EVALUATION OF ADULT PACIFIC LAMPREY PASSAGE AT THE CASCADES ISLAND FISHWAY AFTER ENTRANCE MODIFICATIONS, 2010

Report for Project
ADS-P-00-8

by

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for

U.S. Army Corps of Engineers
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Executive Summary

As part of ongoing efforts to improve passage conditions for adult Pacific lamprey (Lampetra tridentata), the USACE modified the Cascades Island fishway opening during winter 2008-2009 to reduce maintenance requirements and improve hydraulic conditions for lampreys. The modifications included a variable-width entrance weir, bollards (“artificial rocks”) designed to provide reduced near-floor water velocity refuges for lampreys, and construction of a new lamprey passage structure (LPS) inside the fishway opening. We evaluated behavior and passage success near and inside the modified Cascades Island fishway using radiotelemetry and half-duplex PIT-tag (HD-PIT) studies; use of the LPS by adult lamprey will be reported separately (Moser et al., in prep).

Lamprey entrance efficiency at the Cascades Island fishway was significantly higher in the post-modification years (2009 = 59.5%; 2010 = 61.1%) than pre-modification years (2008 = 33.3%; 2007 = 0.50; P<0.001), suggesting some post-modification benefit for lampreys. Entrance efficiency at the Bradford Island fishway entrance (located at the south end of the spillway and similar in structure to the Cascades Island entrance prior to modifications) did not differ significantly among years or pre-/post-modification periods, also supporting the hypothesis that the increased entrance efficiency at Cascades Island in 2009 and 2010 was related to the modifications. However, comparison of other lamprey performance metrics between years and locations provided equivocal evidence of a benefit. For example, exit ratios at the Cascades Island fishway were similar or higher in post-modification years, and passage times associated with the Cascades Island entrance were similar to or longer than in previous years. Overall, the results suggest the modifications provided an improvement to movement into the fishway, but that poor passage conditions for adult lamprey persist between the entrance and transition pool, probably upstream of the bollard field.

Detection efficiency at the new the HD-PIT antenna system in the Cascades Island entrance was high in 2009 and 2010: 80-87% of lampreys tagged with both radio transmitters and HD-PIT tags were detected on the PIT antenna system. The high detection rate suggested that adults entered near the fishway floor, within the influence of the modified hydraulic field produced by the bollards. The pattern of detections on four separate antennas indicated that a majority (67-76%) of lamprey entered on the north half of the fishway channel. Overall, the analyses indicated that the Cascades Island modifications likely improved entrance efficiency for adult Pacific lamprey and did not have strong positive or negative effects on other passage metrics, possibly because of passage impediments upstream of the modifications.
Introduction

The need to identify passage obstacles for Pacific lamprey (*Lampetra tridentata*) and develop better aids to lamprey passage has become critical with the diminishing adult runs at lower Columbia River dams. Work thus far has included both structural and operational changes at Bonneville Dam to facilitate lamprey passage, and monitoring throughout the drainage with video, radiotelemetry and half-duplex passive integrated transponder (HD-PIT) tags to identify problematic passage sites and conditions (e.g., Clabough et al. 2009; Johnson et al. 2010; Keefer et al. 2009, 2010, 2011). At Bonneville Dam, lamprey passage structures (LPSs) have been installed at Bradford Island and Washington-shore auxiliary water supply (AWS) channels, and a prototype lamprey collector was developed for the northwestern main entrance to the Washington-shore fishway (e.g., Moser et al. 2011).

During the 2008-2009 winter maintenance period the USACE modified the Cascades Island (CI) fishway opening to reduce maintenance needs and improve entry rates for adult Pacific lamprey. The modifications included a variable-width entrance weir, installation of bollards (a.k.a. “artificial rocks” fabricated as 18” high x 12” diameter stainless steel columns set on 24” centers; Figure 2) designed to provide reduced near-floor water velocity refugia for lampreys, and a new LPS inside the fishway opening that allowed lamprey volitional passage to the elevation of the dam forebay. In 2010, we evaluated adult lamprey behavior and passage success near and inside the modified CI fishway using radiotelemetry and half-duplex PIT-tag (HD-PIT) studies. Evaluation of the new CI LPS will be presented in a companion report (Moser et al. *in prep*).

