Technical Report 2018-2 FINAL

ADULT SALMONID AND PACIFIC LAMPREY BEHAVIOR NEAR THE NEW WASHINGTON-SHORE UPSTREAM MIGRANT TUNNEL JUNCTION LAMPREY PASSAGE STRUCTURE (UMTJ-LPS) AT BONNEVILLE DAM, 2017

A Report for Study Code LMP-P-17-1

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Department of Fish and Wildlife Sciences
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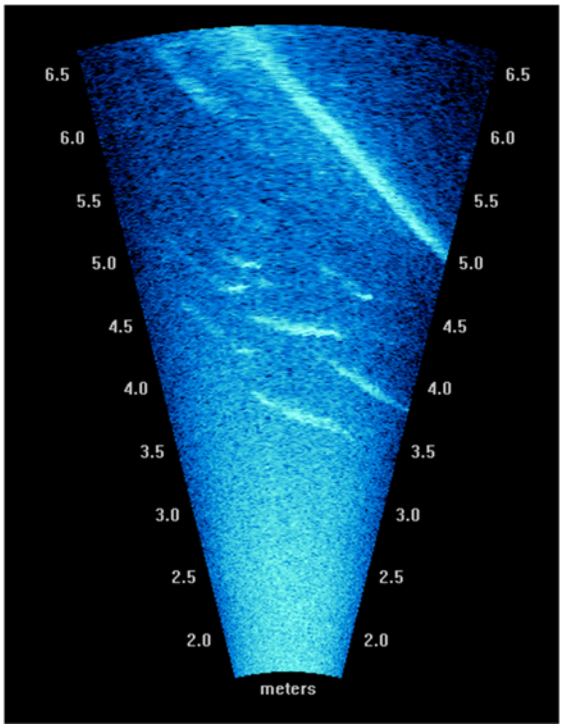

For

U.S. Army Corps of Engineers
Portland District, Portland OR

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Acknowledgements

Many people assisted with this project and its successful completion was made possible through their efforts. Funding for this work was provided by the USACE Portland District through Cooperative Ecosystem Studies Unit (CESU) agreement W912HZ-16-2-0013 with administrative assistance from Deberay Carmichael, Sherry Whittaker and Glenn Rhett (USACE), and Cheryl Chambers and Cathryn Knock (UI). The project was facilitated by Ricardo Walker and Sean Tackley (USACE). On-site work at Bonneville Dam was by Brian Bissell (USACE), Noah Hubbard, Tim Blubaugh, Chuck Boggs, Grant Brink, and Steve Lee (UI). Sarah Hanchett (UI) helped with DIDSON review and Bill Hanot (Sound Metrics) provided technical support.

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Executive Summary

In 2017, we used dual-frequency identification sonar (DIDSON) to evaluate adult salmonid and Pacific lamprey behavior near a newly-deployed fishway structure designed to aid the upstream passage of lamprey at Bonneville Dam. The lamprey passage structure (LPS) consisted of two ramps extending to the fishway floor and was installed ~10 m upstream from where the Upstream Migration Tunnel joins the Washington-shore fishway (henceforth the UMTJ-LPS). The primary objectives of the 2017 study were to: (1) monitor behaviors of adult salmonids and adult Pacific lampreys near the new UMTJ-LPS; and (2) monitor for potential, adverse effects of the structure on salmonid passage such as startle responses, frequent turn-arounds near the ramps, or holding within the hydraulic influence of the structure. A secondary objective was to use optical video to assess if any jumping behavior occurred near the UMTJ-LPS by steelhead (*O. mykiss*) or other adult salmonids.

We collected DIDSON data in a randomized block design that initially included three deployments. In late July, we added two additional deployments due to the poor image quality at two of the initial deployments. Monitoring began in late April and ended in early October among the five deployments. We randomly reviewed DIDSON files from throughout the data collection period and classified the image quality. Images were only viewed and scored for data summaries if the visibility of underwater structures and fish imagery met minimum thresholds. Optical video was collected to check for potential adult salmonid jumping or otherwise reacting to the discharge on the UMTJ-LPS ramps.

We enumerated all adult salmonid-sized targets moving upstream or downstream in the first 2 min of each randomly-selected, 10-min, daytime file to estimate relative abundance through the seasons and over diel cycles. We scored individual fish tracks at 2-min, pre-set points in each file. Fish location at the start and end of each track, fish orientation, and track duration were recorded for each individual and any adverse reactions (e.g., turn-arounds, startle responses, etc.) were noted. Pacific lamprey scoring was limited to randomly-selected nighttime files. As with the salmonid scoring, we recorded the number of upstream and downstream events in the first two minutes in each 10-min file and scored individual fish tracks at pre-set points in the files. In contrast to the salmonid scoring, we had viewers rank their confidence in the identification of the target as a lamprey for each event based on previously-established guidelines. We used the individual fish tracks to calculate passage times and to calculate the percentage of fish that turned around in each deployment. We also used track start and end points to graph straight-line vectors of the routes fish used to pass through each deployment, which provided an indication of where fish were moving upstream and downstream in the fishway and in relation to the LPS.

DIDSON estimates of total adult salmonid abundance generally tracked the seasonal patterns in adult Chinook salmon and steelhead abundance as indexed by the daily WA-shore adult counts. Proportionately more salmon were oriented upstream than downstream for their entire tracks and very few fish initially moved upstream and then turned around during their track. Differences in proportions of salmonids moving downstream between deployments at a quasi-control site indicated that many fish moved upstream near the fishway floor but moved downstream closer to the water surface. Among the subset of fish tracks that started with upstream orientation, from 0.0-4.0% (among deployments) turned around and moved downstream, with relatively little variability across the study period. Salmonids moving upstream with routes close to the UMTJ-LPS (within ~1 m) moved around the structure with essentially no delay. Fish that were initially oriented downstream moved faster than upstream-moving fish. We did observe some salmonids holding position at night during our review of

lamprey behavior, but holding was not clearly associated with the UMTJ-LPS. We observed no salmonid jumping behavior near the UMTJ-LPS based on optical video review.

Estimates of lamprey abundance derived from DIDSON data paralleled the adult Pacific lamprey counts at the WA-shore fishway and an LPS located upstream in the auxiliary water supply (AWS-LPS). Most lamprey (~65-83% among deployments) were oriented upstream for their entire track and < 1% of all lamprey that were initially moving upstream turned around during their track. Many lampreys passed in close proximity (within ~1 m) of the south LPS ramp but we did not observe any lamprey definitively entering the UMTJ-LPS. Track duration was similar across deployments for lamprey moving upstream and closely paralleled results for salmonids. On balance, we concluded that the deployment of the UMTJ-LPS did not impede upstream passage by adult salmonids or Pacific lamprey in 2017.

Introduction

Some adult Pacific lampreys (*Entophenus tridentatus*) have difficulty entering and passing through fishways at Columbia and Snake River dams (Moser et al. 2002; Johnson et al. 2012a; Keefer et al. 2013a; McIlraith et al. 2017). At Bonneville Dam, the serpentine weir sections of the fishways have been identified as particularly challenging areas for adult lamprey passage. In recent studies, approximately one-fifth to nearly one-third of radio-tagged lampreys that were detected reaching the serpentine weirs failed to pass (Keefer et al. 2013a; 2013b; 2014). Passage improvements in these locations are likely to provide some of the highest overall benefit to passing lamprey upstream relative to improved passage in other locations (Keefer et al. 2013b; 2014) because of the large number of adults that reach the sites and their low passage rate. Additionally, improved passage would likely reduce poorly understood milling behavior near the adult count stations and serpentine weirs that contributes to enumeration uncertainty in these locations (Clabough et al. 2012).

The development and installation of Lamprey Passage Systems (LPS; Moser et al. 2011; Corbett et al. 2015) in fishways has been a strategy to bypass areas of difficult passage for lamprey. During the winter of 2016-2017, the U.S. Army Corps of Engineers (USACE) installed a LPS with two ramps extending into the Bonneville Dam Washington (WA)-shore fishway downstream from the adult count station and upstream from the upstream migrant tunnel (UMT) junction with the main WA-shore fishway. The new structure, named the UMTJ-LPS, connects to an existing LPS in the adjacent auxiliary water supply channel (AWS; Figure 2). The combined system allows adult lamprey to bypass the adult count station and the serpentine weir section of the WA-shore fishway. Installation and operation of the UMTJ-LPS will potentially affect upstream passage of all fish species, including adult salmonids (*Oncorhynchus* spp) protected under the U.S. Endangered Species Act, and therefore an assessment of potential effects was required.

In 2017, we used dual-frequency identification sonar (DIDSON) to evaluate adult fish behavior near the UMTJ-LPS. Sonar imaging (DIDSON) has provided efficient and effective passive monitoring of adult and juvenile fish (primarily salmonids) during migration (Holmes et al. 2006; Maxwell and Gove 2007; Pipal et al. 2010; Petreman et al. 2014). Sonar provides a non-invasive sampling tool that is effective at medium ranges (1 to 7 meters) and provides nighttime and low-light imagery that is not possible with optical video. In several studies conducted from 2011-2014, we developed methods to monitor adult Pacific lamprey movements and passage rates in fishways using DIDSON at lower Columbia River dams including Bonneville, John Day and McNary dams (Johnson et al. 2012b, 2013; Kirk et al. 2015; Thompson et al. 2016; Keefer et al. 2017).

The primary objectives of the 2017 study were to use DIDSON: (1) to monitor behaviors of adult salmonids and adult Pacific lampreys near the new UMTJ-LPS; and (2) to monitor for potential adverse effects of the structure on salmonid passage such as startle responses, turn-arounds near the ramps, or holding within the hydraulic influence of the structure. A secondary objective was to use optical video to assess if any jumping behavior occurred near the UMTJ-LPS by steelhead (*O. mykiss*) or other adult salmonids.

Methods

Study site

During the winter of 2016-2017, the U.S. Army Corps of Engineers (USACE) installed a LPS with two ramps extending into the Bonneville Dam WA-shore fishway downstream from the adult count station and upstream from the UMT (Figures 1 and 2). The new structure is called the UMTJ-LPS. University of Idaho (UI) personnel installed an I-beam on the north fishway wall downstream from the north UMTJ-LPS ramp where a dual-frequency identification sonar (DIDSON) was mounted (Figure 2).

