Development of Passage Structures for Adult Pacific Lamprey at Bonneville Dam, 2011-2012

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Report of research by

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EXECUTIVE SUMMARY

In 2011-2012, we continued a multi-year study to evaluate and improve adult Pacific lamprey passage at Bonneville Dam. As in previous years, modifications and improvements to lamprey passage structures (LPSs) were made prior to the adult lamprey migration period. During the migration period, we evaluated LPSs and modifications with the following objectives:

1) Determine use of LPSs located at the auxiliary water supply (AWS) channels
2) Assess the effects of providing refuge areas in AWS channels
3) Determine lamprey use of the LPS located at the Cascades Island fishway entrance
4) Develop methods to collect lamprey from alternate locations at Bonneville Dam

To achieve the monitoring objectives, we used two approaches. First, we counted individual river-run lamprey passage in the new and existing structures. For these counts, we used lamprey-activated counters in the Washington Shore and Bradford Island AWS structures and in the terminal trap boxes in the Cascades Island and the Washington Shore fishway structures.

Second, we marked lamprey with passive integrated transponder (PIT) tags, released them below Bonneville Dam, and monitored their upstream movements within the LPSs. In 2011, we tagged 1,014 migrating adult lamprey with a PIT tag. Of these fish, 85 fish were also tagged with a juvenile salmon acoustic telemetry system (JSATS) tag for a separate study. In 2012 we tagged 1,197 adult lamprey migrants with a PIT tag, and 299 of these were also tagged with a JSATS tag. Antennas to detect PIT tags were integrated into all of the lamprey passage structures, and an antenna was also operated at the top of the Cascades Island fishway.

From 25 May to 29 June 2011, we raised the picketed leads at the entrances to the Washington Shore and Bradford Island AWS channels by 3.8 cm, and this increased lamprey access to the passage structures at these locations. In addition, we installed a ramp leading into the Washington Shore AWS channel and reduced picket spacing adjacent to the count window. These modifications appeared to result in higher lamprey use of the Washington Shore LPS in 2011 relative to other years of operation.

In 2012, Bonneville project personnel installed a new picketed lead at the entrance to the Bradford Island AWS channels and raised it using a 2.5-cm metal spacer. The picketed lead at the entrance to the Washington Shore AWS channel remained lowered to the fishway floor throughout the season. Lamprey use of the LPS in each

AWS channel was lower than in previous years. Of all PIT-tagged lamprey released below Bonneville Dam, the proportion that used an AWS LPS to pass the dam was 15% in 2011 and 11% in 2012. At the Bradford Island AWS LPS, passage efficiency was 100% in 2011 and 98% in 2012. At the Washington Shore AWS LPS, passage efficiency was 88% in 2011 and 93% in 2012.

Two prototype lamprey refuge boxes were operated in the Washington Shore AWS channel from 28 June to 7 November 2011 and 30 May to 17 October 2012. Total numbers of PIT-tagged lamprey detected in these boxes were 19 in 2011 and 37 in 2012 (one of which had been tagged in 2011). Mean residence time in refuge boxes was 9.1 h in 2011 and 49.7 h in 2012. A surprisingly large percentage (79% in 2011 and 78% in 2012) of these fish was subsequently detected in the Washington Shore LPS. In fact, of all lamprey detected exiting the Washington Shore LPS or fishway in both years, 9.6% had used a refuge box, indicating that lamprey were able to find and take advantage of these relatively small refuge areas.

The LPS at the Cascades Island fishway entrance was operated from 6 June to 15 September 2011 and from 23 May to 20 September 2012. In the terminal trap box of this LPS, we collected 485 river-run lamprey in 2011 and 2,472 lamprey in 2012. Of the PIT-tagged lamprey released downstream from Bonneville Dam, 11 (1%) volitionally entered and were detected in this LPS in both 2011 and 2012 (also 1%). Most of these fish ascended the structure to reach the terminal trap box, and median passage time between the upstream and downstream PIT detectors was 1.5 h in 2011. In 2012, only 1 was detected at both LPS antennas; passage time between antennas was 100.8 h for this fish.

In 2011 we planted 20 lamprey into the Cascades Island LPS and found that 29% of these fish fell back downstream within the structure and never ascended to the terminal trap box. In 2012, to reduce fallback within this structure we made improvements to the entry fyke design of one rest box. We then planted 50 lamprey into the LPS, and found that the fallback rate within the structure dropped to 18%. In 2011 and 2012 we also tested the effects of a subtle flow manipulation in the lower part of the LPS, but we found no significant differences in mean catch rates between high and low flow treatments in either year.

In an attempt to capture lamprey prior to their entry into the fishways at Bonneville Dam, we deployed two cylindrical traps at the north and south monoliths adjacent to the north and south downstream entrances to the Washington Shore fishway. In 2011, these traps were deployed over 93 d between 31 May and 31 August, but no lamprey were captured. In 2012 traps were deployed over 64 d between 23 May and

7 August, but only 2 lamprey were captured. This trap design was the same as that of traps used successfully within fishways and open river systems, indicating that the traps were not deployed in areas that could effectively intercept adult lamprey.

In past years, adult lamprey have been detected and observed accumulating in the Cascades Island auxiliary water supply channel, an obsolete fishway exit that has no direct access to the forebay. In 2012 we deployed two cylindrical traps at this location over 30 d between 16 August and 20 September, and 268 lamprey were captured. As in past years, we continued to monitor use of this area by PIT-tagged lamprey. Of all PIT-tagged lamprey released downstream from Bonneville Dam, 8% in 2011 and 10% in 2012 were detected at this location. These results were consistent with those from past years and indicated that high numbers of adult lamprey are occupying this area. We concluded that these fish should be either provided with an outlet to the forebay or systematically trapped and transported upstream.

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INTRODUCTION

Background

Pioneering research has shown that adult Pacific lamprey passage at dams can be facilitated with lamprey-specific fishways. These lamprey passage structures (LPSs) were designed to take advantage of lamprey swimming and climbing performance, while minimizing searching and fallback behavior (Reinhardt et al. 2008; Kemp et al. 2009; Keefer et al. 2011; Moser et al. 2011). In traditional fishways, lamprey make multiple entrances and repeatedly fall back and mill about in difficult passage areas (Moser et al. 2002a; Keefer et al. 2013a). Successful LPS design eliminates downstream movement of lampreys and allows rapid ascent 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 (kilometer 235, Figure 1). Here adult lamprey have difficulty entering fishways, and those that successfully enter are often obstructed or delayed near the top of the fishways (Moser et al. 2002b; Johnson et al. 2009a, 2009b; Keefer et al. 2013a). In these areas, serpentine weirs present an

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.

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).

Lamprey enter AWS channels through connecting diffuser gratings 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). Moreover, the AWS channels are "salmon-free" areas where in situ experiments to develop lamprey passage can be conducted (Moser et al. 2011).

Bradford Island

The first LPS was installed in 2004 at the AWS channel near the top of the Bradford Island fishway (Figure 2). Lamprey enter the structure via one of two collector ramps and then pass through a series of wetted aluminum ramps, rest boxes and horizontal flumes that lead upward to an exit slide at elevation 7.9 m. The overall horizontal distance is 35.6 m (Figure 3). Lamprey exit the LPS into the forebay of Powerhouse 1 immediately upstream from the Bradford Island fishway exit (Figure 2).

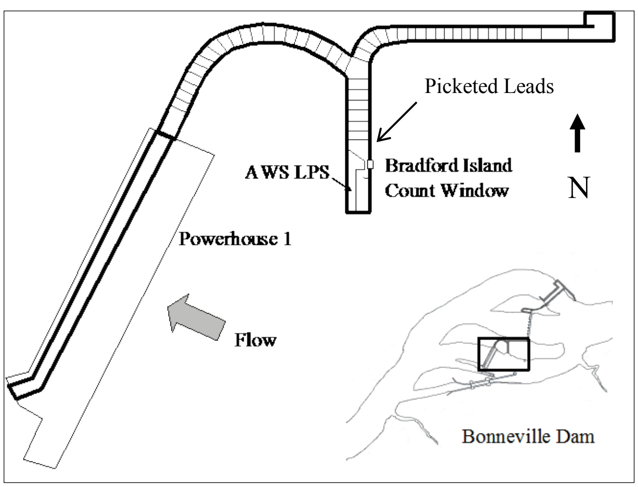

Figure 2. Schematic drawing of the Bradford Island fishway system at Bonneville Dam with locations of the auxiliary water supply lamprey passage structure (AWS LPS) and count window.

Columbia River water is 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 is regulated by pumping water into an upwelling trap box at the top of the LPS. Pumps are operated to maintain a depth of 3 cm on the ramps and approximately 10 cm in the closed tubes. As lamprey exit the LPS into the forebay, they actuate a limit switch, and data from these exit events are used to evaluate lamprey use of the structure each year.

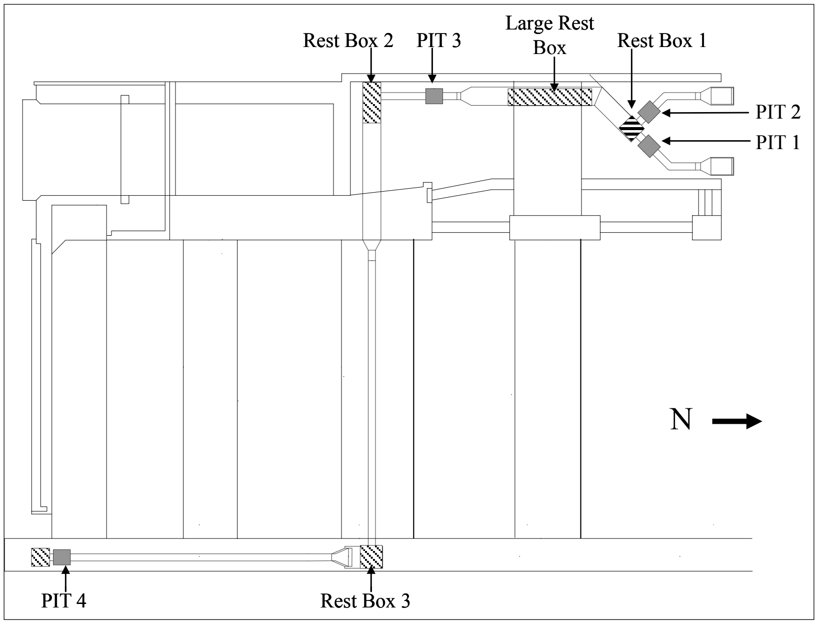

Figure 3. Top view of the Bradford Island LPS with locations of half-duplex PIT-tag detection antennas (PIT 1-4) and rest boxes indicated.

To monitor passage of lamprey tagged with passive integrated transponder (PIT) tags, the LPS was constructed with a series of four half-duplex 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. Each antenna was a loop 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 is calculated by dividing the number of fish detected at the LPS exit by the total number detected entering the LPS. At the Bradford Island LPS in 2004, passage efficiency was 90-100%, and median passage time for PIT-tagged lamprey was less than 1 h (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). These newer structures are briefly described below.

Washington Shore

While the LPS in the Washington Shore AWS was in many respects similar to the LPS at Bradford Island, 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 prevented lamprey from moving back down the LPS by allowing them to exit only in an upstream direction. However, due to the width of ramps in the Washington Shore LPS, the fykes for this structure were wider than those at Bradford Island. Ramp grades in the Washington Shore and Bradford Island AWS LPSs were similar (45°), as were the water supply systems and lamprey counters at the exit slide. The Washington shore LPS featured a "switchback" design (Figure 5) with broad crests at the top of each ramp to facilitate lamprey progress. The overall length of the Washington Shore AWS LPS was approximately 19 m, with an elevation gain of 9.1 m (Figure 5).

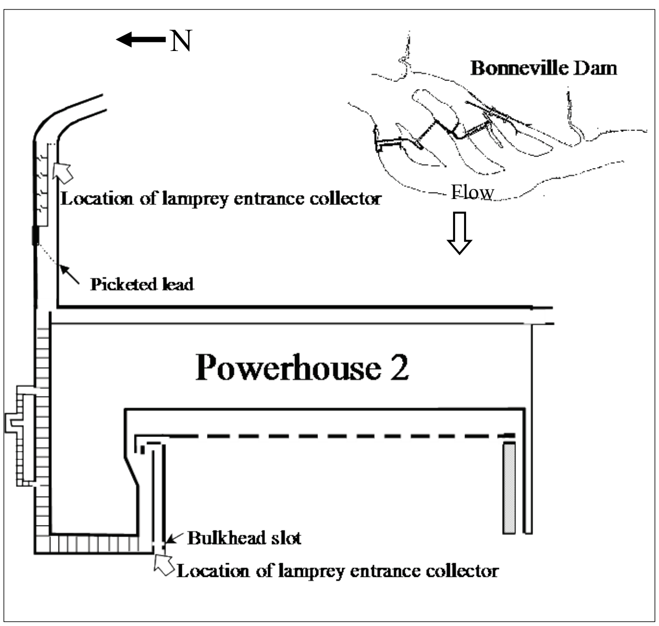

Figure 4. Locations of lamprey structures at the Washington Shore fishway.

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). Lamprey that have been able to pass through this structure have done so quickly (median passage time < 0.5 h, Moser et al. 2012). However, it is unknown whether using an LPS could compromise lamprey fitness, by either requiring excessive energy or by exposing lamprey to greater predation pressure.

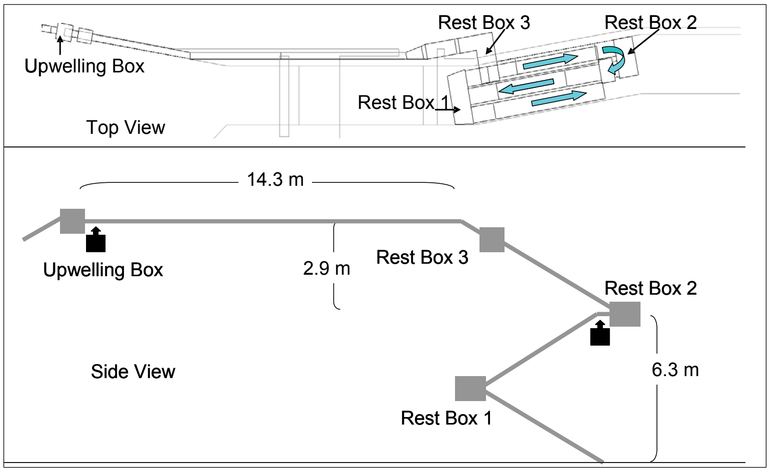

Figure 5. Top and side views of the Washington Shore AWS LPS. The shaded arrows indicate the direction of water flow on the switchback ramps. Black boxes indicate the position of half-duplex PIT antennas.

Cascades Island

The Cascades Island LPS incorporated many design features of other AWS structures, but was much longer (92.4 m, Figure 6). Rest Boxes 1 and 2 could not be accessed from the deck, so they were fitted with remotely operated valves to de-water them. Otherwise, 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 fykes (Moser et al. 2012). The Cascades Island LPS was fitted with two HD-PIT antennas to monitor passage of PIT-tagged lamprey (Figure 6).