We evaluated passage behavior and success through the modified CI fishway by comparing lamprey passage metrics obtained using radio- and HD-PIT telemetry at the CI entrance to estimates from two pre-modification years (2007, 2008) and two post-modification years (2009, 2010) and by comparing 2010 metrics at CI with those at the similarly-configured Bradford Island (BI) entrance at the south end of the spillway. Specifically, our objectives were to: 1) evaluate passage times and behaviors of radio-tagged lampreys at Bonneville Dam; 2) compare CI entrance use and passage efficiency for lampreys radio-tagged in 2010 to those in previous years; and 3) evaluate detections of HD-PIT tagged and double-tagged (radio and HD-PIT) lampreys at the new CI HD-PIT antenna location. (Note: a parallel radiotelemetry evaluation of spring–summer Chinook salmon behavior at the CI entrance was summarized in Jepson et al. 2010 and Jepson et al. 2011).
Methods

Tagging and monitoring

Near record-low adult lamprey counts at Bonneville Dam in 2010 resulted in reduced lamprey collection and modifications to our original study objectives. The primary changes were a major reduction in the number of fish tagged solely with HD-PIT tags and a nearly 50% reduction in the number of radio-tagged lamprey compared to the two previous study years (2008-2009). From 30 May-24 August 2010, we collected and surgically implanted radio-transmitters into 312 adult Pacific lampreys at the Adult Fish Facility at Bonneville Dam (Figure 1). Additionally, HD-PIT tags were inserted into all of the 312 radio-tagged lampreys (i.e., they were double-tagged, a departure from previous years when a portion of the sample was a radio-tag-only group). Tagged fish were released ~3 km downstream from the dam near Tanner Creek and Hamilton Island. We collected and tagged a total of 19 lampreys with HD-PIT tags (hereafter, the HD-PIT-only group) from 4 June to 9 September 2010 at the Adult Fish Facility at Bonneville Dam. Thirteen were collected in early June and released ~3 km downstream from the dam at Hamilton Island and six were collected in early September and released directly into the Cascades Island LPS. Methods and release locations were similar to those used in previous years and a description of the collection and tagging methods is presented in Keefer et al. (2009).

We compared lamprey passage times, fallback rates, and efficiency metrics in 2010 to similar data collected in 2007-2009. In all analyses, we excluded all telemetry records that were recorded after 30 September (small numbers of lamprey were recorded after this date in all years \( n = 1-3 \)) in an effort to make the datasets comparable across years.

Radiotelemetry. We monitored movement of tagged lampreys at Bonneville Dam and the CI and BI entrances using an extensive array of radio-telemetry receivers (Appendix Figures A.1 and A.2). Receivers deployed at the two study entrances monitored for fishway approach, fishway entrance, and transition pool passage.

Half-duplex PIT tag monitoring. We intended to monitor movements into the CI entrance using an array of four antennas arranged in two plates spanning the fishway entrance, as in 2009 (Figure 2). However, lamprey detection data were collected at only two of the four floor-mounted HD antennas inside the CI entrance (Figure 2) due to an equipment failure at the two upstream antennas in late 2009. Antennas were operated from prior to release of tagged lamprey through 19 October 2010 (Appendix Figure A.1). We calculated HD-PIT detection efficiency using the double-tagged fish recorded at HD and/or radiotelemetry antennas inside the CI entrance.
Figure 1. The number of adult Pacific lampreys radio-tagged and released downstream from Bonneville Dam and the number of adult lampreys counted passing the dam during the day in 2010.

Figure 2. Locations of half-duplex antennas at the Cascades Island entrance: 1 (downstream south), 2 (upstream south), 3 (downstream north), and 4 (upstream north). Note antennas 2 and 4 were not operating in 2010.
**Passage Metrics**

We evaluated six passage time and passage efficiency metrics using radio-telemetry data to help assess potential effects of the CI entrance modifications on radio-tagged adult lamprey behavior:

1) **CI entrance efficiency** defined as the ratio of unique fish recorded entering the CI fishway to the number that approached the CI fishway (entries/approaches).

2) **CI exit ratio** defined as the ratio of unique fish recorded exiting the CI fishway into the tailrace to the number that entered the CI fishway (exits/entries).

3) **CI entrance time** defined as the passage time from first CI fishway approach to first CI fishway entrance.

4) **CI entrance to base of ladder time** defined as the passage time from first CI fishway entrance to the first record at the antenna located in the transition pool at the base of the ladder.

5) **Extended passage time percentage** defined as the percentage of fish that required > 1 h to pass through the two passage segments: 5A) approach to entry and 5B) entry to ladder.

6) **Proportion past transition pool** defined as ratio of unique fish approaching or entering to the number recorded at the first antenna upstream from the transition pool: 6A) approach to past transition pool and 6B) entry to past transition pool.

