Development and evaluation of a wetted wall for adult lamprey passage at the Bradford Island Fishway, 2017-2018

Kinsey E. Frick, Steve C. Corbett, Gabriel Brooks

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

for

Portland District, U.S. Army Corps of Engineers
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Executive Summary

In 2017-2018, we consulted on design and installation of an experimental wetted wall passage structure for adult Pacific lamprey *Entosphenus tridentatus* in the Bradford Island Fishway at Bonneville Dam. Following design completion, U.S. Army Corps of Engineers staff constructed a prototype wetted wall structure, which was installed in February 2018. During the 2018 lamprey passage season (April-September), we used non-invasive methods to evaluate efficacy and potential negative effects of the prototype structure. The wetted wall was designed to guide lamprey from the main fishway to the adjacent makeup water supply channel (MUWS). Objectives for the evaluation component were:

1) Evaluate adult lamprey use of and behavior near the wetted wall structure, including enumeration of lamprey diverted from the main fishway to the MUWS channel
2) Evaluate possible risk of the wetted wall structure to migrating adult Pacific salmon *Oncorhynchus* spp. through injury or delay
3) Assess potential benefits of the structure by evaluating relative passage route use and by identifying the fate of radio- and PIT-tagged lamprey using the structure

To achieve these monitoring objectives, lamprey use and salmonid responses to the structure were evaluated using video. During the 2018 lamprey passage season, we recorded video of the vertical collector and exit sections of the wetted wall. Video was evaluated over three time periods: 1-23 May, 24 July-8 August, and 3-10 September. To help determine the percentage of available lamprey that used the structure, we compared structure use with counts from the nearby count window and monitored the wetted wall exit to detect PIT-tagged lamprey.

During the three video review periods combined, we observed 343 individual lamprey using the wetted wall structure during passage through the Bradford Island fishway. At least three PIT-tagged lamprey that used the wetted wall were detected. Of lamprey using the wall, 99.7% passed at night, and average passage time was 2.5 minutes to complete the climb and exit the structure. Throughout all video review periods and at all flow levels, no instances of salmonid interaction with the structure were observed. Video observations provided valuable insight into lamprey passage that can inform operation and design modifications. In its first year of operation, the wetted wall provided a useful alternative passage option to lamprey in the serpentine weir section of the Bradford Island fishway and ultimately to passage over the dam.

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Introduction

Background

Pacific lamprey are anadromous, and adults in the interior Columbia River Basin must pass up to nine hydropower dams and associated reservoirs to reach historical spawning areas. At the dams, lamprey passage efficiency is defined as the percentage of lamprey that successfully passed the dam from all those that approached the dam base. Early radio-telemetry work indicated that adult Pacific lamprey passage efficiency at Bonneville Dam was less than 50% in all years (Moser et al. 2002a; Moser et al. 2005).

Of particular concern was the poor performance of lamprey at fishway entrances, through collection channels/transition areas, and past vertical slot and serpentine weir sections at the tops of Bonneville Dam fishways (Moser et al. 2002a; Johnson et al. 2009; Clabough et al. 2011; Keefer et al. 2013). Radio-telemetry results indicated that most lamprey pass the count windows, but are obstructed in the section of the fishway ladder containing the vertical-slot and serpentine weirs upstream from the count stations (Moser et al. 2003b; Johnson et al. 2009; Keefer et al. 2013). Video and radio-telemetry data also indicate substantial lamprey milling and "turn-arounds" in the upper ladder section of the Washington shore and Bradford Island ladders (Clabough et al. 2012).

Radio-telemetry results and visual observations indicated that lamprey are obstructed by the serpentine weir section at the top of the fishways and therefore can accumulate in the adjacent makeup water supply channel (Keefer et al. 2013; Kirk et al. 2016). Because this area is an impediment to lamprey passage, we developed structures to collect adult lamprey from the makeup water supply channels at the top of the Bonneville Dam fishways (Keefer et al. 2011, Moser et al. 2011). These structures allowed lamprey to move directly from the makeup water supply channel to the forebay.

Lamprey passage structures (LPSs) are now used regularly by adult lamprey and have become a method for routing lamprey around passage obstacles in fishways (Moser et al. 2011). In the Columbia River hydropower system, LPSs have been installed in the makeup water supply channel sections of the Bradford and Washington-shore ladders and inside the entrances of the Cascades Island Fishway at Bonneville Dam and the John Day Dam North Fishway. A lamprey flume structure (LFS) on the Washington shore at Bonneville Dam takes a similar approach from the tailrace.

Installation of new passage structures or improvements at several locations could yield further benefits to lamprey passage. Once lamprey are in the serpentine weir section, they have to move downstream to access existing LPSs. Such downstream movement may induce ladder fallback with no subsequent passage attempt, as a high percentage of lamprey that fall back fail to re-ascend and pass Bonneville Dam (Keefer et al. 2013). Serpentine weir sections of fishways are not well suited to installation of a typical LPS: the 3-dimensional footprint of a traditional LPS entrance ramp is precluded due to space constraints and usage of the fishway by other species, including ESA-listed Pacific salmon *Oncorhynchus* spp.

More recently, a novel wetted wall, or "climbing wall" concept was conceived in the laboratory (Kemp et al. 2009; Moser et al. 2012a) and pioneered in the field at Winchester Dam on the Umpqua River, Oregon. The design takes advantage of Pacific lamprey vertical climbing ability. A wetted wall in the serpentine weir section of the Bradford Island fishway could provide Pacific lamprey with an alternate direct route into the makeup water supply channel at Bradford Island. The wetted wall design does not require 3-dimensional structure in the serpentine weir section and is based on an experimental structure used successfully in lab tests during 2014 (Corbett et al. 2015, Frick et al. 2017).