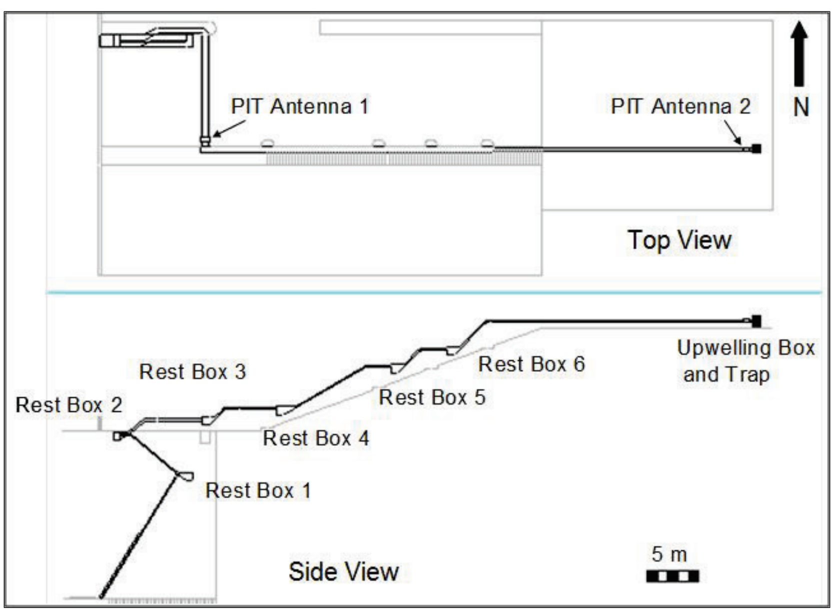

Figure 6. Top view (upper panel) and side view (lower panel) of new Cascades Island LPS collector. Locations of PIT monitors are shown in top view and rest boxes are shown in the side view.

While lamprey have clearly been able to find and use the Cascades Island structure, improvements were needed. There was evidence that lamprey often fell back through the rest boxes and did not enter the terminal trap. Moreover, low lamprey runs in recent years have resulted in few test animals with which to evaluate this structure (Moser et al. 2012). We theorized that improvements to the fyke design at the rest box entrances could reduce fallback in the structure. In addition, we sought a source of "naïve" lamprey to test in this structure in order to boost sample sizes and the subsequent accuracy of evaluations. These were among the objectives for work conducted in 2011 and 2012.

Study Objectives in 2011-2012

The greatest limitation to lamprey use of passage structures in the AWSs has been relatively poor collection efficiency (Moser et al. 2011). Collection at these structures has been limited both by poor access to the AWS channels and the fact that lamprey often leave these channels (fallback) before finding the LPS. To improve lamprey access to the AWS channels, we slightly raised the picketed leads at both AWS channel entrances (Figures 2 and 4).

Additional structural changes were 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 and reduce fallback, two refuge boxes were installed in the channel to provide dark and safe holding areas during the day.

To date, lamprey tagged for assessing passage through the Washington Shore fishway have been collected primarily at traps in the Adult Fish Facility fishway bypass at Bonneville Dam. Consequently, these fish have already demonstrated the ability to successfully enter a fishway and negotiate transition pools and the lower section of the Washington Shore pool and weir area. Because these fish represent only that part of the population with passage experience, there is a research need for collection of potentially "naïve" fish, or those that have not demonstrated the ability to enter fishway entrances.

Obtaining these fish would permit a less biased evaluation of lamprey passage. In addition, characteristics of fish collected in this way could be evaluated and compared to those of fish collected inside fishways. Because half of the lamprey that approach Bonneville Dam typically are unable to pass, successful trapping to access this large reservoir of fish could provide an additional source of lamprey for both research and restoration.

In 2011 and 2012 our objectives were to:

1) Determine lamprey use of Bonneville Dam lamprey passage structures (LPSs) located at the auxiliary water supply (AWS) channels
2) Assess the effects of providing refuge areas in AWS channels
3) Determine lamprey use of the Cascades Island LPS
4) Develop methods to collect lamprey from alternate locations at Bonneville Dam

To achieve the monitoring objectives, we used two approaches. First, we assessed the use of LPSs based on counts of river-run adult migrating lamprey from cameras and lamprey-activated counters at the Washington Shore and Bradford Island AWS channels. A terminal trap box was used for counts of lamprey using the Cascades Island LPS.

Second, we captured and tagged adult Pacific lamprey with passive integrated transponder (PIT) tags, released them downstream from the dam, and recorded passage events using detection 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.

PRE-SEASON STRUCTURAL MODIFICATIONS

Washington Shore AWS Entrance Ramp

Both field observations and laboratory experiments have identified right-angle elevation gains (steps) in fishways as problematic for lamprey at upstream passage locations (Keefer et al. 2010). A typical example of such a step is at the entrance of the Washington Shore auxiliary water supply (AWS) channel (Figure 7). To bridge this step, a 45° polished aluminum ramp was fabricated and installed prior to the lamprey migration in 2011.

Figure 7. Dewatered entrance area of the Washington Shore AWS channel during winter maintenance before (left) and after installation of aluminum ramp.

Picketed Lead Modifications

Lamprey enter AWS channels primarily through picketed leads located just downstream from count window stations (Figure 8). In 2010, we observed lamprey gaining access to the area behind the count window crowder in the Washington Shore AWS (Figure 8) and ascending the traditional fishway. In an attempt to discourage lamprey from entering this area and to encourage them to use the Washington Shore AWS LPS, a new picketed lead was fabricated and installed prior to the lamprey migration period in 2011. Spacing between pickets was reduced from 2.5 cm to 1.9 cm on both the upstream and downstream ends of the crowder (Figure 9).

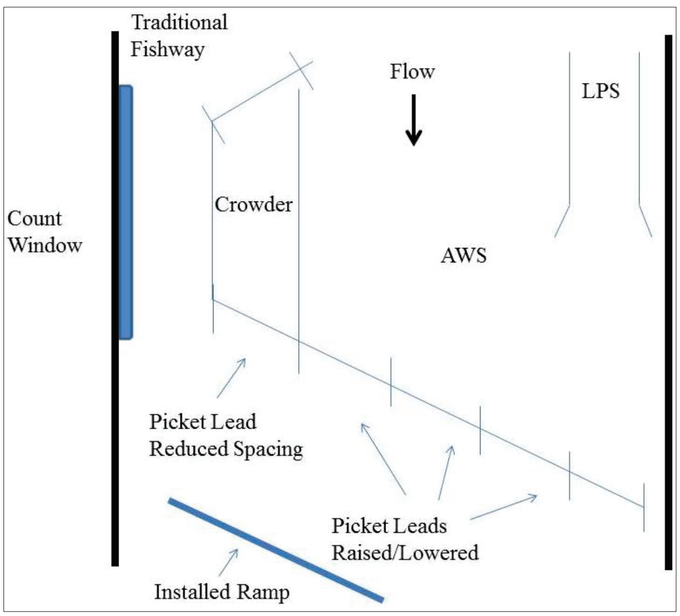

Figure 8. Schematic drawing of structural modifications made to the Washington Shore AWS entrance.

Figure 9. Picket spacing was reduced to discourage lamprey entrance into the area behind the Washington Shore crowder in 2011.

In 2012, in an effort to reduce access of salmonids to the Bradford Island AWS channel, a new picketed lead was fabricated and installed at the AWS channel entrance by Bonneville Project personnel prior to the lamprey migration period (Figure 10).

Figure 10. New picketed lead installed adjacent to old picketed lead (right) at Bradford Island AWS channel. Note bent pickets on old structure that likely allowed both lamprey and salmonid passage into the Bradford Island AWS channel. Photo courtesy of A. Traylor, U.S. Army Corps of Engineers.

In 2010, picketed leads at the Washington Shore AWS channel had been raised to improve lamprey access to the LPS without impacts to salmonids (Moser et al. 2012; Figure 11). This condition was left the same in 2011. On 25 May 2011, prior to the lamprey migration, the picketed leads at the Bradford Island AWS were also raised in an attempt to improve lamprey passage at that fishway. At the Washington Shore fishway, this was done during the de-watering period, and the picket was known to be approximately 3.8 cm from the floor. At Bradford Island, which was not de-watered in 2011, the picket was raised using a 2.5-cm metal spacer (Figure 11), but actual height from the floor was unknown.

In 2012, a new picketed lead was installed at the entrance to the Bradford Island AWS channel. The new lead had uniform picket spacing of 2.5 cm (1 in). At its base, a notched spacer and aluminum plate were placed to allow for a uniform, 2.5-cm (1 in) spacing between the picketed lead and fishway floor (Figure 12). This installation was completed prior to the lamprey migration.

On 29 June, 2011, Bonneville Project staff observed that sockeye salmon had entered the AWS channels of both Washington Shore and Bradford Island, presumably via gaps beneath the raised picketed leads. To protect migrating salmonids, spacers between the picketed leads and the AWS floor were removed on 30 June 2011. After this date, picketed leads in both AWSs were operated with pickets extending nearly to the bottom of the channel; this modification restricted lamprey access. In 2012, the picketed lead at the entrance to the Washington shore AWS channel was lowered to the fishway floor during the entire lamprey migration period to protect migrating salmonids.

Figure 11. Photo at right shows de-watered picketed lead looking downstream from inside the Washington Shore AWS channel. Shaded arrows indicate the locations of 2.5-cm metal spacers (inset at top right). Photo at left shows pickets raised approximately 3.8 cm from channel floor.

Figure 12. Upper left: de-watered picketed lead looking upstream from inside Bradford Island AWS channel. Upper right and lower left: aluminum plate installed on channel floor. Lower right: pickets raised approximately 2.5-cm above channel floor. Photos courtesy of A. Traylor, U.S. Army Corps of Engineers.

Remote Counter System and Cameras

Lamprey counting systems at the Washington Shore and Bradford Island AWS LPSs were upgraded in 2011 and further refined in 2012 in an attempt to provide accurate, real-time lamprey counts. Automated count data were provided to regional managers via a password-protected web site. The 2011 upgrade involved installation and testing of a new counter and radio uplink, as well as a new count validation method using security cameras installed at each LPS exit. In 2012 we refined the system to reduce signal interference and the frequency of outages. These changes included installation of shielded cable between the counter and exit-door switch and isolation of the counter unit from associated electronics.

OBJECTIVE 1: Evaluate Use of AWS Lamprey Passage Structures

Evaluations Based on Count Systems and Collection Efficiency Estimates

Count Data Collection and Retrieval

As in 2010, an event logger was operated at each LPS exit slide to enumerate river-run migrating adult lamprey that reached the forebay (Comet† S7841 with internal battery pack). These event logger counts were validated every 7 d by physically engaging the LPS exit door at an established time and frequency. This known event was subsequently checked against the data recorded by the event logger and then subtracted from the lamprey passage count. Additionally, on 19 July 2011 count systems were further validated by visual observations of lamprey at the LPS exits, which were also checked against data recorded by the event logger. Both the recorded number and time of each passage event were validated by visual observation.

Prior to 2011, count records of lamprey exiting each LPS were retrieved through weekly site visits, where the data were obtained either by recording the value reported on a cumulative counter or by physically downloading an event logger. In an attempt to automate data retrieval, a system was developed to allow event loggers to be downloaded from off-site locations. Event loggers at the exit of each LPS were connected by radio uplink to a host computer housed in the tailrace south tower (Figure 13). The host computer could be accessed from off-site locations via an internet connection to an IP address.

In 2011, the LPSs at both Bradford Island and Washington Shore AWS were operated and passage event recorded from 26 May to 9 November. During this period there were several gaps in the count record at both LPSs. Outages occurred at Bradford Island during 6-13 June, 6-7 July, and 20-25 July. Outages occurred at Washington Shore during 9-13 June, 13-15 July, and 3-4 August. In some cases, these outages were due to known events (i.e., hacking of the IP address, power outages, logger failure). In other cases, the cause of outages was not known, but may have been due to interuptions in the radio link or other communication failures. In addition, periodic signal interference, presumably generated by pump and or gatewell activity, created blocks of spurious data that precluded the recording of LPS exit events.

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

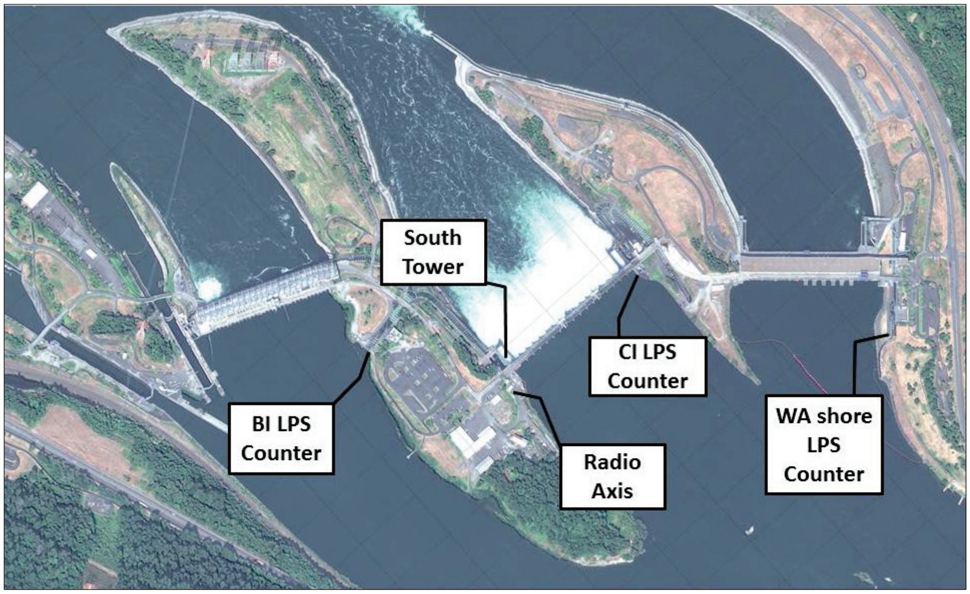


Figure 13. Aerial photo of Bonneville Dam showing locations of LPS counters and the radio uplink for retrieval of count records. Photo courtesy Google Earth Pro.

These outages resulted in an underestimate of lamprey counts from LPSs in auxiliary water supply channels during 2011. In 2011, the total lamprey count at the Bradford Island LPS was 7,612 if partial counts from outage days are included or 7,476 if they are excluded (Figure 14). In 2011, the count at the Washington Shore LPS was 6,440 if partial counts from outage days are included or 6,345 if they are excluded (Figure 15).

In 2012, the Bradford Island LPS was operated from 2 June to 26 November (counting occurred 2 June to 9 November) and the Washington Shore LPS from 2 June to 11 November (counting occurred 2 June to 10 November). During this period there were again several gaps in the LPS count record. Outages occurred at Bradford Island during 17-18 June, 26-31 July, 3-7 August, and 8-11 and 17-20 September. Outages occurred at Washington Shore during 14-15 June, 9-12 July, 7-8 August, and 15-17 and 25-26 September. These outages resulted in an underestimate of lamprey counts from LPSs in the auxiliary water supply channels during 2012. As in 2011, some outages were due to known events (i.e., power outages, logger failure), while the cause of others was not known but may have been due to interuptions in the radio link or other communication failures.