We used Chi-square tests to evaluate if entrance efficiencies were different in 2010 compared to prior individual years (2007, 2008, and 2009) and also to evaluate post modification years 2009 and 2010 compared to 2007-2008 (pre-modification years). We also used Kruskal-Wallis tests (Zar 1999) to compare median travel times from approach to CI entry and from CI entry to the base of the ladder. We also calculated similar metrics for the Bradford Island entrance and tested for differences between locations using Chi-square tests. HD-PIT telemetry data could not be used to directly assess effects of the modification because no pre-modification data or data from the Bradford Island entrance were available.

**Results**

**Tagging and general lamprey passage behavior**

In 2010, a total of 5,735 adult lampreys were counted passing the dam during the day through the end of August, a count that was the lowest on record (Columbia River DART: http://www.cbr.washington.edu/dart/). Radio-tagged lampreys represented ~ 5.4% of the lampreys counted at the dam (day only) during the tagging period and an estimated 1.6% of the total combined day count, night count (USACE video), and LPS count. The low count resulted
in revised study objectives and restrictions to target sample size after consultation with USACE
biologists and regional fisheries managers in an effort to minimize any potential negative effects
of tagging on the population of returning adults. Compared to 2007-2009, the summer river
environment through September 2010 had high levels of total discharge and spill in mid to late
June (Figure 3). The Bonneville Dam Water Quality Monitoring station (WQM; Columbia River
DART) water temperatures in June and July in 2010 were generally below average. The
temperature profile in 2010 was similar to 2008 and was cooler than in 2007 and 2009.

The proportion of adults recorded approaching and passing Bonneville Dam after release was
higher in 2010 than 2007-2009 (Table 1). Of the 312 lampreys radio-tagged and released
through 24 August 2010, 306 (98%) were recorded on receiver sites in the tailrace (located near
the release sites) and 275 (88%) were recorded at the dam (Table 1). Of the 312 fish released,
125 (40%) passed the dam, and another 3 (1%) were recaptured in the lamprey traps and were
released into an LPS (Table 1). Fifty-eight passage events (46%) were recorded at the Bradford
Island fishway exit and 66 (53%) were recorded at the Washington-shore fishway exit (including
adults using the Cascades Island entrance). One (<1%) lamprey was documented as possibly
passing upstream through the navigation lock. The 40% escapement (excluding recaptured fish)
past Bonneville Dam in 2010 was higher than in either 2007 (21%), 2008 (25%) or 2009 (30%).
We recorded 4 fallback events (3.2%) by 4 unique lampreys in 2010; one had re-ascended the
dam by 30 September.

Below we describe passage metrics across all entrances at Bonneville Dam and then report
specific results for the Cascades Island entrance.

**Locations of first fishway approaches and entries**

The locations where radio-tagged lamprey first approached fishways at Bonneville Dam were
similar to those observed in 2007-2009 (Figure 4). In 2010, about 24% of all the first fishway
approaches by radio-tagged lampreys were recorded at Powerhouse 1 and 40% were recorded at
Powerhouse 2 (Figure 4). About 9% of first fishway approaches were at the Cascades Island
entrance and 15% were at the Bradford Island fishway entrance. Four percent of first approaches
were at unknown locations. Initial entries into fishways in 2010 were most common at
Powerhouse 2 south entrances (~19%) and Powerhouse 1 south entrances (~17%) and were least
common at Powerhouse 2 north entrances (~8%) and Powerhouse 1 north entrances (~11%)
(Figure 4). The percentage of fish entering Powerhouse 2 north in 2010 was lower than in
previous years and slightly higher at Cascades Island than in previous years. Similar to 2009, a
high percentage of fish had unknown entries (18%) in 2010 because PH2 orifice gates were open
and unmonitored.
Figure 3. Mean daily river discharge (A), spillway discharge (B), and water temperature (C) at Bonneville Dam from 10 May to 30 September, 2007-2010.
Table 1. Numbers of radio-tagged adult Pacific lampreys released downstream from Bonneville Dam and later recorded approaching, entering or passing the dam in 2010.