Study Objectives

In 2017-2018, we consulted on design and installation of an experimental wetted wall passage structure for adult Pacific lamprey *Entosphenus tridentatus* in the Bradford Island Fishway at Bonneville Dam. Following design completion, the U.S. Army Corps of Engineers Bonneville Dam staff constructed a wetted wall structure, which was designed to guide lamprey from the main fishway to the adjacent makeup water supply channel. The new structure was installed in February 2018. During the 2018 lamprey passage season (April-September), we used non-invasive visual tools to evaluate efficacy and potential negative effects of the prototype wetted wall structure. Objectives of the evaluation component were to:

1) Evaluate adult lamprey use of and behavior near the wetted wall structure, including enumeration of lamprey diverted from the main fishway to the makeup water supply channel.
2) Evaluate possible risk of the wetted wall structure to migrating adult salmonids through injury or delay.
3) Assess potential benefits of the wetted wall structure using passage route comparisons and fate of radio- and PIT-tagged lamprey that used the structure.

To achieve these monitoring objectives, lamprey use and salmonid responses to the structure were observed by video monitoring. During the 2018 lamprey passage season we recorded video of lamprey use at the wetted wall vertical collector and at the wetted wall exit. Video was recorded and evaluated over three periods: 1-23 May, 24 July-8 August, and 3-10 September. To help determine the percentage of available lamprey that used the structure, we compared wetted wall exit detections with totals from the nearby counting window. For these comparisons, we did not tag study fish but monitored lamprey PIT-tagged for other studies.

Objective 1: Consult on Design, Fabrication, and Installation of a Prototype Wetted Wall Passage Structure

Prototype Wetted Wall

The prototype wetted wall passage structure in the Bradford Island fishway was installed to allow adult Pacific lamprey to pass from the serpentine weir section of the fishway into an adjacent makeup water supply channel, or MUWS (Figure 1). Thus, the wetted wall would provide access to an existing lamprey passage structure, or LPS (Moser et al. 2011). Design of the prototype was based on an experimental wetted wall structure tested in 2014 (Corbett et al. 2015, Frick et al. 2017).

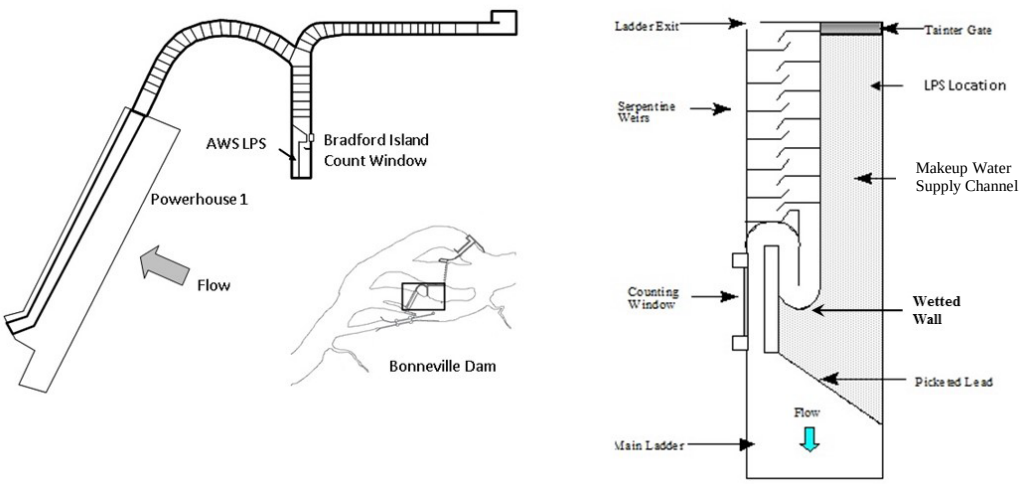

Figure 1. Schematic drawing of the Bradford Island fishway system at Bonneville Dam with locations of the makeup water supply LPS (labeled AWS LPS), count window, and wetted wall.

The entire wetted portion of the prototype structure was constructed of aluminum. A vertical collector wall was attached flush to the concrete wall of the fishway (Figure 2, left). The aluminum collector wall was 24-in wide and covered the vertical height of the fishway from the submerged floor to the top of the concrete wall (exposed to air). The vertical wall was connected to a 6-inch-radius crest leading into a shallow pan, which narrows to 4 inches at the exit. A hood over the collector wall provided shade to the structure and protection from predation for passing fish (Figure 2). Water was supplied to internal reservoirs via a pump located in the makeup water supply (MUWS) channel, with flows set at the minimum required to wet the climbing surface with a continuous sheet of water.

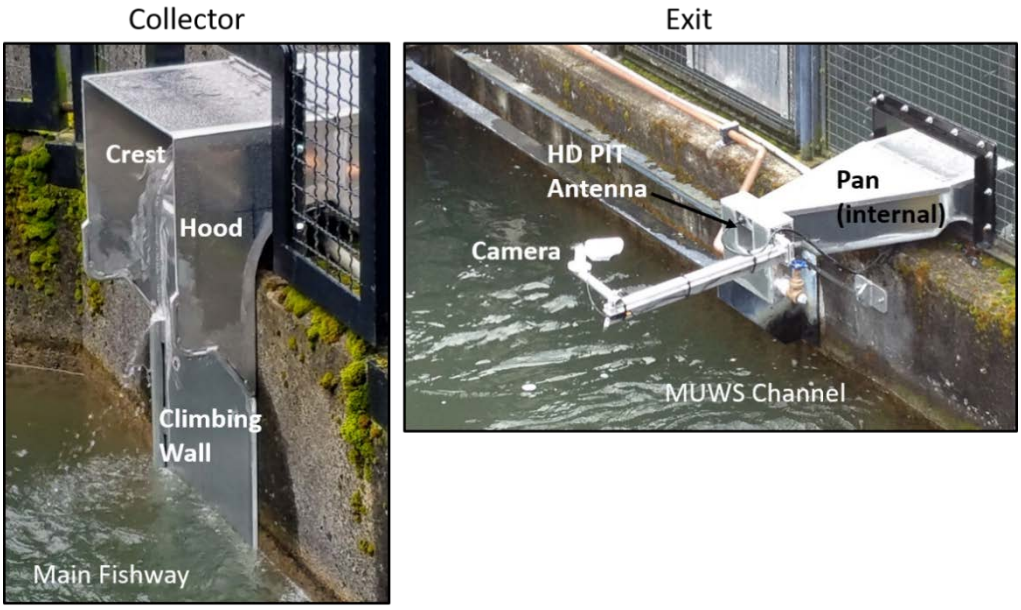

Figure 2. Views of wetted wall structure showing the collector (left) and exit (right) sections. The prototype wetted wall was installed in the serpentine weir section of the Bradford Island fishway at Bonneville Dam.

