville Dam with locations of the auxiliary water supply LPS (AWS LPS) and count window.

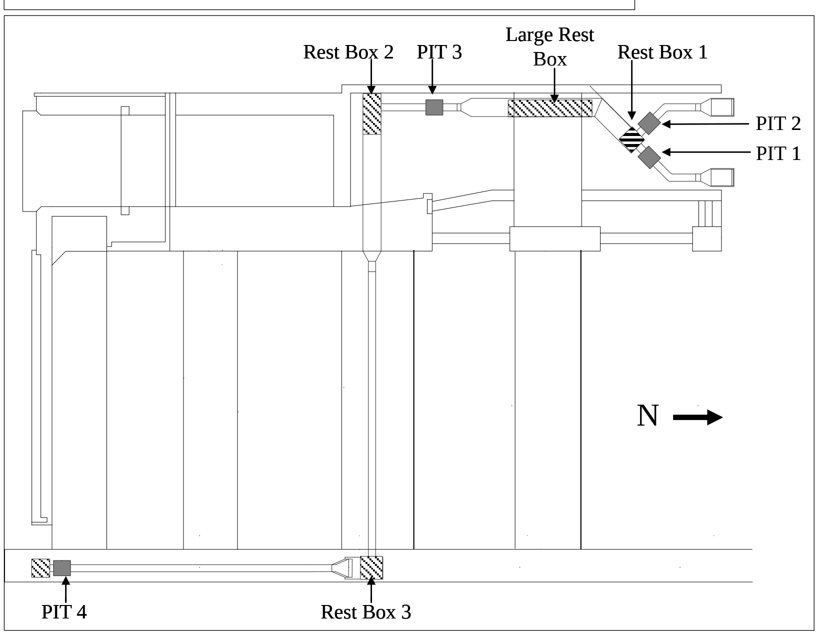


Figure 3. Top view of the Bradford Island LPS with locations of half-duplex PIT-tag detection antennas (PIT 1-4) and rest boxes indicated.

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 tubes. Lamprey actuated a limit switch as they exited the LPS into the forebay, and these exit data were used to evaluate lamprey use of the structure in each year.

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 was inserted seamlessly into the chutes leading to Rest Boxes 1, 2, and 4. The PVC prevented the aluminum from attenuating the PIT signal. Each reader was comprised of a loop antenna of 10-G 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.

Passage efficiency of PIT-tagged lamprey (number detected at LPS exit divided by total number detected entering the LPS) was 90-100%, and median passage time for PIT-tagged lamprey was less than 1 h in 2004-2008 (Moser et al. 2011). The success of this structure prompted further development. We installed a fishway entrance collector at the Washington Shore fishway in 2005 (Figure 4; Moser et al. 2008) and a second full LPS at the Washington Shore AWS channel in 2007 (Figure 5; Moser et al. 2011).

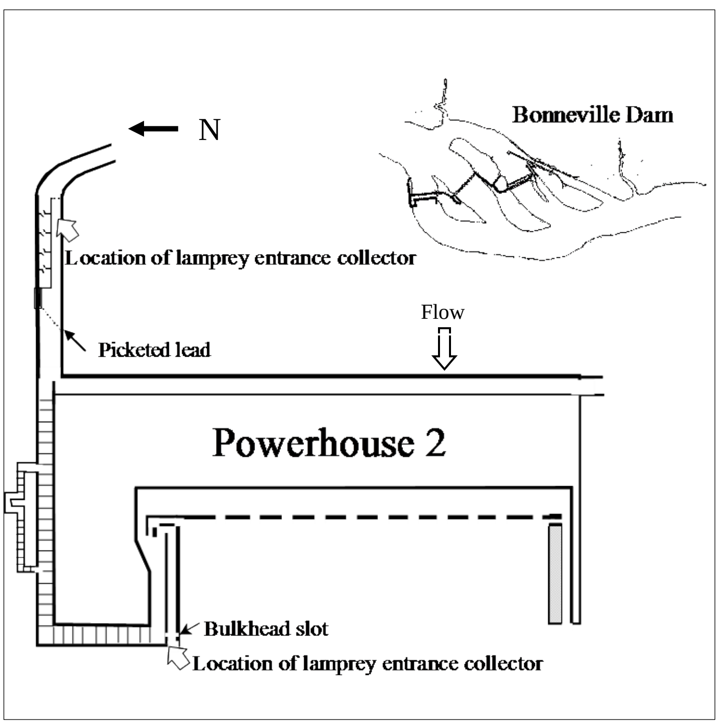


Figure 4. Locations of lamprey structures at the Washington Shore fishway.

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, the Washington Shore LPS 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 down the LPS.

However, due to the width of the 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), and 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).

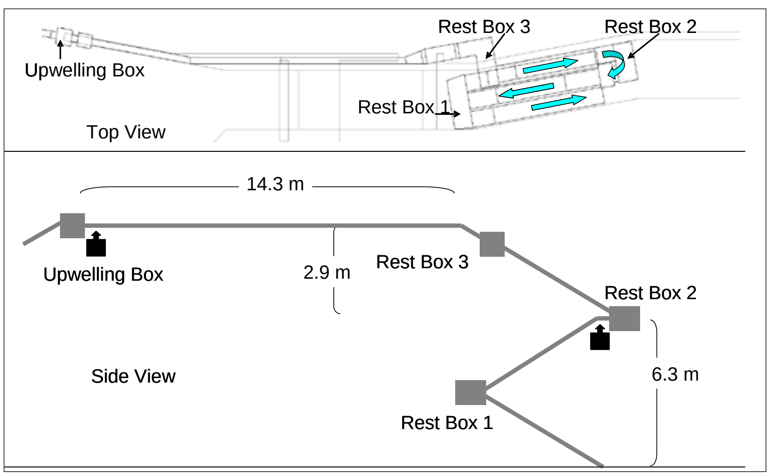


Figure 5. Top and side views of the Washington Shore AWS LPS. Shaded arrows in top view indicate the direction of water flow on the switchback ramps. Black boxes in side view indicate the position of half-duplex PIT antennas.

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, lamprey that were able to pass through the structure did so quickly (median passage time < 0.5 h; Moser et al. 2012). However, it is unknown whether the energy used to make these rapid ascensions will compromise lamprey fitness.

The greatest limitation to lamprey use of the AWS structures was relatively poor collection efficiency (Moser et al. 2011). Lamprey collection at the LPSs was limited both by lamprey access to and retention in the AWS channel. 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 to aid lamprey access to the channel. To improve lamprey retention in the channel, two refuges were installed; these provide dark and safe holding areas during the day.

In 2013, the picketed leads at the Washington Shore and Bradford Island AWS channels were raised to 3.8 and 2.5 cm, respectively, for the entire season. In addition, two more refuges were installed downstream from the Washington Shore AWS channel near the confluence with the upstream migrant tunnel (UMT). These changes were made based on previous years of operation that indicated lamprey use of refuge areas and an improvement in lamprey access to the AWS channels when picketed leads are 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.

A third LPS was installed in 2009 at the Cascades Island fishway entrance (Figure 1). 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 AWS structures, but was much longer (92.4 m; Figure 6). 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).

Data from PIT detections indicated that lamprey could fall back through the rest boxes. Consequently, we tested new, narrower, rigid-entrance "fyke" designs in 2012 (Corbett et al. 2013). In 2013, a further modification was made to further improve the fyke entrance. Light-weight metal "fingers" were added to the entrance fyke at one rest box. The purpose of this design was to reduce fallback whilst allowing lamprey to push through the fingers and gain entry to the rest box.

The original Cascades Island LPS terminated in a trap box. High lamprey use of the structure in 2012 (Corbett et al. 2012) increased the need to provide a volitional exit (i.e., a flume allowing lamprey egress from the structure without capture). In this way, maintenance could be reduced and handling stress eliminated. In 2013 we designed, built, and installed an "exit structure" that lamprey could use to move from the top of the LPS into the forebay whilst reducing the potential for fallback over the spillway. A primary objective of work in 2013 was to assess lamprey use of this exit structure.

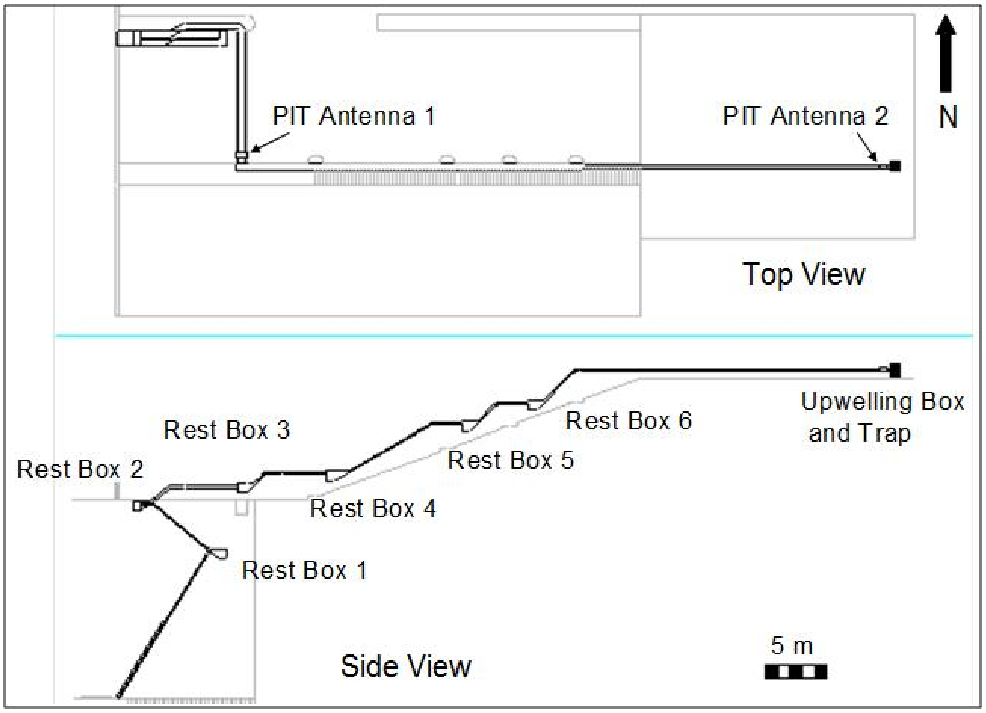


Figure 6. Top (upper panel) and side views of new Cascades Island LPS collector. Locations of PIT monitors are shown in top view and rest boxes are shown in the side view.

The increasing need to collect lamprey to satisfy research and tribal restoration needs has prompted exploration of new trapping sites. Therefore, in 2013 we continued trapping operations in the Cascades Island AWS channel for research and restoration and to determine areas where lamprey accumulate in this channel.

In 2013, we also initiated monitoring of a newly installed lamprey trap at the John Day Dam South Fishway. The structure was installed in the AWS channel of this count station to improve tribal lamprey collection efforts at this location and to ultimately produce a more reliable estimate of lamprey passage at this site.

Our objectives in 2013 were to:

1) Determine lamprey use of lamprey passage structures (LPSs) located at the auxiliary water supply (AWS) channels at Bonneville Dam.
2) Assess the effects of providing refuge areas at AWS channels and fishways.
3) Determine lamprey use of the LPS located at the Cascades Island fishway entrance.

4) Develop methods to collect lamprey from LPSs with no outlet to the forebay at Bonneville Dam.

5) Develop methods to enumerate lamprey entering a newly installed trap at the south fishway of John Day Dam.

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

Second, we tagged adult Pacific lamprey with passive integrated transponder (PIT) tags, released them downstream from the 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 passage rate at each structure using detections of PIT-tagged lamprey. PIT detections were also used to evaluate lamprey use of the refuges and the trap at John Day Dam.

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

Development of Remotely Accessed Counter Systems

Counting systems at both lamprey passage structures (LPSs) were upgraded in 2011, refined in 2012, and further refined in 2013 in an attempt to provide accurate, real-time lamprey estimates to regional managers. The 2013 upgrade involved replacement of a downloadable event-logger system (Corbett et al. 2013) with a wireless pulse-measuring system. The replacement system packaged data for both day and night intervals in a format that was acceptable to regional users and that delivered data automatically via email. Sealed limit switches were also added at each LPS exit door to prevent corrosion from water and subsequent failure. A foam cushion was added to absorb exit-door swing and thereby prevent bounces of the door that led to overcounting at the Washington Shore LPS exit.

In 2013 lamprey were observed climbing the concrete fishway exit wall opposite of the Washington Shore LPS exit. This wall became wetted from excessive flow spilling from the outfall of the Washington Shore LPS exit. To prevent the wall from becoming wetted, a discharge gap was added to drain the excess flow from the exit slide before it reached the outfall.

Evaluations based on Estimates and Video Imagery

Methods

Lamprey use of the Washington Shore and Bradford Island LPSs was monitored by a lamprey-activated limit switch connected to a wireless pulse-measuring data logger (RTR-505, TandD Corporation[1]) at the LPS exit door. The data logger bundled lamprey passage counts at 30-s intervals and transmitted collected data to a network base station at the LPS exit (RTR-500NW, TandD Corporation). The base station communicated data by radio uplink to a local area network housed in the tailrace south tower (Figure 7). Raw pulse count data were delivered twice daily via email at 0500 and at 2100.

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Data from the AWS LPS exit slide pulse counter were validated every 7 d by physically engaging the LPS exit door to mimic lamprey passage events at an established time and frequency. Passage event totals were subsequently checked against the pulse-counter record and subtracted from the lamprey passage count. On two different dates the exit slide pulse counter was validated by a human observer, who recorded the frequency and times that individual lamprey were observed exiting the LPS over an established period. These observations were subsequently checked against data recorded by the pulse counter. At the Washington Shore LPS, pulse counter data were further validated by comparison to video imagery recorded over 10 3-h periods in June by USACE Fisheries Field Unit personnel (N. Zorich, personal communication).