<table>
<thead>
<tr>
<th>Passage metric</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Released</td>
<td>398</td>
<td>595</td>
<td>596</td>
<td>312</td>
</tr>
<tr>
<td>Recorded at tailrace</td>
<td>368</td>
<td>92.5</td>
<td>569</td>
<td>95.6</td>
</tr>
<tr>
<td>Recorded at dam</td>
<td>271</td>
<td>68.1</td>
<td>444</td>
<td>74.6</td>
</tr>
<tr>
<td>Known to pass dam</td>
<td>83</td>
<td>20.8</td>
<td>156</td>
<td>26.2</td>
</tr>
<tr>
<td>Recaptured, released upstream(^1)</td>
<td>10</td>
<td>1.7</td>
<td>21</td>
<td>3.5</td>
</tr>
<tr>
<td>Recorded first fishway approach(^2)</td>
<td>260</td>
<td>65.3</td>
<td>385</td>
<td>64.7</td>
</tr>
<tr>
<td>Recorded first fishway entrance(^2)</td>
<td>169</td>
<td>42.5</td>
<td>190</td>
<td>31.9</td>
</tr>
<tr>
<td>Recorded ladder exit</td>
<td>71</td>
<td>17.8</td>
<td>130</td>
<td>21.8</td>
</tr>
</tbody>
</table>

\(^1\) included in the ‘known to pass dam’ category  
\(^2\) only includes known time and location of approach and entry

First fishway approach efficiency

In 2010, the percentage of first fishway approaches that resulted in first fishway entries at the same site ranged from 5% (\(n = 65\) first approaches) at the PH2 north entrance (adjacent to the powerhouse) to 80% (\(n = 25\)) at the Cascades Island entrance (Figure 4). Percentages at other sites in 2010 were 48% (\(n = 62\)) at the south entrance at PH1, 48% (\(n = 42\)) at the B-Branch entrance, 42% (\(n = 24\)) at the PH1 north entrance, and 38% (\(n = 45\)) at the PH2 south entrance. The 2010 estimates were sometimes higher and sometimes lower than those in 2007-2009; the Cascades Island first entrance efficiency estimate in 2010 was higher than in previous years.

Passage Times

Dam-wide patterns of median passage times in 2010 were quite variable, and were both higher and lower than times recorded in 2007-2009 (Table 2). The median time from lamprey release to first fishway approach at any site in 2010 (1.82 d, \(n = 259\)) was intermediate to the 2007-2009 times (Table 2). The median release to first fishway entrance time in 2010 (3.54 d, \(n = 187\)) was similar to previous years. The median time from first fishway approach to first fishway entry in 2010 (1.70 h, \(n = 187\)) was the slowest of the four years. The median time tagged lampreys used to swim from first fishway entry to the ladder top was 7.27 d in 2010 (\(n = 93\)), the slowest time for this segment. The median time for radio-tagged lampreys to pass Bonneville Dam (release to ladder top) in 2010 was 12.55 d (\(n = 119\)), the slowest compared to 2007-2009.
Figure 4. Locations of first fishway approaches (A), fishway entries (B) and entrance efficiency (C; entry events/approach events) by site for radio-tagged adult Pacific lampreys at Bonneville Dam through 30 September, 2007-2010. Unknown (Unk) category includes fish recorded in the transition pools at PH1 or PH2 without clear approach and/or entry record. Note differences in y-axes scales.
Table 2. Pacific lamprey median passage times at Bonneville Dam through 30 September, 2007-2010. All fishways and antenna sites combined.

<table>
<thead>
<tr>
<th>Passage metric</th>
<th>2007</th>
<th></th>
<th>2008</th>
<th></th>
<th>2009</th>
<th></th>
<th>2010</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Median</td>
<td>n</td>
<td>Median</td>
<td>n</td>
<td>Median</td>
<td>n</td>
<td>Median</td>
</tr>
<tr>
<td>Release to first approach</td>
<td>260</td>
<td>2.84 d</td>
<td>385</td>
<td>1.57 d</td>
<td>444</td>
<td>2.70 d</td>
<td>259</td>
<td>1.82 d</td>
</tr>
<tr>
<td>Release to first entry</td>
<td>169</td>
<td>3.54 d</td>
<td>190</td>
<td>3.54 d</td>
<td>254</td>
<td>3.14 d</td>
<td>187</td>
<td>3.54 d</td>
</tr>
<tr>
<td>Release to pass dam</td>
<td>71</td>
<td>7.56 d</td>
<td>130</td>
<td>5.56 d</td>
<td>149</td>
<td>8.65 d</td>
<td>119</td>
<td>12.55 d</td>
</tr>
<tr>
<td>First approach to first entry</td>
<td>169</td>
<td>0.81 h</td>
<td>190</td>
<td>1.37 h</td>
<td>254</td>
<td>0.58 h</td>
<td>187</td>
<td>1.70 h</td>
</tr>
<tr>
<td>First fishway entry to pass dam</td>
<td>62</td>
<td>1.23 d</td>
<td>84</td>
<td>1.94 d</td>
<td>99</td>
<td>2.75 d</td>
<td>93</td>
<td>7.27 d</td>
</tr>
</tbody>
</table>