Modifications to the Experimental Wetted Wall

The prototype structure installed in the Bradford Island fishway was modified in several respects relative to the experimental structure tested in 2014. Key modifications are detailed below.

Water supply

The Bradford Island wetted wall was supplied with water only by a sidewelling supply mechanism. Water filled the pan, and flow from the pan was directed down over the climbing surface as well as out through the exit. Thus, water from the sidewelling supply was deposited into the fishway via the wetted wall collector and into the makeup water supply channel via the wetted wall exit. The goal of the sidewelling supply mechanism was to provide smooth flow in all areas.

The structure was originally constructed with simultaneous sidewelling and upwelling water supplies, but water supply was modified prior to installation to create a smooth floor for continuous lamprey attachment. This change increased the water pressure through the sidewelling holes and resulted in water spraying onto the pan and exit area at most water supply rates. However, continuous sheeting of water on the climbing surface was maintained.

Observation and monitoring

To observe lamprey exiting the structure, an arm was mounted near the exit for attachment of a video camera. This provided the ability to count passing lamprey, as well as to observe exit behavior.

To monitor use of the structure by PIT tagged lamprey, a half-duplex detection system was installed at the exit. The antenna for this system was comprised of a 28-μH coil of 22-AWG litz wire encased in a polymer housing fabricated with a 3D printer. The antenna housing was and coated with resin for water-tightness and mounted to the roof of the hood with non-ferrous bolts. Read-range tests during installation indicated that the antenna detection field covered the entire exit area. Detection efficiency based on test tags was 100% during all periods of monitoring.

Objective 2: Evaluate Use of the Prototype Wetted Wall Structure

Previous lamprey passage structures have been assessed using a combination of mechanical counts, PIT and radiotelemetry detections, and video observation. Evaluation of the experimental wetted wall structure was conducted using similar non-invasive visual and detection tools. Location of the Bradford Island wetted wall was feasible for video monitoring. We also used detections from concurrent studies that released PIT-tagged adult lamprey downstream of Bonneville Dam. We looked at efficacy and potential negative effects of the structure in terms of its ability to guide Pacific lamprey from the main fishway to the makeup water supply channel.

Methods

Evaluation of the Bradford Island wetted wall structure was based on video monitoring of the climbing surface, water interface in the serpentine weir section, and behavior at the structure exit. A two-analog HD CCTV camera (1080P) and DVR system (AZONE, Inc.) was used for video monitoring. The video system was equipped with infrared capability, allowing 24-hour monitoring of both day (0600-2000 PST) and night periods (2000-0600). A half-duplex PIT antenna detected tagged lamprey passing at the exit.

Video and PIT monitoring at the wetted wall were initiated on 1 May 2018. Pumps were turned off and the system was dewatered on 10 September 2018. Within that time frame, monitoring was conducted continuously during three periods: 1-23 May, 24 July-12 August, and 3-10 September. Power interruptions incapacitated the monitoring system for the intervening time periods during the migration season (Table 1).

From video of the climbing surface and water interface, all recorded hours were reviewed at 4× actual speed. Video was reviewed in real time when lamprey attached to the wall were identified. For each attachment of a lamprey above the water surface, we noted attachment time, time to the crest of the vertical climbing section of the structure, and time to exit. While all exit events were counted, exit times were recorded only when it was possible to connect an individual lamprey viewed on the climbing surface with the same fish at the exit based on video time stamps. Passage attempts resulting in falls back into the fishway were also recorded.

Table 1. Timeline of operation and monitoring for the wetted wall structure at Bradford Island, 2018.

Date (2018)	Event description
20 Feb	Count and PIT systems installed
21 Feb	Systems tested
17 Mar	Wetted wall watered
1 May	Lamprey passage enumeration begins
23 May-24 Jul	System outage, no passage enumeration
24 Jul	System restarted, wall flow increased
8 Aug-3 Sep	System outage, no passage enumeration
3 Sep	System restarted
10 Sep	Wetted wall dewatered

Lamprey use of the wetted wall was estimated as the number of fish passing via the structure per day over entire migration season. We also report relative use of the wetted wall for each day as a percentage of the daily total from the Bradford Island count window. Relative use was important because all lamprey passing the count window had access to the wetted wall, whether traveling upstream or downstream. Finally, because of the strong propensity of lamprey to pass during nighttime hours, we calculated use based on night window counts only.

To estimate the total number of lamprey that used the wetted wall over the entire season, we calculated the average proportion of lamprey using the wall of those in the fishway during periods when video records were available. We repeated this calculation for total daily counts and nighttime-only counts from the Bradford Island count window. We also calculated percent of the total counted run that was counted during the review periods. The total number of failed attempts was also recorded.

Video review included observation for potential interactions by salmonids. At least 10 minutes of each hour during daylight were reviewed in real time to note salmonid jumping or nosing at the wetted wall.

Results

The wetted wall was initially operated at the minimum flow necessary to produce sheeting water on the vertical climbing surface. This flow produced no splash at the water interface and no cascading from structural components of the wetted wall. During the night of 24 July, the flow pattern on the wetted wall changed. Prior to that date most of the water had passed out the wetted wall exit. After 24 July, more water began cascading down the vertical surface of the wetted wall (Table 1). This change was likely due to a pump malfunction. Nevertheless, the change increased visible flow on the vertical climbing portion of the wall and caused some splash at the water surface and off of the upstream hood edge. The flow remained this way for the remainder of the review period.