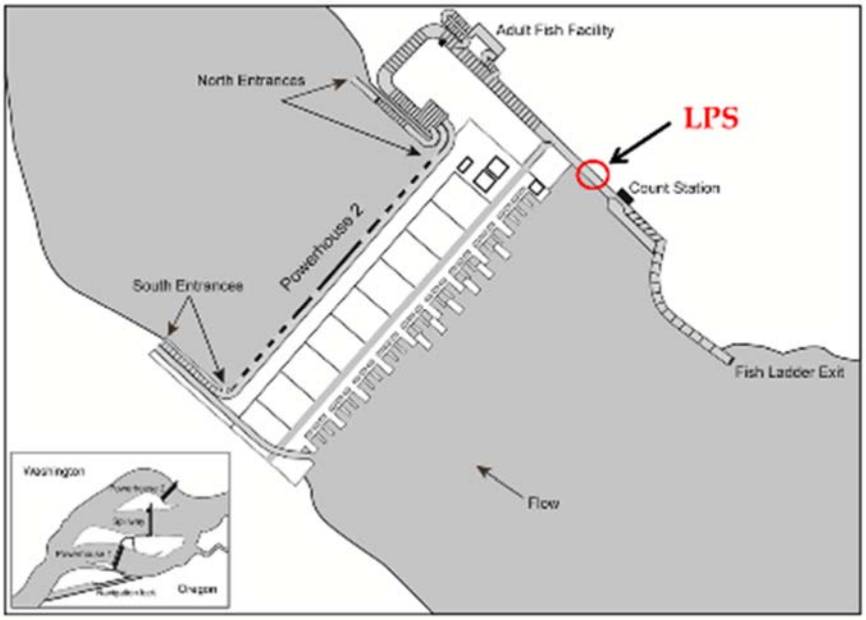

Figure 1. Location of the new lamprey passage structure (UMTJ-LPS) installed upstream from the upstream migrant tunnel (UMT) junction and downstream from the WA-shore fishway count station in the winter of 2016-2017 at Bonneville Dam.

DIDSON operation

We deployed a DIDSON (model 300 M, Sound Metrics Corp., Bothel, WA) from 24 April to 21 October at Bonneville Dam in 2017. The DIDSON consisted of a transducer array, acoustic lens, and electronics contained in a waterproof housing. The DIDSON transmitted data to a topside control box using a cable. A laptop was used to control the DIDSON settings and displayed images in real-time. The DIDSON sonar was mounted to an aluminum trolley that was attached onto a steel I-beam and retrieved using a Thern Series 5122 portable davit crane (Thern, Inc., Winona, MN). The laptop computer and control box were housed in a waterproof storage unit near the I-beam. Data were first recorded on a 4 TB removable storage drive (Western Digital, San Jose, CA), then copied to a 1 or 2 TB drive for transfer to the UI and finally stored on a larger 300 TB UI network drive. High-resolution video files were saved in 10-min increments to facilitate data management and data review. The frame rate was set to 10 frames per second, which provided adequate resolution to identify salmonids and lamprey. All monitoring in 2017 was conducted with the DIDSON in high frequency (1.8 MHz) and standard (i.e. ‘landscape’) orientation, where acoustic imagery appeared as though it was filmed from overhead (Keefer et al. 2017). In the high frequency mode, each beam was 0.3° in the horizontal and 14° in elevation. There were 96 beams spanning 29° in the horizontal direction for a total sample volume of 29° (horizontal) × 14° (vertical). The DIDSON was manually moved between deployment locations and pitch was adjusted (‘tilt angle’: -13.3 and -3.3 degrees). We did not use the spreader (auxiliary) lens because the desired sample volume could be captured without it.

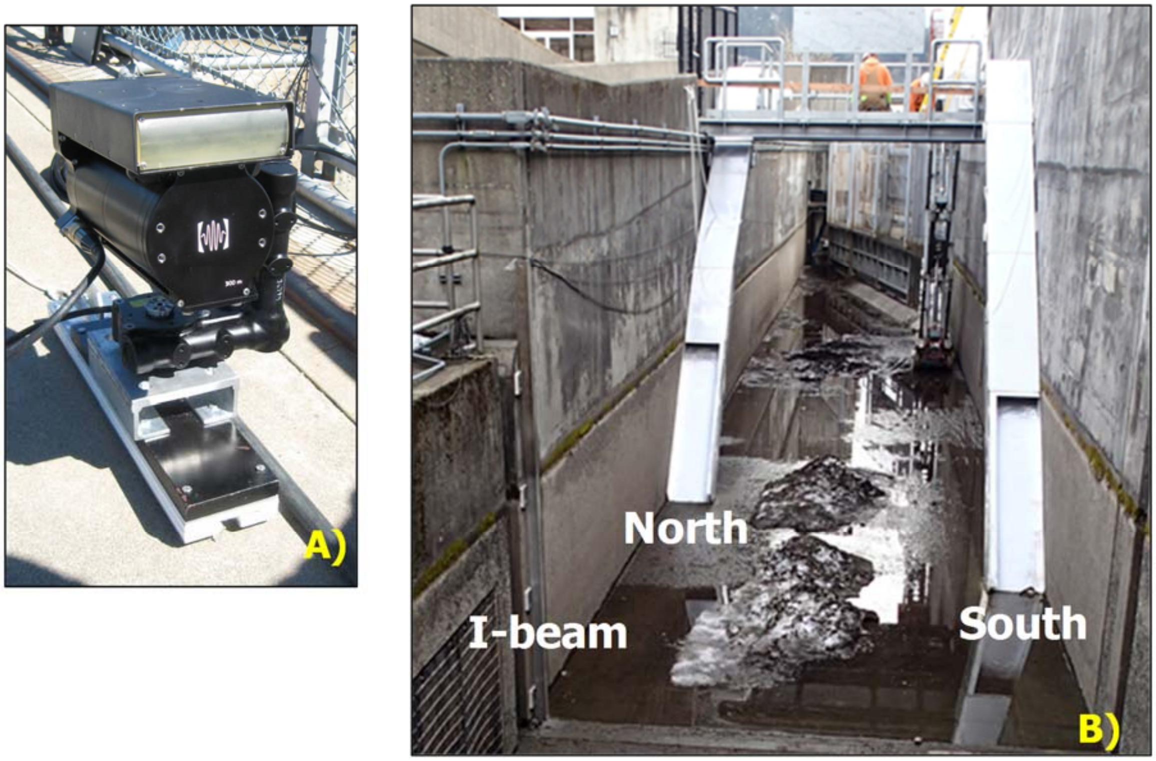

Figure 2. Photos of (A) the dual-frequency identification sonar (DIDSON), and (B) the north and south UMTJ-LPS ramps located below the WA-shore fishway count station and the I-beam where the DIDSON was deployed at Bonneville Dam in 2017.

DIDSON deployments

River discharge during 2017 sampling was unusually high and consequently we were forced to deviate from the *a priori* randomized block sampling design by adjusting camera orientations and testing new deployments when collected imagery was initially of poor quality. We collected DIDSON data in a randomized block design that initially included three deployments: LPS_North, LPS_South, and Downstream that alternated approximately every two days (Figure 3). The random schedule was designed before the study began but was altered (though still randomized) in response to image quality issues and decisions about which deployments to prioritize evolved (see below). The LPS_North and LPS_South deployments covered the entrances and lower sections of the LPS ramps and the adjacent fishway channel (Figures 4-5). The Downstream deployment was oriented directly down the channel to the junction of the UMT and WA-shore fishway channel, with the junction column visible in the middle of the imagery (Figure 6). In this initial study design, the Downstream deployment was considered a quasi-control where fish behaviors would be unaffected by the UMTJ-LPS and could be compared to behavior in the vicinity of the UMTJ-LPS. In late July, two additional deployments, Across_Top and Across_Bottom, were used due to the poor image quality at the LPS_North and Downstream deployments (see Results). The two Across deployments covered the area directly across the fishway channel from the DIDSON I-beam, sampled the top and bottom of the water column, and also served as quasi-control imagery (Figure 7). Deployments were random with respect to date for the remainder of the season and were restricted to the Across and South_LPS deployments, which provided the highest quality fish imagery.

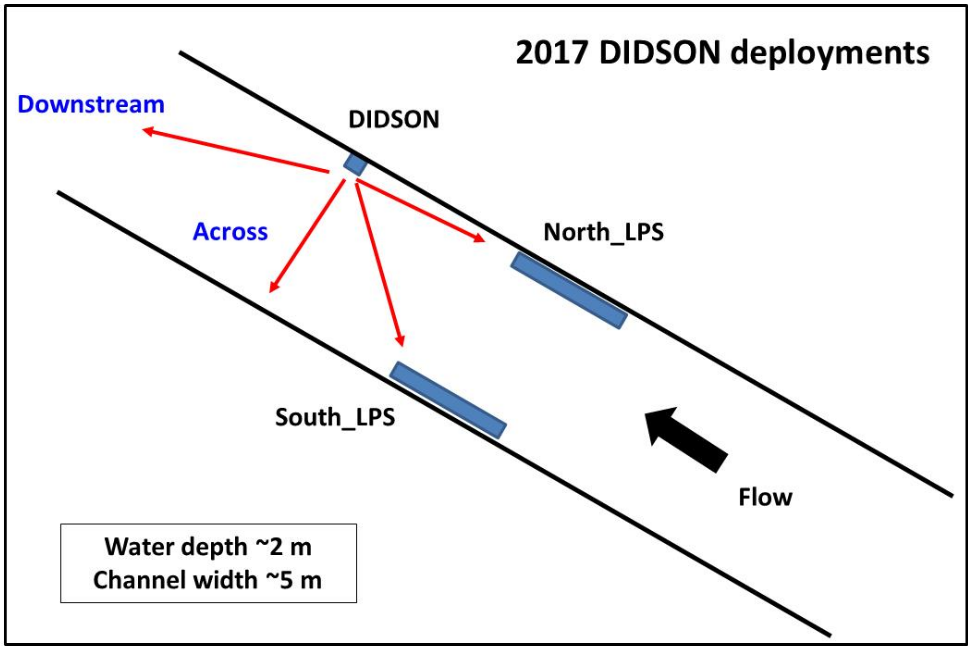

Figure 3. Plan (or overhead) view showing the north and south ramps of the UMTJ-LPS in the WA-shore fishway at Bonneville Dam, the location of the DIDSON camera, and the basic deployment orientations (red arrows) used for the evaluation of fish behavior in 2017. See Table 1 for details.