**Passage metrics**

**Radiotelemetry Metrics.** Metric 1. The CI entrance efficiency estimate in 2010 was 0.611 ($n= 90$ radio-tagged fish approached the CI entrance; Table 3). This was higher than in 2007 (0.500), 2008 (0.333), and 2009 (0.595). In a chi-square test comparison of all four years, entrance efficiency differed significantly among years ($P = 0.007, 2 \times 4 \chi^2$ test). Pair-wise comparisons between 2010 and each pre-modification year indicated CI entrance efficiency was significantly higher in 2010 than in 2008 ($P < 0.001, 2 \times 2 \chi^2$ test) but not 2007 ($P = 0.254$). The latter result may have been due to a small effect size between 2007 and 2010 and/or smaller sample size in 2007. When pre-modification years (2007-2008) were pooled and compared to post modification years (2009 and 2010 pooled) entrance efficiencies were significantly higher during post modification years ($P = 0.001, 2 \times 2 \chi^2$ test).

For comparison, the point estimate of entrance efficiency at the unmodified Bradford Island fishway entrance was also higher in 2010 (0.542) than in the previous three years (0.462-0.540, Table 4). There were no statistically significant differences in entrance efficiency at this site among years ($P = 0.567, 2 \times 4 \chi^2$ test). When years were grouped into pre and post modification groups, no differences between periods were found at BI ($P = 0.167, 2 \times 2 \chi^2$ test).

Metric 2. The CI exit ratio in 2010 was 0.582 ($n = 32$ of 55 fish that entered subsequently exited into the tailrace; Table 3) compared to 0.588 ($n = 17$ fish entered) in 2007, 0.167 ($n = 18$ fish entered) in 2008, and 0.620 ($n = 50$ fish entered) in 2009. In a chi-square test comparison of all four years, exit ratio was significantly different among years ($P = 0.007, 2 \times 4 \chi^2$ test). In pairwise chi-square tests, the exit ratio in 2010 was significantly higher than in 2008 ($P = 0.002, 2 \times 2 \chi^2$ test) but not compared to 2007 ($P = 0.964$) or 2009 ($P = 0.690$). When pre-modification years (2007-2008) were pooled and compared to post modification years (2009 and 2010 pooled) exit ratios were significantly higher during post modification years ($P = 0.018, 2 \times 2 \chi^2$ test). The exit ratio at Bradford Island was similar among years ($P = 0.266, 2 \times 4 \chi^2$ test). No differences were found in BI exit ratios when years were grouped into pre and post modification groups ($P = 0.543, 2 \times 2 \chi^2$ test).
**Metric 3.** The 2010 median passage time from first CI approach to first CI entry was 32 minutes \((n = 21)\), trending slightly longer than in 2007 but faster than in 2008 and 2009. These differences were not significantly different \((P = 0.164, \text{K-W test; Table 3})\). Median times from approach to entry at Bradford Island were similar to those at CI with 2010 times being slightly longer than in 2007 and less than times in 2008 and 2009 (Table 4).

**Metric 4.** After fish entered the CI fishway, the median time to reach the ladder base was 27 minutes in 2010 \((n = 27)\), versus 7-9 minutes in 2007 and 2008 and 17 min in 2009 (Table 3). The 2010 estimate was significantly longer compared to all previous years \((P <0.001, \text{K-W test})\). In contrast, median times from fishway entry to the ladder were faster at Bradford Island in 2010 compared to previous years (Table 4).

**Metric 5.** 5A) Approach to entry time: In 2010, 30% of the lampreys took >1 h to pass through the CI approach to CI entry segment \((n = 6)\), a value intermediate to 2007 and 2008 estimates and similar to 2009. 5B) Entry to ladder time: 22% took >1 h to pass from CI entry to the base of the ladder \((n = 6, \text{Table 3})\), a higher percentage than in 2007 and 2008 but lower than in 2009.