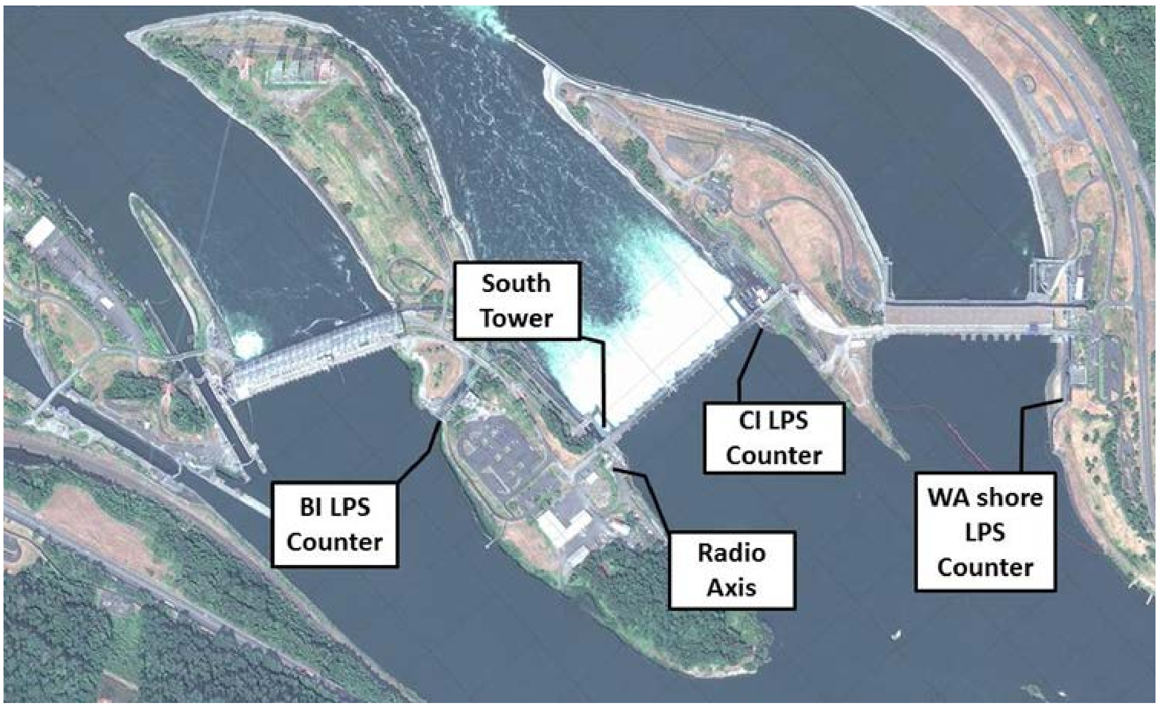


Figure 7. Aerial photo of Bonneville Dam with the locations of LPS lamprey counters and the radio uplink indicated.

Results

In 2013, LPSs at both the Bradford Island and Washington Shore AWS were operated from 6 May to 16 October, and passage events were estimated from 16 May to 16 October. During this period there were occasional gaps in the LPS count record due to exit door damage, power failure, and limit switch corrosion. These gaps occurred at Bradford Island during 18-30 August and at Washington Shore during 18-20 and 22-23 May and during 2 and 7-10 June.

At the Washington Shore AWS, the mechanical door at the terminus of the LPS exit slide was damaged due to periodic high numbers of lamprey exiting the system. This resulted in periods of inaccuracy and complete outage of the exit counter, as shown by physical and video validations. The angle of the LPS exit slide at Washington Shore (51 degrees) is steeper than that of the exit slide at Bradford Island (25 degrees). As a result, lamprey exiting via this slide contact the paddle that activates the limit switch with greater force.

This condition, combined with high numbers of lamprey passing in short durations at this LPS, caused damage to the paddle/arm/limit-switch configuration. Reduced arm tension and distortion of the paddle angle caused lamprey passage to not be counted at times. Wear to the cushion that absorbs the swing of the paddle arm led to occasional paddle bounce and overcounting.

Data obtained from the USACE Fisheries Field Unit video recordings at the Washington Shore AWS LPS suggested that lamprey counts at the AWS LPSs were overestimates for at least some of the season. To account for periods of possible overcounting, Fisheries Field Unit personnel requested that Washington Shore LPS counts be adjusted for all dates of operation. The adjustment was calculated for groups of multiple detections reported within a 30-s bundle. Totals for these detections were divided by two and the quotient rounded up to the nearest whole number. Single detections remained unadjusted. The sum of single detections and adjusted multiple detections produced a total adjusted number of lamprey counted for each date during the period of LPS operation (Table 1).

Table 1. Correction applied to Washington Shore LPS counts to obtain an adjusted passage estimate.

Adjusted counts from Washington Shore lamprey-actived counter	
Original mulitple count (n) during 30-s interval	Adjusted count (count ÷ 2, rounded up)
6	3
5	3
4	2
3	2
2	1

In 2013, the total lamprey count at the Bradford Island LPS was 13,120 (Figure 8). The adjusted total count at the Washington Shore LPS was 18,487 and the unadjusted total count at the Washington Shore LPS was 25,316 (Figure 9).

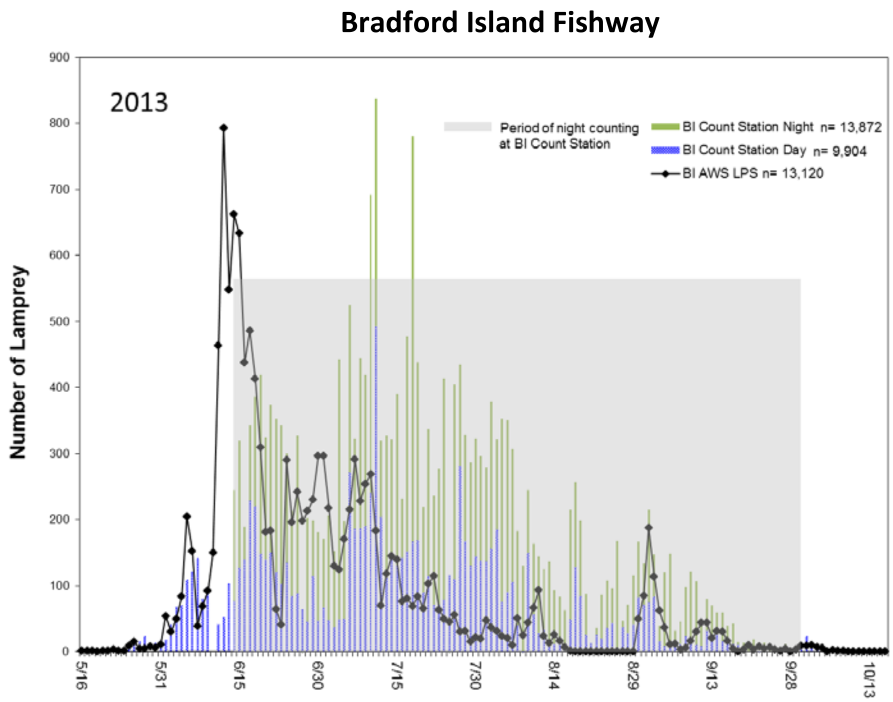


Figure 8. Number of lamprey counted at the Bradford Island count station during the day (blue) and night (green) and at the AWS LPS exit slide (closed diamonds) during the periods of LP operation in 2013. Total values reported for the count station and LPS.

Washington Shore Fishway

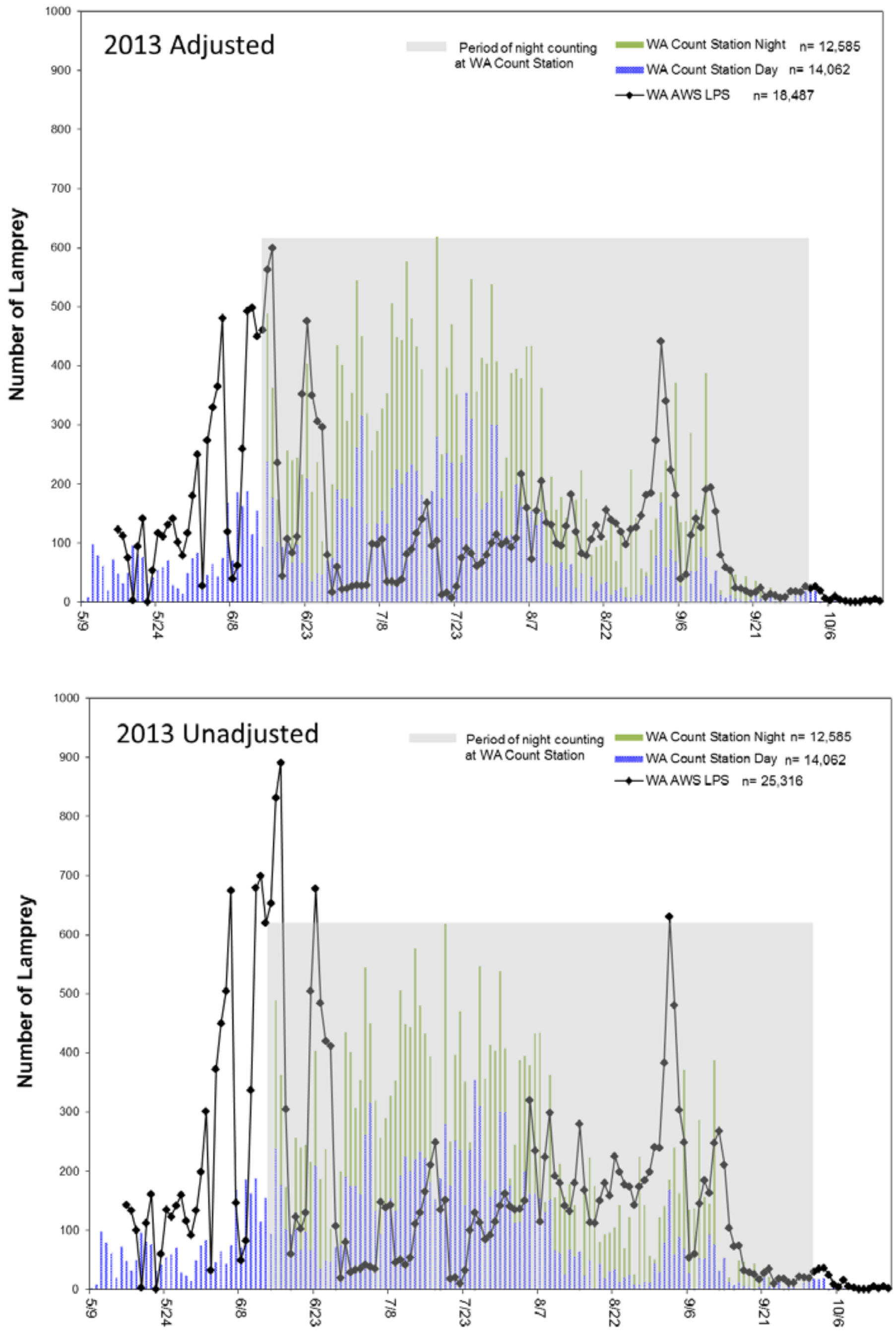


Figure 9. Number of lamprey counted at the Washington Shore count station during the day (blue) and night (green) and adjusted (top panel) and unadjusted (bottom panel) number of lamprey counted at the AWS LPS exit (closed diamonds) during periods of LPS operation in 2013. Total values reported for the count station and LPS.

We evaluated the efficacy of modifications made in 2013 by comparing both inter- and intra-annual estimated collection efficiencies at the AWS LPSs. We estimated collection efficiency by estimating total lamprey abundance at the top of each ladder. This was done by tripling the count station totals for each ladder in each year. The AWS LPS counts were then divided by the estimate of total lamprey abundance (Table 2). These were conservative estimates based on daytime count extrapolations, since approximately two-thirds of migrating lamprey typically pass count stations at night (Moser and Close 2003).

Table 2. Lamprey abundance estimates (visual daytime counts × 3), LPS counts, and collection efficiency ((LPS count/abundance) × 100) at each structure in 2007-2013. In-season collection efficiency values are also given for 2011 when pickets were raised (1-29 June) and when they were lowered to protect salmonids (1-30 July). Total values reported for the count station and LPS include only days when the LPS counter was operational (i.e., outage days are not included in either count). For 2013 the adjusted Washington Shore LPS count was used.

	Bradford Island (n)		Washington Shore (n)	
	Abundance (daytime count × 3)	LPS count and efficiency (%)	Abundance (daytime count × 3)	LPS count and efficiency (%)
2004	35,913	7,490 (21)		
2005	30,771	9,242 (30)		
2006	44,586	14,975 (34)		
2007	19,420	7,387 (38)	22,551	2,517 (11)
2008	15,903	6,441 (40)	16,125	1,985 (12)
2009	6,597	3,302 (50)	11,886	1,199 (10)
2010	4,959	1,933 (39)	10,143	2,961 (29)
2011	22,134	7,476 (34)	24,666	6,345 (26)
1-29 Jun 2011	792	241 (30)	2,292	934 (41)
1-30 Jul 2011	9,762	3,160 (32)	10,431	1,707 (16)
2012	24,600	4,392 (18)	49,176	5,686 (12)
2013	29,805	13,066 (44)	38,514	18,329 (48)

Lamprey video counts have been conducted at night at Bonneville Dam since 2009, but are only conducted from June 15 to September 30 each year; they do not encompass the entirety of the lamprey migration. Figures 8 and 9 include count station counts at each ladder, but we focus on extrapolated counts in these analyses to maintain continuity across study years and to cover the entire migration season. For 2013, the adjusted count from the Washington Shore LPS was used. These estimates indicated that in 2013, overall collection efficiency was 44% at Bradford Island and 48% at Washington Shore (Table 2).

Evaluations Based on Monitoring of Tagged Lamprey

Methods

Lamprey were collected for tagging at the adult fish facility (AFF) and from the Cascades Island AWS channel in 2013. We deployed two portable traps and two fixed traps at weirs in the Bonneville Dam AFF fishway. All traps were set each night from approximately 2100 to 0700 PST. Each morning the trapped lamprey were transferred to a holding tank with running Columbia River water for tagging.

After anaesthetizing the lamprey using 60-ppm eugenol, we measured 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) of each fish. For PIT-tagged fish, we then 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 then released in the evening. Release sites were approximately 3 km downstream from Bonneville Dam (Hamilton Island boat ramp), upstream from Bonneville Dam at the Stevenson boat ramp (rkm 235.1), in Rest Box 3 of the Cascades Island LPS, and in the Bonneville Dam forebay at the upstream end of Cascades Island.

Lamprey implanted with a Juvenile Salmon Acoustic Telemetry System (JSATS) tag also received a half-duplex PIT tag (see Noyes et al. 2012 for JSATS tagging methodology). For these double-tagged fish, a larger incision was made, and the PIT tag was inserted first. These fish were released in the morning within 1 h of tagging at various locations either upstream (Stevenson boat ramp and Cascade Locks) or downstream (Hamilton boat ramp and Tanner Creek) from Bonneville Dam.

Lamprey implanted with a radio tag also received a PIT tag (see Moser et al. 2002 and Johnson et al 2009a,b for radio tagging methodology). These fish were released at dusk within 9 h of tagging at the Cascades Island LPS or the forebay of Bonneville Dam.

Results

In 2013, we tagged 937 lamprey with a PIT tag only. Of these fish, 876 were released downstream from Bonneville Dam, 39 were released upstream from Bonneville Dam, and 22 were released to the LPS at the Cascades Island Fishway (Table 3). These fish were tagged between 10 June and 23 September 2013 (mean date 14 July) and they had a mean length of 64.9 cm (range 51.0-79.0 cm).