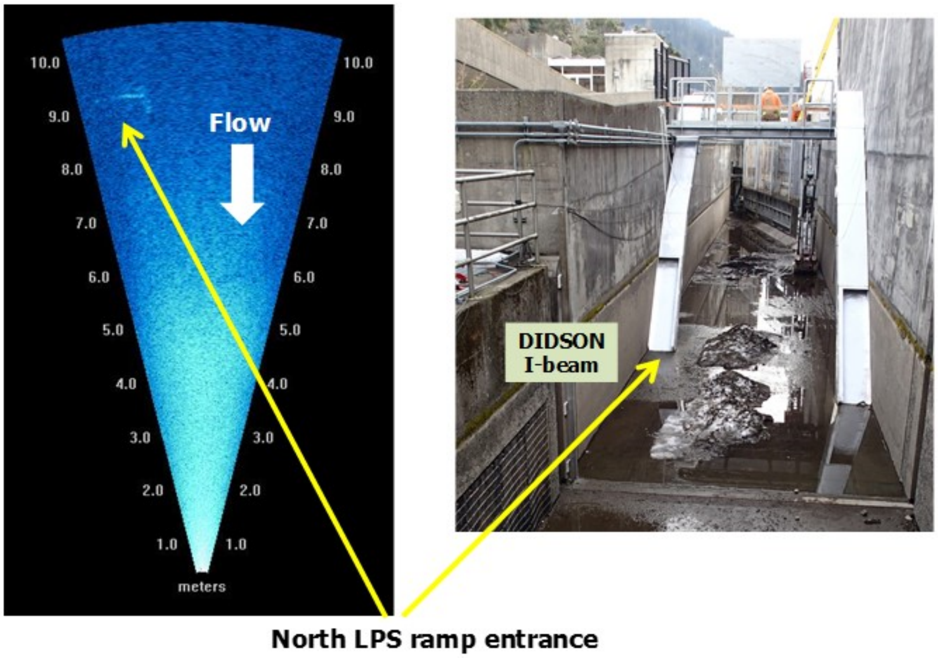

Figure 4. DIDSON camera deployment towards the north ramp of the UMTJ-LPS in 2017 inside the WA-shore fishway at Bonneville Dam.

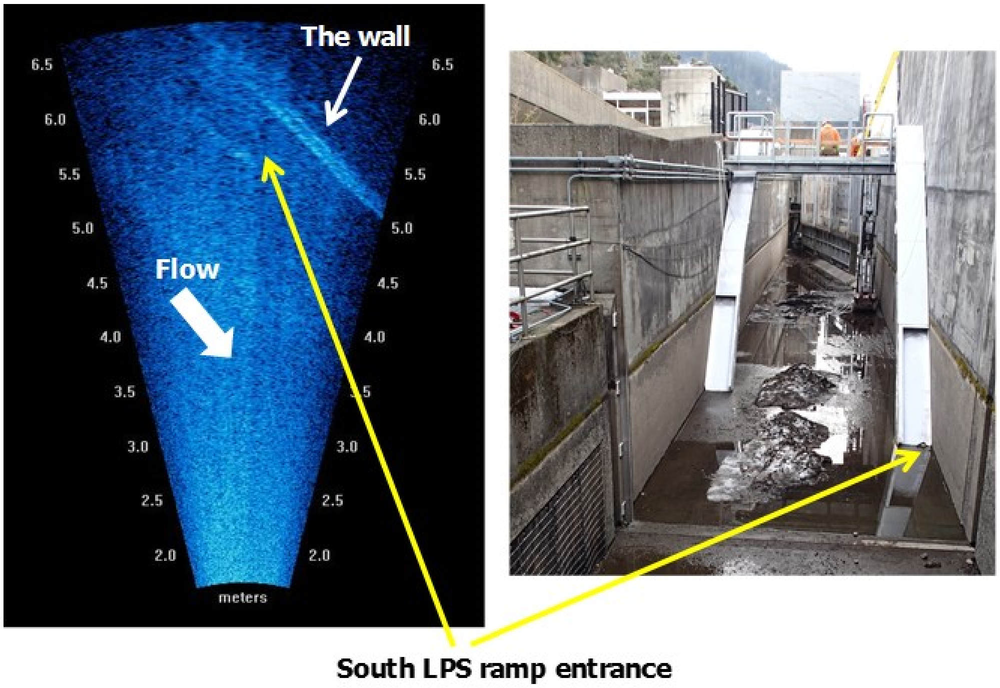

Figure 5. DIDSON camera deployment towards the south ramp of the UMTJ-LPS in 2017 inside the WA-shore fishway at Bonneville Dam.

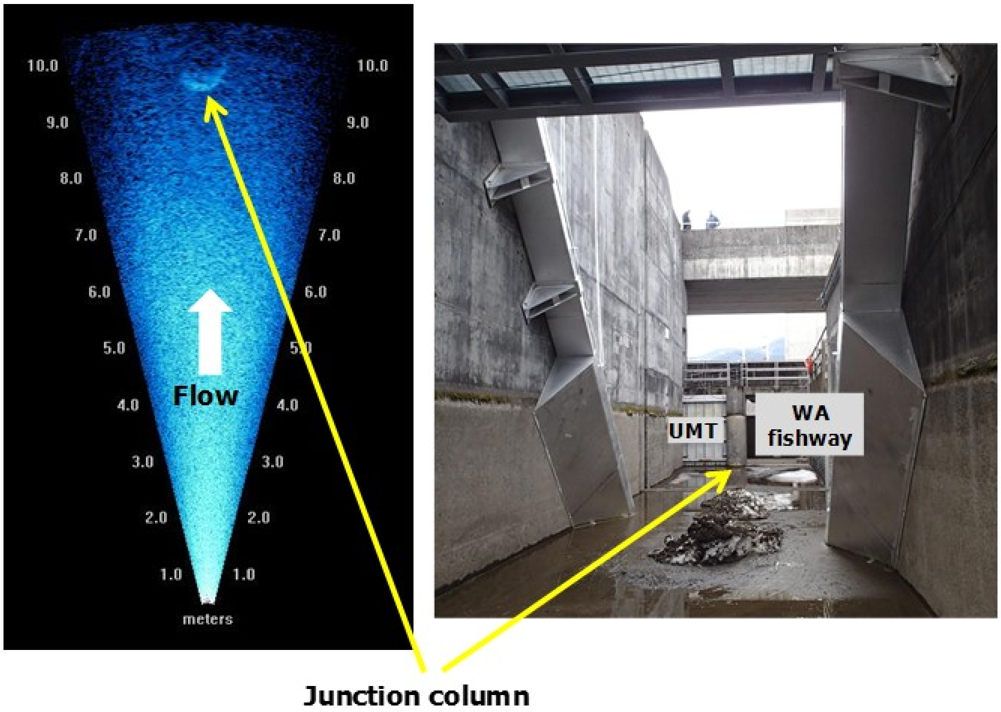

Figure 6. DIDSON camera deployment looking downstream from the UMTJ-LPS in 2017 inside the WA-shore fishway at Bonneville Dam.

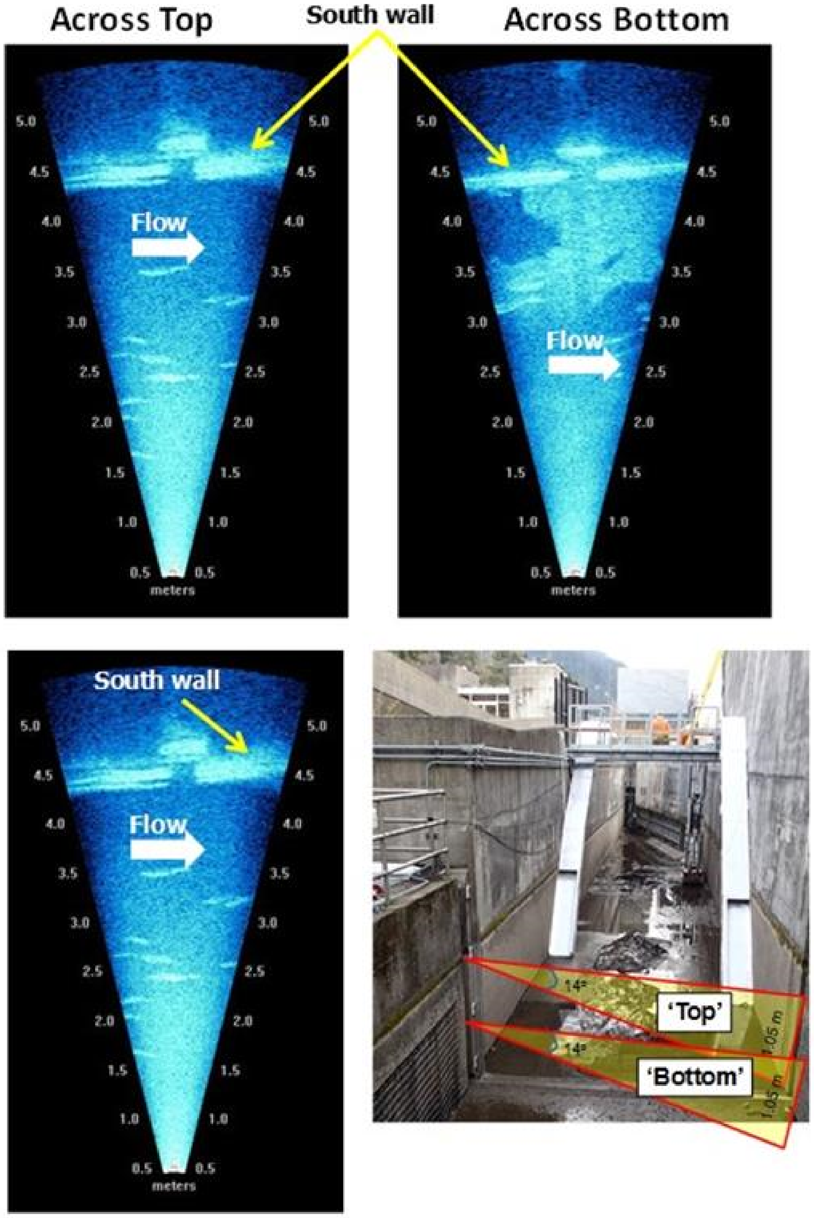

Figure 7. DIDSON camera Across deployments just downstream of the UMTJ-LPS ramp entrances in 2017 inside the WA-shore fishway at Bonneville Dam. 'Top' and 'Bottom' deployments imaged the upper and lower water column, respectively.