**Metric 6.** A) In 2010, the proportion of lamprey that approached CI and subsequently moved upstream of the transition pool was 0.356, which was slightly less than in 2009 but similar to 2007 and 2008 (Table 3). B) The proportion of lamprey that entered CI and passed upstream of the transition pool in 2010 was 0.582, lower than in all previous years (0.686-0.792). However, there were no significant differences among years \((P = 0.282, 2\times4 \chi^2 \text{test})\) or when pre-modification years (2007-2008) were pooled and compared to post modification years (2009 and 2010 pooled; \(P=0.130, 2\times2 \chi^2 \text{test}\)). There were also no significant differences at Bradford Island among years \((P = 0.998, 2\times4 \chi^2 \text{test})\) or when pre-modification years (2007-2008) were pooled and compared to post modification years (2009 and 2010 pooled; \(P=0.964, 2\times2 \chi^2 \text{test}\)).

<table>
<thead>
<tr>
<th>#</th>
<th>Cascades Island metrics</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Entrance efficiency</td>
<td>36</td>
<td>0.500</td>
<td>58</td>
<td>0.327</td>
</tr>
<tr>
<td>2</td>
<td>Exit ratio</td>
<td>17</td>
<td>0.588</td>
<td>18</td>
<td>0.167</td>
</tr>
<tr>
<td>3</td>
<td>Median time: approach to entry</td>
<td>16</td>
<td>9 min</td>
<td>17</td>
<td>35 min</td>
</tr>
<tr>
<td>4</td>
<td>Median time: entry to ladder</td>
<td>15</td>
<td>7 min</td>
<td>15</td>
<td>9 min</td>
</tr>
<tr>
<td>5A</td>
<td>Approach to entry time &gt; 1 hr</td>
<td>16</td>
<td>13%</td>
<td>17</td>
<td>41%</td>
</tr>
<tr>
<td>5B</td>
<td>Entry to ladder time &gt; 1 hr</td>
<td>15</td>
<td>7%</td>
<td>15</td>
<td>7%</td>
</tr>
<tr>
<td>6A</td>
<td>Proportion past TP: approach past TP</td>
<td>36</td>
<td>0.361</td>
<td>60</td>
<td>0.333</td>
</tr>
<tr>
<td>6B</td>
<td>Proportion past TP: entry past TP</td>
<td>18</td>
<td>0.722</td>
<td>24</td>
<td>0.792</td>
</tr>
</tbody>
</table>
Table 4. Bradford Island fishway entrance efficiency metrics through 30 September, 2007-2010. Metrics were calculated using the total number of unique radio-tagged Pacific lamprey at the entrance, and were not limited to first detections (TP = transition pool).

<table>
<thead>
<tr>
<th>#</th>
<th>Bradford Island metrics</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>n</td>
<td>Estimate</td>
<td>n</td>
<td>Estimate</td>
</tr>
<tr>
<td>1</td>
<td>Entrance efficiency</td>
<td>80</td>
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<td>106</td>
<td>0.462</td>
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<td>Exit ratio</td>
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<tr>
<td>3</td>
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<td>39</td>
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<td>48</td>
<td>32 min</td>
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<tr>
<td>4</td>
<td>Median time: entry to ladder</td>
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<td>15 min</td>
<td>30</td>
<td>16 min</td>
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<tr>
<td>5A</td>
<td>Approach to entry time &gt; 1 hr</td>
<td>39</td>
<td>18%</td>
<td>48</td>
<td>35%</td>
</tr>
<tr>
<td>5B</td>
<td>Entry to ladder time &gt; 1 hr</td>
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<td>22%</td>
<td>30</td>
<td>7%</td>
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<tr>
<td>6A</td>
<td>Proportion past TP: approach past TP</td>
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<td>107</td>
<td>0.234</td>
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<tr>
<td>6B</td>
<td>Proportion past TP: entry past TP</td>
<td>39</td>
<td>0.513</td>
<td>49</td>
<td>0.510</td>
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Half-duplex PIT tag monitoring. Fifty-five double-tagged lampreys were recorded entering the CI fishway in 2010 using the radiotelemetry system through 30 September, allowing us to estimate detection efficiencies for the HD PIT antennas. Forty-four of these fish were also detected on one or more HD antennas for an overall HD PIT detection efficiency of 80%.

We used the HD-PIT tagged samples to estimate release to entry rate and the double-tagged sample to evaluate the CI antenna array and estimate detection efficiencies for both telemetry and HD-PIT systems. A total of 49 lampreys with HD-PIT tags were recorded at one or more of the HD antennas inside the CI fishway through 20 October 2010. Of these, 3 (8%) were HD-PIT-only fish and 44 (92%) were double-tagged fish. The remaining two were from lamprey tagged in 2009, which represents <1% of the HD-PIT tagged sample from 2009. The percent of the HD-PIT-only sample detected on the CI HD-PIT antenna (16%, 3 of the 19 HD-PIT-only group released) was similar to the radio-tagged sample that entered (e.g., Figure 4).