We tagged an additional 400 lamprey with both a PIT and JSATS tag (Noyes et al. 2014). Of these double-tagged fish, 197 were released downstream and 203 released upstream from Bonneville Dam (Table 2). Fish were JSATS-tagged between 29 June and 23 September 2013 (mean date 26 July) and had a mean length of 64.8 cm (range 51.0-75.5 cm).

An additional 50 lamprey were double tagged with a PIT and radio tag (S. Lopez-Johnston, Portland State University, personal communication). Of these fish, 25 were released to the Bonneville Dam forebay and 25 were released to the LPS at the Cascades Island Fishway. Radio-tagged fish (n = 10) were tagged on five different dates (10, 16, 24, and 31 July and 11 September 2013). Mean length of these fish was 65.6 cm (range 56.5-71.5 cm).

Table 3. Number of lamprey tagged in 2013 with only a PIT tag, or a PIT tag and radio or JSATS tag (double-tagged), and their release locations relative to Bonneville Dam.

Tag treatment and release location relative to Bonneville Dam	Number released (n)
PIT-only	
Released downstream	876
Released to LPS	25
Released upstream	39
Double-tagged (PIT + JSATS or radio)	
Released downstream	197
Released to LPS	25
Released upstream	228
Total PIT tagged	1,390

Bradford Island—Of the 876 PIT-only fish released downstream from Bonneville Dam in 2013, 35 (4%) were detected at the Bradford Island AWS LPS. Similarly, 8 (4%) of the 197 double-tagged fish released downstream from Bonneville Dam were detected at this structure in 2013 (Table 4). This occurred in spite of the fact that double-tagged fish were not all released at the same location downstream from the dam. None of the fish tagged in 2012 were detected in this structure in 2013.

Table 4. Number of PIT-tagged fish detected in the LPSs in the Bradford Island and Washington Shore auxiliary water supply (AWS) channels 2007-2013. These values as a percentage of 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 both there and at Tanner Creek.

	Number and percent of tagged lamprey detected after release													
	2007		2008		2009		2010		2011		2012		2013	
Tag treatment	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
	Detected at Bradford Island AWS LPS													
PIT only	31	4	55	9	26	7	0		60	8	40	5	35	4
PIT+ JSATS/radio	--		14	5	10	3	10	3	0		5	3	8	4
	Detected at Washington Shore AWS LPS													
PIT only	26	3	16	3	10	3	5	38	59	7	56	7	199	23
PIT+ JSATS/radio	--		0		17	5	5	2	3	13	6	4	28	14

Table 5. Number of PIT tagged lamprey released downstream from Bonneville Dam and subsequently detected at a Bonneville Dam LPS 2013.

	Detections of tagged lamprey				
Detection location (LPS)	PIT only (n)	Double tag (n)	Total (n)	Total detected at a Bonneville LPS (n = 742) (%)	Percent of total released below Bonneville (n = 1,073) (%)
Bradford Island AWS	35	8	43	5.8	4.0
Washington Shore AWS	199	28	227	30.6	21.2
Cascades Island	2	1	3	0.4	0.3

In 2013, 42 of the 43 PIT-tagged fish detected at the top of a collector ramp were subsequently detected at the exit slide (i.e., passage efficiency through the Bradford Island AWS LPS was 98%). Similarly, in 2011 and 2012, most fish detected in the Bradford Island AWS LPS were detected at the exit slide (i.e., passage efficiency was 100 and 98%, respectively).

In 2013, for all PIT-tagged fish, median passage time from a collector to the exit slide was 0.65 h (range 0.25-1.89 h). Median passage time from a collector to the exit slide was 0.65 h (range 0.25-1.89 h) for PIT-only fish and 0.70 h (range 0.37-1.00 h) for double-tagged fish.

PIT-tagged lamprey were also detected using the Bradford Island fishway exit, either in addition to or instead of the LPS. In 2013, 66 PIT-tagged lamprey (6% of those released downstream) were detected at the fishway exit but not detected in the LPS. Of the 43 fish detected in the LPS during 2013, 6 (12%) were subsequently detected after having fallen back into the fishway exit; none of these were subsequently detected at upstream dams. In comparison, 121 PIT-tagged fish (12% of those released downstream) were detected at the fishway exit but not detected in the LPS in 2012. Of the 45 fish detected in the LPS during 2012, 1 (2%) was subsequently detected at the fishway exit, and this fish was not detected at upstream dams.

Some lamprey that exited the LPS or Bradford Island fishway exit were later detected at upstream PIT-tag monitoring sites. In 2013, 21 (49%) of the fish that used the LPS were detected at upstream sites. Of fish that used this LPS in previous years, 26 (58%) were detected at upstream sites in 2012 and 32 (53%) in 2011. Of fish detected exiting the Bradford Island fishway without using the LPS, the respective percentages detected at upstream sites were 80% in 2009, 57% in 2010, 74% in 2011, and 72% in 2012.

Washington Shore—Of the 876 PIT-only fish released downstream from Bonneville Dam in 2013, 199 (23%) were detected at the Washington Shore AWS LPS. Of the 197 double-tagged fish released downstream fom Bonneville Dam, 28 (14%) were detected using this structure in 2013 (Table 4). Note that some of the double-tagged fish were not released at the same location as PIT-only fish.

In 2013, 6 lamprey were detected only on the upper PIT antenna and were missed by the lower antenna, which had a detection efficiency of 97% (Figure 5). Of the 199 PIT-only lamprey that were known to have entered this LPS, 36 were not detected at the upper antenna near the exit slide; passage efficiency through the Washington Shore AWS LPS was 82%. Of the 28 double-tagged lamprey, 25 (89%) were detected at the exit slide. Median travel time from the first antenna to the exit slide was 0.57 h (range 0.28-3.72 h) for PIT-only fish and 0.49 h (range 0.22-0.97 h) for double-tagged fish.

At Washington Shore, the LPS empties into the fishway downstream from the fishway exit. In 2013, 122 PIT-tagged fish that had not been detected in the LPS were detected at the Washington Shore fishway exit. Of the 227 fish that used the LPS in 2013, 121 (53%) were detected at the fishway exit. Of the remaining 106 fish, 78 were detected at upstream dams, indicating low detection efficiency at this fishway exit antenna.

After passage at Bonneville Dam, lamprey were often detected at PIT monitoring sites upstream. In 2013, 139 of 227 (61%) fish that used the Washington Shore LPS were detected at upstream sites, while of the 122 fish detected only at the traditional fishway exit, 81 (66%) were detected at upstream sites (Table 6.).

Table 6. Number of PIT-only and double-tagged (PIT and JSATS) lamprey released downstream from Bonneville Dam and subsequently detected at the Washington Shore auxiliary water supply channel LPS antenna and at sites upstream from Bonneville Dam, 2007-2013 after using the Washington Shore ladder for passage. Note that PIT-only fish were released at the Hamilton Island boat ramp, while double-tagged fish were released both there and at Tanner Creek.

	Number detected at Washington Shore AWS LPS (%)				Subsequently detected upstream n (%)			
	PIT-only		Double-tagged		after exiting WA Shore LPS		exited WA Shore without using LPS	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
2007	26	3						
2008	16	3	0					
2009	10	3	17	5	3	18	53	41
2010	5	38	5	2	7	33	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

Cascades Island—In 2013, of the fish PIT-tagged and released downstream from Bonneville Dam, 81 (8%) were detected at the entrance to the Cascades Island AWS channel. Of these 81 fish, 72 had only a PIT tag and 9 had a PIT and JSATS tag (Table 7). Thus, 8% (72/876) of PIT only and 5% (9/197) of double-tagged fish were detected at this site. No fish tagged in 2012 were detected at this site. Of the 81 lamprey detected at the Cascades Island flow-control area from releases below Bonneville Dam, 30 (37%) were subsequently detected at upriver sites (Table 7).

Table 7. Number of PIT-only and double-tagged (PIT and JSATS) lamprey released downstream from Bonneville Dam and subsequently detected at the Cascades Island auxiliary water supply channel antenna (CI AWS) and at sites upstream from Bonneville Dam, 2007-2013. Note that PIT-only fish were released at the Hamilton Island boat ramp, while double-tagged fish were released both there and at Tanner Creek.

	Number detected at Cascades Island AWS channel (%)						Subsequently detected upstream n (%)	
	PIT-only		Double-tagged		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

Discussion

In 2013, lamprey use of LPSs at both AWSs was high relative to previous years based on both passage estimates and PIT-detection data (Corbett et al. 2013). The PIT data indicated that over three times as many lamprey used the Washington Shore AWS LPS in 2013 than in 2011 and 2012 (Corbett et al. 2013), while use of the Bradford Island LPS was similar to previous years. This likely reflected the change to a larger gap at the bottom of the picketed lead at the Washington Shore AWS. This change was made to afford lamprey greater access to this AWS channel, and it seems to have worked. Increasing the gap height of the picketed lead may be in order to increase collection efficiency at the Bradford Island LPS.

Data from detections of PIT-tagged lamprey indicated that collection efficiency[2] at the Washington Shore LPS was high in 2013. However, passage efficiency[3] was lower in 2013 (82%) than in 2011 (88%) and 2012 (93%). Moreover, the number of lamprey that fell back after exiting the LPS into the Washington Shore fishway was high relative to previous years (Corbett et al. 2013).

These observations suggest that some lamprey have difficulty completing passage through the Washington Shore AWS LPS, in contrast to the Bradford Island LPS, where passage efficiency is regularly 100% (Moser et al. 2011). There are several possible explanations for the reduced passage efficiency at Washington Shore. One hypothesis is that missed detections of PIT-tagged fish at the terminal PIT detector produced this result. There was strong evidence that this happened in 2010 for 82% of double-tagged fish that used this structure (Moser et al. 2012). In 2013, 3% of the lamprey detected in the Washington Shore LPS were only detected at the upper antenna site. Improved PIT antenna performance may be needed at this LPS.

An alternative hypothesis is that lamprey exhibit fallback after entering the Washington Shore structure: camera imagery has shown some lamprey moving downstream just before they reached the terminal PIT detector (Corbett et al. 2013). In addition, PIT-tagged lamprey have been documented falling back within the Cascades Island LPS, which features ramp and rest box designs similar to those of the Washington Shore AWS LPS. In particular, the fykes at rest-box entry locations are conducive to downstream movement in both structures.

[2] Collection efficiency: percentage of fish detected in LPS from releases below the dam.
[3] Passage efficiency: percentage of fish released below LPS that successfully negotiated the structure.

At Washington Shore in most years, some lamprey that were known to have exited the LPS were not subsequently detected as they exited the top of the fishway to access the dam forebay. A number of these fish are missed by the PIT antenna at the Washington Shore fishway exit; this antenna spans a large area and is known to have relatively low (79%) detection efficiency (Keefer et al. 2012).

In most years, some lamprey exiting the LPS have fallen back downstream through the fishway and have not reascended to upstream sites. This group of fish was larger in 2013 than in previous years. Changes to construction of the exit slide might have resulted in a higher incidence of fallback. This should be examined in future years to ensure that lamprey using the LPS have a likelihood of attaining upstream sites that is as high or higher than that of fish using traditional fishways.

At the Bradford Island AWS LPS, we noted that, as in previous years, a significant number of PIT-tagged lamprey detected using the LPS were subsequently detected as they fell back downstream into the Bradford Island Fish Ladder exit (Moser et al. 2012). This was likely due to configuration of the exit slide. At low forebay heights, lamprey drop a considerable distance from the end of the exit slide (> 2m) before entering the water. In addition, the forebay entry site of the LPS is only a few meters upstream from the fish ladder exit. To remedy this problem, the exit slide should be extended to both reduce the drop distance and release lamprey further upstream from the fish ladder exit.

In spite of these potential problems, the LPSs at both of these AWS channels provided an important passage route for lamprey. Data from PIT-detections indicated that in 2013, 25% of PIT-only lamprey released downstream from Bonneville Dam used an AWS LPS, as opposed to 15% in 2011 and 12% in 2012 (Corbett et al. 2013). This increase was probably due to improved access to the Washington Shore AWS channel provided in 2013. If so, we expect to see similarly high LPS use in future years, barring any future changes to the position of the picketed lead.

These data and detections of PIT-tagged lamprey in the Cascades Island AWS channel indicate that lamprey could benefit from an LPS in this area. Our PIT antenna only spans the area at the entrance to the flow-control portion of the fishway detecting fish as they entered this channel. Thus, tagged lamprey that entered the AWS channel directly were not monitored.

In 2011-2013, significant percentages (8-10%) of PIT-only fish released downstream from Bonneville Dam were detected at the Cascades Island flow-control area. This is a potentially conservative estimate of the number of fish using the entire area, as this antenna has a very limited range of detection. Tagged lamprey that swim by in the main fishway are out of detection range, as are those that enter the AWS channel directly through the picket leads.

In addition, relatively low numbers (<40%) of these fish were detected on upstream antennas, indicating poor passage success. Therefore, installation of an LPS to afford lamprey access to the forebay could provide a passage route out of this dead-end at the top of the Cascades Island fishway (see Cascades Island AWS trapping section).

Overall, lamprey that use the LPSs were detected on upstream antennas in lower percentages than those that used a traditional fishway exit. There were several possible reasons for this. Lamprey that use an LPS tend to be smaller, and smaller fish typically have lower overall escapement than their larger cohorts (Keefer et al. 2013). It is also possible that there is a fitness cost to lamprey use of the LPS; they may incur higher energetic costs in climbing the LPS than in using traditional fishways. Further research is needed to ensure that LPS use does not incur any loss in reproductive potential for lamprey that choose this passage route.

The U.S. Army Corps of Engineers (USACE) reported that at Washington Shore, the AWS LPS passage count was biased high by 7-30%, based on 10 3-h video validations during 2-10 June 2013 (N. Zorich, USACE, personal communication). To account for this, collected count data were adjusted to reflect a more conservative passage rate at the Washington Shore AWS LPS. The problem of exit door bounce and resultant overcounting was identified by various validation techniques and was frequently addressed with maintenance on an *ad hoc* basis when personnel were on site. Consequently, the Washington Shore AWS LPS unadjusted count (Figure 9) is likely an overestimate.

However, the Washington Shore AWS LPS adjusted count (Figure 9 and Table 2) is likely an underestimate for the following reasons:

1. Video validations were conducted only during periods when NOAA personnel were not able to monitor and maintain LPS counting systems. Physical and observational validations by NOAA confirmed that LPS counts were accurate during most periods that the LPS was operated.
2. Video validation equipment did not provide a time-stamp with which to synchronize with LPS counting equipment. As a result, comparisons of passage between the two systems could only be estimated.
3. Neither the unadjusted nor the adjusted counts included lamprey that passed during periods of counter outage.