Deployments varied with different tilt angles and camera start lengths throughout the study period (Table 1). Tilt angle and camera start length were adjusted while searching for the most effective deployment viewing area. DIDSON imagery was collected at the Downstream and North_LPS sites from late April until early July, at the South_LPS through the entire monitoring period, and at the Across deployments from early August to mid-October (Figure 8).

Table 1. DIDSON camera parameters for each deployment near the UMTJ-LPS in the WA-shore fishway at Bonneville Dam in 2017. The DIDSON was in landscape mode with the standard lens.

Deployment	Deployment code	Tilt	Camera depth (m)	Ladder water elevation (m)	Camera start (m)	Camera range (m)
Downstream	F	-10.9 to -11.1	0.50	20.8	2.92	10.0
	H	-5.6 to -5.8	0.50	20.8	0.42	10.0
	G	-10.9 to -11.9	0.50	20.8	0.42	10.0
North_LPS	D	-11.5 to -11.6	0.50	20.7	2.92	10.0
	E	-5.6 to -5.8	0.50	20.8	0.42	10.0
	C	-11.2 to -12.4	0.50	20.7 to 20.8	0.42	10.0
South_LPS	J	-3.3 to -8.7	0.50, 0.70	20.7 to 20.8	1.67	5.0
	I	-9.7 to -12.7	0.50, 0.70	20.6 to 20.8	1.67	5.0
Across_Top	B	-13.2 to -13.3	0.50	20.7	1.67	5.0
	M	-10.1 to -13.6	0.70	20.7	0.42	5.0
Across_Bottom	A	-11.3 to -13.2	0.95	20.7	1.67	5.0
	L	-10.3 to -13.0	0.95	20.7	0.42	5.0

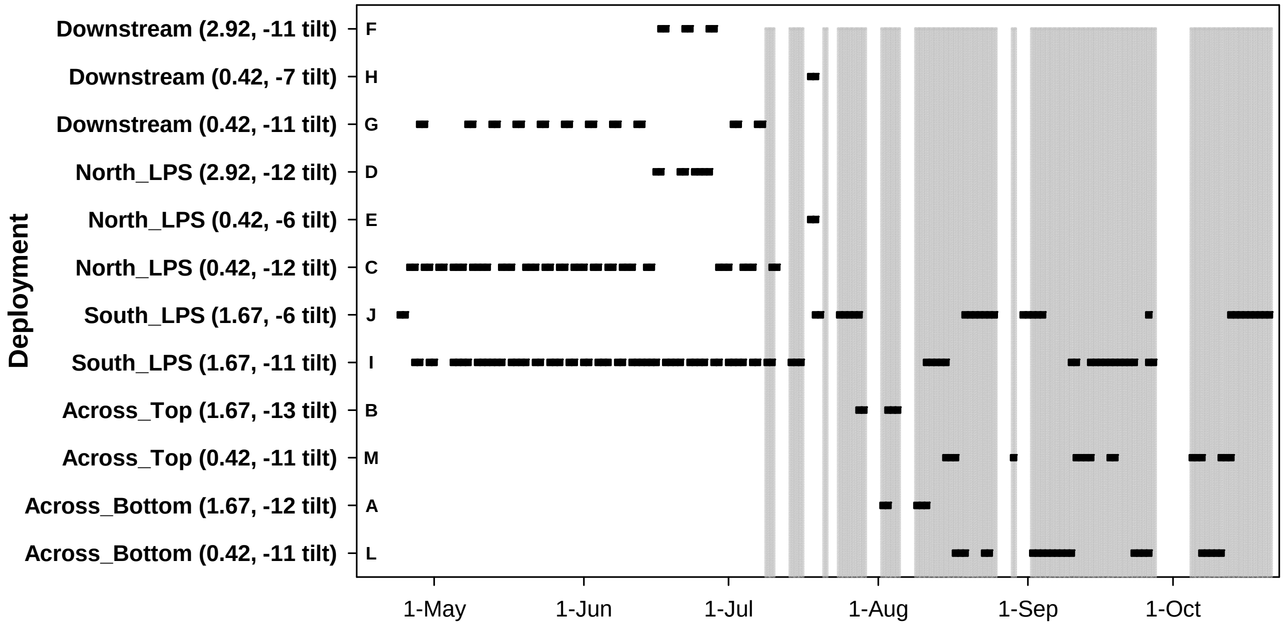

Figure 8. Distributions of dates for all DIDSON deployments from 21 April to 21 October near the UMTJ-LPS in the WA-shore fishway at Bonneville Dam in 2017. Camera start length (m) and average tilt (° from horizontal) shown in parentheses. Vertical gray bars are on dates when fish imagery was rated a 2 or "normal". Note that deployment changes occurred during the day and so there is apparent overlap on dates with changes.

DIDSON image quality evaluation

We randomly subsampled and reviewed DIDSON files from throughout the data collection period, and classified the image quality of visible structures including the LPS structures, the bulkhead at the UMT junction (downstream deployment), the fishway walls, and adult fish (Figure 9). Visibility of structures was rated in four categories: not visible (0), poor (1), visible (2), and excellent (3). Fish imagery was classified as "poor" with no fish visible or fish shadows only (0), "fair" with fish shadows and some fish visible (1), and "good" with all fish visible (2) (Table 2). Images were only viewed and scored for data summaries if the visibility of structures was rated visible (2) or excellent (3) and fish imagery was at least a (1) or (2). Among this subset of higher quality files, we scored randomly-selected files from each deployment.

DIDSON review and analysis

Raw data files were processed by trained UI fisheries staff using DIDSON v5.25.25 software (Sound Metrics Corp., Lake Forest Park, WA). We previously established several criteria to aid in the identification of adult Pacific lamprey versus other species in DIDSON imagery (Kirk et al. 2015; Keefer et al. 2017), including:

1. *Lamprey exhibit anguilliform swimming motion, as opposed to the subcarangiform motion of salmonids (*Oncorhynchus *spp.) and American shad (*Alosa sapidissima*). In particular, the wavelength relative to the body length of swimming lamprey was shorter in lamprey than in salmonids or shad. A full waveform was often visible in lamprey but only one half a waveform was visible in salmonids and shad. In other words, lamprey frequently appeared s-shaped, while salmonids and shad appeared c-shaped.*

2. *Target shape, including length:width ratio and lack of protruding fins*.

3. *Lamprey target size of ~50-80 cm; this criterion was less used as diagnostic given the substantial overlap with adult salmonid target size.*

4. *Other characteristic lamprey behaviors such as attachment to surfaces.*

Once a fish was identified, we used tools in the Sound Metrics software to measure the image range (distance from camera) and image angle (location in the horizontal plane in standard mode) with respect to the DIDSON. Range and angle were recorded for the first and last image of each individual salmonid/lamprey target that was included in the individual tracks summary. Viewers also recorded salmonid/lamprey heading (i.e., facing upstream or facing downstream), and – for lamprey – whether they attached to substrate and the attachment location. We also recorded details of the DIDSON file (filename, site, file date, review rate [frames/sec], review date). Review rates ranged from 6-10 frames/sec. Display threshold and intensity settings were manually adjusted to optimize the contrast of the fish targets. Data for each salmonid/lamprey track were entered into spreadsheets and events recorded by all viewers were compiled into a master database. Day and night were assigned to each file based on sunrise and sunset times April through October (https://sunrise-sunset.org/us/north-bonneville-wa). Test files, files less than or longer than 10 min (generally transition files between deployments), and files where the camera malfunctioned were excluded from the review.