Bradford Island Fishway

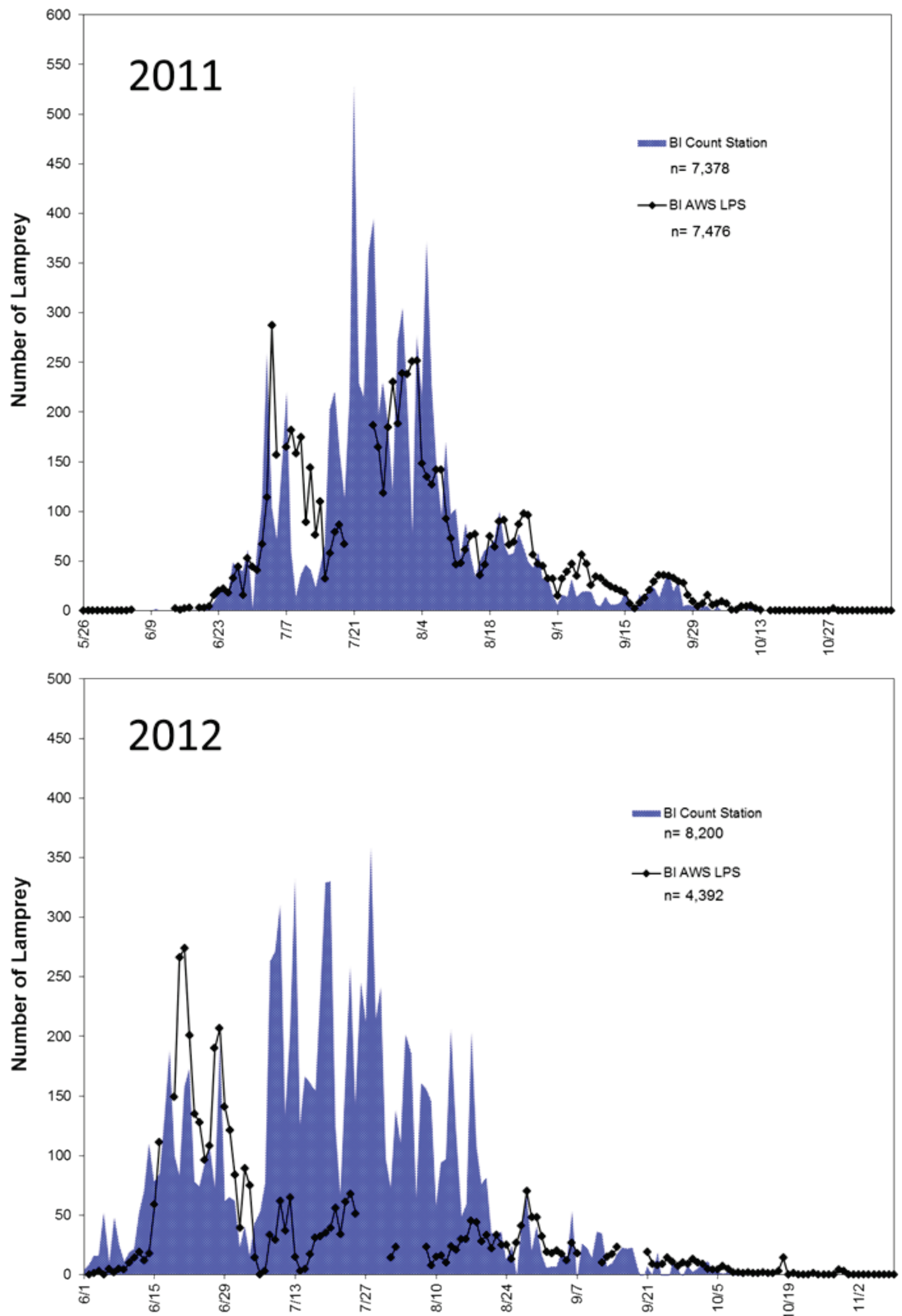


Figure 14. Number of lamprey counted at the Bradford Island count station (shaded areas) vs. the AWS LPS exit slide (closed diamonds) during LPS counter operations in 2011 and 2012. Total values reported for the count station and LPS include only days when the LPS counter was operational (i.e., outage days are not included in either count).

Washington Shore Fishway

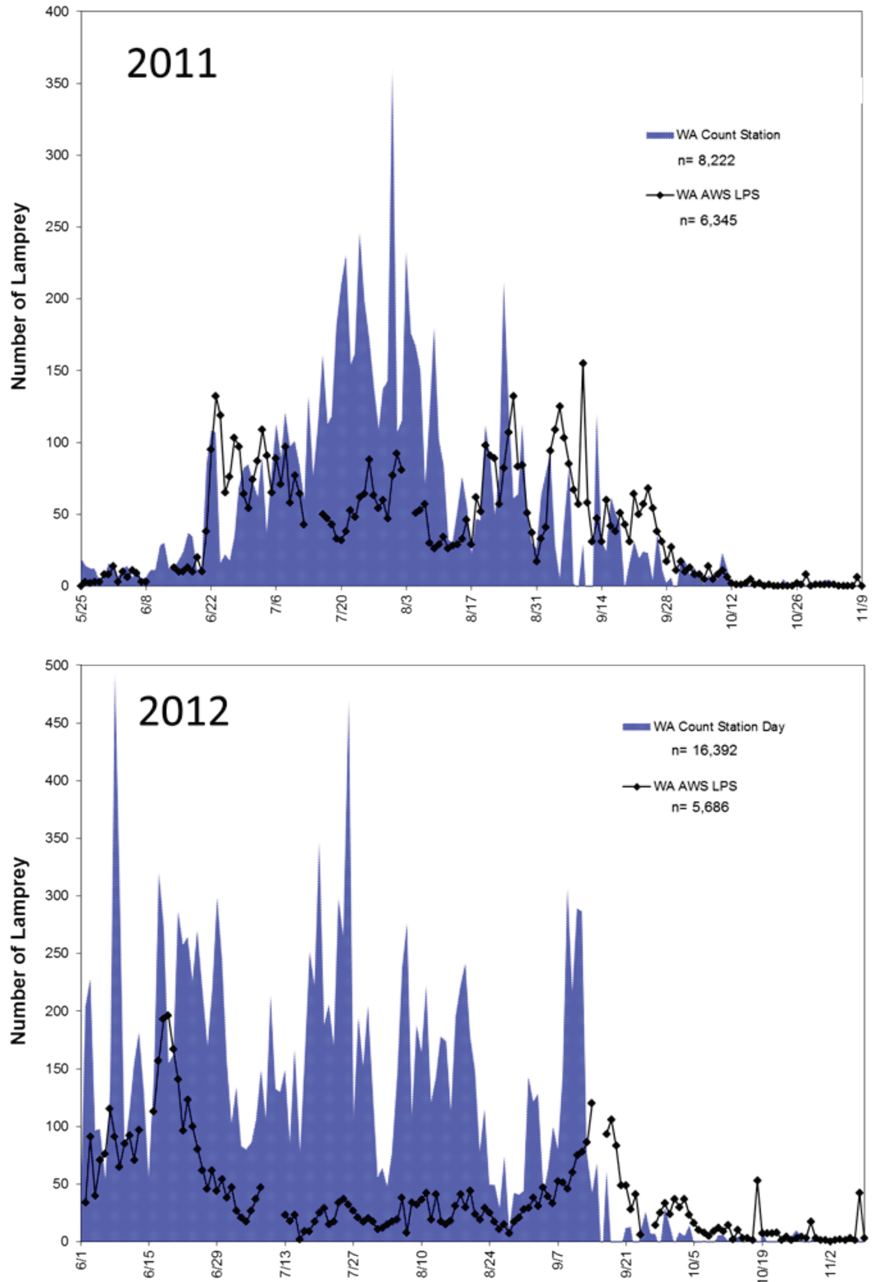


Figure 15. Number of lamprey counted at the Washington Shore count station (shaded areas) and at the LPS exit slide (closed diamonds) during the periods of LPS counter operation in 2011 and 2012. Total values reported for the count station and LPS include only days when the LPS counter was operational (i.e., outage days are not included in either count).

In 2012, we modified the communication system between LPS counters and the host computer, and we shielded the counters from electromagnetic interference generated by the pumps and gatewells. These modifications resulted in fewer data anomalies. In 2012, the total lamprey count at the Bradford Island LPS was 4,543 if partial counts from outage days are included or 4,392 if they are excluded (Figure 14). In 2012, the count at the Washington Shore LPS was 5,822 with partial counts from outage days included or 5,686 if they are excluded (Figure 15).

Collection Efficiency Estimates

We evaluated the efficacy of modifications made in 2011 and 2012 by comparing both inter- and intraannual collection efficiency estimates at LPSs in the auxiliary water supply channels. We estimated collection efficiency by estimating total lamprey abundance at the top of each ladder. This was done by tripling the count station counts at each ladder in each year. These were conservative estimates, since count-station counts were made only during the day, while approximately two-thirds of migrating lamprey typically pass count stations at night (Moser and Close 2003). Estimates of abundance were then divided by the LPS count in each year for each ladder (Table 1).

In 2011, we estimated an overall collection efficiency of 34% at Bradford Island and 26% at Washington Shore (Table 1). In contrast, overall collection efficiency estimates in 2012 were 18% at Bradford Island and 12% at Washington Shore (Table 1).

We used counts at the Washington Shore LPS to help evaluate whether the structural changes made in 2011 (reduced picket spacing and ramp installation) had improved lamprey access to the AWS relative to 2009 and 2010 (before these changes were in place). Collection efficiency in 2011 during the period that pickets were raised was 41% and was higher than collection efficiency recorded in 2010 when pickets were also raised (29%, Table 1). Collection efficiency in 2011 during the period when pickets were down was also higher than collection efficiency estimates for 2007-2009, when pickets were also down but no structural improvements had been made (Table 1).

In contrast to 2011, results from 2012 did not show significant improvement in collection efficiency at the Washington Shore LPS as a result of structural improvements made in 2011. In 2012, collection efficiency was 12%, which is similar to collection efficiencies recorded in 2007-2009, when the picketed lead was down but no structural changes had been made.

Table 1. Lamprey estimated abundance (visual daytime count × 3) and LPS counts with estimated collection efficiency per count (LPS count/abundance × 100) at each AWS structure from 2004 to 2012. Separate collection efficiency values are given for the 2011 period when pickets were raised (June 1-29) vs. when they were lowered to protect salmonids (July 1-30). Counts from days when an outage occurred are not included in either count.

	Bradford Island		Washington Shore	
	Estimated abundance	LPS count and estimated efficiency (%)	Estimated abundance	LPS count and estimated 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 June	792	241 (30)	2,292	934 (41)
1-30 July	9,762	3,160 (32)	10,431	1,707 (16)
2012	24,600	4,392 (18)	49,176	5,686 (12)

Collection efficiencies at both LPSs were used to assess the efficacy of raising picket leads in 2011 and 2012. For the Washington Shore LPS in 2011, collection efficiency was higher in June, when pickets were raised (41%), than in July when pickets were lowered to protect salmonids (16%; Table 1). However, at Bradford Island in 2011, LPS collection efficiency was similar between June, when pickets were raised (30%), and July, when they were lowered (32%; Table 1).

In 2012, collection efficiency at the Bradford Island LPS was 18%, as compared to 30% in June of 2011. This result provided further evidence that raising the pickets by 2.5 cm at Bradford Island in 2012 was less effective than raising them by 3.7 cm at the beginning of 2011. Additionally, the lowered pickets at Washington Shore in 2012 resulted in significantly lower passage there (Table 1).

Conclusions and Recommendations

Based on counts at both AWS LPSs, use of these structures in 2012 was low relative to 2011 and previous years. Counts indicated a decline of over 50% in estimated collection efficiency at both structures in 2012 relative to 2011. Much of this discrepancy can be ascribed to relatively low LPS use in mid-summer (July-August 2012), which was also the peak of lamprey passage. It may also have been a consequence of the unusually large proportion of lamprey that passed via fish ladders, as evidenced by the large run of lamprey recorded at both count windows in 2012.

One possible reason for this observation is that during high abundances, a greater percentage of the lamprey pass count windows during the day. A second explanation is that visual counts at the count windows were artificially inflated (Clabough et al. 2011). To test this hypothesis, we computed collection efficiencies in 2011 and 2012 using abundance estimates derived from both expanded daytime counts (as in Table 1) and actual daytime and nighttime counts. For both methods, collection efficiencies in 2012 at both ladders were substantially lower in 2012 than in 2011.

A third possible explanation is that lamprey at both fishways had limited access to the AWS channel in 2012 relative to 2011. This was likely at the Washington Shore fishway because picketed leads were lowered for the entire season in 2012 but were raised 3.8 cm in June 2011. At the Washington Shore AWS this conclusion was further supported by 2011 results, which indicated that more lamprey used the AWS LPS in June when picketed leads were raised than in July when they were lowered.

At the Bradford Island fishway, a new picketed lead was installed in 2011, which may also have resulted in fewer lamprey accessing the AWS channel. Estimated collection efficiency for lamprey at Bradford Island AWS LPS in 2012 was the lowest recorded since this structure was installed in 2004 (Table 1; Moser et al. 2011). Moreover, collection efficiencies derived from PIT detections also indicated that fewer lamprey used this structure in2012 relative to previous years. We surmise that the straight pickets and even spacing of the new picketed lead resulted in lower lamprey access to the AWS channel, even though it was raised 2.5 cm throughout the 2012 season.

The chronology of changes made at the Washington Shore AWS channel made it difficult to tease out effects of structural modifications installed in 2012 (AWS ramp at step and reduced picket spacing at crowder). In 2011, these changes seemed to improve AWS access relative to previous years. However, 2012 results indicated that collection efficiency at the Washington Shore AWS LPS decreased to pre-2009 levels (Moser et al. 2011). Hence, further research is needed to separate the effects of structural and operational changes put into place at the same time.

It has been challenging to obtain accurate, real-time counts of lamprey as they use the LPSs in AWS channels. Extreme environmental conditions (heat, moisture, high frequency noise) and the vagaries of lamprey behavior have conspired to make obtaining and interpreting lamprey exit counts a difficult and labor-intensive task. In 2011-2012 the count system was modified to make the next step in evolution toward radio-linked, web-accessible count data. However, the complexity of this system and its large number of components made it susceptible to outages. We recommend incorporating count data from the LPSs in AWS channels with fish passage data from the count stations. This would bypass the need to transmit lamprey count data across the Bonneville project.

Evaluations Using Photographic Images

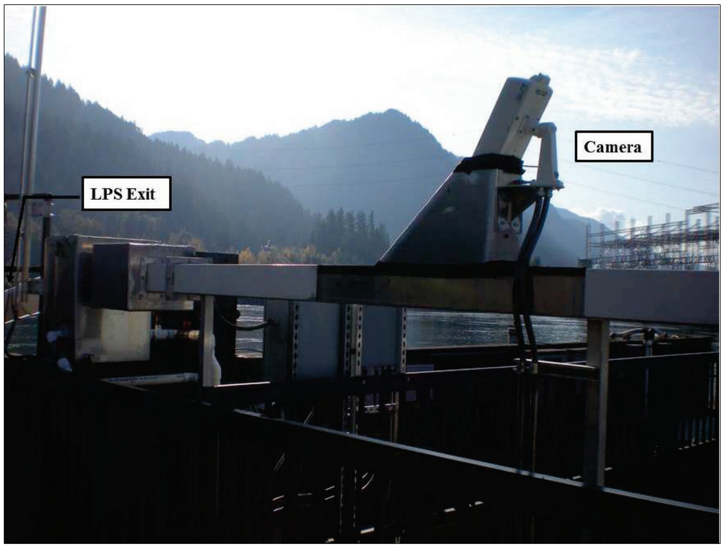
Methods

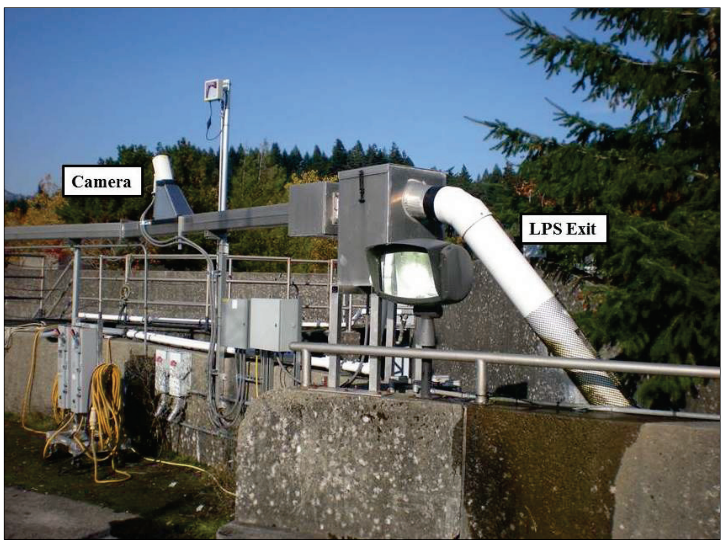
In 2011, motion-activated cameras (Sony IPELA SNC-CH240) were installed near the exit/terminus of all three LPSs in an attempt to validate the counter systems as well as provide insight into lamprey behavior in the terminal regions of the LPSs. As a lamprey entered the field of view from either a downstream or upstream direction, its motion was detected, activating the camera shutter and recording a single image to a memory card within the camera (Figure 16). At the Washington Shore LPS between August 25 and October 15 the camera was set to record a 10-second video clip upon motion detection. Camera images and videos were recorded to memory cards and uploaded to an off-site host computer using the same uplink system used for LPS exit counters.