During the 46 days of video monitoring, 343 Pacific lamprey passed from the Bradford Island fishway into the adjacent makeup water supply channel via the wetted wall. The majority of these (340 lamprey) passed during the 24 July-12 August review period (Figure 3). Of the total lamprey run counted passing the Bradford Island counting station during the periods when the wetted wall was operated (10 May-10 September 2018), 15.0% passed during our 21-day monitoring window (Figures 3-4).

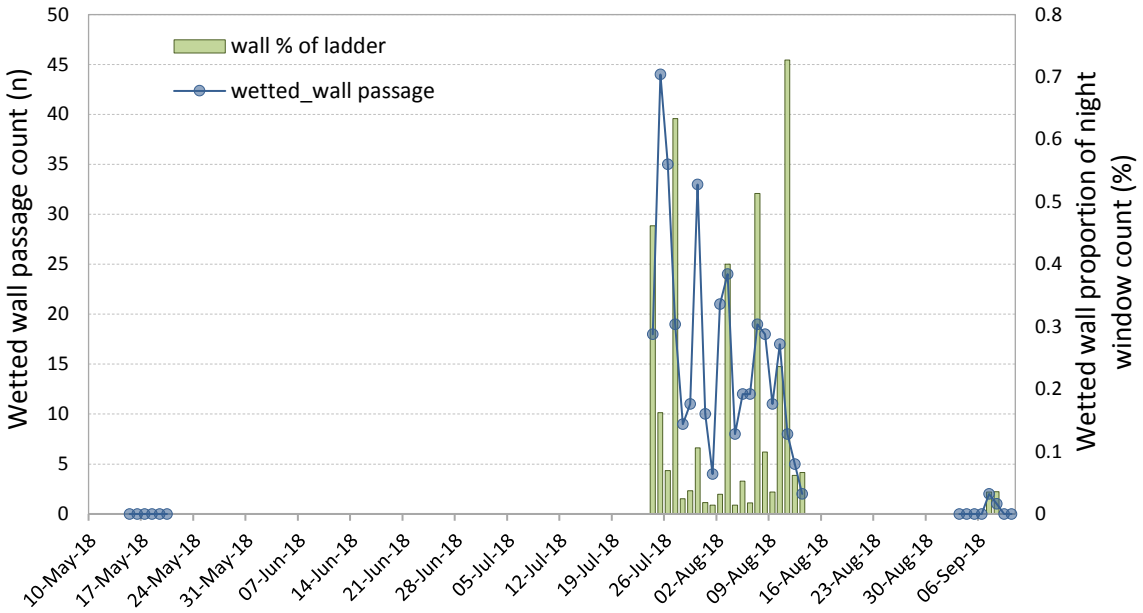

Figure 3. Adult Pacific lamprey passage at the Bradford Island wetted wall as the number counted using the wall (wetted wall passage) and as the proportion of lamprey using the wall from the total counted at the nearby count window during night periods (wall % of ladder).

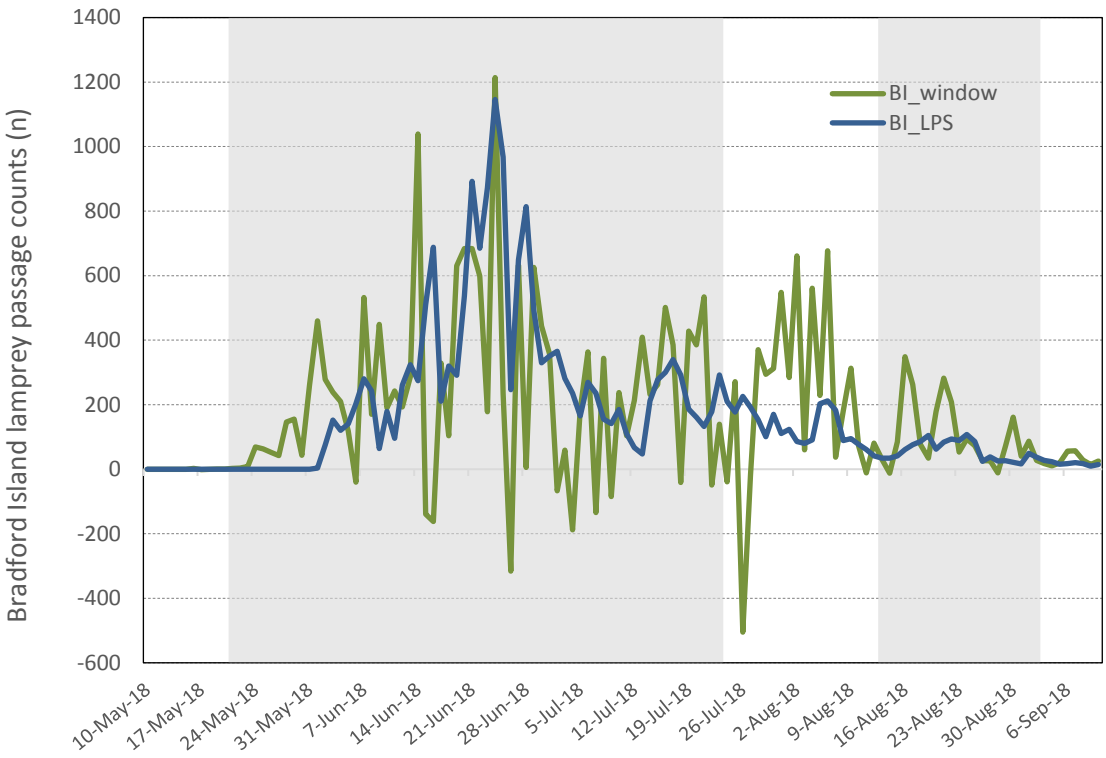

Figure 4. Pacific lamprey passage counts from the Bradford Island count window at night (green lines) and from the Bradford Island lamprey passage structure (LPS) during wetted wall operation, 10 May-10 September 2018. Gray shading indicates periods when the Bradford Island wetted wall was operational but not being monitored by video.

All but one of the wetted wall passage events occurred at night (Figure 5), representing 99.7% of passages. Night counts during our monitoring period represented 19.8% of the total nighttime passage of lamprey at the counting station. The single daylight passage event occurred at 1900 PDT.