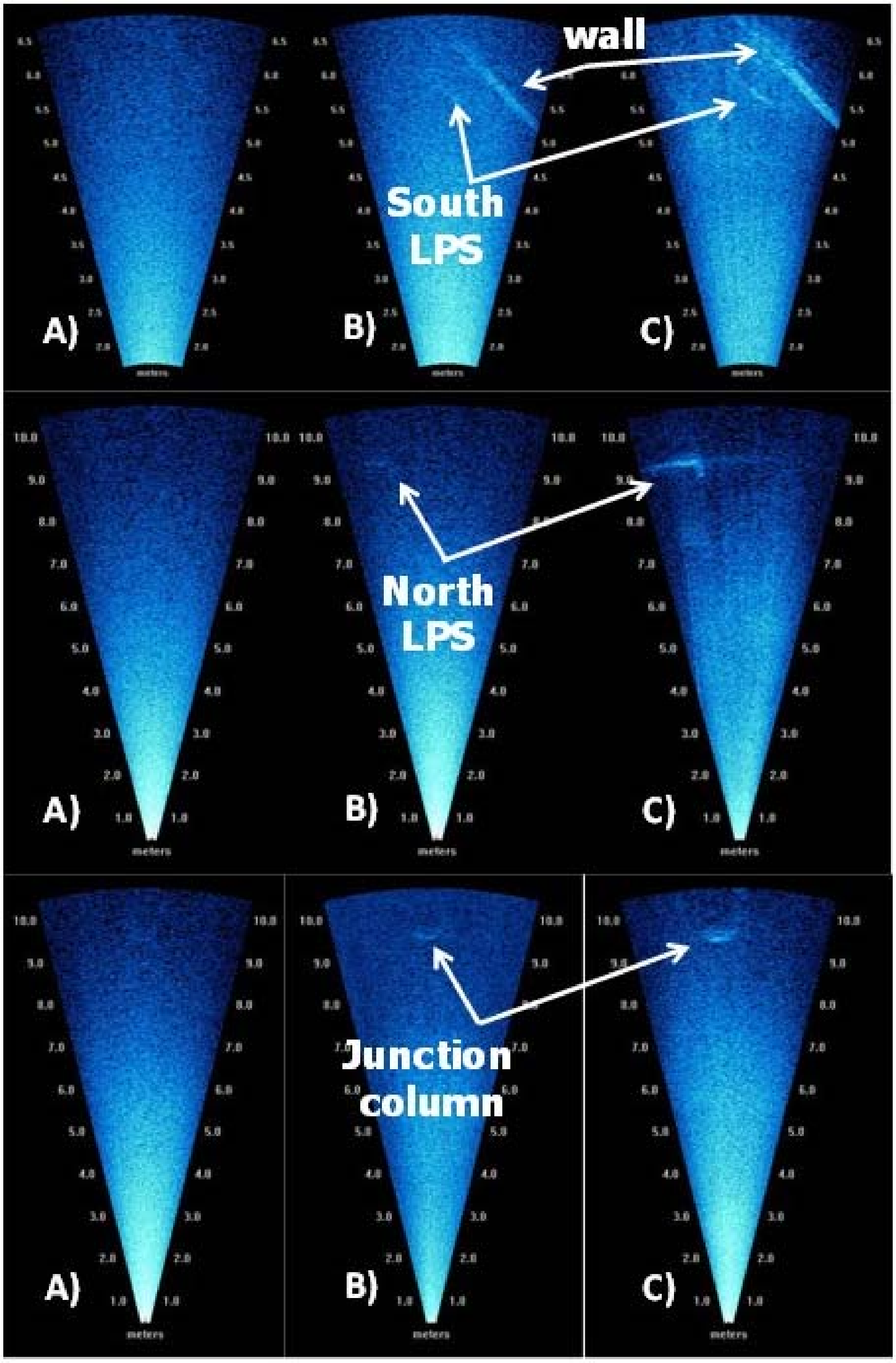

Figure 9. DIDSON images showing structure visibility of the South LPS (top panel), North LPS (middle panel) and downstream (bottom panel) deployments. Visibility categories of not visible (A), poor (B), and visible (C) examples are shown at three deployment locations in 2017.

DIDSON scoring for the adult salmonid objectives used two methods. First, to estimate relative abundance (i.e., an index of abundance) through the seasons and over diel cycles, we enumerated all adult salmonid-sized targets in the first 2 min of each randomly-selected daytime file. Second, to characterize behaviors near the UMTJ-LPS and in the quasi-control Across deployments, we scored individual focal fish at pre-set times in each 10-min file. Files were divided so that 10 focal fish would be sampled (e.g., the focal fish were the first fish observed entering the sample volume at frames 400, 800, 1200, 1600, etc.). Fish location at the start and end of each track, fish orientation, and track duration were recorded for each individual. Any adverse reactions (e.g., turn-arounds near the UMTJ-LPS, apparent startle responses, etc.) were noted in a comments field.

Pacific lamprey scoring was limited to randomly-selected nighttime files. As with the salmonid scoring, the numbers of upstream and downstream events in the first two minutes in each 10 min file were recorded and more detailed scores were collected for focal lamprey sampled at designated frames as described for focal salmon. Based on previous DIDSON studies, where there was considerable among-viewer variability in Pacific lamprey scoring, we had viewers rank their confidence in each event (see Johnson et al. 2012b, 2013 and Keefer et al. 2017 for details). ‘High’ confidence was assigned to events that met most or all of the lamprey identification criteria described above. ‘Medium’ confidence was assigned to events that had one or two of the characteristics, and ‘low’ confidence was assigned to events that were potentially lamprey but had few conclusive characteristics. These scores were necessarily qualitative given considerable variability in the time lamprey were in the field of view (i.e., often < 1 sec; <10 frames), the number of other fish present, and image differences related to the image quality and orientation of lamprey to the camera.

Comparisons of fish behavior among deployments were also qualitative as there was no true control condition and the ensonified area differed among deployments. We used the individual fish tracks to calculate passage times and to calculate the percentage of fish that turned around in each deployment. Turn-arounds were identified when a fish was oriented upstream at the beginning of a track but downstream at the end of a track (or vice versa). Some tracks started or ended ambiguously with regards to fish orientation, including when fish moved laterally or vertically out of the ensonified area. These outcomes were scored as ‘other’ rather than turn-arounds. We also used track start and end points to graph straight-line vectors of the routes fish used to pass through each deployment, which provided an indication of where fish were moving upstream and downstream in the fishway and in relation to the LPS.

Optical video to assess potential salmonid jumping near the UMTJ-LPS

Optical cameras (high resolution 800 $^+$ TVL, Foscam Digital Technologies, Houston, TX) were mounted to the conduit on the north wall just upstream from the DIDSON I-beam to monitor the surface water near each UMTJ-LPS ramp. Video was stored on a digital video recorder (DVR; 960H Amcrest, Foscam Digital Technologies) that was placed in a waterproof container on the deck near the north wall. The video was collected to check for potential adult salmonid jumping or otherwise reacting to the discharge on the UMTJ-LPS ramps. Jumping behavior has been reported at other discharge point sources in FCRPS fishways, typically by adult steelhead. Video was recorded during the expected peak of the steelhead run at Bonneville Dam (3-15 August) from 0500 to 2000 h each day. We reviewed randomly-selected 10-min daytime video files from each deployment (north and south, Figure 10) and recorded all fish observations.

Figure 10. Optical camera screenshot images from optical video collected at: (A) the north UMTJ-LPS ramp, and (B) the south UMTJ-LPS ramp to monitor salmonid jumping behavior in the WA-shore fishway in 2017.

Results

Adult salmonid counts at the Washington-shore ladder

A total of 171,274 adult spring-summer Chinook salmon were counted at the adult count stations at Bonneville Dam from 15 April through 31 July and 65% (111,267) passed the WA-shore station (Figure 11A). The 2017 spring-summer Chinook salmon total count was 70% of the 10-year average and the run arrived later than average. The 2017 WA-shore Sockeye salmon (*O. nerka*) count (46,744) was 53% of the total Sockeye salmon count at Bonneville Dam (87,686) between 1 May and 03 September (Figure 11B). The total Sockeye salmon count in 2017 was 28% of the 10 year average (315,131).

A total of 317,247 adult fall Chinook salmon were counted passing Bonneville Dam from 1 August to 30 November and 66% (209,506) passed the WA-shore station (Figure 12A). The 2017 fall Chinook salmon count was 61% of the 10-year average and peaked later than average. The 2017 WA-shore steelhead count (67,236) was 58% of the total steelhead count at Bonneville Dam (114,961) from 15 April to 31 October (Figure 12B). The total steelhead count in 2017 (114,961) was 35% of the 10-year average (327,393).

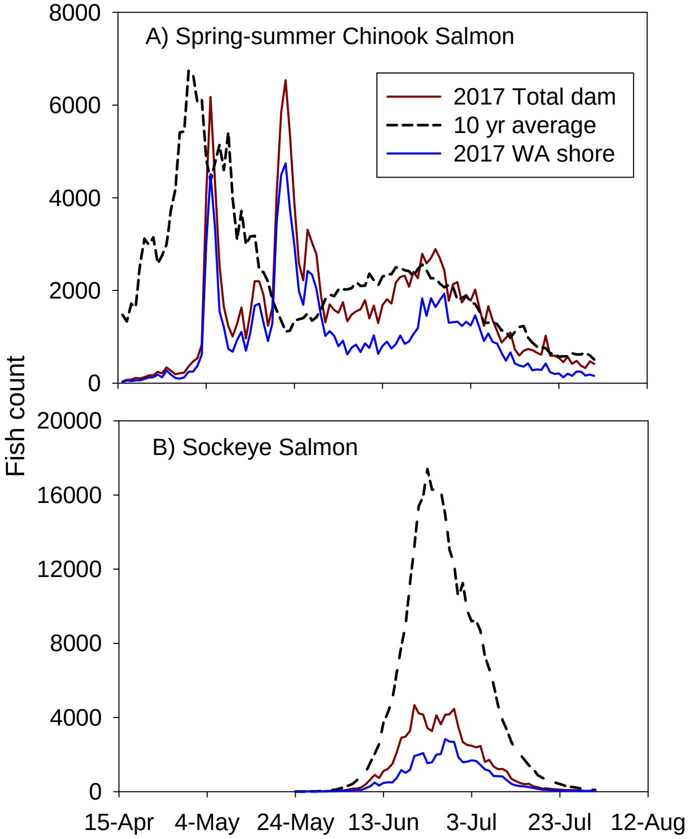

Figure 11. Total counts of: (A) Spring-summer Chinook salmon and (B) Sockeye salmon in 2017 at Bonneville Dam and the WA-shore count station and the 10-year average counts (2007-2016). Data were collected from http://www.cbr.washington.edu/dart/query/adult_daily and http://www.fpc.org/environment/home.asp.

Adult Pacific lamprey counts at the Washington-shore ladder

A total of 165,012 adult Pacific lamprey were counted passing the WA-shore fishway and the AWS-LPS at Bonneville Dam in 2017 from 1 May until 31 October. Twenty-five percent passed the ladder during the day, 21% passed the ladder at night, and 54% passed the AWS-LPS (day & night) (Figure 13A). The 2017 WA-shore day count was 169% of the 10 year average (24,309) (Figure13B). The total WA-shore count (day, night, & AWS-LPS) was 57% of the 2017 total dam-wide count (290,475) (Figure 13C).