Still images were recorded for adult river-run lamprey occupying terminal regions of the LPS during the 2011 and 2012 periods shown in Table 2. Video images were also recorded at Washington Shore from 25 August to 15 October 2011, but no video images were recorded in 2012.

Table 2. Periods during which the exits of all three AWS lamprey passage structures were monitored with a motion-detection camera.

Camera location (LPS exit)	2011	2012
Bradford Island	9 June-8 November	2 June-21 November
Washington Shore	3 June-8 November	23 May-9 November
Cascades Island	7 June-9 November	29 May-10 August





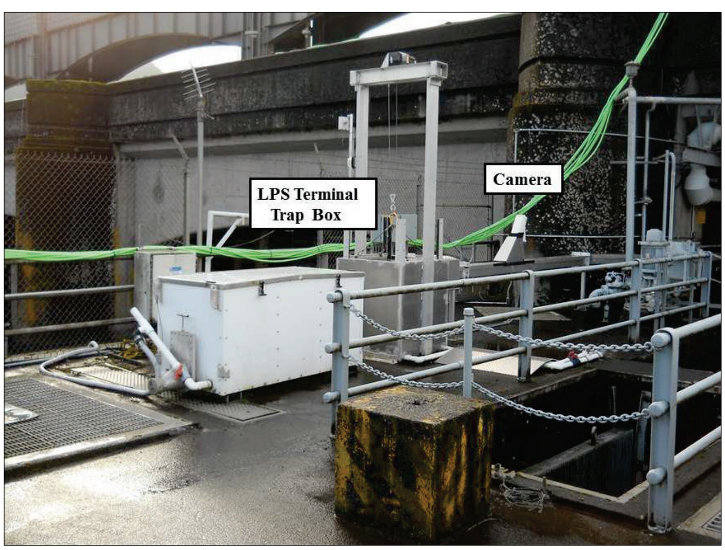


Figure 16. Camera and LPS terminus locations at the Bradford Island AWS channel (top), Washington Shore AWS channel (middle), and Cascades Island LPS terminal trap (bottom).

Results

As a primary LPS counting system, the camera proved inadequate for several reasons. The motion-activated shutter was triggered repeatedly when a single lamprey would occupy the camera field of view for an extended period. This resulted in several images of the same individual (Figure 17A). The motion sensor was also triggered by water turbulence, which resulted from either movement by lamprey upstream from the field of view or from pump anomalies. Either trigger produced a photo of the flume with no lamprey (Figure 17B).

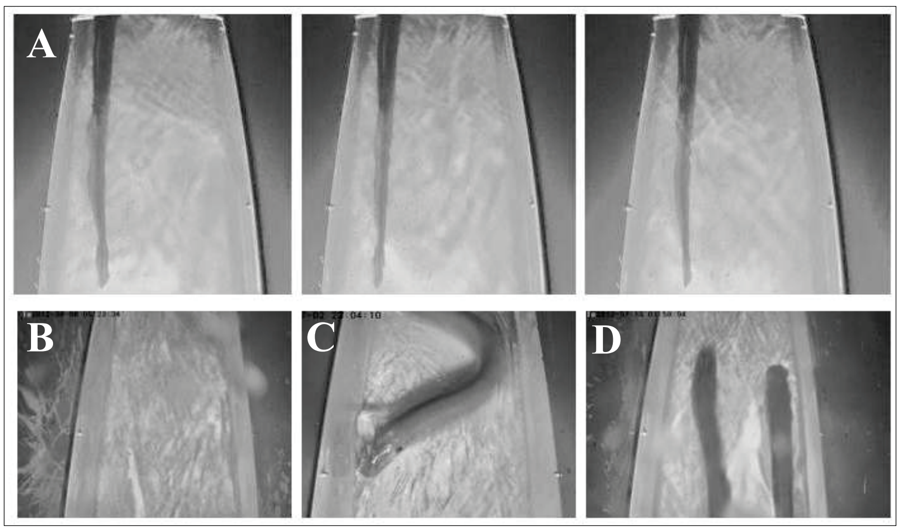


Figure 17. Examples of how camera imagery failed to help enumerate lamprey passage. Upper three photos (A) show repeat images of a single lamprey that attached within the view field. Photo B was produced when the shutter was activated by upstream turbulence. Photo C shows lamprey moving in a downstream direction. Photo D shows multiple lamprey in the view field.

Individual lamprey were also photographed a second time if they re-entered the field of view from upstream (Figure 17C). During periods of peak lamprey migration, multiple lamprey were often captured in a single image (Figure 17D). With more than one lamprey in the image, it was not possible to pair an individual with its corresponding exit event recorded by the LPS counter.

Pairing images with LPS exit events recorded at the counter was also difficult due to the length and variability of time required to pass between the camera view field and LPS exit slide. Prior to camera monitoring, we had assumed that lamprey would reach the LPS exit shortly after ascending the final elevation gains. However, comparisons of the time stamp on the camera with those on the exit counter showed that in many cases lamprey required up to 55 min to travel the last 9 m to the LPS exit. Asynchronous time stamps between the camera and the counter were also caused by clock drift and/or hacking events, further confounding the pairing of an individual lamprey's image with its subsequent exit slide count.

As configured in 2011-2012, the cameras did not provide an adequate tool for fine-scale validation of counts. However, the images did provide valuable insight into fish behavior, especially with regard to exit timing. Analysis of the video recorded in 2011 showed that fallback occurred between the final rest box and the area downstream of the camera field (Figure 18).

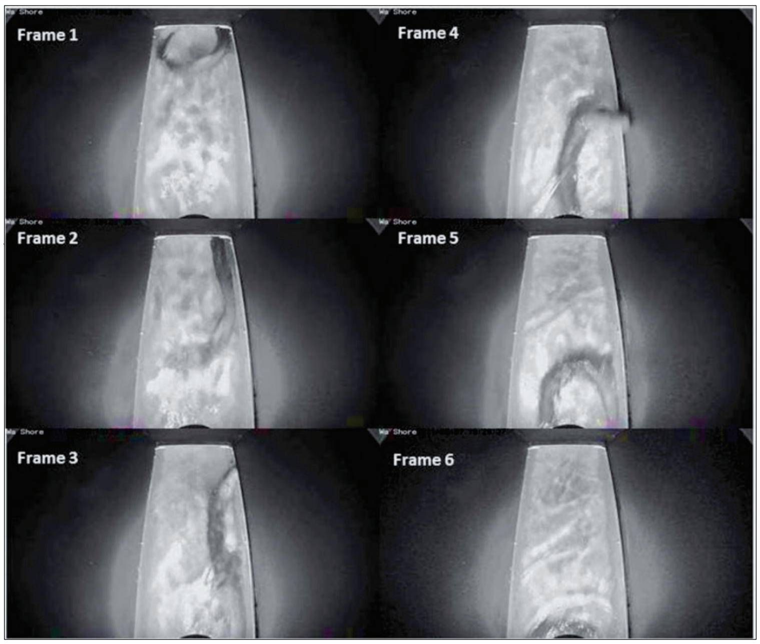


Figure 18. Still frames from video camera at Washington Shore AWS LPS showing a lamprey moving back downstream within the LPS.

Conclusions and Recommendations

Installation of motion-activated security cameras near the terminus of each AWS LPS in 2011-2012 was intended as a further step toward obtaining accurate counts. However, as a fine-scale validation tool, the cameras proved inadequate. Although the camera systems could not be used to obtain absolute counts at the AWS LPSs, they were useful for coarse validation and to provide insight into lamprey behavior. We used camera imagery to identify count-system outages and spurious data reported by the count system. Moreover, the cameras provided evidence for fallback and simultaneous ascension by multiple lamprey. They also indicated that lamprey require a longer time than previously thought to traverse the short distance between the camera site and LPS exit slide.

Imagery from the AWS LPS cameras was of high quality and has potential for future use in counting systems. While labor-intensive, it would be possible to use human interpretation to obtain accurate counts from video collected continuously at each site. These data would need to be carefully processed after collection, as is done for night video of lamprey at count stations.

Due to the high cost of video processing, we do not see an immediate role for cameras in the production of AWS LPS counts. However, this could change with improved technology. Reducing the camera view field, increasing data storage capability, and use of sophisticated count-based software could make use of these camera systems a viable alternative to existing counter systems.

Monitoring of Tagged Lamprey

Methods

In 2011, lamprey were collected for tagging at the adult fish facility and from the terminal trap at the Cascades Island LPS. In 2012, lamprey were collected at these locations as well as at two locations in the Bonneville Dam tailrace and the Cascades Island AWS channel. In both years we deployed two portable traps and two fixed traps at weirs in the fishway of the adult facility. All traps were set each night at approximately 2100 to 0700 PST. Each morning trapped lamprey were transferred to a holding tank with flow-through river water prior to 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 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 ~3 km downstream from Bonneville Dam at the Hamilton Island boat ramp, just upstream from Bonneville Dam at the Stevenson boat ramp (rkm 235.1), and in Rest Box 3 of the Cascades Island LPS (Figure 6). We were required to release all fish collected at the Cascades Island LPS upstream from Bonneville Dam. Lamprey released into the Cascades Island LPS were used for evaluation of that structure.

Some study fish were also implanted with a Juvenile Salmon Acoustic Telemetry System (JSATS) tag for a separate study (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. Double-tagged fish were released in the morning within 1 h of tagging at various locations either upstream or downstream from Bonneville Dam.

In 2011, 929 lamprey were tagged with only a PIT tag. Of these fish, 800 were released downstream from Bonneville Dam, 109 were released upstream from Bonneville Dam, and 20 were released into the Cascades Island LPS (Table 3). These fish were tagged between 25 May and 2 September (mean date 17 July) and had a mean length of 64.8 cm (range 53-79.5 cm). An additional 85 lamprey were tagged with both a PIT and JSATS tag (Noyes et al. 2012). Of these, 23 were released downstream from Bonneville Dam and 62 were released upstream from the dam (Table 3). These fish were tagged between 11 June and 3 September (mean date 23 July) and had a mean length of 65.0 cm (range 52.5-78.0 cm).

Table 3. Number of lamprey tagged in 2011 and 2012 with only a PIT tag, or a PIT and JSATS tag (double-tagged), and their release locations.

Tag type/Release location	2011 (N)	2012 (N)
PIT tag only		
Below Bonneville Dam	800	823
Cascades Island LPS	20	50
Released above Bonneville Dam	109	25
Double tag (JSATS and PIT)		
Below Bonneville Dam	23	153
Cascades Island LPS	0	0
Above Bonneville Dam	62	146
Total PIT tagged	1,014	1,197

In 2012, 898 lamprey were tagged with only a PIT tag. Of these fish, 823 were released below Bonneville Dam, 25 were released upstream from Bonneville Dam, and 50 were released to the LPS at the Cascades Island fishway (Table 3). These fish were tagged between 30 May and 7 September (mean date 17 July) and had a mean length of 65.2 cm (range 52.0-79.5 cm). An additional 299 lamprey were double tagged with a PIT and JSATS tag (Noyes et al. 2013). Of these fish, 153 were released downstream from Bonneville Dam and 146 were released upstream from the dam (Table 3). Double-tagged fish were tagged between 5 June and 1 September (mean date 7 July) and had a mean length of 67.0 cm (range 56.0-79.5 cm).

Results

Bradford Island—Of the 800 PIT-only fish released downstream from Bonneville Dam in 2011, 60 (8%) were detected at the Bradford Island AWS LPS. In contrast, none of the 23 double-tagged fish released downstream from Bonneville Dam were detected at this structure in 2011 (Table 4), and neither were any of the fish tagged in 2010.

Of the 823 PIT-only fish released downstream from Bonneville Dam in 2012, 40 (5%) were detected at the Bradford Island AWS LPS. In contrast, 5 (3%) of the 153 double-tagged fish released downstream from Bonneville Dam were detected at this structure in 2012 (Table 4), as were four fish tagged in 2011.

Table 4. Number of detections of PIT-tagged fish in the Bradford Island AWS lamprey passage structure, 2007-2012. These values as a percentage of PIT-tagged fish released downstream from Bonneville Dam are given in parenthesis. In 2008-2010 double-tagged lamprey carried a PIT and radio tag. In 2011-2012 double-tagged lamprey carried a PIT and JSATS tag.

	Number of lamprey detected (%)					
Bradford Island LPS	2007	2008	2009	2010	2011	2012
PIT only	31 (4)	55 (9)	26 (7)	0	60 (8)	40 (5)
Double tag	--	14 (5)	10 (3)	10 (3)	0	5 (3)

Passage efficiency at the Bradford Island LPS in 2011 was 100%, with all PIT-tagged fish detected at the top of a collector ramp being subsequently detected at the exit slide. In 2012, passage efficiency at this LPS was 98%, with 44 of 45 PIT-tagged fish that were detected at the top of a collector ramp being subsequently detected at the exit slide. Similarly, in 2009 and 2010, passage efficiency was 100%, with all fish detected in the Bradford Island LPS subseqently detected at the exit slide.

In 2011, median passage time from a collector to the exit slide was 0.60 h (range 0.32-1.96 h). In 2012, median passage time from a collector to the exit slide was 0.63 h (range 0.42-5.96 h) for PIT-only fish and 0.71 h (range 0.47-0.84 h) for double-tagged fish. This was similar to results from 2010, where 5 PIT-only fish detected at the top of the collector ramps exhibited a median passage time of 0.61 h (range 0.52-1.4 h).

PIT-tagged lampry were also detected using the Bradford Island fishway exit, either in addition to or instead of the LPS. In 2011, 108 PIT-tagged fish were detected at the fishway exit but not in the LPS. Of the 60 fish detected in the LPS during 2011, 12 (20%) were subsequently detected in the fishway after having fallen back into the fishway exit; 5 of these were subsequently detected at upstream dams.

In 2012, 121 PIT-tagged fish were detected at the fishway exit but not in the LPS. Of the 45 fish detected in the LPS during 2012, one (2%) was subsequently detected at the fishway exit, and this fish was not detected at an upstream dam. In comparison, 47 (14%) of the PIT-tagged fish detected at the fishway exit in 2010 were not detected at the LPS. Of the 11 lamprey that used the LPS in 2010, one (9%) was subsequently detected at the Bradford Island fishway exit, and this fish was not detected at an upstream dam.

In each year, some lamprey that exited the Bradford Island LPS or fishway exit were later detected upstream. In 2011, 32 (53%) of 60 fish that used the LPS were detected at an upstream site; In 2012, 26 (58%) of 45 fish that used the LPS were detected at an upstream site. These results were similar to those in previous years: numbers of fish that used the LPS and were later detected upstream were 18 (50%) in 2009 and 7 (64%) in 2010. Proportions of fish that did not use the LPS but were detected upstream after being detected at the Bradford Island fishway exit were 80% in 2009, 57% in 2010, 74% in 2011, and 72% in 2012.

Washington Shore—In 2011, 59 (7%) of the 800 PIT-only fish released downstream from Bonneville Dam were detected in the Washington Shore AWS LPS. Of the 23 double-tagged fish released downstream fom Bonneville Dam, 3 (13%) were detected using this structure in 2011 (Table 5).

In 2012, 56 (7%) of the 823 PIT-only fish released downstream from Bonneville Dam were detected at the Washington Shore AWS LPS. Of the 153 double-tagged fish released downstream fom Bonneville Dam, 6 (4%) were detected using this structure in 2012 (Table 5).

In 2011, 7 of the 59 PIT-only fish detected at the first PIT-tag monitoring antenna in the Washington Shore AWS LPS were not detected at the exit slide (i.e., passage efficiency was 88%). Only one (33%) of the three double-tagged fish was detected at the exit slide. Median travel time from the first antenna to the exit slide was 0.39 h (range 0.19-1.72 h) for PIT-only fish and 0.50 h for double-tagged fish.