4. Detection data indicate that 23% of PIT-only lamprey used the Washington Shore LPS (Table 4). This proportion, relative to visual count data, suggests that LPS passage was underestimated by both the adjusted and unadjusted counts in 2013.
5. We have greater confidence in PIT detection data than in data from LPS and visual counting systems combined. In all previous years of operation, the PIT detections have indicated that LPS use was lower than fishway use. However, in 2013, the proportion of PIT detections in the LPS eclipsed that in the fishway exit, indicating that more lamprey exited the LPS than the main fishway. Count adjustments shifted the proportional use of these passage routes in the opposite direction from that indicated by the PIT data.

Improvements to the design of the LPS mechanical exit door could reduce periods of counter outage and overcounting, particularly at LPSs that pass high numbers of lamprey. Also, tests of alternative fish-passage monitoring techniques would be informative. Techniques such as electrical impedance, acoustic tagging, and laser or video monitoring could potentially avoid the mechanical aspects of the counter system that are subject to damage by passing lamprey. Using either the unadjusted or adjusted counts, the number of lamprey documented passing via the Washington Shore or any other LPS was unparalleled in 2013.

Obtaining accurate, real-time counts of lamprey as they use the AWS LPSs has been challenging. Extreme environmental conditions (heat, moisture, high-frequency radio interference), power failures, and the vagaries of lamprey behavior have combined to make obtaining and interpreting lamprey exit counts a difficult and labor-intensive task. Improvements in 2013 provided the next step in the evolution towards a reliable, radio-linked, network-accessible count system. However, the complexity of this system and its large number of components make it susceptible to outages.

We recommend that LPS count systems be powered by more consistent sources of AC power. At each of the fish counting stations, eventual incorporation of counts from the AWS LPSs would eliminate the need for transmission of count data across the Bonneville Project by radio link. In the meantime, equipment associated with AWS LPS exit counts must be accessible from the forebay decks for regular assessments, maintenance, and validations.

Collection efficiencies at both the Bradford Island and Washington Shore LPS were higher in 2013 than in 2011 and 2012 (Corbett et al. 2013). After 1 July 2011 and during the entire migration period of 2012, the picketed lead at the Washington Shore AWS was lowered to the fishway floor to protect migrating salmonids. In 2013, the picketed lead at the Washington Shore AWS was raised 3.8 cm from the fishway floor during the entire lamprey migration period (A. Traylor, personal communication).

Collection efficiency in 2013 (48%) was considerably higher than in 2012 (12%) and also higher than during the period in 2011 when the picket lead was lowered (16%). However, collection efficiency in 2013 was similar to that recorded in 2011 during the period when the picketed lead was raised (41%).

At the Bradford Island AWS, the condition of the picketed lead was unchanged in 2013, although in 2012 it was raised 2.5 cm from the fishway floor for the entire lamprey migration period. Nevertheless, collection efficiency in 2013 (44%) was substantially higher than in 2012 (18%). This may have been due to the relative newness of the structure in 2012, and potentially repellant odors present on the "unseasoned" metal surfaces in that year.

The capacity of present LPS designs is unknown. Across years of study, lamprey counts in the LPSs drop, while window counts rise at the peak of the migration. We have no direct capacity measurements of the current lamprey passage structures, nor of lamprey response to crowding. If lamprey abundance increases, the number of lamprey using the LPSs will put new demands on systems developed during periods of very low lamprey abundance. 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 such as AWS channels, where these fish concentrate in large numbers.

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

Introduction

Research has shown that lamprey 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). We designed and constructed refuges that were intended to provide cover from light during daylight hours and retain lamprey in the fishways that would otherwise fall back or seek low-light areas in which to hold.

Design and Installation of Refuges

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. Both refuges were operated throughout the 2013 lamprey migration period (Figure 10, Corbett et al. 2013). Two additional refuges of similar design were installed in the Washington Shore fishway downstream from the AWS channel and near the confluence with the upstream migrant tunnel (UMT).

These two new refuges were installed during the 2012-2013 winter maintenance period and were located along the north and south walls of the fishway downstream from its junction with the UMT. Metal guides attached to the walls were used to lower and position the refuges along each wall (Figures 11 and 12). These prototype refuges consisted of a 40.6- by 114.3-cm weighted box with openings at both ends. Refuge boxes were 17.8 cm high and featured cobble substrate cemented to the bottom of the upstream end.

The long axis of each box was oriented with the flow (Figure 13), and a single HD-PIT antenna was fitted to the perimeter. Antennas and transceivers for the refuge boxes were powered by AC outlets for refuge boxes in the AWS channels and by a solar panel for boxes in the fishway, where grid power was not available. Lamprey tagged with PITs as part of Objectives 1 and 3 were used to assess the lamprey use of these devices.

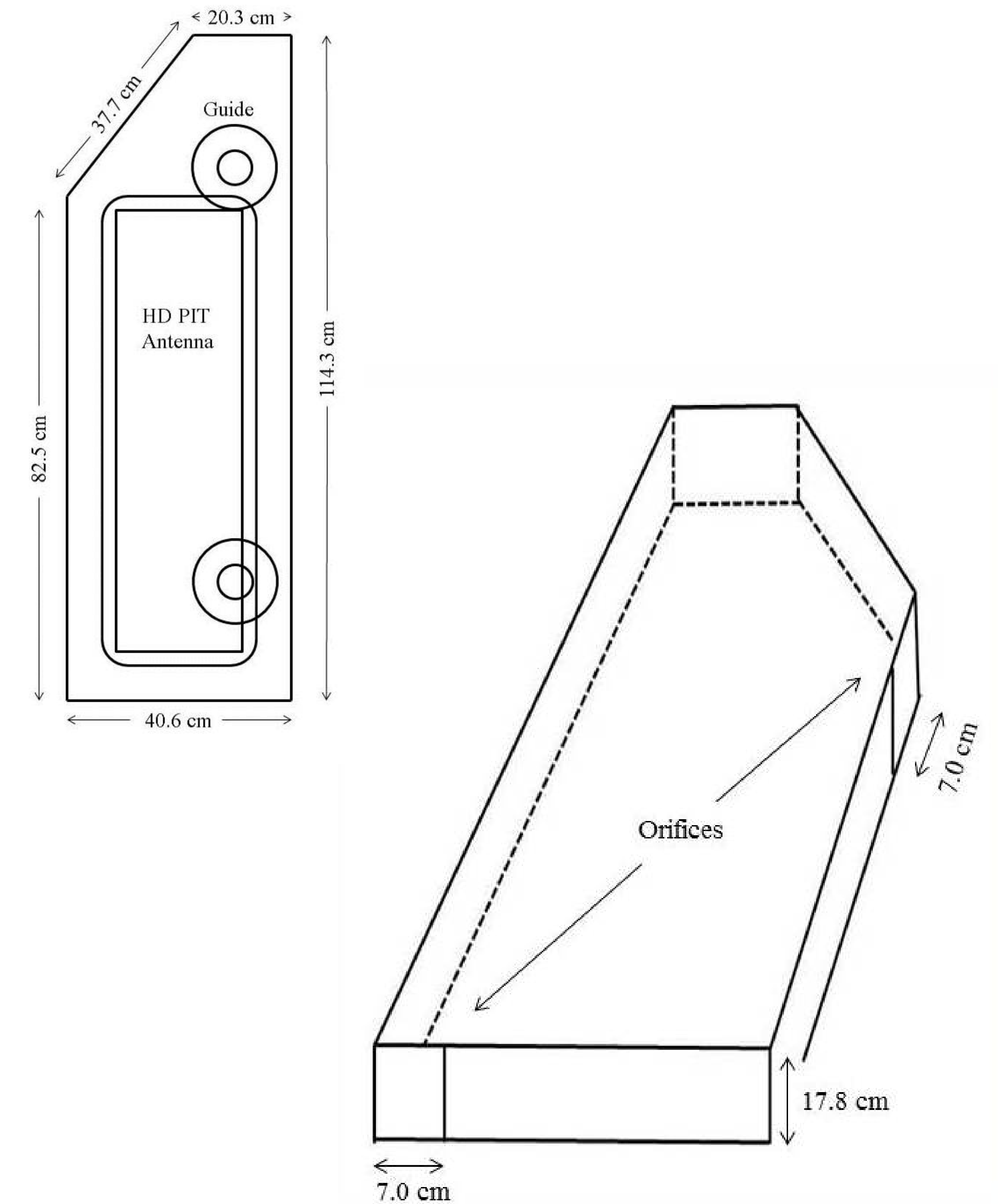


Figure 10. Plan view (upper left) and oblique view (lower right) of refuge boxes installed in the Washington Shore AWS channel and fishway.

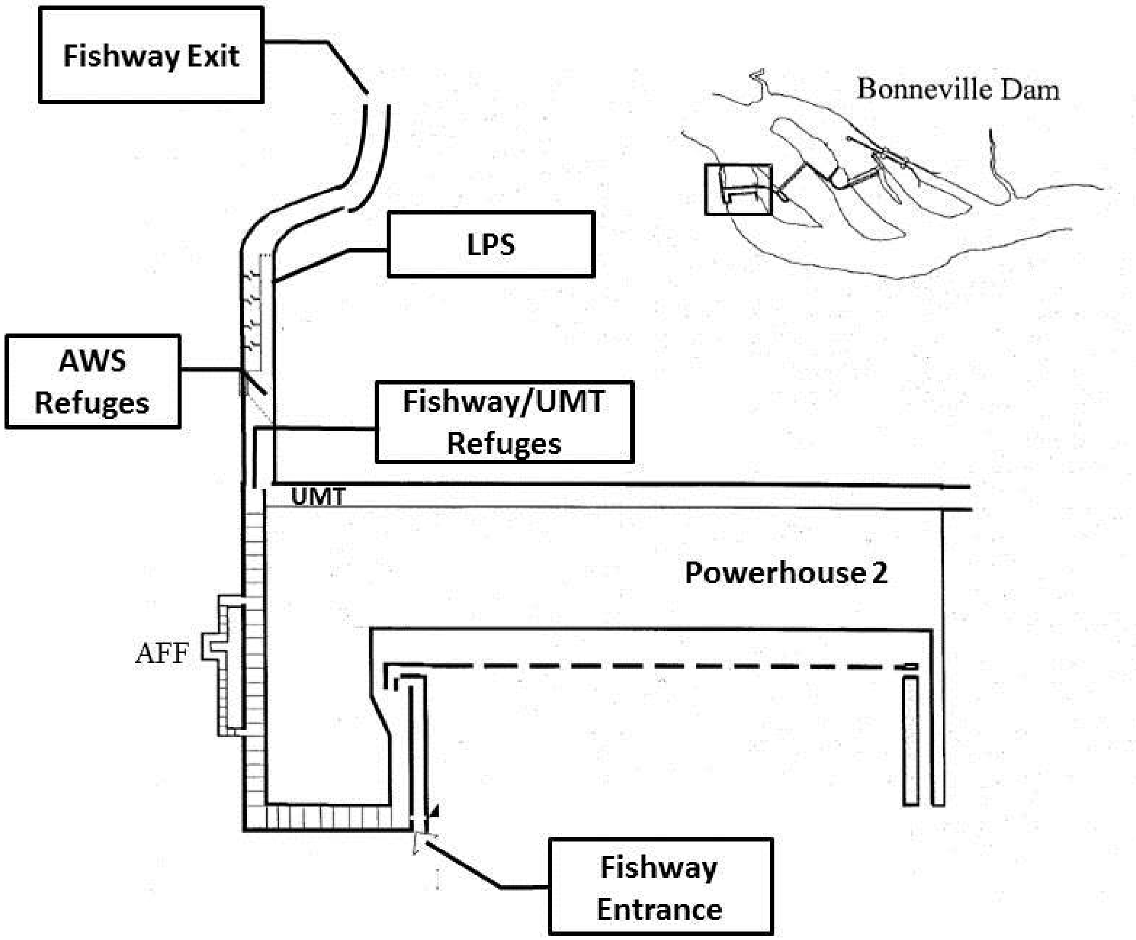


Figure 11. Location of refuge boxes in the Washington Shore AWS channel and fishway at Bonneville Dam.

AWS Refuges **Fishway Refuges**

Figure 12. Location of refuge boxes in the Washington Shore AWS channel and fishway at Bonneville Dam.

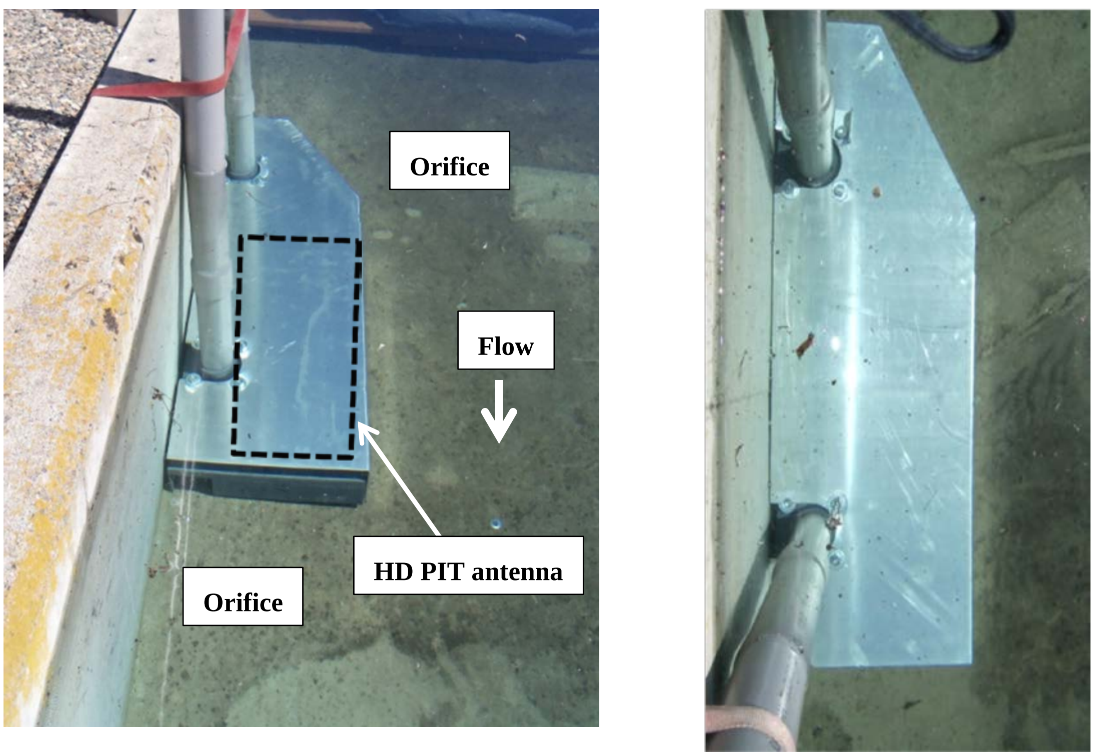


Figure 13. Photographs of refuge box design and placement.