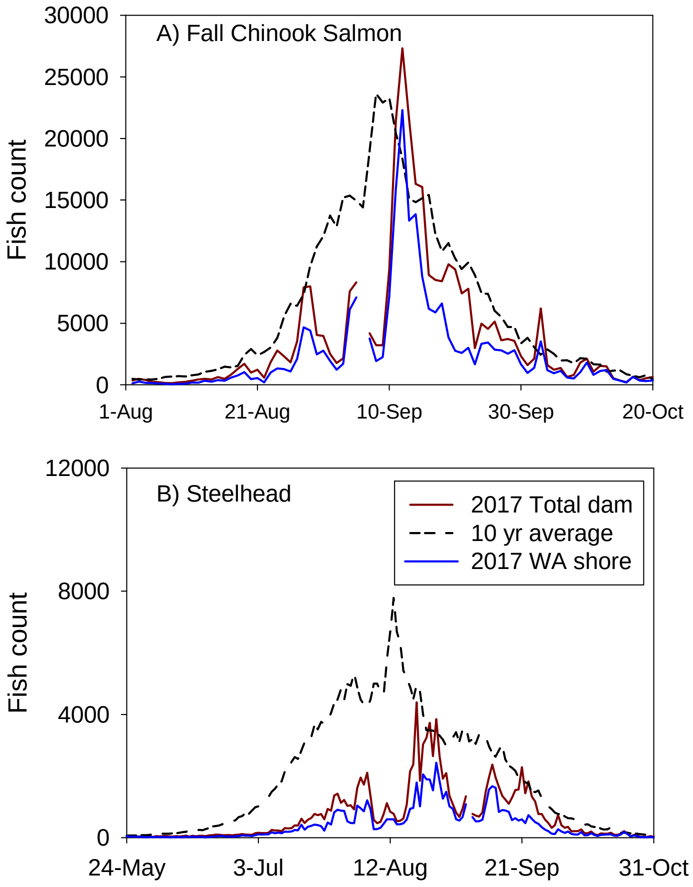

Figure 12. Total counts of: (A) Fall Chinook salmon and (B) steelhead in 2017 at Bonneville Dam and the WA-shore count station and the 10-year average counts (2007-2016). Data were from http://www.cbr.washington.edu/dart/query/adult_daily and http://www.fpc.org/environment/home.asp.

2017 Environmental conditions

Average daily Columbia River discharge in 2017 from April through June was 108 kcfs higher than the 10-year average (Figure 14B). Along with the high discharge in 2017, turbidity was also very high in April, May, June, and part of July. Secchi disk visibility (April-June) was 1.5 feet (0.46 m) lower, on average, then the 10-year average (4.4 ft, 1.34 m) during that same time period (Figure 14C). The maximum difference in Secchi disk visibility between 2017 and the 10-year average was on 4 June at 2.4 ft (0.73 m). In 2017, water temperatures peaked at Bonneville Dam on 10 August at 23.2 °C, which was 1.6 °C warmer than the 10-year average maximum daily temperature from 15 April to 31 October (Figure 8A).

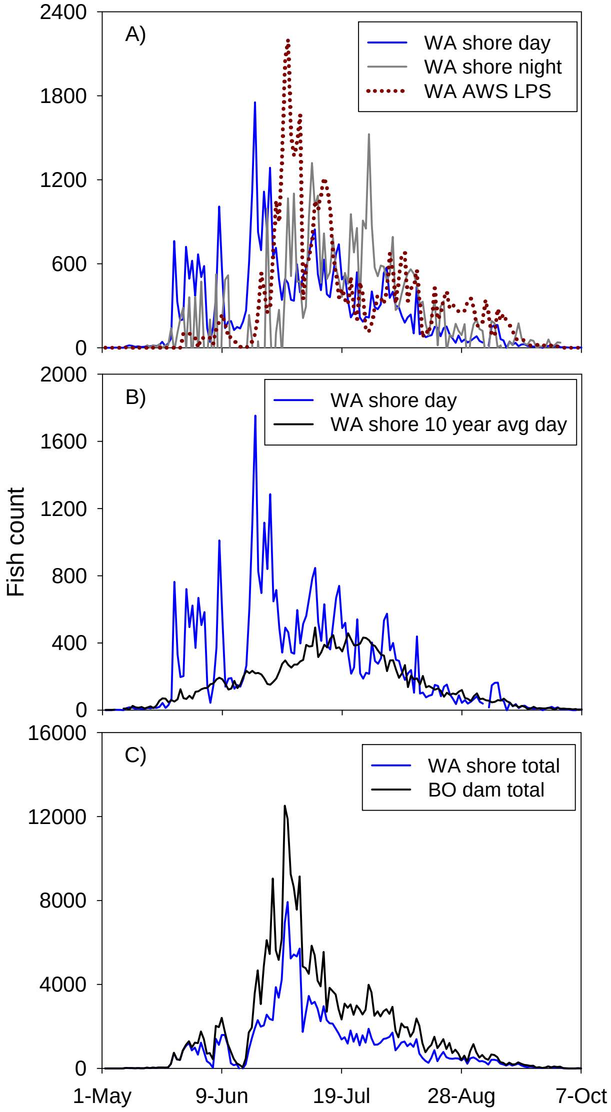

Figure 13. Pacific lamprey counts at the Bonneville WA-shore fishway by: (A) 2017 day, night, and AWS-LPS, (B) 2017 day and 10-year average counts, and (C) 2017 WA-shore total count and Bonneville Dam total count. Data were collected from http://www.cbr.washington.edu/dart/query/adult_daily and http://www.fpc.org/environment/home.asp. Note corrected WA-shore AWS-LPS and Bonneville Dam total counts were used per N. Zorich (30-Dec-17, USACE).

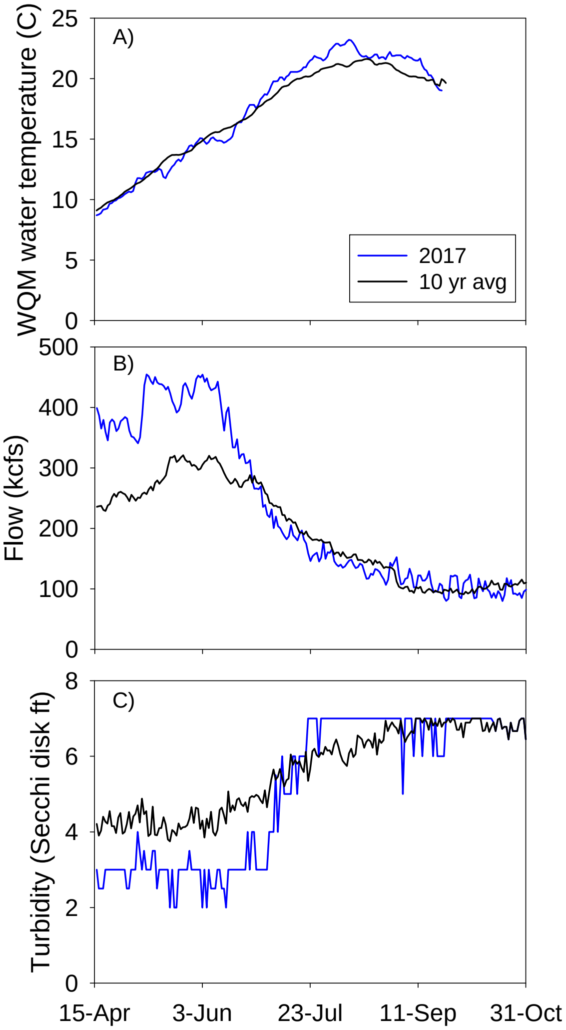

Figure 14. Environmental conditions at Bonneville Dam in 2017 showing A) temperature recorded at the WQM site, B) total flow and C) turbidity (Secchi disk visibility in ft) and the 10-year averages (2007-2016). Data were collected from http://www.cbr.washington.edu/dart/query/river_daily and http://www.nwdwc.usace.army.mil/dd/ common/dataquery/www/

DIDSON data quality assessment

Very high turbidity during spring and early summer resulted in severely degraded DIDSON image quality for several weeks due to a combination of acoustic backscatter and silt filling the DIDSON casing (daily cleaning was required for several weeks). No ‘good’ fish imagery was recorded in April-June (Table 2). At the LPS_South deployment, fish imagery was rated as normal or good for 47% of the data collection period. Data from the Downstream and LPS_North deployments were very low quality, even after turbidity started to decrease in mid-summer, and these deployments were terminated. All data (100%) were considered ‘normal’ for both Across deployments, reflecting the timing of those deployments after turbidity declined substantially and more favorable viewing angles relative to fish position (Table 2). All DIDSON imagery was considered good quality at the South_LPS and Across deployments from August through October.

Table 2. Numbers and percentages of the DIDSON files classified by the quality of fish imagery and grouped by month and deployment in 2017.

Month/location	Fish Imagery Poor (0)	 Fair (1)	 Good (2)
April	698 (89%)	88 (11%)	-
May	2,629 (69%)	1,165 (31%)	-
June	1,644 (39%)	2,537 (61%)	-
July	-	1,849 (65%)	1,007 (35%)
August	-	-	2,426 (100%)
September	-	-	3,517 (100%)
October	-	-	1,108 (100%)
Downstream	1,003 (44%)	1,267 (56%)	-
LPS_North	2,282 (55%)	1,858 (45%)	-
LPS_South	1,686 (21%)	2,514 (32%)	3,708 (47%)
Across_Top	-	-	1,541 (100%)
Across_Bottom	-	-	2,809 (100%)

DIDSON data collection and review effort

From 24 April through 21 October 2017, a total of 7,857 day files (salmonids) and 5,840 night files (Pacific lamprey) were collected near the UMTJ-LPS. We reviewed 4.8% of the daytime files and 2.7% of the nighttime files collected from April to October (Table 3). Among individual deployments, we reviewed 3-8% of daytime files except proportionately more files (20%) were reviewed for one of the Across_Top deployments (Table 4). Nighttime files were reviewed for the South_LPS and Across deployments, with 2-15% viewed for the three deployments (Table 4). Scoring was pooled across tilt angles and camera start angles within deployment for all data summaries.

Table 3. Number and percentage of DIDSON files watched during the day and night by month in 2017.

Month	Salmonids (daytime) # of files	 # of files watched	 % of files watched	Lamprey (nighttime) # of files	 # of files watched	 % of files watched
April	52	4	7.7	36	0	-
May	737	56	7.6	428	0	-
June	1606	60	3.7	931	0	-
July	1770	63	3.6	1086	45	4.1
August	1385	60	4.3	1041	45	4.3
September	1801	95	5.3	1716	70	4.1
October	506	0	-	602	0	-
Total	7857	338	4.3	5840	160	2.7

Table 4. Number and percentage of DIDSON files watched during the day and night by DIDSON deployment and deployment code (Dep.) in 2017.