Table 5. Number of detections of PIT-tagged fish in the Washington Shore AWS lamprey passage structure, 2007-2012. These values as a percentage of PIT-tagged fish released downstream from Bonneville Dam are given in parenthesis. In 2008-2010 double-tagged lamprey carried a PIT and radio tag. In 2011-2012 double-tagged lamprey carried a PIT and JSATS tag.

Washington Shore LPS in AWS channel	Number of lamprey detected (%)					
	2007	2008	2009	2010	2011	2012
PIT only	26 (3)	16 (3)	10 (3)	5 (38)	59 (7)	56 (7)
Double tag	--	0	17 (5)	5 (2)	3 (13)	6 (4)

In 2012, 4 of the 56 PIT-only fish detected at the first HD-PIT antenna were not detected at the exit slide (i.e., passage efficiency through the Washington Shore AWS LPS was 93%). Four (67%) of the six double-tagged fish were detected at the exit slide. Median passage time from the first antenna to the exit slide was 0.47 h (range 0.26-1.6 h) for PIT-only fish and 0.52 (range 0.31-0.97 h) for double-tagged fish.

The Washington Shore LPS empties into the Washington Shore fishway downstream from the fishway exit. In 2011, 134 PIT-tagged fish that had not been detected in the LPS were detected at the Washington Shore fishway exit. Of the 62 fish that used the LPS in 2011, 42 (68%) were detected as they migrated upstream and passed through the fishway exit; of the remaining 20 fish, 10 were detected at upstream dams, indicating low detection efficiency at the Washington Shore fishway exit antenna.

In 2012, 141 PIT-tagged fish that had not been detected in the LPS were detected at the Washington Shore fishway exit. Of the 62 fish that used this LPS in 2012, 46 (74%) were detected as they migrated upstream and passed through the fishway exit; of the remaining 16 fish, 6 were detected at upstream dams.

After passage at Bonneville Dam, lamprey were often detected at PIT monitoring sites upstream. Of fish detected at an upstream site in 2011, 27 (44%) had used the Washington Shore LPS and 85 (63%) had been detected using only the traditional fishway exit. Of fish detected at upstream locations in 2012, 22 (35%) had used the LPS, while 84 (60%) had been detected exiting the fishway without using the LPS. These values were high relative to previous years of monitoring. Numbers of fish detected using the LPS and later detected at upstream sites were 3 (18%) in 2009 and 7 (33%) in 2010. In comparison, proportions of the fish detected upstream after exiting the Washington Shore fishway without using the LPS were 41% in 2009 and 30% in 2010.

Cascades Island—In 2011, 8% (n = 62) of the fish released below Bonneville Dam were detected at the entrance to the Cascades Island AWS channel. Of these fish, 61 were marked with only a PIT-tag and 1 was double-tagged (Table 6). Thus, 8% (61/800) of PIT-tag only and 4% (1/23) of double-tagged fish were detected at this site. No fish tagged in 2010 was detected at this site. In 2011, of the 62 lamprey detected at the Cascades Island flow-control area, 23 (37%) were subsequently detected at upriver sites (Table 6).

In 2012, 10% (n = 96) of the fish released downstream from Bonneville Dam were detected in the Cascades Island AWS channel area. Of these fish, 85 were tagged with only a PIT tag and 11 were double tagged (Table 6). Thus, 10% (85/823) of PIT only and 7% (11/153) of the double-tagged fish were detected at this site. In 2012, we also detected two fish that had been tagged in 2011. In 2012, of the 96 lamprey detected at the Cascades Island flow control area that had been released downstream from Bonneville Dam in 2012, 37 (39%) were subsequently detected at upriver sites.

Table 6. Number of PIT-only and double-tagged lamprey released downstream from Bonneville Dam and subsequently detected at Cascades Island auxiliary water supply channel antenna (CI AUX) and at sites upstream of Bonneville Dam 2007-2012. In 2008-2010 double-tagged lamprey carried a PIT and radio tag. In 2011-2012 double-tagged lamprey carried a PIT and JSATS tag.

	Detections at Cascades Island auxiliary water supply channel (CI AUX)			
			PIT only and double tag combined (%)	
	PIT tag only N (%)	Double-tagged N (%)	N (%)	Subsequent detection upstream N (%)
2007	64 (8)	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	7 (2)	7 (2)	1 (14)
2011	61 (8)	1 (4)	62 (8)	23 (37)
2012	85 (10)	11 (7)	96 (10)	37 (39)

Conclusions and Recommendations

Washington Shore—Detections of PIT-tagged lamprey at the Washington Shore AWS LPS indicated that collection efficiency was the same in 2011 and 2012. However, passage efficiency (the percentage of fish successfully negotiating this structure) was low in 2011 (88%) and 2012 (93%) relative to previous years for fish bearing only PIT tags. Moreover, passage efficiency was particularly poor for double-tagged fish in both years (33% in 2011 and 67% in 2012).

These observations suggest that some lamprey have difficulty passing to the terminus of the Washington Shore AWS LPS. This finding is in contrast to results at the Bradford Island AWS LPS, where passage efficiency is regularly 100% (Moser et al. 2011). There are several possible explanations for the reduced passage efficiency at the Washington Shore AWS LPS. One explanation is that PIT tagged fish were missed by the antenna at the LPS terminal. There was strong evidence of this in 2010, when 82% of the double-tagged fish that used this structure were missed by PIT detectors (Moser et al. 2012).

An alternative hypothesis is that lamprey fell back after entering the Washington Shore AWS structure. Some lamprey were observed moving downstream in camera imagery at a position before they reached the terminal PIT detector. In addition, PIT-tagged lamprey were documented falling back within the Cascades Island LPS, which features a ramp and rest box design similar to that of the LPS in the Washington Shore AWS channel. In particular, the fykes at rest box entry locations are conducive to downstream movement in both structures (see results of testing in Objective 3).

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

In spite of these potential problems, the LPSs at both AWS channels provided an important passage route for lamprey. PIT-tag detections indicated that 15% of PIT-only lamprey released downstream from Bonneville Dam used an AWS LPS in 2011 and 12% did so in 2012. This has been consistent over many years of operation for these structures (e.g., 2008 = 12% and 2009 = 10%; Moser et al. 2010, 2012).

Cascades Island—Data from the two LPSs in AWS channels and from PIT-detections at the Cascades Island AWS channel indicate that lamprey could benefit from an LPS in this area. In both 2011 and 2012, significant percentages of PIT-only fish released downstream from Bonneville Dam were detected at the Cascades Island flow control area. In addition, relatively low numbers of these fish were detected at 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.

Overall, a lower percentage of lamprey that use an LPS are detected at upstream antennas than those that use a traditional fishway exit. There are several possible reasons for this. Lamprey that use an LPS tend to be smaller, and smaller fish typically have lower overall escapement than larger lamprey (Keefer et al. 2013a). It is also possible that there is a fitness cost to lamprey use of the LPS. Further research is needed to ensure that LPS use does not incur any loss in reproductive potential for lamprey that choose this passage route.

OBJECTIVE 2: Assess the Effects of Providing Refuge Areas in AWS Channels

Methods

Research has shown that lamprey seek refuge from light during daylight hours (Binder and McDonald 2007). Results from radiotelemetry studies have indicated that upstream-migrating lamprey fall back downstream through the AWS channels at Bonneville Dam, and that these fallbacks are rarely followed by re-ascension (Keefer et al. 2013a). We designed and constructed refuge boxes to provide cover from light and retain lamprey in fishways during daylight, when lamprey often fall back or seek low-light areas to hold.

During the winter maintenance period prior to the 2011 lamprey migration, we installed two prototype refuge boxes in the Washington Shore AWS channel (Figure 19). Metal guides were attached to the south and north walls of the Washington Shore AWS channel upstream from the picketed lead. These guides were used to lower and position the refuge boxes along each wall (Figures 20 and 21).

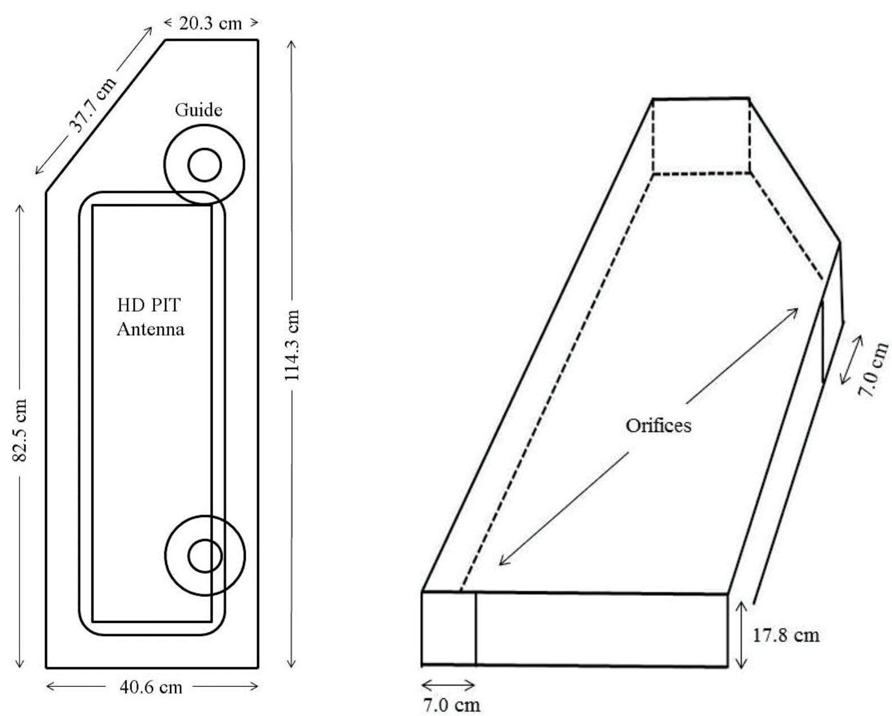


Figure 19. Top view (left) and oblique view (right) of refuge boxes installed in the Washington Shore AWS channel.

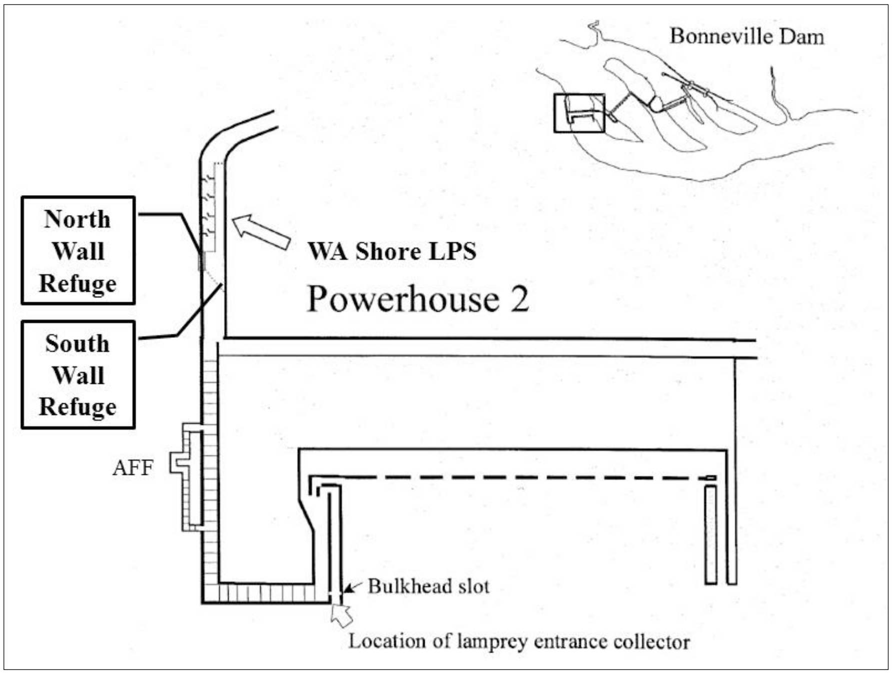


Figure 20. Location of refuge boxes at north and south walls of Washington Shore AWS channel.

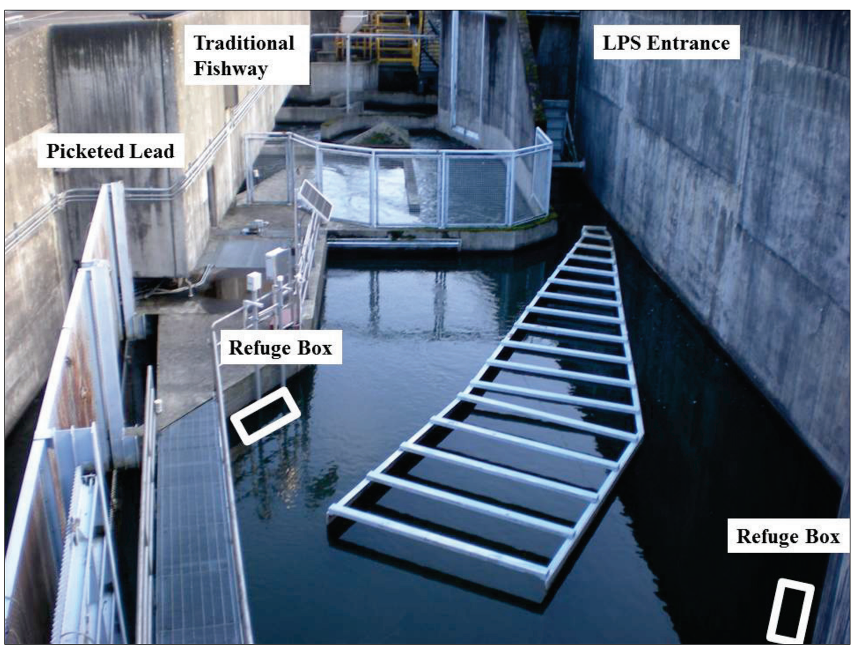


Figure 21. Location of refuge boxes relative to other structures in the AWS channel.

Prototype refuge boxes were 40.6-cm wide by 114.3-cm long by 17.8-cm high. They were constructed from weighted aluminum with openings at both ends and featured a cobble substrate cemented to the bottom of the upstream end. The long axis of the box was oriented with the flow (Figure 22), and a single HD-PIT detection antenna was fitted to the box perimeter. Lamprey tagged for Objectives 1 and 3 were used to assess use of these devices.