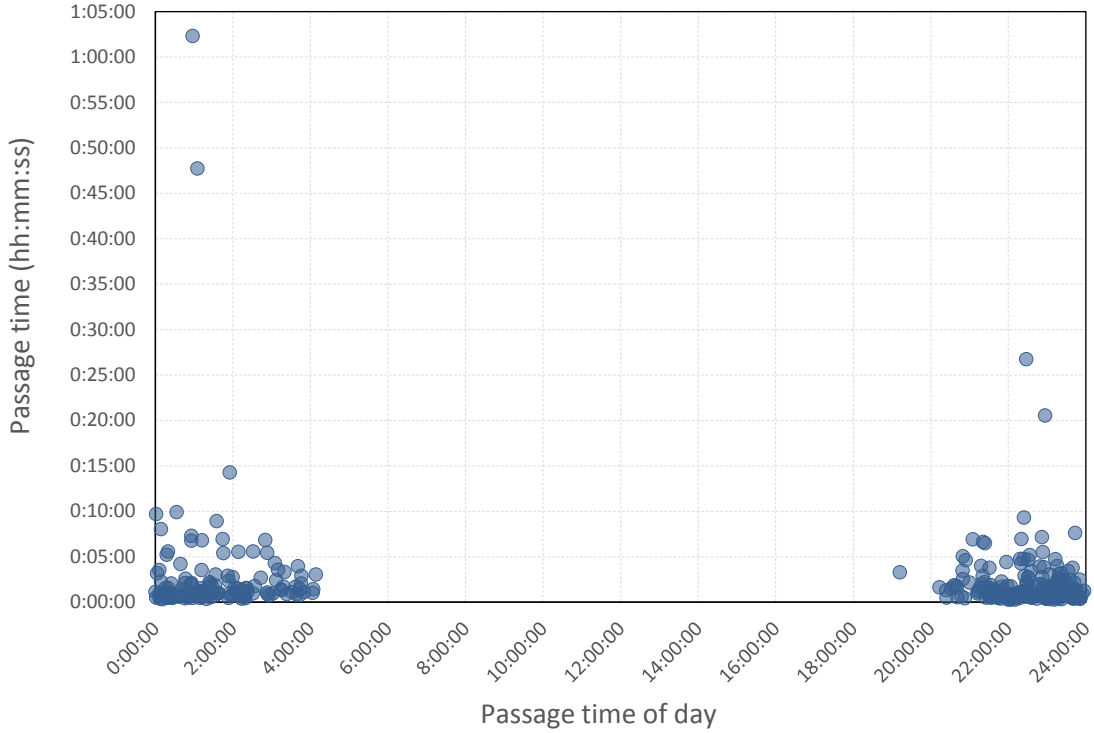

Figure 5. Distribution of lamprey passage time vs. time of day during passage over the Bradford Island wetted wall. Passage time was calculated as the time from attachment above the water level to time of exit from the structure. Passage time was calculated only for successful passage attempts.

To estimate use of the wetted wall over the entire lamprey migration season, we projected counts of lamprey using the wetted wall during observation periods. Over the study period from 10 May-10 September, the nighttime ladder count from the Bradford Island fishway was 22,289 while the total (day plus night) window count was 47,467. Based on projected numbers, lamprey using the wetted wall comprised an average of 14.38% of the nighttime window counts on review days (Figure 6) and an average of 4.28% of the total window count on those days.