		Salmonids (daytime)			Lamprey (nighttime)		
Deployment	Dep.	# of files	# of files watched	% of files watched	# of files	# of files watched	% of files watched
Downstream	F	225	13	5.8	151	0	-
	H	197	5	2.5	158	0	-
	G	351	27	7.7	185	0	-
North_LPS	D	182	11	6.0	100	0	-
	E	85	5	5.9	53	0	-
	C	919	38	4.1	519	0	-
South_LPS	J	811	44	5.4	601	45	7.5
	I	2855	90	3.2	1955	50	2.6
Across_Top	B	51	10	19.6	68	10	14.7
	M	724	40	5.5	698	15	2.1
Across_Bottom	A	265	15	5.7	172	15	8.7
	L	1192	40	3.4	1180	25	2.1

Index of adult salmonid activity near the UMTJ-LPS

The seasonal patterns in adult Chinook salmon and steelhead abundance as indexed by the daily WA-shore adult counts generally tracked total adult salmonid activity observed in the South_LPS DIDSON imagery, derived from the first 2 min of each reviewed file including both upstream and downstream movements (Figure 15; see Figures 11 and 12 for count data). Similarly, the DIDSON activity data from August-September at the South_LPS and both Across deployments reflected the surge in Fall Chinook salmon passage in mid-September (Figure 9). Salmonids were active in the scored DIDSON imagery throughout the daytime hours reviewed (Figure 16).

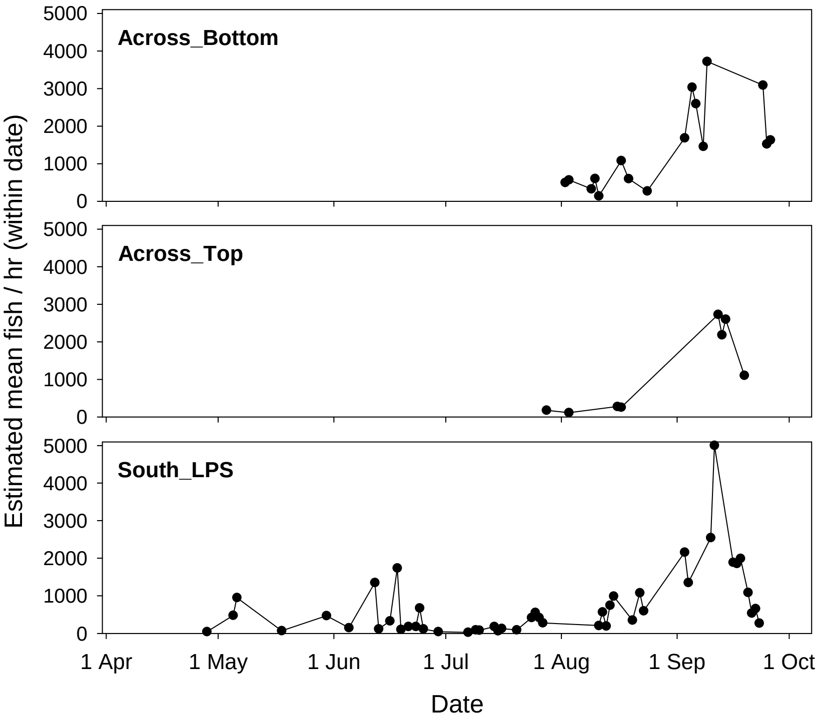

Figure 15. Expanded numbers of adult salmonids counted per hour in DIDSON files at the South_LPS and Across deployments near the UMTJ-LPS in 2017. Estimates were expanded from the first two minutes of each reviewed file to fish/h for each day and included fish movements in all directions. Note: the Across deployments did not begin until late July.

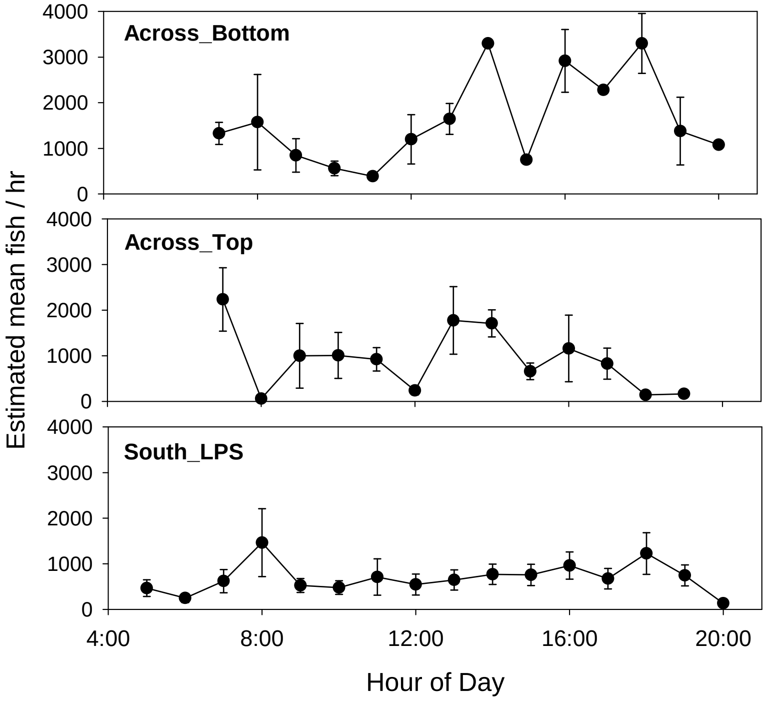

Figure 16. Expanded numbers (± SE) of adult salmonids counted per hour in DIDSON files at the Across and South_ LPS deployments near the UMTJ-LPS in 2017. Estimates were expanded from the first two minutes of each reviewed file to fish/h for each hour across all dates and included fish movements in all directions.

Adult salmonid orientation and turn-around near the UMTJ-LPS

We scored a total of 1,772 adult salmonid tracks in the three deployments with good DIDSON imagery (Table 5). Proportionately more fish were oriented upstream for their entire track (Up-Up) in the Across_bottom (71.4%) than in the Across_top (54.5%) or South_LPS (66.0%) deployments. Very few fish initially moved upstream and then turned around during their track, at 0.6-1.3% of the tracks in each deployment. Downstream movement was most frequently observed in the Across_top imagery, at 42.1% of all tracks; this may indicate that many fish moved upstream near the fishway floor but moved downstream closer to the water surface. Among the subset of fish tracks that started with upstream orientation (Table 6), from 0.0-4.0% turned around during the track and moved downstream with relatively little variability across the study period. Ambiguous orientations at the end of a track (i.e., fish oriented laterally or moving out of the ensonified area) were more common in the South_LPS imagery than in the Across imagery, due in part to the larger and obliquely-imaged volume in the South_LPS deployment.

Adult salmonids generally moved upstream and downstream in each deployment and exited the field of view with almost no fish stopping and holding position during the day (Figures 17-19). However, we did observe some salmonids holding position at night in all three deployments during our review of lamprey behavior. Salmonids moving upstream tended to favor routes close to the south fishway wall in the Across_top and South-LPS deployments. Those with routes in close proximity to the UMTJ-LPS (within ~1 m) moved around the structure with essentially no delay. Downstream movements were more directed than upstream movements, on average, and were distributed across a larger portion of the fishway (Figure 17-19).

Table 5. Numbers of adult salmonid tracks scored in the Across and South_LPS DIDSON deployments and the percentages of fish that were oriented upstream (Up) and downstream (Down) at the beginning and end of each track.

	Events	Fish orientation at start and end of event				
Deployment	(*n*)	Up-Up	Up-Down	Down-Down	Down-Up	Other[1]
Across_bottom	503	71.4%	0.6%	27.4%	-	0.6%
Across_top	378	54.5%	1.3%	42.1%	0.6%	1.6%
South_LPS	891	66.0%	1.1%	23.6%	0.1%	6.7%

[1] Other = lateral or ambiguous orientation direction at start or end of track

Table 6. Monthly numbers of adult salmonid tracks scored in the Across and South_LPS DIDSON deployments where fish were initially oriented upstream and the percentages of fish that were oriented upstream (Up) and downstream (Down) at the beginning and end of each track.

Month	Deployment	Events (n)	Fish orientation at start and end of event Up-Up	 Up-Down	 Up-Other[1]
April	South_LPS	7	85.7%	0.0%	14.3%
May	South_LPS	78	79.5%	1.3%	19.2%
June	South_LPS	93	89.2%	0.0%	10.8%
July	Across_top	21	85.7%	4.8%	9.5%
	South_LPS	156	96.2%	0.0%	3.8%
August	Across_bottom	131	97.7%	0.8%	1.5%
	Across_top	72	97.2%	2.8%	0.0%
	South_LPS	104	88.5%	4.8%	6.7%
September	Across_bottom	233	99.1%	0.9%	0.0%
	Across_top	120	98.3%	1.7%	0.0%
	South_LPS	203	96.1%	2.0%	2.0%

[1] Other = lateral or ambiguous orientation direction at end of track

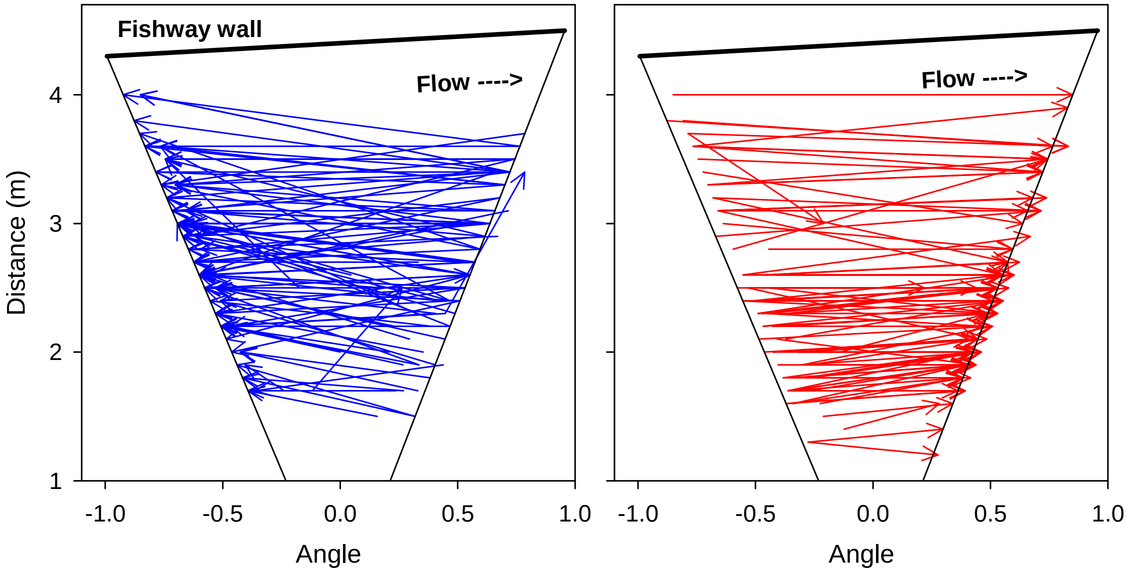

Figure 17. Straight-line vectors of randomly-selected adult salmonid tracks from the Across_bottom deployment where fish were initially oriented upstream (left, n = 100) or downstream (right, n = 100).