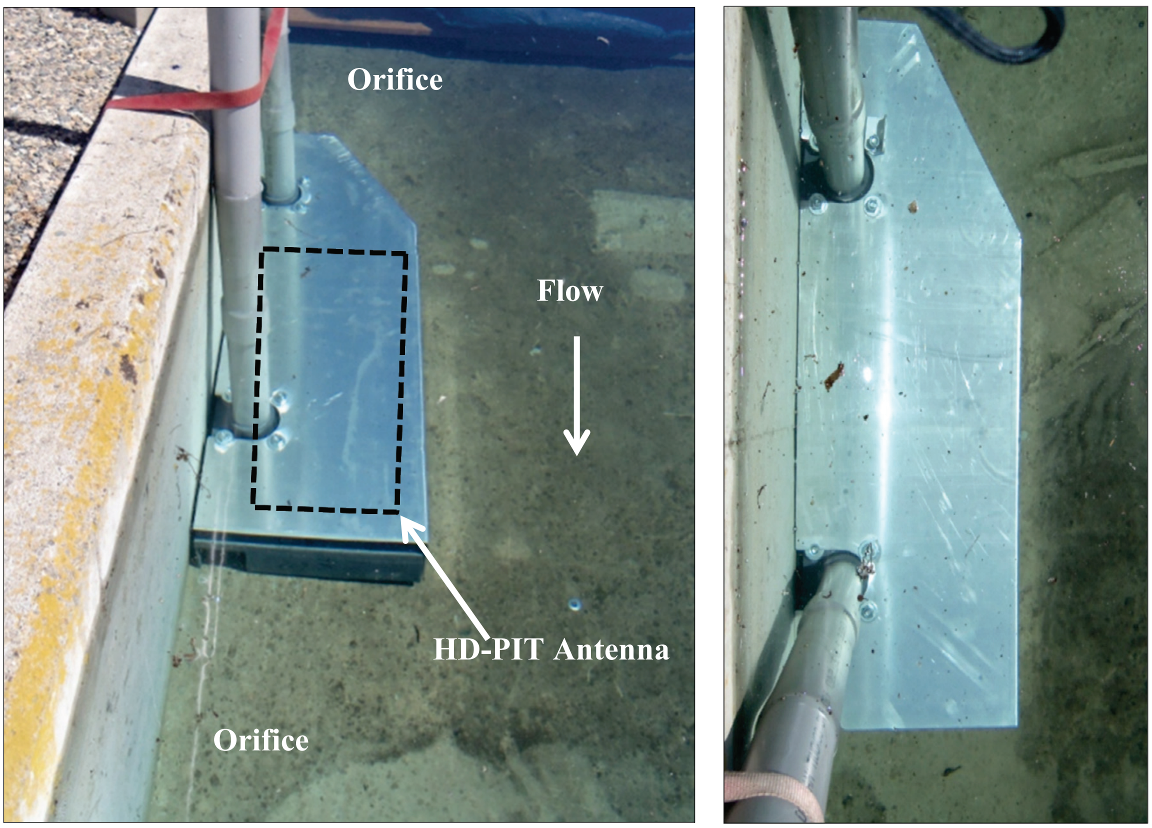


Figure 22. Photographs of refuge box design and placement.

Results

The two prototype refuge boxes were in place prior to the lamprey migration in 2011 and 2012. In 2011, north and south refuge boxes were monitored during alternating weeks due to electromagnetic interference between detection antennas at the two sites. In 2012, the boxes were wired together to eliminate this interference, and both boxes were monitored continuously throughout the migration period.

Lamprey detected in each box were enumerated, and we calculated the percentage of these individuals that were subsequently detected in the LPS at the Washington Shore AWS channel. We also screened LPS and fishway exit detections to determine the fate of fish that had used refuge boxes. In addition, the duration of box residence was determined by tallying the time from first to last detection at a box antenna for each individual.

In 2011, the two prototype lamprey refuge boxes were operated in the Washington Shore AWS channel from 28 June to 7 November. Nineteen of 823 (2.3%) lamprey PIT-tagged and released downstream from Bonneville Dam in 2011 were detected in a refuge box. Of these 19 lamprey, 15 (78.9%) were subsequently detected at the AWS LPS immediately upstream from the refuge box. Moreover, of the lamprey detected in the LPS at the Washington Shore AWS channel, 23% had used a refuge box.

Of the 194 PIT-tagged lamprey detected at the exits of either the Washington Shore fishway or LPS in the AWS channel, 14 (7.2%) had previously been detected in a refuge box. Of these 14 fish, 5 (35.7%) were subsequently detected at locations upstream from Bonneville Dam. Mean residence time of PIT-tagged lamprey within a refuge box was 9.1 h (± 20.3 h, range 0-23 h).

In 2012, lamprey refuge boxes were operated at the same locations in the Washington Shore AWS channel from 30 May to 17 October. In addition to one lamprey tagged in 2011, 36 of the 976 (3.7%) lamprey PIT-tagged and released downstream from Bonneville Dam in 2012 were detected in a refuge box. Of these 36 lamprey, 28 (77.8%) were subsequently detected in the LPS.

Of the 212 PIT-tagged lamprey detected at the exit of either the Washington Shore LPS or fishway, 25 (11.8%) had previously been detected at a refuge box. Of these 25 fish, 14 (56%) were subsequently detected at a location upstream from Bonneville Dam. Mean residence time of PIT-tagged lamprey within a refuge box was 49.7 h (± 76.2 h, range 0-355.6 h).

We examined the timing of lamprey entry and exit from the refuge boxes in 2012, as the PIT antennas were operated continuously in each box that year. As expected, more lamprey exited the boxes as evening approached and fishway environs started to darken (Figure 23). In contrast, more lamprey entered the boxes during the middle of the night when the fish are most active and in early morning hours when the fishway began to lighten (Figure 23).

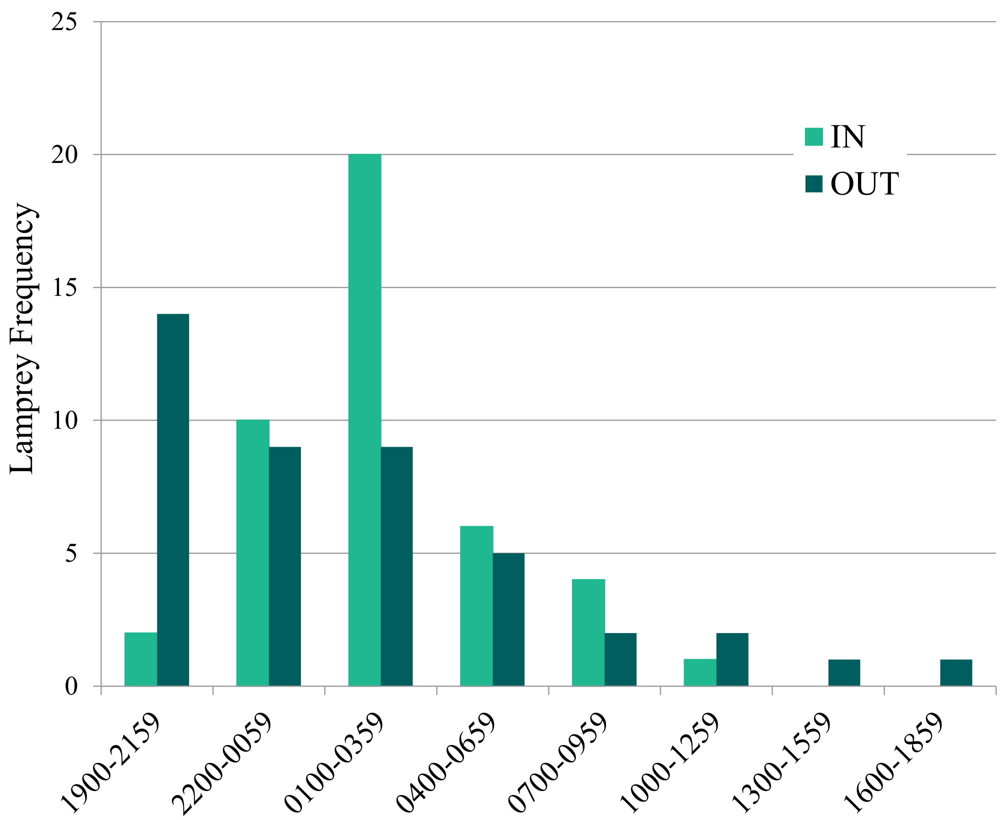


Figure 23. Diel frequency of entries to (light bars) and exits from (dark bars) prototype refuge boxes in 2012.

Conclusions and Recommendations

A substantial percentage of PIT-tagged lamprey at the top of the Washington Shore fishway used refuge boxes, in spite of their relatively small footprint. The AWS channel where these refuge boxes were deployed is 7.3 m wide. Consequently, these refuge boxes represented just 11% of the cross-sectional floor area at this location. Nevertheless, approximately one-quarter of lamprey using the AWS LPS visited a refuge box.

Lamprey that used refuge boxes also had a higher LPS collection efficiency (79-80%) than those that did not (see Objective 1). Of all lamprey detected exiting the fishway in each year, 7-12% were also detected using a refuge box. However, due to the high probability of PIT-tag signal collision at the refuge box antennas, this proportion was likely an underestimate. In some cases, a single PIT-tagged lamprey resided in a refuge box for several weeks. During this period, any other PIT tags entering the box would potentially be missed due to signal collision. Video monitoring is needed to produce a more accurate evaluation of refuge box use, but the PIT data clearly indicated that lamprey were seeking out the relatively small refuge boxes in the AWS channel.

Mean lamprey residence times in the refuge boxes were 9.1 h in 2011 and 49.7 h in 2012. The lengthier residence times recorded in 2012 were likely due to differences in monitoring rather than differences in lamprey behavior. In 2011, each refuge box antenna was operated only on alternate days, due to electromagnetic interference between refuge-box antennas. Consequently, residence time would be truncated for any tagged lamprey residing in a box when the antenna was switched. In 2012, the antennas were multiplexed so that they could both be operated continuously and provide a more accurate representation of lamprey residence.

Lamprey were detected in the boxes for periods ranging from several seconds to several weeks in 2012. Tagged lamprey were regularly detected in refuge boxes during the day and for periods in excess of 8 h, suggesting that the boxes functioned to retain lamprey that might otherwise have fallen back downstream within the fishway (Keefer et al. 2013a). Interestingly, lamprey that used a refuge box also had a higher probability of detection at upstream sites than those that did not. While sample sizes were low, this very encouraging finding further supports the idea that refuge boxes can confer a passage advantage to lamprey that use them.

While the refuge box prototypes showed great promise for improving lamprey retention, the next step is to test their efficacy in the actual fishway areas where lamprey retention is desired. Keefer et al. (2013a) 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 have shown a high potential for fallback by radio-tagged lamprey. Moreover, lamprey that fall back from areas at the top of fishways have been less likely to make further passage attempts than those that fall back from other fishway segments (Keefer et al. 2013a).

For these reasons, we recommend that the refuge-box concept be tested in fishways near the top of the Washington Shore fishway. Ideally, fish tagged with both radio and PIT tags could be used to monitor relative fishway retention rates of lamprey that use refuge boxes vs. those that do not. In addition, video monitoring is needed to establish the actual number of lamprey that enter refuge boxes and whether refuge box entry is density dependent. Video monitoring could also provide information on potential effects of refuge boxes on salmonids and other fishway occupants.

OBJECTIVE 3: Evaluate use of the Cascades Island Lamprey Passage Structure

The Cascades Island LPS was installed in 2009 and was the first structure to allow volitional passage by lamprey over the entire distance from the tailrace to the forebay level of Bonneville Dam (Figure 24). This structure is composed of a series of 0.15-m wide aluminum ramps wetted to a depth of approximately 3 cm and interspersed with horizontal flumes and rest boxes. As lamprey ascended the LPS, they passed through a PIT detection antenna integrated into the horizontal flume immediately before entering Rest Box 3 (details in Moser et al. 2012). After ascending to above the +85 deck level (elevation 27 m), lamprey continued through a horizontal aluminum flume (0.15 m deep × 0.2 m wide × 25 m long) before passing through another PIT antenna and into a terminal trap box (Figure 24).

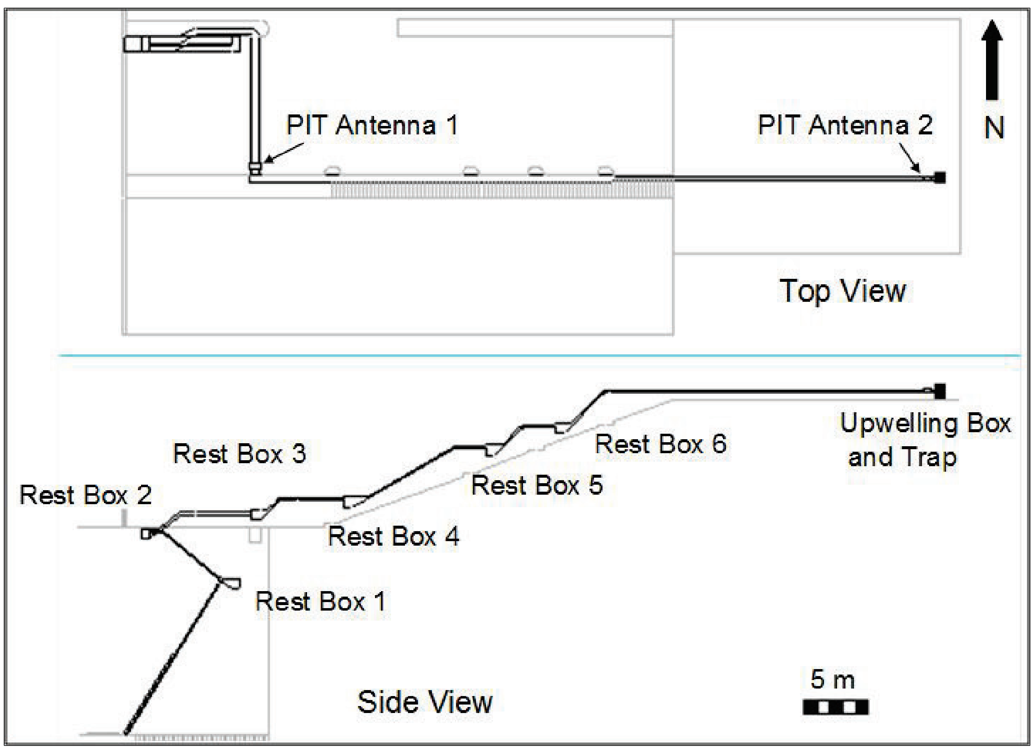


Figure 24. Diagram of Cascades Island LPS (top view in top panel, side view in bottom panel) with locations of HD-PIT antennas and rest boxes indicated.

The Cascades Island LPS was evaluated in 2009 and 2010 using trap captures and detections of PIT-tagged lamprey (Moser et al. 2012). Initial results were disappointing, indicating that relatively few lamprey used the structure. In 2010, flow through the structure was reduced in an effort to improve LPS collection efficiency, with little improvement (Moser et al. 2012).

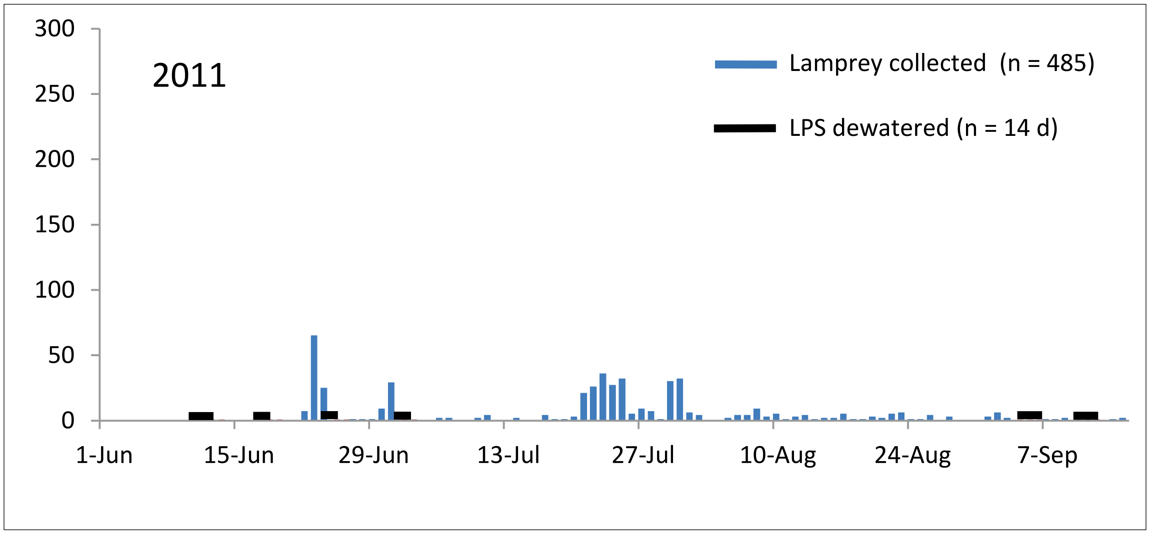
In 2011-2012 further testing was conducted using captures in the terminal trap box as well as a comparison of alternating flow treatments to assess passage through the lower part of the structure. We also tested a new design for the fyke mesh cones that lead into each rest box and are intended to reduce lamprey fallback. A new fyke design was fabricated from aluminum and installed at the entrance to Rest Box 3 so that any PIT-tagged lamprey that fell back downstream could be detected and an accurate fallback rate computed. In both years we also deployed a motion-sensing camera near the LPS terminus to assess lamprey behavior as they neared the terminal trap.