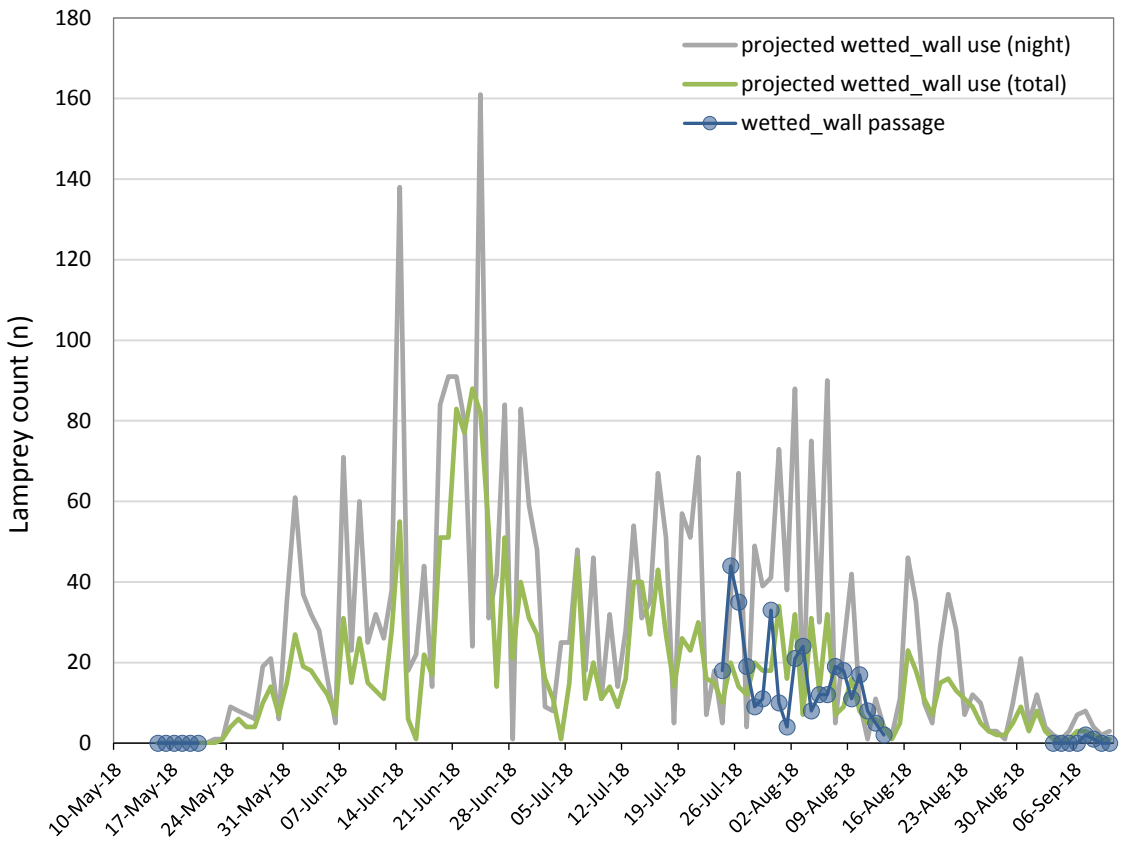

Figure 6. Adult lamprey use of the Bradford Island wetted wall as the number recorded using the wetted wall (blue circles), the projected number that used the wall over the entire season (gray line), and the projected number that used the wall based on passage percentage from Bradford Island nighttime window counts (green line). Projected usage over the season was calculated from the average percent of lamprey recorded passing the wetted wall on video from the total window count.

Based on these expanded numbers, the total number of lamprey projected to have used the wall during its operational period was 3,205 lamprey (night) or 2,029 lamprey (day plus night), respectively. During review periods, 15.0% of the total lamprey run for the time of operation passed the counting window, and this percentage expanded to a projection of 2,287 lamprey using the wetted wall. Using nighttime counts only, 19.8% of lamprey migrated during this period, for a projected wall use of 1,735 lamprey. Thus, the range of projected use of the wetted wall structure over the operating season was 1,735-3,205 lamprey.

The half-duplex PIT detector at the wetted wall exit detected three PIT-tagged lamprey that had been released downstream from Bonneville Dam for other research purposes. Of these fish, two subsequently passed Bonneville Dam via the Bradford Island LPS located in the MUWS where lamprey were deposited after climbing the wetted wall. Of the three detected lamprey, one re-entered the Bradford Island fishway from the forebay and remained in the serpentine weir section into the winter season (presumably overwintering). A second had no additional detection information associated with its PIT tag. The remaining PIT-tagged lamprey was last detected at the wetted wall exit, and its fate is as yet unknown (T. Clabough, Univ. of Idaho, pers. comm.).

Lamprey using the wetted wall passed over the structure with an average time of 0:02:22 (SD 0:04:59), with a range of successful passage times from 0:00:17 to 1:02:19 (Table 2, Figure 5). Passage times were calculated for 317 individuals.

Linear regression tests indicated that time to pass was not correlated with either date of passage (R^2 = 0.0000284, P = 0.663) or time of day (R^2 = 0.0114, P = 0.058). We also examined the time required to pass two components of the structure. The first component was the vertical wall from the water interface to the crest at the apex of the vertical climb. The second component the pan section from the crest to the structure exit. Average passage time for the first and second components was similar at 00:01:09 and 00:01:15, respectively (Table 2).

Table 2. Time taken by lamprey to climb and exit the wetted wall climbing structure. Results are for individual attachment attempts; not all results presented for wall touch to crest resulted in successful passage.

	Time (hour:min:second)		
	Water interface to crest	Crest to exit	Water interface to exit (total time)
Lamprey in calculation	(n = 325)	(n = 325)	(n = 325)
Average	0:01:09	0:01:15	0:02:22
Minimum	0:00:14	0:00:01	0:00:17
Maximum	0:09:37	1:00:19	1:02:19
SD	0:01:10	0:04:47	0:04:59

The longer maximum time was observed in the pan section (1:00:19). Upon exiting, some lamprey flipped around and attached to the smooth back of the upwelling box before dropping into the MUWS channel (Figure 7). The rate of this occurrence was approximately 20% and generally lasted less than 15 seconds. Lamprey remained in the exit splash zone (attached but wet) during these events.

When lamprey found and attached to the wetted wall structure, they generally climbed it successfully. We observed 91 fallbacks, most from the vertical wall or the crest. Fallbacks represented 21.0% of attachment events on the vertical wall above the water line. Twenty-eight of these fallbacks were observed in a single night and likely resulted from the same large fish; other instances of fallback were more evenly distributed over the review periods.

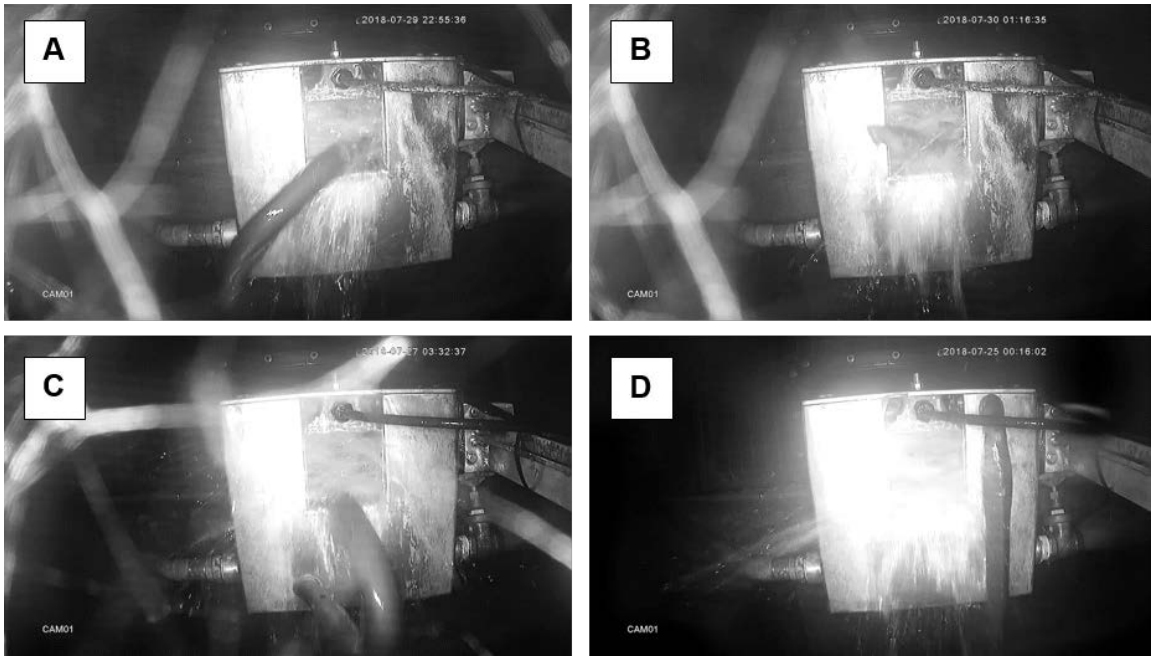

Figure 7. Examples of observed lamprey exit behaviors. Panel A: clean exit. Panel B: hesitation/searching. Panel C: attachment upon exit. Panel D: backclimbing.