A majority of fish in 2010 were first recorded on the northern most antenna (antenna 3; 67%; n=33) of the pair of operational antennas (1 and 3), a pattern similar to the detections for the 2009 sample (Figure 5). Seven double-tagged lampreys in 2010 moved downstream through the UMT channel and exited into the tailrace through the CI fishway opening. None of these seven fish were recorded on the HD antennas (detection efficiency = 0%), perhaps indicating they were relatively high in the water column while moving downstream.

Comparison of all detections in both years revealed higher use of the northern half of the fishway (Figure 5). Upstream and downstream movements could not be assessed in 2010, though results from 2009 suggested rapid movement upstream. In 2009, many lampreys were recorded on more than one CI antenna. The largest number of HD-PIT tagged fish were recorded on antenna 3 (58 lampreys, 85% of those detected; Figure 5). Detections at the other antennas ranged from 17 fish (25%) at antenna 4 to 31 fish (46%) at antenna 2. In 2009, the majority (n = 52, 76%) were first recorded at antenna 3, followed by 15 (22%) first recorded at antenna 1 and one (2%) first recorded at antenna 2 (Figure 5). We note that, late in the season, one of the antenna cables supplying power to antenna 4 was broken, contributing to the lower relative detection rate (Figure 5). Detection patterns suggested most fish moved from
downstream directly to upstream antennas (i.e., from antenna 3 to antenna 4 or from antenna 1 to antenna 2), but there were a variety of movements.

Figure 5. Overhead view of the four floor-mounted HD-PIT antennas (1-4) located inside the Cascades Island fishway entrance in 2009-2010. A) Percentage of HD-PIT tagged lampreys recorded on each antenna in 2009 ($n = 68$) and 2010 ($n = 49$) and B) distribution of first detections of HD-PIT tagged lamprey among the four antennas. Percentages at antennas 2 and 4 were conservative because the power cable was broken in 2009 and antennas 2 and 4 were not operational in 2010.
Discussion

The size of the adult population returning to Bonneville Dam in 2010 was the lowest recorded. In contrast, radio-tagged lamprey passage performance at all entrances at Bonneville Dam in 2010 was similar to or slightly better than in 2007-2009. Proportionately more lampreys passed the dam (~40%) in 2010 than had in the three previous years (21-30%). Passage time results were mixed in comparison to previous years. The median passage from release past the dam was longer than in any earlier study, but passage through shorter segments was generally comparable. The longer total passage times were associated with long lamprey passage times in mid- to late June when discharge, spill and tailwater elevation were above average and water temperatures were below seasonal means.

The primary goal of this study was to evaluate the effects of the Cascades Island entrance modification on lamprey passage performance. We used two lines of evidence to evaluate the effects. First, we compared radio-telemetry results at CI from pre- and post-modification periods. Second, we compared passage metrics between CI (modified) and Bradford Island (unmodified) entrances because these two entrances are structurally similar and both are located on the edges of the Bonneville Dam spillway channel. In addition, we also qualitatively assessed behavior and performance using HD-PIT antennas installed within the bollard field as part of the CI modification. We hypothesized that the modifications would have the greatest potential effects on movements approaching and entering the fishway at CI because the modified weir and bollards affect the hydraulic plume extending from the entrance (the attraction plume) as well as velocity and turbulence at the entrance slot and just upstream. Passage conditions of the upper entrance (above the bollard field and LPS) should have remained constant across years. Consequently, we examined movements above and below the modifications, and also examined whether any effects in the lower entrance translated into higher passage rates into the fish ladder and to the fishway exit.

The 2009-2010 CI evaluations suggest that entrance modifications have likely provided a benefit to adult lamprey entrance. Entrance efficiencies at CI during the post-modification period (59-61%; 2009-2010) were significantly higher than during the two years prior to modifications (33-50%). There was no detectable difference in entrance efficiency among years at Bradford Island (despite larger sample sizes in most cases), supporting the hypothesis that the observed increase in efficiency at CI was related to the modifications rather than to inter-annual variation in river environment or other large-scale factors.