Monitoring of Tagged Lamprey

Methods

The two AWS refuges were in place prior to the lamprey migration in 2013. Lamprey use of these refuges was monitored continuously by HD-PIT antennas throughout the 2013 migration period. The two fishway refuges were newly installed prior to the lamprey migration in 2013. Lamprey use of these refuges was monitored sporadically by HD-PIT antennas throughout the migration period in 2013 due to outages and system failures resulting from inadequate power.

In 2013, at each refuge, PIT-tagged lamprey that were detected in each refuge were enumerated, and the percentage of these individuals that were subsequently detected in the Washington Shore LPS was calculated. We also determined the fate of fish that used the refuges by screening LPS and fishway exit detections for fish that had used a refuge. In addition, the duration of refuge residence was determined by subtracting the time of first detection from last detection at a refuge antenna for each individual.

Results

In 2013, lamprey refuges were operated in the Washington Shore AWS channel from 27 June to 23 October. Of the 1,073 lamprey PIT-tagged and released downstream from Bonneville Dam, 153 (14%) were detected in an AWS refuge in 2013. Also detected in the refuges was one lamprey that was released to another structure at Bonneville Dam.

Of the 154 lamprey detected in a refuge, 95 (62%) were subsequently detected at the LPS, 94 (61%) were subsequently detected at the LPS and/or fishway exit, and 77 (50%) were subsequently detected upstream from Bonneville Dam. Of the 353 PIT-tagged lamprey detected exiting the Washington Shore AWS LPS or fishway, 99 (28%) had previously been detected at an AWS refuge. Mean residence time of PIT-tagged lamprey within an AWS refuge was 57.2 h (± 126.8 h, range 0.003-987.6 h).

Lamprey refuges were operated in the Washington Shore fishway from 3 June to 7 November 2013. Monitoring at these refuges was not continuous due to outages and system failures resulting from unreliable power. Of the 1,073 lamprey PIT-tagged and released downstream from Bonneville Dam in 2013, 152 (14%) were detected in a fishway refuge, along with one fish tagged in 2012. Of these 153 lamprey, 50 (33%) were subsequently detected at the LPS, 70 (46%) were subsequently detected at the LPS and/or fishway exit, and 76 (50%) were subsequently detected upstream from Bonneville Dam.

Of the 353 PIT-tagged lamprey detected exiting the Washington Shore AWS LPS or fishway, 71 (20%) had previously been detected at a fishway refuge. Mean residence time of PIT-tagged lamprey within a fishway refuge was 52.8 h (± 112.3 h, range 0.003-687.6 h). Three lamprey were detected at a fishway refuge for over 1,000 h and were excluded from the residence time analysis.

A total of 352 PIT-tagged lamprey were detected exiting at the Washington Shore LPS and/or fishway. Of these 352 fish, 135 (38%) were detected at one or more of the AWS and/or fishway refuges. Of the 135 lamprey detected in a refuge, 80 (59%) were subsequently detected upstream from Bonneville Dam. The remaining 218 lamprey were detected exiting the Washington Shore LPS and/or fishway but were not detected in an AWS or fishway refuge. Of these fish, 124 (57%) were subsequently detected at antennas upstream from Bonneville Dam.

In 2013, a total of 245 unique PIT-tagged lamprey were detected at one or more of the AWS and/or fishway refuges. Of the 245 PIT-tagged lamprey detected at a refuge, 135 (55%) were detected exiting at the WA shore LPS and/or the WA shore fishway and 80 of those 135 (59%) were detected at antennas upstream from B**o**nneville Dam. Of the remaining 110 PIT-tagged lamprey detected at a refuge but not detected exiting at the WA shore LPS and/or the WA shore fishway, 49 (45%) were detected at antennas upstream from Bonneville Dam.

Discussion

A substantial percentage of PIT-tagged lamprey that reached the top of the Washington Shore fishway used refuges, in spite of their relatively small footprint. The AWS channel where these refuges were deployed is 7.3 m wide. Consequently, the refuge footprint represents just 11% of the cross-sectional floor area at this location. Nevertheless, 38% of lamprey exiting the fishway (either via the LPS or traditional fishway) had visited an AWS refuge. Similarly, even though they were only operational for a portion of the lamprey migration, fishway refuges at the terminus to the UMT were used by 20% of the fish detected at the fishway exit.

Lamprey that used refuges also had an LPS collection efficiency (33-62%) similar to the overall collection efficiency at the Washington Shore LPS (48%, see Objective 1). While a substantial number of all lamprey detected exiting the fishway in each year had used a refuge, this number was likely underestimated due to the high probability of PIT-tag collision at the 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, where two or more PIT signals are transmitted simultaneously and neither is read correctly. Video monitoring is needed for a more accurate evaluation of refuge use, but the PIT data clearly indicated that lamprey were seeking out these relatively small refuges in the AWS channel.

Mean lamprey residence time was 57.2 h for AWS refuges and 52.8 h for fishway refuges. The shorter residence times recorded in the fishway refuges were probably due to intermittent operation of the PIT detection antenna. For any tagged lamprey residing in a refuge when the antenna was switched off, residence time would be truncated. Future monitoring at this site needs to be powered by a grid source, as solar power at this site was not reliable.

Lamprey were detected in the refuges for periods ranging from several seconds to several weeks. Tagged lamprey regularly were detected in the refuges during the day and for periods in excess of 8 h, suggesting that the refuges functioned to retain lamprey that might otherwise have fallen back downstream within the fishway (Keefer et al. 2013).

Based on detections of PIT-tagged lamprey at the WA shore LPS and /or the fishway exit and subsequent detections upstream from Bonneville Dam, passage success was similar for the tagged lamprey that used a refuge (59%) and those that did not (57%). There is some indication that passage success was under-estimated for lamprey that used a refuge box; 49 of the 245 (20%) PIT-tagged lamprey that were detected at a refuge were not subsequently detected at the WA shore LPS and /or the fishway exit but were detected at locations upstream from Bonneville Dam.

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 a high potential for turn-arounds within the fishway by radio-tagged lamprey. Moreover, fallback from areas at the top of ladders was less likely to be followed by further passage attempts than those from other fishway segments (Keefer et al. 2013). Furthermore, Keefer et al. (2014) reported that at both Bradford Island and Washington Shore, increased upstream passage efficiency near the top of fishways had the potential to increase overall dam passage success more than improvements at any other fishway section. For these reasons, siting refuges must be carefully considered so that lamprey are afforded a haven during the day in areas where turn-arounds without reascension are common.

Pilot testing of lamprey refuges in the fishway proper 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, as power failures resulted in a gross underestimate of fishway refuge use.

Ideally, fish tagged with both radio and PIT tags could be used to monitor 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.

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. (Figure 14; Moser et al. 2012; Corbett et al. 2013). In 2013, prior to the lamprey migration period, the terminal trap was removed and the LPS extended to the forebay to allow lamprey to volitionally pass from tailrace to forebay (Figure 15).

Extension of the Cascades Island Lamprey Passage Structure

In 2013, the trap box at the former terminus of the Cascades Island LPS was removed and replaced with flume sections to allow for volitional lamprey passage upstream from tailrace to forebay. A 9-m, 8-inch rectangular flume section was added at the site of the removed terminal trap and connected the lower sections of the LPS via an upwelling box/slide to a transition “pond” (Figure 15, Panel A). A PIT antenna was incorporated into the flume 4 m downstream from the pond.

The transition pond is a structure that 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. 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, 10-inch-diameter pipe and 10-m, 10-inch-diameter exit slide were added (Figure 15, Panel B), connecting the lower structure and pond to the forebay.

Figure 14. Photo of the Cascades Island LPS terminal trap in place 2009-2013. This trap was replaced in 2013 with a flume section that connected the lower LPS to the exit extension.

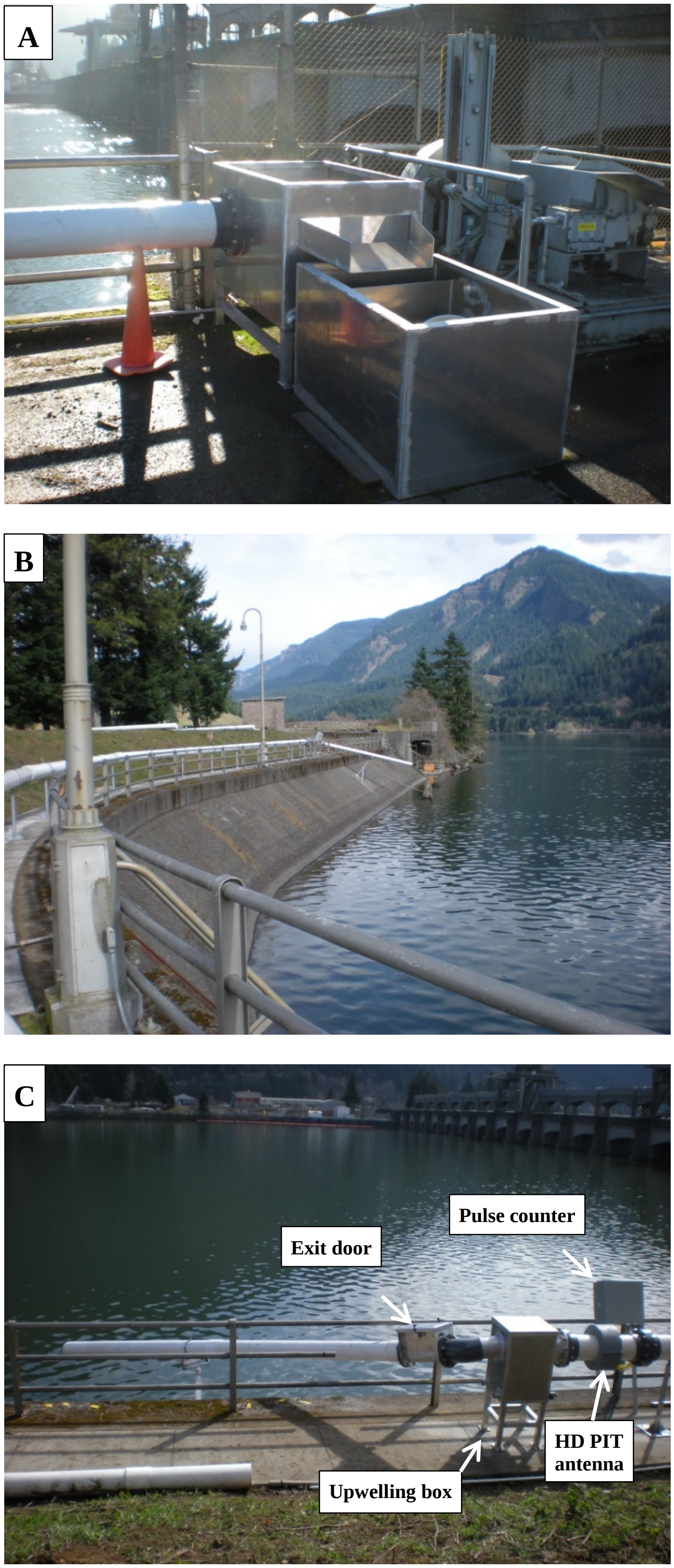


Figure 15.
Photos of transition pond, pipe, and exit sections newly added to the Cascades Island LPS in 2013.

Columbia River water was supplied to the top of the LPS and into the trap box by two 3-hp submersible pumps via a 10.2-cm-diameter PVC pipe. A PIT antenna was installed between the pipe terminus and the upwelling box (Figure 15, Panel C). The exit door (activated for lamprey counting) was located at the highest portion of the exit slide so that it could be easily accessed for maintenance from the forebay deck. A prototype design for the exit door was incorporated to the passage count system (Figure 16).

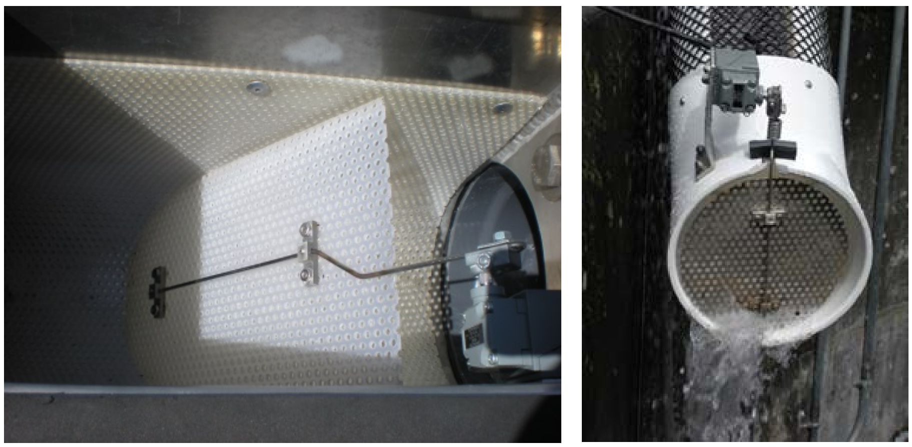


Figure 16. Prototypical and traditional door paddle and limit switch configurations at Cascades Island (left) and Washington Shore LPS (right).

In 2013, we evaluated use of the Cascades Island LPS using observations of lamprey in the rest boxes and pond, passage estimates and video observations at the exit slide counter location, and detections of PIT-tagged lamprey. Detections of PIT-tagged lamprey released downstream from Bonneville Dam were used to assess relative collection efficiency and passage rates through the LPS.

Due to low sample sizes of PIT-only tagged lamprey, we released some PIT-only lamprey directly into Rest Box 3 (Figure 6) of the LPS in 2013 to further evaluate the structural and operational changes to this structure**.** In addition, 25 double-tagged lamprey (radio and PIT) were released into Rest Box 3 and at the tip of Bradford Island (Figure 7) to assess relative rates of fallback.

In 2013, the nylon mesh, conical fyke at the entrance to Rest Box 4 (Corbett et al. 2013) was replaced with an experimental one-way gate entrance (Figure 17).

Figure 17. Photos of the 2013 experimental one-way gate entrance (closed at left and open at right) to Rest Box 4 of the Cascades Island LPS.

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 exit of the LPS (RTR-500NW, TandD Corporation). The base station communicated by radio uplink to a local area network (LAN) housed in the tailrace south tower (Figure 7). Raw pulse count data were delivered twice daily via email at 0500 and 2100.