Throughout the review of recorded video, no salmonids were observed interacting with the wetted wall, regardless of the flow situation. Video review periods covered the peak of the spring Chinook *O. tshawytscha* migration and the latter part of the fall Chinook migration, as well as the peak summer steelhead *O. mykiss* migration and some of the coho *O. kisutch* migration (Figure 8). Few sockeye *O. nerka* were present in the fishway during times when video records of the wetted wall were available.

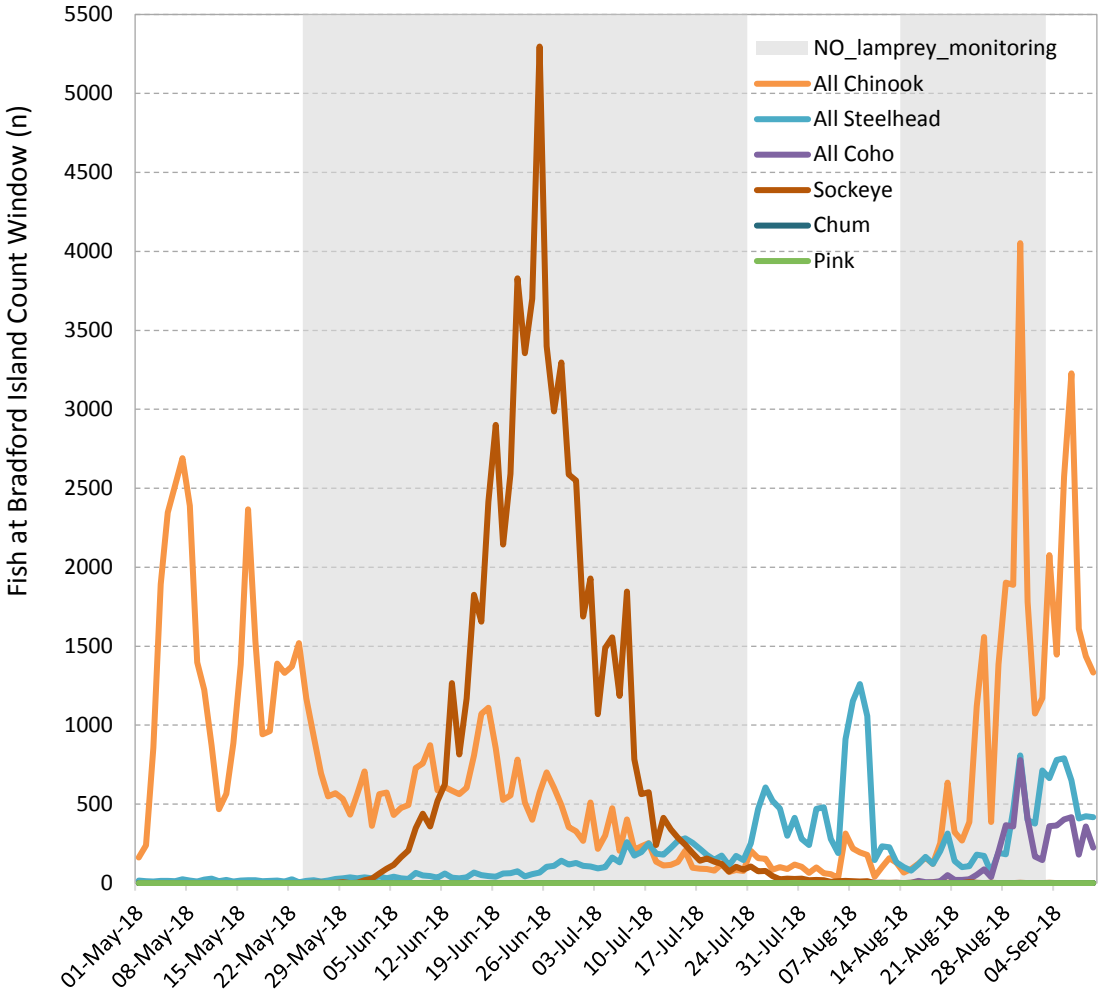

Figure 8. Salmonids present in the Bradford Island fishway based on count station data. Periods in gray are when the wetted wall was operational but not being monitored by video.

Discussion

The experimental wetted wall structure in the Bradford Island fishway was effective at passing lamprey out of the fishway and into the adjacent MUWS (makeup water supply channel). Pacific lamprey found the structure, navigated it quickly, and used it with high passage success. While some components could be modified for water supply control and to improve lamprey behavioral responses, no visible elements of the design appeared problematic for lamprey attempting to navigate the structure.

The average time required by Pacific lamprey to navigate this structure in its entirety was under 2.5 minutes with a maximum passage time of just over 1 h (Table 1). Use of the structure did not add substantial time for lamprey passing Bonneville Dam, which typically takes 4.4 d (Moser et al. 2002b). The two components of the structure, the vertical wall and upper pan, required similar time for passage, and each allowed lamprey to attach and rest as part of their navigation. Passage through the pan section could not be visually monitored with the existing system, and this area was most affected by unanticipated design changes. From the exit video, some lamprey were observed searching for an attachment surface (not perforated) and withdrawing back into the hooded area. This behavior confounded the counting process somewhat. However, counts show these lamprey ultimately exited rather than turning around and falling back down the vertical wall.