Trap Box Captures

In both 2011 and 2012, we used trap captures and releases of PIT-tagged lamprey to evaluate lamprey use of the Cascades Island LPS. Trap captures were compared to daytime counts at the Bonneville Dam count windows to assess interannual changes in LPS use. Detections of PIT-tagged lamprey released downstream from Bonneville Dam were used to assess relative collection efficiency and passage rates through the LPS in both years. Due to the low sample sizes of tagged lamprey captured in the terminal trap, we also planted PIT-tagged lamprey directly into Rest Box 3 of the LPS in 2011-2012 to further evaluate the structural and operational changes to this structure.

The trap box at the terminus of the Cascades Island LPS was monitored each day for lamprey use. On each day of LPS operation, the trap box was hoisted to allow transfer of lamprey to an insulated aluminum tank (capacity >2 m^3). From this tank, lamprey were enumerated prior to release upstream from Bonneville Dam at the boat ramp near Stevenson, WA. In 2011, some trapped lamprey were PIT-tagged prior to release. In both 2011 and 2012, some lamprey were transported to tribal holding facilities for restoration purposes.

In 2011, the Cascade Island LPS was operated for 82 days, mostly on weekdays from 6 June to 15 September. During this period, 485 lamprey were captured in the terminal trap box (Figure 25). These 485 lamprey represented 3.8% of the daytime lamprey count from both count windows at Bonneville Dam on the days of trap operation in 2011.



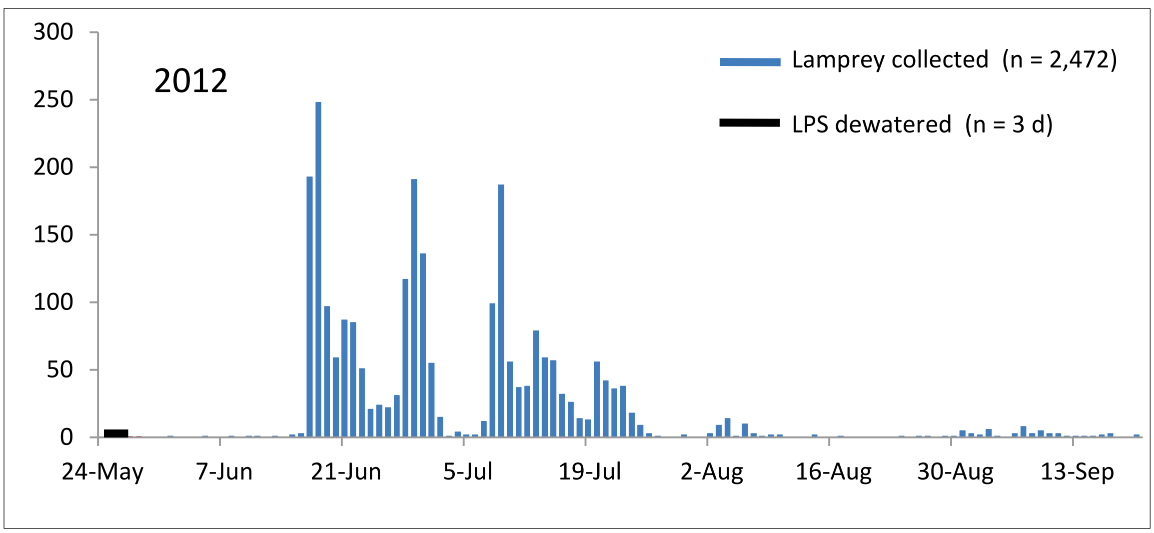


Figure 25. Number of lamprey collected (minus recaptured and experimental lamprey) from the terminal trap box (vertical bars) in 2011 (top) and 2012 (bottom). Horizontal bars indicated periods of dewatering at the Cascades Island LPS by date.

In 2012, the Cascade Island LPS was operated for 119 days from 23 May to 20 September. During this period, 2,472 lamprey were captured in the terminal trap box of the LPS (Figure 25). These 2,472 lamprey represented 13.4% of the daytime lamprey count from both count windows at Bonneville Dam on the days of trap operation in 2012.

Evaluations Using Tagged Lamprey

Tagged lamprey used to evaluate the Cascades Island LPS were the same fish collected and released for study Objective 1 (see Table 3). In addition to these fish, we tagged lamprey collected from the terminal trap box of the Cascades Island LPS. Of fish collected from the trap box, 108 were tagged with a PIT tag only and 25 were tagged with both a JSATS and PIT tag. All lamprey caught at the terminal trap box were released upstream from Bonneville Dam at the Stevenson boat ramp. In 2012, no lamprey collected at the terminal trap were tagged.

In 2011, 11 of the 823 (1.3%) lamprey PIT-tagged and released downstream from Bonneville Dam were detected in the Cascades Island LPS and/or recaptured at the terminal trap. All 11 of these fish were marked with a PIT tag only, and 7 were recaptured at the terminal trap. Of the remaining 4 lamprey, none were detected at antennas in other Bonneville structures, but 3 were detected at sites upstream. Eight lamprey were detected at one or more antennas within the LPS, and 5 were detected at both the entrance and terminus antennas. For these fish, median passage time between antennas was 1.5 h (range 1.2–19.7 h). A total of 169 PIT-tagged lamprey released downstream from Bonneville Dam were detected on antennas at the Cascades Island fishway entrance downstream from the LPS collector ramp (see Keefer et al. 2012 for details of antenna locations and operation).

In 2012, 11 of 976 (1.1%) lamprey PIT-tagged and released downstream from Bonneville Dam were detected in the Cascades Island LPS and/or recaptured at the terminal trap. All of these 11 fish were marked with a PIT tag only, and 6 were recaptured at the terminal trap. Of the remaining 5, none were detected at antennas in other Bonneville structures, but 2 were detected at a site upstream of Bonneville Dam. Eight fish were detected at least once in the LPS, but only 1 of these was detected at both LPS antennas; passage time between antennas was 100.8 h for this fish. In 2012, no PIT-tagged lamprey were detected at the Cascades Island fishway entrance antennas.

In 2011, we planted 20 PIT-tagged lamprey into Rest Box 3 of the LPS (Figure 24) to evaluate passage success and timing. Three of these fish were not detected at either antenna or recaptured in the terminal trap box. Twelve of the remaining 17 fish (71%) were either recaptured in the terminal trap or last detected at the upper antenna. Of these 12 fish, 5 (42%) were detected at the lower antenna (downstream of the release point), indicating that they fell back before ultimately ascending the LPS. Five of the 17 detected lamprey (29%) were last detected at the lower antenna and not recaptured, indicating that these fish fell back out of the LPS. Two of these 5 (40%) were subsequently detected in other Bonneville Dam fishways or at sites upstream.

In 2012, we planted 50 PIT-tagged lamprey into Rest Box 3 of the Cascades Island LPS (Figure 24) to evaluate passage success and timing. All of these fish were subsequently detected in the LPS. Forty-one of 50 (82%) were either recaptured at the terminal trap or last detected at the upper antenna. Of these, 4 of 41 (10%) were detected at the lower antenna (downstream of the release point), indicating that they fell back before ultimately ascending the LPS. Nine of 50 (18%) were last detected at the lower antenna and were not recaptured, indicating that they fell back out of the LPS. Six of these 9 (67%) were subsequently detected at antennas in other Bonneville Dam fishways or at sites upstream of Bonneville Dam.

While the exact time required for lamprey to pass from Rest Box 3 to the upper PIT antenna is unknown, we were able to establish that of the fish planted in Rest Box 3, 10 of the 20 released in 2011, and 25 of 50 released in 2012 ascended within 24 hours of the release time. In 2011, median time from release to detection at the upper antenna was 5.9 h (range 1.5-32.5 h). However, this value was probably a gross over-estimate, since the actual time between release to the rest box and the point at which lamprey started to ascend the structure is unknown. In 2012, median time from release to detection at the upper LPS antenna was 3.5 h (range 1.5-97.9 h).

Alternate Flow Treatments

Columbia River water was supplied to the top of the LPS and into the terminal trap box via a 10.2-cm diameter PVC pipe with river water pumped from the forebay with a 3-hp submersible pump. To determine optimal flows for lamprey passage, we experimentally manipulated the water volume through the lower part of the structure. A low flow condition was created through the lower part of the LPS by drawing down water from Rest Box 3 (Figure 24) to reduce water depth at the collector ramp and potentially ease lamprey passage. This treatment was tested on alternate days in both 2011 and 2012. In both years the number of trapped lamprey was compared between treatments using a two-tailed, paired *t*-test.

In 2011, the trap was operated on most days. However, the trap was dewatered on days when the Cascades Island LPS was not operated. To dewater the structure, lamprey were enumerated and manually removed from the terminal trap box and from Rest Boxes 3-6. The pump was then shut down, and any lamprey in Rest Boxes 1 or 2 were evacuated by activating the remotely operated valves. Lamprey removed in this way were enumerated as they dropped into the fishway. In 2012, the LPS and trap were operated continuously throughout the lamprey migration period.

To evaluate lamprey fallback and passage rates through the upper part of the Cascade Island LPS, we released some tagged lamprey directly into the lower portion of the structure. Lamprey captured from traps at the Washington Shore fishway and Cascades Island AWS channel were PIT-tagged (see Objective 1 for 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 terminal PIT antenna and the degree of fallback.

In 2011, alternating flow treatments were conducted from 5 July to 27 August. During these treatments, an average of 8.2 lamprey per day were collected while the LPS was operated at low flow and and average of 5.1 lamprey per day were collected while operated at high flow. A two-tailed *t*-test was used to compare lamprey catch between flow treatments, and results indicated that the number of lamprey collected during the low flow treatment was not significantly higher than the number collected during the high flow treatment ($t = -1.4$, $df = 8$, $P = 0.21$).

In 2012, alternating flow treatments were conducted from 29 May to 7 August. Averages of 34.9 lamprey/d during low flow and 32.0 lamprey/d during high flow were recorded. A two-tailed *t*-test was used to compare lamprey catch between flow treatments and indicated that the number of lamprey collected during the low flow treatment was not significantly higher than the number collected during the high flow treatment ($t = -0.37$, $df = 19$, $P = 0.71$).

Rest Box Entrance Modification

In 2012, prior to the lamprey migration, the flexible mesh entry fyke to Rest Box 3 of the Cascades Island LPS was replaced with a newly designed rigid, metal fyke in an effort to reduce fallback (Figure 26). The plastic mesh fyke material was replaced with perforated aluminum plate to prevent attachment as lamprey entered the rest box. In addition, the fyke exit was narrowed from 36 cm to 18 cm to discourage lamprey from re-entering the fyke from inside the rest box.

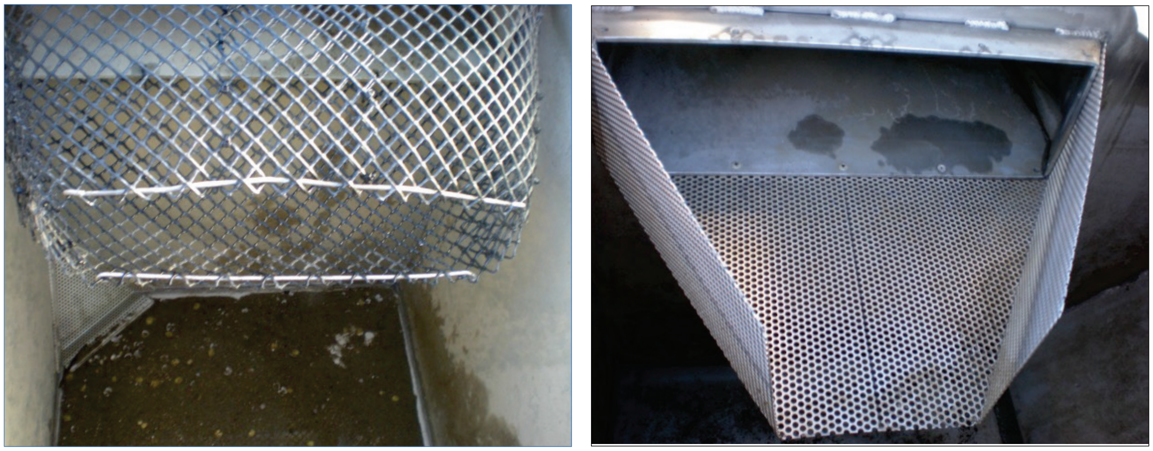


Figure 26. Photos of fyke mesh entrance to Cascades Island LPS Rest Box 3 in 2011 (left) and 2012 (right).

We attributed the large increase in LPS collections in 2012 to the structural changes made to the fyke at Rest Box 3. PIT-tagged lamprey planted in Rest Box 3 exhibited a much reduced fallback rate from this rest box relative to 2011 (26 vs. 59%). Changing fykes at other rest box entrances, both at the Cascades Island and Washington Shore LPSs, may result in more lamprey being retained in the structures and higher passage efficiencies. In addition to improving LPS efficiency, reducing fallback may lessen the energetic cost to lamprey of LPS passage and result in greater fitness for fish that use this passage route.

Camera Evaluations

In 2011, a motion-activated camera was operated on an experimental basis at the terminus of the structure, immediately downstream from the trap. Imagery from this site was archived on memory cards and was also accessed remotely via a radio-link to a laptop located in a tower at the south end of the Bonneville Dam spillway (see Objective 1).

In 2011, at the Cascades Island LPS, camera images of migrating lamprey were captured between 7 June to 9 November using these motion-activated cameras. Notable was the observation that lamprey periodically turned around and were observed moving downstream in the camera field of view (Figure 18).

Conclusions and Recommendations

In 2011 and 2012, lamprey use of the Cascades Island LPS increased relative to previous years. Trap captures at the Cascades Island LPS in 2010 represented only 1.4% of the daytime lamprey count at Bonneville Dam. This proportion increased to 3.8% in 2011 (485 fish) and 13.4% in 2012 (2,472 fish).

In 2011, we hypothesized that the increase in collection efficiency at this structure stemmed from high tailwater elevations that occurred at the start of the lamprey migration period (Figure 27). We reasoned that when tailwater elevation is high, the length of the collector ramp that lamprey must climb in air is much shorter. However, regression analysis indicated that tailwater elevation had no significant effect on lamprey catch at the terminal trap ($r^2 = 0.005$, $F = 0.43$, $P = 0.51$). In fact, most lamprey were collected later in the season, during periods of relatively low tailwater elevation (Figure 27).

A second hypothesis is that the increases observed in 2012 were due to "seasoning" of the structure. This phenomenon has been observed at other LPSs (Moser et al. 2011). Lamprey use is low in the first years of operation, possibly due to unfamiliar olfactory cues and smooth polished surfaces of brand new metal components. After several years of use, the metal surfaces are colonized by a biofilm that may be more attractive to lamprey.

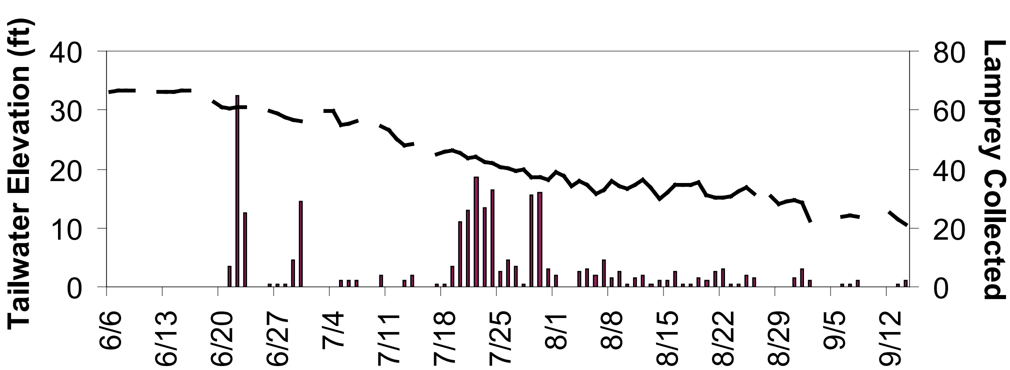


Figure 27. Bonneville Dam tailwater elevation in 2011(line) and number of lamprey collected at the Cascades Island LPS trap in that year (bars).