In 2013, a motion-activated camera (Sony IPELA SNC-CH240) was operated on an experimental basis at the LPS exit to provide information on counter performance and passage behavior. Imagery from the camera was archived on memory cards, and camera records of lamprey passage events were paired with passage events recorded by the pulse counter.

Results

In 2013, the Cascades Island LPS was operated for 103 d, from 24 June to 4 October. During this period, the total number of lamprey counted exiting to the Bonneville Dam forebay from the LPS was 155 (86 day, 69 night). Forty-seven

PIT-tagged fish were released to the lower portion of the LPS, and 36 of these were detected at the antenna near the LPS exit and were possibly counted exiting the LPS. During the counting period there were gaps in the LPS count record (29 June-1 July and 9-19 July) due to inconsistent re-setting of the limit switch at the prototype LPS exit door.

In 2013, at the Cascades Island LPS exit slide, camera images of migrating lamprey were captured between 30 August and19 September using a motion-activated camera. Fourteen of 15 (93%) lamprey passage events recorded by the camera were also recorded by the pulse counter. 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.

During validations, we noted that the arm to the exit paddle was at a level of tension that would not allow activation of the pulse counter. Hence, there is a high likelihood that lamprey were exiting the LPS without being counted during some periods. The tension on the arm was adjusted several times throughout the migration period in an attempt to resolve this. From video footage it appeared that some lamprey did not lift the exit paddle high enough for the pulse counter to be activated. In addition, the angle of exit slide (8°) was not steep enough. Attachment surfaces within the exit slide allowed lamprey to attempt upwards swimming or back-climbing within the exit slide. This was remedied by lining the exposed slide areas with rolled, perforated plate.

Evaluations Based on Monitoring of Tagged Lamprey

Methods

To evaluate lamprey fallback and passage rates through the upper part of the structure, tagged lamprey were released directly into the lower portion of the Cascade Island LPS. Lamprey used for this evaluation were the same fish collected and tagged for Objective 1 (Table 3).

Lamprey captured from traps at the Washington Shore fishway and Cascades Island AWS channel were HD PIT-tagged (see Objective 1 for PIT-tagging methods), transported in a tank truck to the Cascade Island LPS, and placed in Rest Box 3 on the evening of the capture day. Subsequent detections of these fish at PIT antennas were used to assess passage time from Rest Box 3 to the LPS exit and the degree of fallback within the LPS.

Another group of lamprey were tagged with both a radio and PIT tag and released to the forebay upstream from the LPS exit at the tip of Bradford Island (Figure 7). Lamprey were radio-tagged using methods outlined in Moser et al. (2002). Radio-tagged lamprey were released at dusk 8-10 h after tagging. Radio tags were uniquely coded, 18.3 mm in length, 8.3 mm in diameter, and weighed 2.1 g in water (model NTC-4-2L, Lotek Wireless Inc.). Movements of radio-tagged lamprey were tracked using fixed-site telemetry receivers at Bonneville Dam and receiver arrays upstream operated by University of Idaho researchers.

Results

In 2013, 3 (2 PIT-only and 1 double-tagged) of 1,073 (0.3%) lamprey PIT-tagged and released downstream from Bonneville Dam were detected in the Cascades Island LPS. Of these, 2 were detected exiting the LPS to the forebay. The remaining lamprey was detected at the lowest antenna within the Cascades Island LPS and then subsequently at the Bradford Island LPS, where it was detected ascending and exiting. None of these three lamprey were detected at sites upstream from Bonneville Dam.

Two of the three fish detected using the Cascades Island LPS were detected at other Bonneville structures prior to their detection at Cascades Island. One lamprey was detected at all antennas within the LPS. For this fish, passage time between detection at Rest Box 3 and detection at the pond was 1.5 h. Passage time between detection at the pond and exit slide was 0.2 h. Total passage time from Rest Box 3 to the exit slide was 1.6 h.

Over five dates in 2013, we placed 25 PIT-only lamprey into Rest Box 3 of the Cascades Island LPS (Figure 6) to evaluate passage timing and success. Three were recovered as mortalities within 12 hours of release and excluded from the analysis. Six of the 22 used in the analysis were last detected downstream from the release site, indicating that they fell out of the LPS. Four of these 6 were subsequently detected passing Bonneville Dam via other routes. Sixteen of the 22 (73%) were last detected in the Cascades Island LPS exit slide, indicating that they ascended and exited to the forebay. Of these 16 fish, 1 (6%) was detected downstream from the release point, indicating that it fell back before ultimately ascending the LPS. Eight (50%) of the 16 lamprey detected exiting to the forebay were subsequently detected at sites upstream of Bonneville Dam. Median time from release to detection at the LPS exit for these fish was 6.6 h (range 3.9-7.3 h).

We also placed 25 lamprey tagged with a PIT tag and a radio tag into Rest Box 3 of the Cascades Island LPS on five different dates during the passage period. Four of these fish were last detected downstream from their release site, indicating that they fell out of the LPS. One of these four was subsequently detected passing Bonneville Dam by other routes. Twenty-one (84%) of the 25 double-tagged lamprey were detected at the exit slide and/or on a fixed telemetry receiver at the Bonneville Dam forebay, indicating that they ascended and exited the LPS. Of these 21 detections, 15 (71%) were subsequently detected at telemetry arrays upstream; 1 (5%) was detected below the dam after being detected in the forebay, indicating that this fish fell back downstream after ascending and exiting the LPS. Median time from release at Rest Box 3 to PIT detection at the exit slide was 5.0 h (range 1.1-6.6 h) for the 21 double-tagged fish that exited the LPS.

Over five dates, an additional 25 lamprey were tagged with a PIT tag and a radio tag and released into the forebay of Bonneville Dam approximately 0.25 km upstream from the Cascades Island LPS exit. Of these, 14 (56%) were subsequently detected upstream from the release site. None were detected at sites downstream of Bonneville Dam subsequent to being detected at the forebay, indicating that none fell back downstream after being released into the forebay (fallback = 0%).

In 2013, three PIT-tagged lamprey were detected entering the Cascades Island LPS volitionally. Two of these fish ascended the LPS beyond Rest Box 4 through the one-way gate entrance and were detected exiting to the forebay; the third was detected no higher than the antenna immediately downstream of Rest Box 3. Of the 47 PIT-tagged lamprey released to Rest Box 3, 36 (77%) were detected at LPS antennas upstream from the one-way gate entrance at Rest Box 4, and none of these were subsequently detected at the antenna downstream from Rest Box 3 after ascending to these upstream antennas.

Discussion

PIT detections, passage estimates and video imagery confirmed that lamprey using the Cascades Island LPS were able to navigate the new sections of the structure and successfully exit to the dam forebay. Problems with the new counter configuration made it difficult to obtain an accurate count of lamprey use of this LPS. In addition to reducing attachment surfaces in the exit slide, future modifications to the exit slide should include an increase in the slide angle. This would increase the rate of passage through the slide and presumably limit the ability for lamprey to hold, or swim upstream in the slide.

The few PIT-tagged fish that entered this structure provided important insights. Two of three were able to completely pass from the first PIT antenna at Rest Box 3 (Figure 6) to the forebay, but one fell back within the structure and did not reascend. For tagged lamprey placed into Rest Box 3, 20% of radio-tagged and 27% of PIT-only fish fell back out of the structure. Missed detections and lack of complete PIT monitoring at this structure made it difficult to identify places where lamprey turned around. Adding PIT monitoring equipment to other transition areas such as rest box entrances, significant elevation changes, and the pipe section would increase resolution.

Lamprey that passed upstream from Rest Box 3 to Rest Box 4 before falling back could not be distinguished from those that were blocked by the new one-way gate at Rest Box 4. For this reason, the new rest box entrance design should be used with caution. Although it appeared to reduce fallback of fish that ascended to the pond, it may also have reduced the number of fish that were able to get to that point. Observations of lamprey using this type of rest box entrance design should be made in the laboratory before further installations of this type are made.

Eighty-four percent of the radio-tagged fish placed into the Cascades Island LPS ascended to the exit, and 71% of those proceeded to upstream sites. One lamprey (5%) apparently fell back over the spillway after exiting the structure. In contrast, none of the radio-tagged fish that were released upstream from the LPS exit fell back downstream. While sample sizes were low, these tests indicate that some lamprey exiting the LPS fall back downstream, as is the case at AWS LPS exits (see previous chapter). However, even fish released as far upstream as the Stevenson boat ramp have been detected falling back downstream from Bonneville Dam. Larger sample sizes of radio-tagged fish are needed to determine the fate of lamprey using this LPS relative to other treatment groups.

Although we do not have precise passage rates through the Cascades Island structure, data obtained from both volitional entries and releases into Rest Box 3 indicate that passage takes on the order of hours after lamprey start ascending. It was encouraging that one of the volitional entries traversed the entire structure in less than 2 h. This is in contrast to the fact that on average lamprey require several days to negotiate the traditional fishways (Moser et al. 2002b; Keefer et al. 2013).

As noted by Corbett et al. (2013), PIT-tagged fish released directly into Rest Box 3 were regularly missed by LPS antennas. It is possible that this occurred due to tag signal collisions. Further testing is needed to confirm detection efficiencies of these antennas. However, PIT antennas at the Bradford Island AWS LPS have regularly returned 100% detection efficiencies, due to the small interrogation areas and heavily shielded antennas. It seems unlikely that lower efficiencies would occur at the Cascades Island LPS, where identical PIT antenna designs were installed.

Numbers of lamprey using the Cascades Island LPS in 2013 were small compared to the number (n= 2,472) that ascended to the terminal trap box in 2012 (Corbett et al. 2013). This may have been a seasoning effect of the new exit structure. In addition, the use of PVC pipe is unique to this LPS and may have resulted in lamprey rejection of water that had passed over this material. Previous work has confirmed that new structures need to "season" before they become acceptable to lamprey (Moser et al. 2012).

Other changes to the structure (e.g., new one-way gate at Rest Box 4, flume to pond, new pond PIT detector) could also have reduced the number of lamprey accessing the pond. However, it is not possible for lamprey to fall back downstream from the pond. Hence, observations of lamprey in the pond and the lack of dead lamprey in the exit structure indicated that lamprey that attained the pond were eventually able to exit the structure. It is possible to operate the pond as a trap, and this might be useful in future years to provide an accurate count of lamprey to this point. In addition, installation of inspection ports along the exit tube would allow complete monitoring of lamprey residing in the tube, which is currently inaccessible.

In summary, the Cascades Island LPS efficacy continues to improve. Lamrey exhibited the ability to ascend to the structure exit at rapid rates. Extension of the structure to the forebay afforded numerous advantages to lamprey. Fish are no longer handled prior to forebay release or held for extended periods in a high-density trap. However, they may suffer higher fallback rates and this needs to be further evaluated.

Negotiating this type of structure is clearly within the realm of lamprey swimming performance and climbing ability. The Cascades Island LPS is over three times higher and nearly three times longer than any previous structure tested (Moser et al. 2011). It also features the longest and steepest collector ramp (60°) and the greatest number of transitions and direction changes. The fact that lamprey were capable of ascending this full-scale LPS indicates that with some modifications, structures of this kind could be used to facilitate lamprey passage from a dam tailrace to its forebay elevation.

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

Introduction

In past years adult lamprey have been detected and observed accumulating in the Cascades Island AWS channel, a structure that has no direct access to the forebay. Lamprey trap and haul operations at this location were successful in 2012 (Corbett et al. 2013), and likely contributed to the migration success of lamprey that otherwise would have been blocked from or delayed in movements upstream. Also, by trapping at different locations than those from 2012 within the Cascades Island AWS channel, we were able to document areas where lamprey accumulate and identify suitable sites for future LPS collectors within the channel.

Methods

In 2013, portable traps similar to those deployed at the adult fish facility were deployed at the Cascades Island AWS channel upstream from the picketed lead near the fishway exit (Figure 18). Lamprey had been observed accumulating in this area, where PIT-tagged lamprey were detected in 2012 and prior years. Trapping sites were selected both to evaluate lamprey use of the channel and to provide information for future siting of an LPS collector (Figure 19). 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 either used for Cascades Island LPS experiments or transported and released upstream from Bonneville Dam

Results

At the Cascades Island AWS channel, 1-3 portable lamprey traps were deployed at 4 locations on 57 d between 9 July and 23 October 2013. Two portable traps were deployed in the flow-control section upstream from the picketed lead and downstream from the fishway exit. One trap was deployed downstream from the UMT entrance and picketed leads (Figure 19). Traps were recovered 1-2 times per day, checked for lamprey, and re-deployed. A total of 625 adult lamprey were captured at the Cascades Island AWS channel, and 604 were transported and released approximately 1 km upstream from the dam near Stevenson, WA. The remaining 21 lamprey were PIT-tagged and released at the Cascade Island LPS in Rest Box 3.

In addition to the two original trap locations established in 2012, we added two trap locations on 7 August 2013 to determine areas where lamprey accumulate and to help inform the optimal location for placement of an LPS entrance collector (Figure 19).

Additionally, on 26 June, USACE project biologists partially dewatered the upper section of the Cascades Island AWS channel in order to move adult sockeye salmon that had become trapped. During this operation, an estimated 20-30 lamprey were handled and released to the Bonneville Dam forebay. An estimated 200-300 lamprey were observed but not captured in the upper section of this AWS channel (B. Bissell, USACE, personal communication).