However, radio-telemetry data suggest that the benefit was limited to the entrance, and that the proportion of adult lamprey that continue through the transition pool has not increased. Both the Exit Ratio (Metric 2) and Proportion Past the Transition Pool (Metric 6) indicate that a majority of adults that are recorded entering subsequently exit, though values for the latter metric did not change (P>0.05) between pre- and post-modification periods. Because entrance efficiency increased, but net movement through the transition pool did not following the modification, we hypothesize that poor passage conditions upstream of the modified section continue to impede passage into the fishway and over the dam. Potential issues at this site include the 180 degree turn between the entrance and transition pool, turbulence and gratings associated with diffusers, and the transition from conditions in the lower fishway to the overflow weir section of the fish ladder. We note that due to the scale of the entrance relative to the
spatial resolution available with radio-telemetry, it was not clear where the difficult passage conditions occurred relative to the entrance modifications. Specifically, lamprey may have turned around in unmodified upstream sections near the transition to overflow weirs, or near the new CI bollards and LPS. The results from HD-PIT tag adults suggest that the former was more likely than the latter.

We calculated passage times for adult lamprey for various sections because long passage times are thought to be associated with areas of difficult passage. The median passage times from approach to entrance and entrance to ladder were relatively rapid (< 1 hour) in all cases, suggesting that neither pre- nor post-modification conditions were associated with long holding times and the potential for the modifications to markedly improve passage times was limited. Rather, the contrast between pre- and post-modification entrance efficiency and the passage time results suggest the modifications may have largely affected lamprey decision rules during entrance attempts over relatively short time periods (minutes) as opposed to affecting success of long sustained passage attempts (e.g., hours to days of holding or slow movements upstream through high velocity sections, as observed in count station and serpentine weir sections).

At the unmodified Bradford Island entrance, passage times were quite variable across years, and metrics were both higher and lower in 2009-2010 compared to 2007-2008. We suspect that among-year and within-season differences in tailwater elevation, spill, and water temperature likely account for the passage time variability we have recorded.

CI exit ratios were 58-62% in all years except that the 2008 (17%). The reason for the low exit ratio in 2008 remains unknown. Exit ratios at Bradford Island were higher than those in each study year (62-78%). The relatively high point estimates for exit ratio at both fishways in 2009 and 2010 suggests that conditions may have been unfavorable for rapid movement through the transition pool and up the fish ladder, though the ratio was not significantly higher at BI between periods.

Overall the CI entrance modifications improved entrance efficiencies in post modifications years, however passage times and exit ratios were similar or higher during 2009-2010 (post-modification) than pre-modification years. The mixed results may suggest improvements at the CI entrance and indicate other areas of difficult passage upstream of the entrance.

The HD-PIT lamprey data at Cascades Island indicated that the new detection system worked well. The HD detection efficiency was 87% in 2009 (Clabough et al. 2010) and 80% in 2010 despite two antennas being inoperable. Detection ranges for the floor-mounted antennas is believed to be < 2 feet. Therefore, the results indicate that most lamprey moved through the entrance area close to the floor, presumably through the near-bed area of lowered velocity created by the bollards. The majority of HD-PIT lamprey that entered at Cascades Island were first detected at the downstream north antenna in both 2009-2010 (67-76%). This pattern may have been the result of fish approaching the entrance along the shoreline or from a relatively low velocity area behind the unused entrance slot bulkhead visible in Figure 1 and/or the result of lampreys avoiding the high velocity spill plume just to the south (left in Figure 1) of the entrance. The percentage of fish detected by any one antenna was relatively high, ranging from 25% (a likely minimum due to outages) to 85% in 2009.
Although lampreys were collected at the top of the new CI LPS, none of the HD-PIT tagged lampreys were recorded using this structure in 2009. It was not clear whether the relatively limited use was due to LPS location, the distribution of attraction flow inside the fishway and near the LPS (e.g., Keefer et al. 2011), or other factors. In 2010, seven tagged lampreys were released directly into the CI LPS and all but one successfully ascended. In other LPS’s at Bonneville Dam, lamprey use of the structures was relatively lower in the installation year compared to subsequent years (Moser et al. 2011). A possible explanation is that the newly-installed metal is unattractive to some lamprey for olfactory or other reasons. If this is the case with the CI LPS, then it is possible that collection efficiency will improve at this site in future years.
References


Figure A.1. Map of Cascades Island radiotelemetry antennas in 2007-2010. Approach and entrance antennas=CBO1 and CBO2, and transition pool antennas =CBO3, CBO4, XBO3, and XBO4. Note: CBO5 was installed in 2009.
Figure A.2. Map of Bradford Island radiotelemetry antennas in 2007-2010. Approach and entrance antennas = BBO1 and BBO2, and transition pool antennas = BBO3, BBO4, WBO1, WBO2, WBO3.