Tests designed to fine-tune flow levels in the lower portion of the Cascades Island LPS produced equivocal results. In 2011 and 2012, more lamprey were caught when flow rates through the lower section were reduced, but in both years, differences in catch rates between the two flow treatments were not statistically significant. We surmise that lower flows on steep, lengthy ramps may aid lamprey climbing. However, the lower flows may also lessen attraction flow at the interface between the ramp and water surface, thereby reducing collection efficiency. Without the benefit of a more accurate means of assessing flow effects (i.e., laboratory testing), we recommend use of the high flow treatment (i.e., no release of water at Rest Box 3).

In spite of the fact that we do not have precise passage timing through the Cascades Island LPS, data obtained from lamprey planted into Rest Box 3 indicate that it takes on the order of hours. This is far less time than the several days on average that is required for lamprey to negotiate the traditional fishways (Moser et al. 2002b; Keefer et al. 2013a).

Passage efficiency for the Cascades Island LPS is also unknown, due to the unknown fate of several fish released into the structure. Very few PIT-tagged lamprey released downstream from Bonneville Dam were detected using this LPS. However, of those detected in the structure, 64% in 2011 and 55% were recaptured in the terminal trap. These proportions indicated that passage efficiency for volitional entrants was relatively high. These are conservative estimates; we suspect that some PIT detections were missed at recapture, as evidenced by subsequent detections at sites upstream from Bonneville Dam.

It was curious that with the apparent increase in efficacy of the Cascades Island structure in both 2011 and 2012, there was no concomitant increase in detections of PIT-tagged fish released downstream from the dam. Results from releases of PIT-tagged fish directly into Rest Box 3 indicated that PIT-tagged lamprey were regularly missed on both LPS antennas. It is possible that this occurred due to signal collision. Further testing is needed to confirm detection efficiencies of these antennas. Antennas in LPSs at the AWS channels 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.

In both 2011 and 2012, detection data indicated that some lamprey reached the upper antenna but did not enter the terminal trap (a distance of only a few meters more) and regularly fell back out of the structure. Fallbacks were observed from detections and recaptures of lamprey that were experimentally planted and that entered the structure volitionally. It is possible that lamprey avoided the juncture between the LPS and trap box, or that they were repelled by lamprey already in the box. Further study is needed to confirm whether this is a recurrent problem, and this result highlights the need to provide volitional egress from this structure.

In the case of experimentally planted fish in both 2011 and 2012, some lamprey were detected only at the lower LPS antenna (downstream from the release point) and subsequently detected either at other Bonneville Dam structures and/or at sites upstream. Others were never detected again after detection on the lower antenna. These lamprey were judged to have fallen back out of the structure. It is possible that the effects of tagging (anesthesia, PIT tag insertion, transportation) contributed to a higher propensity for fallback in these fish.

In summary, efficacy of the Cascades Island LPS continues to improve, and this structure accounted for a signficant number of lamprey passing Bonneville Dam in 2012. Fish exhibited relatively rapid passage through the structure, and improvements to the entrance of each rest box will likely result in even greater numbers of lamprey ascending to the terminus.

At present, fish that successfully ascend the Cascades Island LPS are held in a trap, transported, and released upstream at the Stevenson boat ramp. The trapping and hauling of nearly 2,500 lamprey in 2012 was very labor intensive and probably resulted in greater stress to the fish than if they could have moved directly into the dam forebay from this LPS (Moser et al. 2002b). In fact, one of the PIT-tagged fish released at the boat ramp was subsequently detected after having fallen back downstream from the dam.

Plans are underway to extend the Cascades Island LPS to exit into the forebay upstream from the spillway. This will provide numerous potential advantages to lamprey: they will no longer be handled prior to forebay release, there will no longer be extended holding in the high-density trap, and lamprey will be able to exit volitionally at any time of day or night.

In 2012, deceased lamprey were collected from the Cascades Island LPS at Rest Box 3 on 3 July (n = 1) and 6 July (n = 1). These mortalities likely occurred during dates when high numbers of lamprey were collected at the terminal trap (28 June n = 117, 29 June n = 191, 30 June n = 136; Figure 26). Carrying capacity of the Cascades Island LPS is unknown; however, removal of the terminal trap and connection of the LPS with an exit to the forebay will likely reduce mortality during periods of high usage.

It is also possible that the presence of trapped lamprey may have reduced the efficacy of this LPS. Lamprey show strong avoidance to dead conspecifics and may also avoid the scent of stressed lamprey in the trap (Imre et al. 2010; Wagner et al. 2011). By allowing lamprey to pass completely through this structure to the forebay (as in AWS LPS sites), we anticipate even higher lamprey use, more rapid passage, and potentially more accurate LPS counts.

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 Alternate Lamprey Collection Methods

To date, lamprey used for tagging evaluations have been primarily collected at traps operated in the fishway of the Adult Fish Facility bypass at Bonneville Dam. Consequently, these fish have a demonstrated ability to successfully enter a fishway and negotiate transition pools in the lower section of the Washington Shore pool and weir area. As such, passage success for these "experienced" fish may not accurately represent that of the population at large. To more faithfully represent the general population in our samples, we attempted to collect fish that are potentially “naïve,” or have not demonstrated the ability to enter fishway entrances. Obtaining these fish would permit more accurate evaluations of lamprey passage. In addition, characteristics of these “naïve” fish could be evaluated and compared to those of "experienced" fish collected from the fishways to assess whether important differences do exist.

Methods

In 2011 and 2012, we attempted to collect adult Pacific lamprey using portable traps (Moser et al. 2008) deployed immediately downstream from Bonneville Dam, at the Washington Shore north and south downstream entrances (Figure 28). The portable traps were deployed from the deck of the dam at locations approved by project personnel. Trapping activity was closely coordinated with project personnel. Traps were attached to a weighted standing wire, to allow ease of deployment while ensuring that they remained firmly in place.

In 2012, portable traps were again deployed at the Washington Shore north downstream entrance at locations closer to the fishway entrances. In addition, two portable traps were deployed at the Cascades Island auxiliary water supply channel upstream from the picketed lead near the fishway exit (Figure 28). In 2012 and in prior years, lamprey have been observed accumulating in this AWS channel; PIT tagged lamprey have also been detected at this location.

Results

In 2011, two portable lamprey traps were deployed on 93 d between 31 May and 31 August. One portable trap was deployed near the south downstream entrance and one near the north downstream entrance of the Washington Shore fishway (Figure 28). Traps were recovered, checked for lamprey and re-deployed once every 4 d. No lamprey were captured in portable traps deployed at either location in 2011.

In 2012, two portable lamprey traps were deployed in the Washington Shore fishway between 23 May and 7 August. The trap at the south downstream entrance was operated for 64 d and the trap at the north downstream entrance for 37 d (Figure 28). Trap locations were slightly closer to the fishway entrances than in 2011. Traps were recovered, checked for lamprey and re-deployed once every 4 d, and 2 lamprey were captured in these portable traps during 2012.

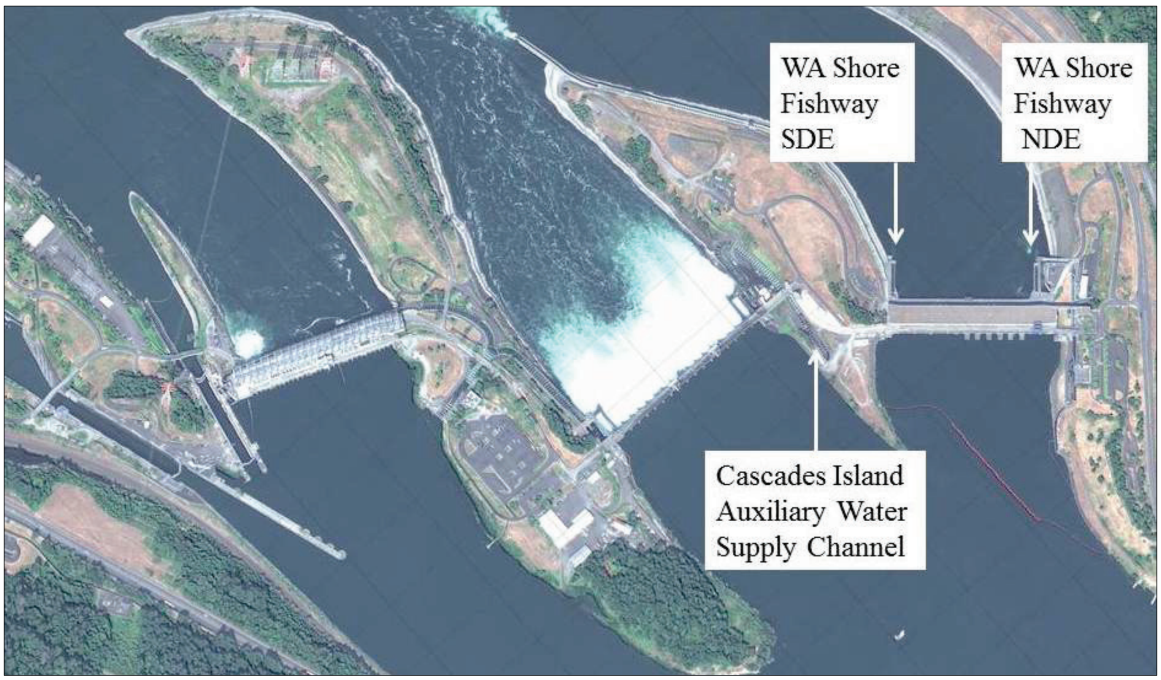


Figure 28. Aerial photo of Bonneville Dam indicating alternative trapping locations at the north and south downstream entrances of the Washington Shore fishway and at the Cascades Island auxiliary water supply channel. Photo courtesy Google Earth Pro.

In 2012, two portable lamprey traps were deployed on 30 d between 16 August and 20 September at the Cascades Island auxiliary water supply channel. Both portable traps were deployed in the flow-control section upstream from the picketed lead and downstream from the obsolete fishway exit (Figure 29). Traps were recovered 1-2 times per day, checked for lamprey, and re-deployed. A total of 268 lamprey were captured at this location, and 243 of these fish were transported and released upstream at Stevenson boat ramp. The remaining 25 were PIT-tagged and planted in Rest Box 3 for evaluations of the Cascade Island LPS.

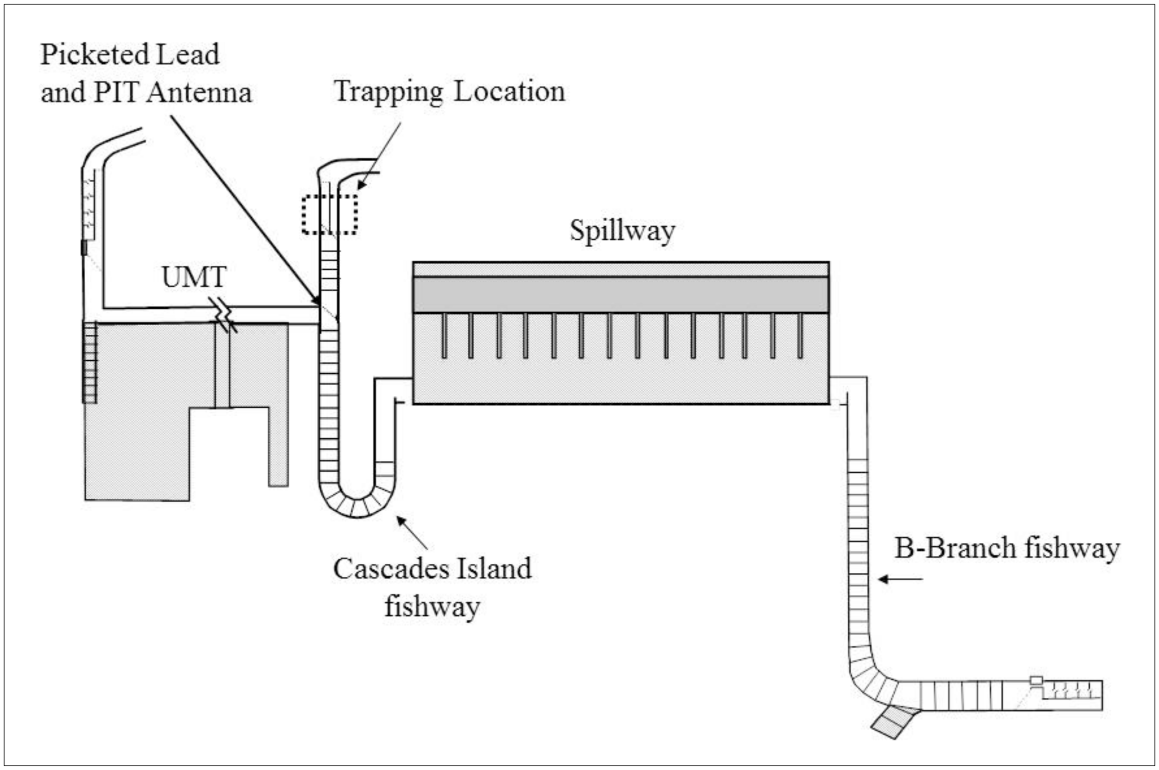


Figure 29. Locations of the HD-PIT antenna at picketed lead and trap deployments at the Cascades Island auxiliary water supply channel.

Conclusions and Recommendations

Adult lamprey have been trapped successfully when traps are set at obstacles to upstream passage or in dam fishways, where migrating adult lamprey concentrate. Since the late 1990s, lamprey have been collected successfully with traps set at the Washington Shore bypass fishway at the Adult Fish Facility (Ocker et al. 2000). In 2011 and 2012, we attempted to identify additional lamprey capture sites outside of the Washington Shore fishway for both restoration and research purposes.

In 2011, to collect potentially naïve adult lamprey, portable traps were set near the fishway entrances, where depths may have precluded lamprey from encountering the trap. Trap deployment locations were constrained to areas outside the fishway entrances to prevent interference with salmonids.

In 2012, portable traps were moved closer to the fishway entrances in an attempt to improve capture efficiency. High velocities at the fishway entrance throughout most of the lamprey migration period frequently prevented the trap from being deployed correctly, particularly at the south downstream entrance to the Washington Shore fishway.

Depths of over 20 m at the fishway entrances prevented visual observation of portable trap orientation relative to the substrate. We suspect that efficacy of the traps was impaired by slope of the bottom and the orientation of the trap entrance in relation to the flow direction, combined with high velocities and depths. Using underwater imaging tools, such as video or DIDSON, to characterize substrate features of the fishway entrance would help to guide modifications to trap design and deployment strategy. We recommend that portable traps of the same design be deployed during periods of minimal spill, when velocities would allow traps to be deployed correctly.

In contrast, trapping was very successful in 2012 at the Cascades Island auxiliary water supply channel upstream of the picketed lead, where lamprey are known to accumulate. Trapped lamprey were transported upstream from Bonneville Dam and released, and this trapping operation contributed to lamprey passage, as these fish would not likely have passed Bonneville Dam otherwise.

In addition to trapping results from 2012, detections of PIT tagged lamprey released downstream from Bonneville Dam between 2007 and 2012 have indicated that high numbers of migrating lamprey accumulate here (Table 4). To improve lamprey passage at Bonneville Dam, fish that access this area should be provided with an outlet to the forebay via a lamprey passage structure. Alternatively, lamprey should be systematically trapped and transported upstream throughout the migration period.

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