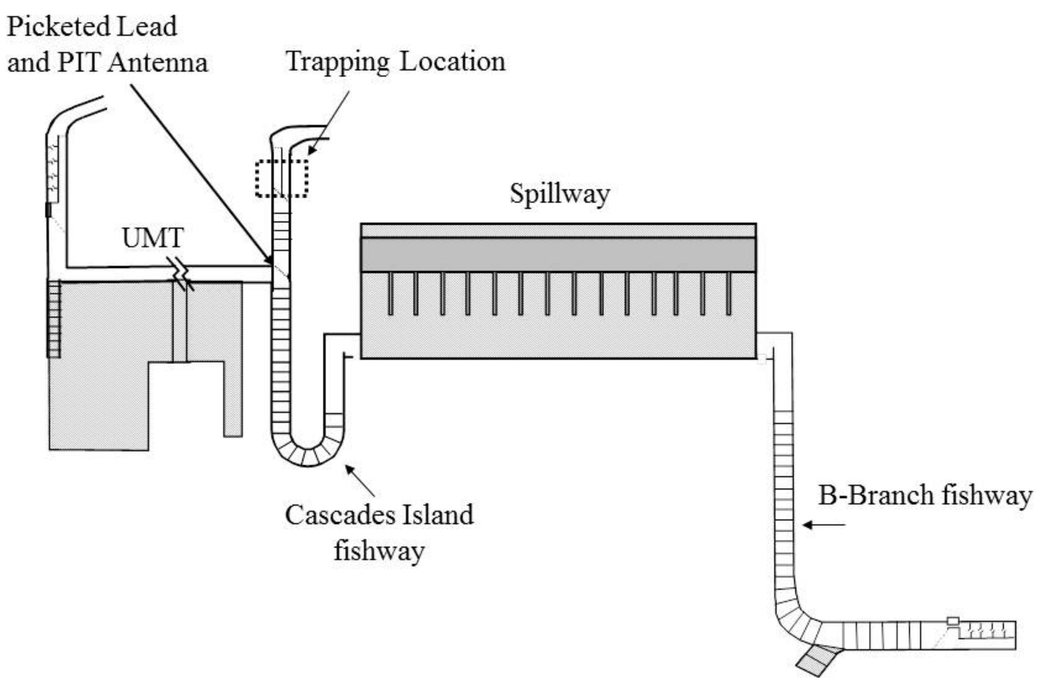
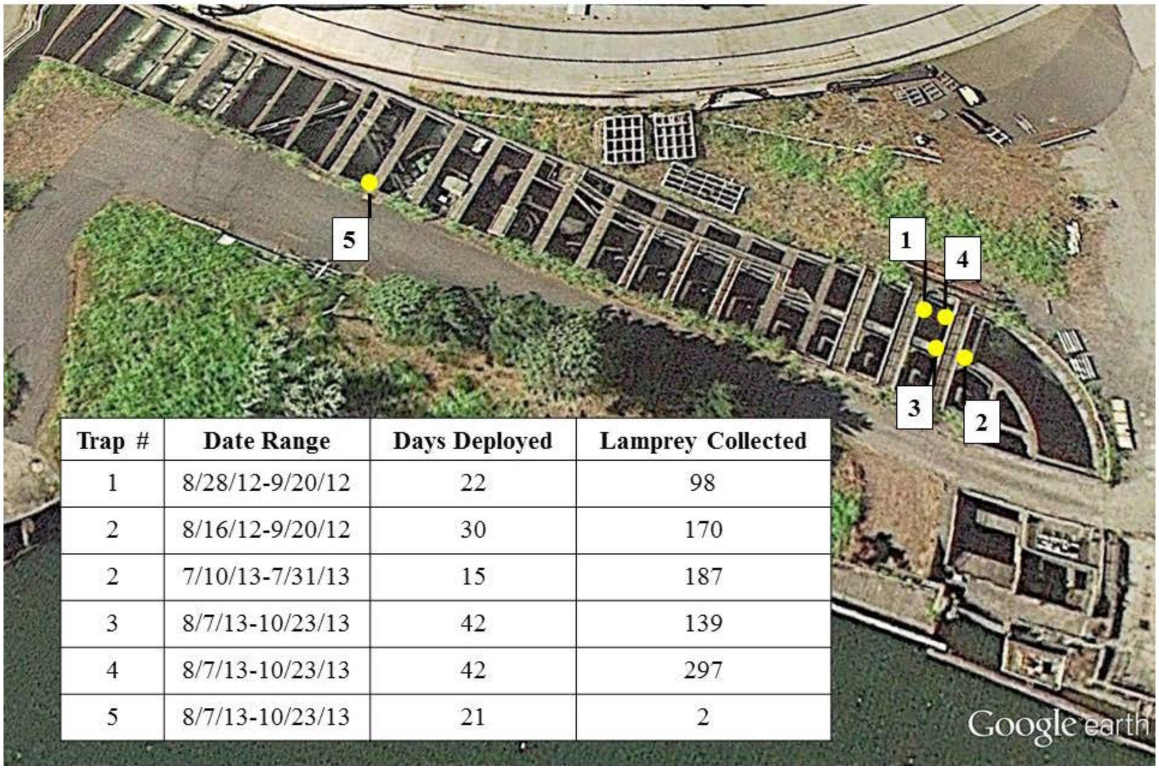


Figure 18. Locations of the HD-PIT antenna at picketed lead and trap deployments at the Cascades Island AWS channel.



Trap #	Date Range	Days Deployed	Lamprey Collected
1	8/28/12-9/20/12	22	98
2	8/16/12-9/20/12	30	170
2	7/10/13-7/31/13	15	187
3	8/7/13-10/23/13	42	139
4	8/7/13-10/23/13	42	297
5	8/7/13-10/23/13	21	2

Figure 19. Locations of 2012 and 2013 trap deployments and associated lamprey captures at the Cascades Island AWS channel.

Discussion

Collection of lamprey was very successful in 2013 at the Cascades Island AWS channel upstream from the picketed lead, where lamprey are known to accumulate. Collected lamprey were transported upstream from Bonneville Dam and contributed to lamprey passage, as they likely would not have passed Bonneville Dam otherwise.

In addition to trapping results from 2012 (Corbett et al. 2013) 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 here (Table 7). To improve lamprey passage at Bonneville Dam, fish that access this AWS should be provided with an outlet to the forebay via a lamprey passage structure. Alternatively, lamprey should be actively trapped and transported upstream throughout the migration period.

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 ladder. Additionally, live lamprey were observed climbing the headgate at the fishway exit to the forebay (Figure 20).

Figure 20. Lamprey ascending headgate of fishway exit at Cascades Island AWS channel.

Trapping results and visual observations indicate that lamprey passage could be improved by placement of an LPS at this AWS. Based on collections of lamprey, LPS entrance collectors should be located along the north and south walls of the AWS at the approximate locations of trap sites 3 and 4 (Figure 19) and connected to the forebay in the design 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 structure was installed at the John Day Dam South Fishway to collect Pacific lamprey for tribal broodstock and enumerate lamprey that migrate upstream (Figure 21). The trap was designed to operate in two modes, one in which lamprey enter and are collected (Figure 23), and one in which lamprey enter and are able to escape upstream (Figure 23). On a pilot basis, a camera system was installed to evaluate the trap by recording numbers of lamprey occupying the trap in both modes. Ultimately, when the camera system is optimized, the recorded video will be used to enumerate lamprey during periods when the trap is operated in the pass-through mode. In addition, a PIT antenna was incorporated into the structure to allow detection of tagged lamprey.

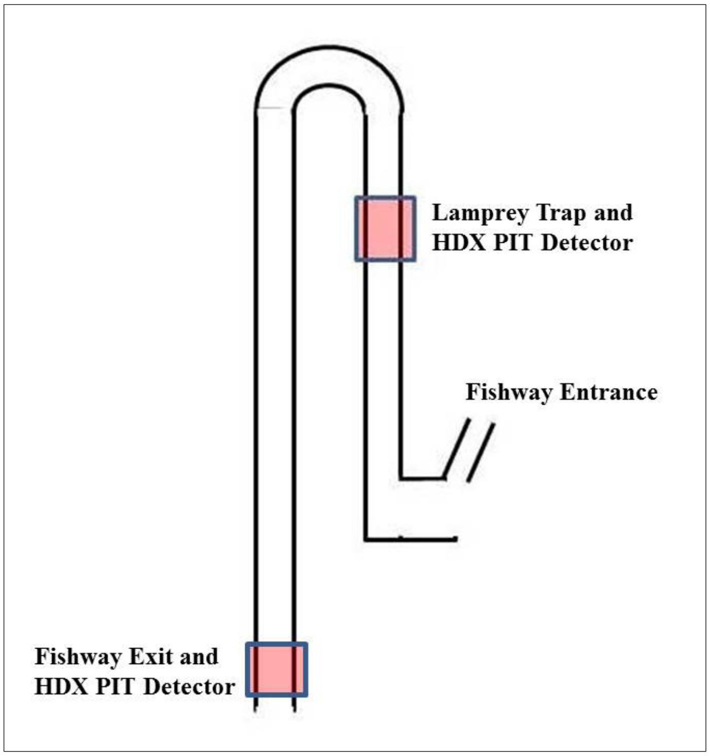


Figure 21. Locations of the HD-PIT antennas and trap deployment at the John Day South Fishway.

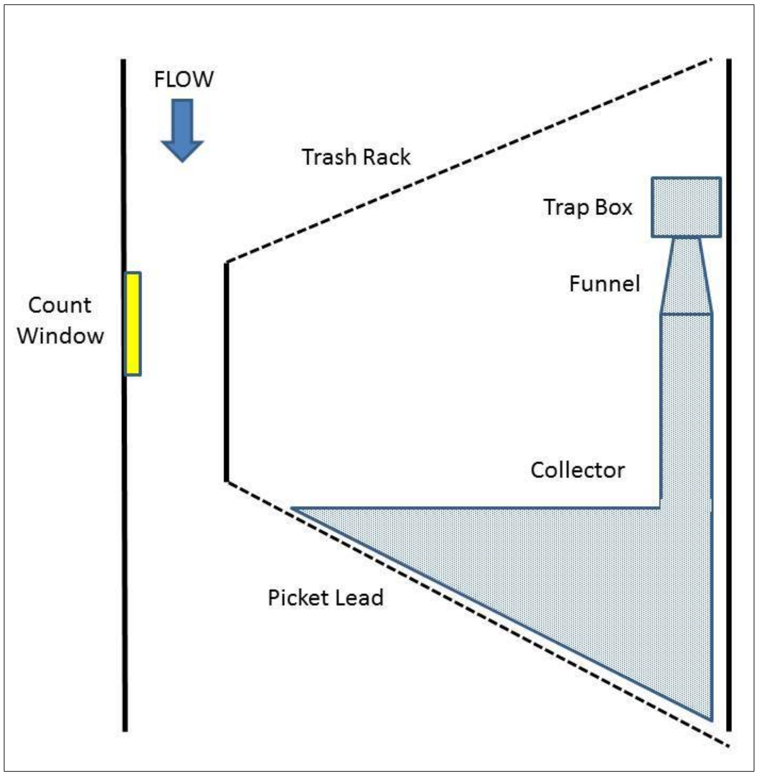


Figure 22. Plan view showing location of trap in relation to other structures within the John Day South Fishway.

Figure 23. Photo of trap and associated features.

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 (VLC media player). Initial tests of the system were conducted with the camera deployed in a vertical position via a camera tube that was incorporated into the original design of the trap equipment (Figures 23-24). Initially, the camera was positioned above and its lens pointed into the 10-cm-diameter tube that enters the trap box (Figure 24). Due to problems with this arrangement (Figure 25), an alternate deployment was tested using the same camera mounted horizontally inside the trap box (Figure 26). In this deployment, the camera lens was pointed towards the 10-cm orifice at the entrance to the trap box (Figure 26).

An HDX PIT antenna and reader (Oregon RFID) were also located at the collector immediately downstream of the trap funnel to detect any PIT tagged lamprey that entered the trap (Figures 21 and 23).

Results

Ninety lamprey were collected at the trap over 18 trapping nights between 24 June and 25 August. Collected lamprey were transported for tribal restoration purposes (A. Jackson, Confederated Tribes of the Umatilla Indian Reservation, personal communication) and for tagging work in the Snake River (C. Peery, USFWS, personal communication).

A total of 39 PIT-tagged lamprey were detected at the trap antenna. Of those detected, one lamprey was tagged with a PIT–tag only in 2012, 25 were tagged with a PIT-tag only in 2013, 12 were tagged with a JSATS and PIT tag, and one was tagged with radio tag and PIT tag. All were originally captured and released within the vicinity of Bonneville Dam. Of the 39 lamprey detected at the trap collector, 26 (67%) were subsequently detected at the south fishway exit. Thirteen lamprey were detected at the trap collector but not subsequently detected either at the fishway exits or at an upstream dam. This suggests that these 13 lamprey fell out of the south fishway and did not pass John Day Dam by any route. However, it is possible that these 13 lamprey were collected during periods when the trap was operated and were transported as broodstock, or passed John Day Dam undetected.

Of the PIT tagged lamprey detected at both the trap collector and south fishway exit, median occupation time at the trap collector was 17.5 h (range 0.2-191.8 h). Median travel time from the trap collector to the south fishway exit for these fish was 7.1 h (range 5.9-54.9 h).

Tests of the vertical camera position deployment were conducted between 10 May and 2 July. No imagery of lamprey entering the trap was recorded during the 605 h of underwater horizontal camera deployment. For the vertical camera (Figure 24), the quality of recorded video degraded within 1 h of deployment due to the accumulation of bubbles at the lens surface (Figure 25). We attempted several different techniques to deflect bubbles from the camera lens but were unsuccessful due to the design of the camera tube.

Tests of the horizontal camera deployment were conducted between 3 and 8 September. No imagery was recorded of lamprey entering the trap during the 144 h of underwater horizontal camera deployment. Recorded imagery was of consistently good quality throughout the test, and it is assumed that had lamprey entered the trap, the entrance events would have been able to be enumerated.

Figure 24. Photo of vertical camera orientation as designed for trap.

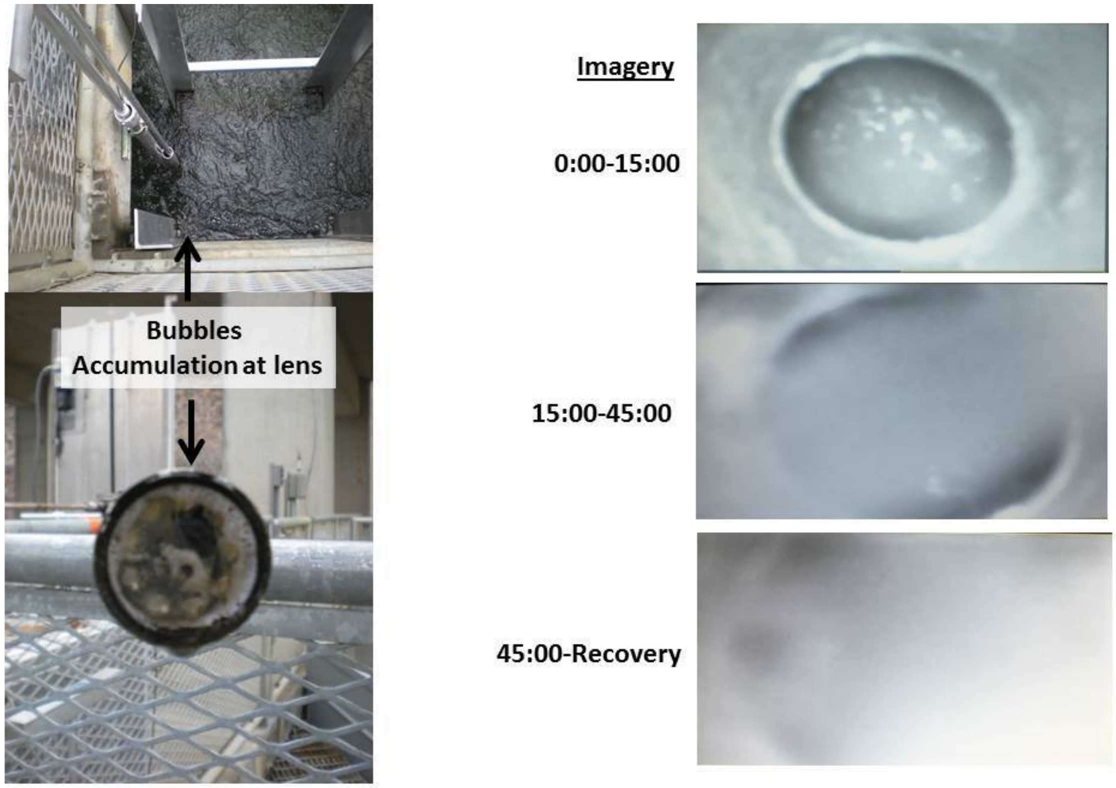


Figure 25. Photos of accumulation of bubbles at camera lens and resulting image degradation over time.