The high-pressure spray of water in the upper pan area was not as intended and was a cause for concern. While the spray may have added some time or stress for passing fish, it did not appear to be a source of confusion that caused fallback behavior. This section will require modification to reduce high-pressure water spray and function as designed, but is not of immediate concern.

Fallback behavior occurred 91 times and was most prevalent on the vertical wall or at the crest. While 21% of attachment events did not result in passage, 28 of these events (31%) occurred on a single night, seemingly by the same large fish. Fallback observations were often attributed to larger fish (estimated at >70 cm). The 6-inch radius of the crest allowed lamprey to navigate the transition from vertical to horizontal progression. However, larger fish sometimes struggled to navigate the crest-to-pan transition. This area induced longer passage times, and the majority of fallbacks observed were also in the crest-to-pan transition area. Transitions with a different radius may elicit a different response or be better for some sizes of lamprey. However, observations with an 11-inch radius showed similar difficulty, potentially for a higher percentage of the fish (R. Lampman, CTUIR, pers. comm.). In fact, a larger radius may

create more difficulties for a larger percentage of the lamprey population at Bonneville Dam.

Pacific lamprey used the wetted wall structure almost exclusively at night, with the exception of a single observation at 0900 PDT. Dominant use of the structure at night led to the use of nighttime window counts for calculating proportional use of the wetted wall by the lamprey population in the ladder. Long periods without wetted wall monitoring and high variability in proportional use relative to window counts were sources of uncertainty in our estimates. As such, we estimated a range of total lamprey use of the wetted wall structure of 1,735-3,205 over the operating season, depending on the method of calculation. Our high estimate could be considered to represent maximum possible use over the season. A more conservative estimate would be between 1,735 and 2,287. These calculations also assumed uniformity in motivation and ability to find and climb the wetted wall throughout the season.

While the wetted wall was equipped with a half-duplex PIT antenna for tracking passing fish, only three tagged individuals used the structure during active monitoring. This small sample size did not allow for inferences regarding the long-term impact of this passage route on lamprey migration success.

Increased flow down the vertical wall and concomitant decreased flow at the structure exit was observed on 24 July. This flow irregularity continued through the remainder of the season with no obvious explanation, although we suspect that it may have resulted from accumulation of debris at the pump impeller. The change occurred in the middle of the night and was not the result of any known manipulation of system function.

There was some concern regarding possible response by salmonids to spray from the upstream edge of the hood, although no salmonid response was observed throughout the season. Furthermore, lamprey were attracted to the spray, which appeared to help them find and investigate the wetted wall. High rates of flow down the climbing surface were likely assistive to lamprey discovery and climbing. Most lamprey were observed climbing on the upstream (western) section of the vertical wall where the highest flow occurred.

However, we have few video records during the lower flow scenario, and those we have are only from recordings at the very beginning of the season. Given the lack of observed response by salmon and the positive response by Pacific lamprey, we recommend a higher flow that can result in some spray off the hood and into the fishway, as observed in late-season recordings. Our observation period covered the migration

season of most Pacific salmon species, with the exception of sockeye. The sockeye migration period should be monitored specifically in a subsequent season.

Minor improvements to the wetted wall structure design can be informed based on additional behavioral observations. We observed that Pacific lamprey in the fishway keyed in on splash along the upstream side of the vertical climbing surface. However, some of these fish were enticed to climb the concrete as a result of the concrete wall being wetted by splash from the climbing surface or by multiple lamprey on the climbing wall. These fish consequently missed the collector hood and fell back into the serpentine weir section of the fishway. To address this problem, we propose widening the climbing surface in a fan shape near the water surface. Blunt edges on the climbing surface would direct climbers to the crest.

Various behaviors were frequently observed to delay exit from the structure, including hesitation/searching, attachment, and backclimbing (Figure 7). Upon exiting, many lamprey flipped around and attached to the wetted back of the upwelling reservoirs. While all of these lamprey fell into the MUWS channel and did not delay for long periods, this behavior could be discouraged by attaching a perforated plate or mesh material to this area.

Pacific lamprey found and used the prototype wetted wall structure located in the serpentine weir section of the Bradford Island fishway. This result supported the concept that a vertical wetted wall can be a useful component of systems to improve passage for Pacific lamprey. Such structures can be used to collect lamprey, particularly from constrained areas where they accumulate, and direct them to alternative passage routes. They may also be useful in guiding lamprey over small barriers or into larger passage systems.

Conclusions and Recommendations

1. The experimental wetted wall structure in the Bradford Island fishway was effective at passing lamprey out of the Bradford Island fishway and into the adjacent makeup water supply channel. Pacific lamprey found the structure, navigated it quickly, and used it with high passage success.

2. High-pressure spraying of water in the upper pan area was not intended. While the high-pressure spray may have added some time or stress for passing lamprey, it did not appear to be a source of confusion that caused fallback behavior. This section will require modification to reduce the high-pressure water spray.

3. To reduce climbing on the wetted concrete adjacent to the wetted wall and reduce fallback behavior, the vertical climbing surface could be widened into a fan-shape near the water surface. Adding blunt edges to the climbing surface would direct climbing lamprey toward the crest.

4. Upon exiting, many lamprey flipped around and attached to the wetted back of the upwelling reservoirs (Figure 7C). All of these lamprey fell into the makeup water supply channel, and most of these attachments did not cause long delays. However, this behavior could be discouraged by attaching a perforated plate or mesh material to the backs of the upwelling reservoirs.

5. Lamprey were attracted to the wetted wall structure when wall flow was high enough to spray water into the fishway from the structure hood. No salmon responded to this spray. Hence, a flow regime with visible flow and some splash should be maintained.

6. Power interruptions exceeding the capacity of the backup power system caused extended outages and affected the ability to provide accurate counts of wetted wall usage. Redundancy in power supply could be employed to reduce power interruption in the future. Changes could include a dedicated power source not linked to work in the area, a visible indicator of power disruption located in the fish counting station, and a remote access system allowing for system checks from off site. Such changes are planned for future monitoring years.

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