Figure 26. Photos of camera mounted in horizontal orientation and obtained imagery.

Discussion

Data from both trap captures and PIT detections indicated that lamprey successfully entered the trap box at this new installation. After having seasoned further, lamprey use may increase at this new metal structure (Moser et al. 2012). In addition, eliminating the perforated plate on the ramp immediately downstream from the trap box would potentially provide lamprey with more attachment areas and allow greater numbers of fish to access the trap box.

It is important to note that when operating this structure in pass-through mode, trap operators must ensure that the entrance gate to the trap box is open and the bypass panel is removed (Figure 23). 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 and not quickly passing through to the trap box (Figure 22). The collector is similar in shape and design to that of the refuges installed at the AWS channel and fishway at Bonneville Dam. Periods of occupation at the trap collector (time at first detection to time of last detection) were similar to those observed at the refuges at Bonneville Dam, suggesting that the trap collector was functioning as a refuge.

The vertical camera infrastructure originally designed for the trap proved faulty. Results from tests of the horizontal camera deployments showed that high-quality imagery can be captured and recorded at this structure. A potential drawback to the horizontal position tested is that because the camera is mounted within the trap box, lamprey may come in contact with the camera. In addition, trap operators must remember to untether the camera's coaxial cable at a junction before recovering the trap box and then restore the cable before re-deploying the trap box. In the vertical position, the camera system is completely independent of the trap box.

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 is pass-through mode.

Conclusions and Recommendations

1. At the Washington Shore AWS LPS in 2013, 3% of lamprey PIT detections occurred only at the upper antenna site. Improved PIT antenna performance may be needed at this LPS.

2. In most years, some lamprey exiting the Washington Shore AWS LPS have fallen back downstream through the fishway and not reascended. This group of fish was larger in 2013 than in previous years. Changes to construction of the exit slide might have increased the incidence of fallback, and this possibility should be examined.

3. At the 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 and may be dropped over 2 m before entering the water at low forebay elevations. To remedy these problems, the exit slide should be extended.

4. From 2011 to 2013, significant percentages (8-10%) of PIT-only lamprey released downstream from Bonneville Dam have been detected at the Cascades Island flow-control area. In addition, relatively low numbers (<40%) of these fish were detected on upstream antennas, indicating poor passage success. Therefore, installation of an LPS at the top of the Cascades Island fishway is recommended to provide a passage route through the flow-control area, which is presently a dead-end for migrating lamprey.

5. Overall, lamprey that use both AWS LPSs are detected on upstream antennas in lower percentages than those that use a traditional fishway exit. Lamprey that use an LPS tend to be smaller, and there may be a fitness cost to lamprey use of the LPS. Further research is needed to insure that LPS use does not incur any loss in reproductive potential for lamprey that choose this passage route.

6. Improvements to the design of mechanical exit doors could reduce periods of counter outage and overcounting, particularly at LPSs that pass high numbers of lamprey. Tests of alternative fish-passage monitoring technologies are also needed (e.g., electrical impedance, acoustic, laser, video). One or more of these technologies could avoid the mechanical aspects of the counter system that are subjected to damage during lamprey passage.

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

8. The capacity of present LPS designs is unknown. If lamprey abundance increases, the number of lamprey using LPSs will put new demands these 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

9. Pilot testing of lamprey refuges in the fishway proper 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, as power failures resulted in a gross underestimate of fishway refuge use.

   Ideally, fish tagged with both radio and PIT tags could be used to monitor 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. Problems with the new counter configuration at the Cascades Island LPS made it difficult to obtain an accurate count of lamprey use. Future modifications to this LPS should include reducing attachment surfaces in the exit slide and increasing the exit slide angle. This would increase the rate of passage through the slide and presumably limit the ability for lamprey to hold, or swim upstream in the slide.

12. Lamprey that passed upstream from Cascades Island LPS Rest Box 3 to Rest Box 4 before falling back could not be distinguished from those that were blocked by the new one-way gate at Rest Box 4. For this reason, the new rest-box entrance design should be used with caution. Although it appeared to reduce fallback of fish that ascended to the pond, it may also have reduced the number of fish that were able to get to that point. Observations of lamprey using this type of rest box entrance design should be made in the laboratory before further installations of this type are made.

13. While sample sizes were low, tests of the Cascades Island LPS indicate that some lamprey exiting the LPS fall back downstream, as is the case at both AWS LPS exits. However, even fish released as far upstream as the Stevenson boat ramp have been detected falling back downstream from Bonneville Dam. Larger sample sizes of radio-tagged fish are needed to determine the fate of lamprey using this LPS relative to other treatment groups.

14. 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 AWS. To improve lamprey passage at Bonneville Dam, fish that access this AWS should be provided with an outlet to the forebay via a lamprey passage structure. Alternatively, lamprey should be actively trapped and transported upstream throughout the migration period.

15. 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 is open and the bypass panel must be is removed. Otherwise lamprey will fall back and be delayed.

    Operators at this trap must also remember to untether the horizontal camera's coaxial cable before recovering the trap box, and to restore the cable before re-deploying the trap box.

Acknowledgements

We thank Mike Hanks (OAI) for providing technical assistance on all aspects of this research. Special thanks to Siena Lopez-Johnston (Portland State University) for help with radiotelemetry. Eric Johnson, Chris Noyes, Dan Joosten, Mark Kirk and Steve Lee (University of Idaho) helped with lamprey collection and tagging. The design, fabrication, and installation of the LPS monitoring systems would not have been possible without the exceptional skills and efforts of Jeff Moser and Bill Wassard of the NOAA Fisheries Pasco Research Station. We also thank Galen Wolf, Louis Tullos, Ron Marr, of the Pasco Station and the rigging crew at Bonneville Dam for help with equipment installations. We thank Chris Peery (USFWS), Frank Loge, and Cristi Negrea (UC Davis) for assistance with underwater videography. Sean Tackley, David Clugston, Andy Traylor, Ben Hausman, Ida Royer, Brian Bissell, Myroslaw Zyndol, Robert Stansell, Nathan Zorich and John Dalen of the U.S. Army Corps of Engineers provided assistance on many fronts throughout the project. Administrative assistance at NOAA Fisheries was provided by Doug Dey, Paula McAteer and Sandy Downing. Mike Jepson and Tami Clabough (University of Idaho) provided administrative and database support. We thank JoAnne Butzerin (NOAA Fisheries) for editing this report. Funding for this work was provided by the U.S. Army Corps of Engineers, Portland District.

References

Binder, T. R., and D. G. McDonald. 2007. Is there a role for vision in the behaviour of sea lampreys (*Petromyzon marinus*) during their upstream spawning migration? Canadian Journal of Fisheries and Aquatic Sciences 64:1403-1412.

Clabough, T. S., E. L. Johnson, M. L. Keefer, C. C. Caudill, and M. L. Moser. 2011. General passage and fishway use summaries for adult Pacific lamprey at Bonneville, The Dalles and John Day dams, 2010. Technical Report 2011-5 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland District.

Clabough, T. S., M. L. Keefer, C. C. Caudill, E. L. Johnson and C. A. Peery. 2012. Use of night video to enumerate adult Pacific lamprey passage at hydroelectric dams: challenges and opportunities to improve escapement estimates. North American Journal of Fisheries Management 32:687–695.

Corbett, S. C., Moser, M. L., B. Wassard, M. L. Keefer, and C. C. Caudill. 2013. Development of passage structures for adult Pacific lamprey at Bonneville Dam, 2011-2012. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Imre, I., G. E. Brown,R. A. Bergstedt, and R. McDonald. 2010. Use of chemosensory cues as repellents for sea lamprey: potential directions for population management. Journal of Great Lakes Research 36:790–793.

Johnson, E. L., T. S. Clabough, M. L. Keefer, C. C. Caudill, C. A. Peery, and M. L. Moser. 2009a. Effects of lowered nighttime velocities on fishway entrance success by Pacific lamprey at Bonneville Dam and fishway use summaries for lamprey at Bonneville and The Dalles dams, 2008. Technical Report 2009-10 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland District.

Johnson, E. L., C. A. Peery, M. L. Keefer, and C. C. Caudill. 2009b. Effects of lowered nighttime velocities on the fishway entrance success by Pacific lamprey at Bonneville Dam and fishway use summaries for lamprey at Bonneville and The Dalles dams, 2007. Technical Report 2009-2 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland District.

Keefer, M. L., W. R. Daigle, C.A. Peery, H. T. Pennington, S. R. Lee, and M. L. Moser. 2010. Testing adult Pacific lamprey performance at structural challenges in fishways. North American Journal of Fisheries Management 30:376-385.

Keefer, M. L., C. C. Caudill, T. S. Clabough, M. A. Jepson, E. L. Johnson, C. A. Peery, M. D. Higgs, and M. L. Moser. 2013. Spatiotemporal variability in fishway passage bottlenecks at a large dam: methods for identification and prioritization. Canadian Journal of Fisheries and Aquatic Sciences 70:1551–1565.

Keefer, M. L., C. C. Caudill, T. S. Clabough, M. A. Jepson, E. L. Johnson, C. A. Peery, M. D. Higgs, and M. L. Moser. 2014. Fishway bottleneck relief models: a case study using radio-tagged Pacific lamprey. Transactions of the American Fisheries Society 143(4)1049-1060.

Keefer, M. L., M. L. Moser, C. T. Boggs, W. R. Daigle, and C. A. Peery. 2009. Effects of body size and river environment on the upstream migration of adult Pacific lampreys. North American Journal of Fisheries Management 29:1214-1224.

Keefer, M. L., C. A. Peery,S. R. Lee, W. R. Daigle, E. L. Johnson, and M. L. Moser. 2011. Behavior of adult Pacific lampreys in near-field flow and fishway design experiments. Fisheries Management and Ecology 18:177-189.

Keefer, M. L., C. C. Caudill, E. L. Johnson, T. S. Clabough, M. A. Jepson, C. T. Boggs, and M. L. Moser. 2012. Adult Pacific lamprey migration in the lower Columbia River: 2011 Half-Duplex PIT tag studies. Technical Report 2012-3 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland District.

Kemp, P. S., T. Tsuzaki, and M. L. Moser. 2009. Linking behaviour and performance: intermittent locomotion in a climbing fish. Journal of Zoology 277:171-178.

Moser, M. L., and D. A. Close. 2003. Assessing Pacific lamprey status in the Columbia River Basin. Northwest Science 77:116-125.

Moser, M. L., M. L. Keefer, H. T. Pennington, D. A. Ogden, and J. E. Simonson. 2011. Development of Pacific lamprey fishways at a hydropower dam. Fisheries Management and Ecology 18:190-200.

Moser, M. L., Matter, A. L., Stuehrenberg, L. C. and Bjornn, T. C. 2002. Use of an extensive radio receiver network to document Pacific lamprey (*Lampetra tridentata*) entrance efficiency at fishways in the lower Columbia River, USA. Hydrobiologia 483:45–53.

Moser, M. L., L. C. Stuehrenberg, W. Cavender, S. G. McCarthy, and T. C. Bjornn. 2002a. Radiotelemetry investigations of adult Pacific lamprey migration behavior: evaluations of modifications to improve passage at Bonneville Dam, 2000. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Moser, M. L., P. A. Ocker, L. C. Stuehrenberg, and T. C. Bjornn. 2002b. Passage efficiency of adult Pacific lampreys at hydropower dams on the lower Columbia River, U.S.A. Transactions of the American Fisheries Society 131:956-965.

Moser, M. L., D. A. Ogden, and C. A. Peery. 2005. Migration behavior of adult Pacific lamprey in the lower Columbia River and evaluation of Bonneville Dam modifications to improve passage, 2002. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Moser, M. L., D. A. Ogden, H. T. Pennington, W. R. Daigle, and C. A. Peery. 2008. Development of Passage Structures for Adult Pacific Lamprey at Bonneville Dam, 2005. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Moser, M. L., D. A. Ogden, H. Pennington, and M. L. Keefer. 2010**.** Development of passage structures for adult pacific lamprey at Bonneville Dam, 2007-2008. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Moser, M. L., D. A. Ogden, H. T. Pennington, M. L. Keefer, and C. C. Caudill. 2012. Development of passage structures for adult Pacific lamprey at Bonneville Dam, 2009-2010. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Negrea, C., D. E.Thompson, S. D. Juhnke, D. S. Fryer, and F. J. Loge. 2014. Automated detection and tracking of adult Pacific Lampreys in underwater video collected at Snake and Columbia River fishways. North American Journal of Fisheries Management 34: 111-118.

Noyes, C. J., C. C. Caudill, T. S. Clabough, D. C. Joosten, E. L. Johnson, M. L. Keefer, and G. P. Naughton. 2012. Adult Pacific lamprey migration behavior and escapement in the Bonneville Reservoir and lower Columbia River monitored using the juvenile salmonid acoustic telemetry system (JSATS), 2011. Technical Report 2012-4 of Idaho Cooperative Fish and Wildlife Research Unit to U.S. Army Corps of Engineers, Portland District.

Noyes, C.J., C.C. Caudill, T.S. Clabough, D.C. Joosten, and Keefer, M.L. 2014. Adult Pacific lamprey migration behavior and escapement in the Bonneville Reservoir and lower Columbia River monitored using the Juvenile Salmonid Acoustic Telemetry System (JSATS), 2013. UI FERL report 2014-7-DRAFT for the US Army Corps of Engineers, Portland District.

Ocker, P. A., L. C. Stuehrenberg, M. L. Moser, A. L. Matter, J. J. Vella, B. P. Sandford, T. C. Bjornn, and K. R. Tolotti. 2001. Monitoring adult Pacific lamprey (*Lampetra tridentata*) migration behavior in the lower Columbia River using radiotelemetry, 1998-99. Report to U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Reinhardt, U. G., L. Eidietis, S. E. Friedl, and M. L. Moser. 2008. Pacific lamprey climbing behavior. Canadian Journal of Zoology 86:1264-1272.

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