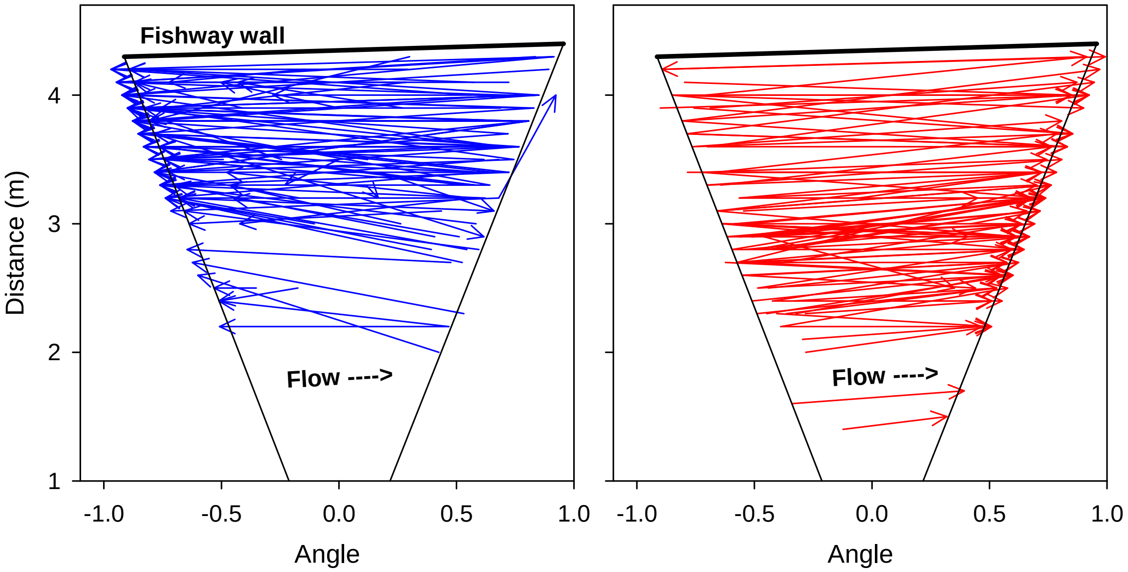

Figure 18. Straight-line vectors of randomly-selected adult salmonid tracks from the Across_top deployment where fish were initially oriented upstream (left, *n* = 100) or downstream (right, *n* = 100). FOV margins are approximate.

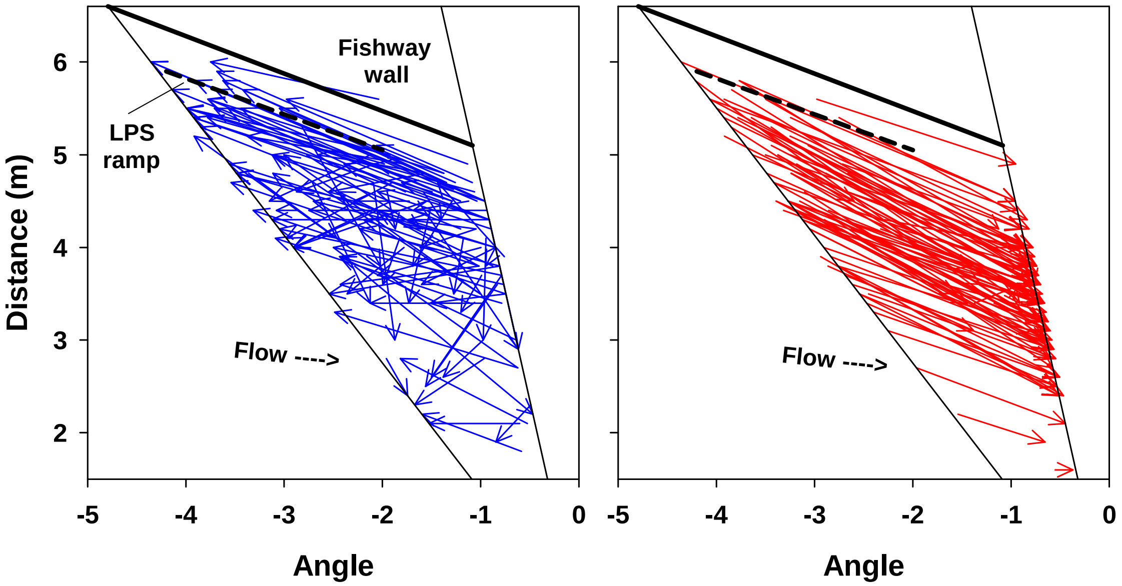

Figure 19. Straight-line vectors of randomly-selected adult salmonid tracks from the South_LPS deployment where fish were initially oriented upstream (left, *n* = 100) or downstream (right, *n* = 100). Dashed line represents the approximate location of the South_LPS ramp. FOV margins are approximate.

Adult salmonid track duration near the UMTJ-LPS

Track duration was similar across deployments for fish moving upstream and downstream. The fish that were initially oriented upstream had average track durations ranging from 2.8-3.4 s (SD = 2.8-

5.0 s) and very few tracks lasted >10 s (Figure 20). The rapid upstream movement near the LPS and in the quasi-control deployments suggests that the LPS did not appreciably slow adult salmonid passage. There was also very little seasonal variation in upstream passage times. Linear regressions of date×time showed little relationship in the Across_bottom ($r^2 = 0.02$, $P > 0.05$, $n = 327$), Across_top ($r^2 = 0.03$, $P > 0.05$, $n = 212$), or South_LPS data ($r^2 = 0.01$, $P > 0.05$, $n = 557$, 1 outlier [1:42 min] excluded). Fish that were initially oriented downstream moved faster than upstream-moving fish, with average downstream track durations ranging from 0.9-1.8 s (SD = 1.0-7.1 s; a single 1:41 min track inflated the SD estimate). Linear regression results were: Across_bottom ($r^2 = 0.00$, $P > 0.05$, $n = 138$), Across_top ($r^2 = 0.03$, $P > 0.05$, $n = 163$, 1 outlier [27 sec] excluded), or South_LPS data ($r^2 = 0.06$, P. 0.05, $n = 201$, 1 outlier [1:41 min] excluded).

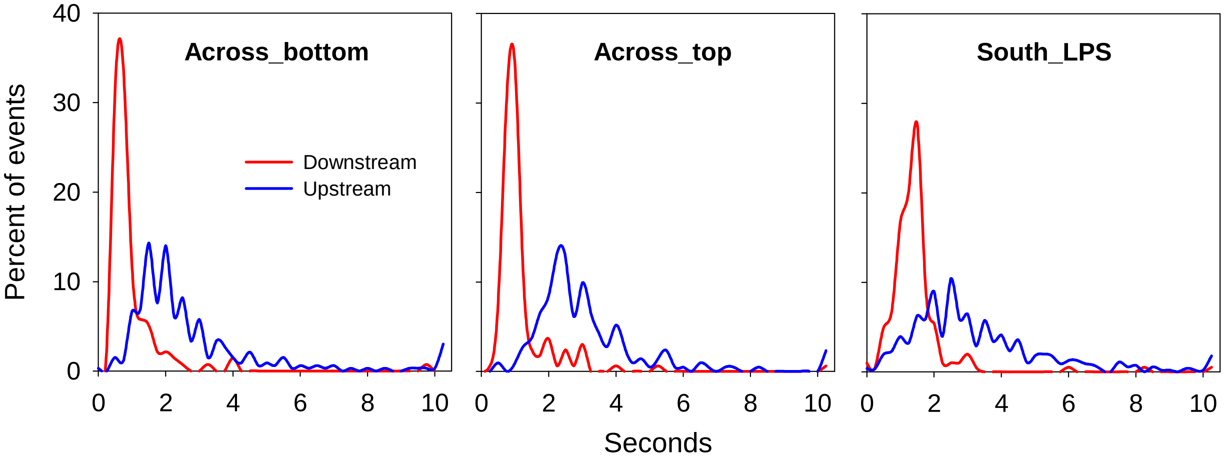

Figure 20. Histograms of the time (s) that adult salmonids were in the DIDSON field of view while moving upstream (blue) or downstream (red) in three deployments. Note that the ensonified volume was larger and fish tracks were longer in the South_LPS deployment than for the Across deployments.

Identification of adult lamprey near the UMTJ-LPS

A total of 865 lamprey tracks were scored and 859 were assigned confidence levels by DIDSON reviewers (Table 7). Large majorities (>95%) of the events in the two Across deployments were scored medium or high confidence regarding lamprey identification. In contrast, more than a third (37.1%) of the events scored in the South_LPS imagery was scored low confidence. The larger volume and upstream angle of the South_LPS deployment resulted in smaller (i.e., lower resolution) and sometimes foreshortened fish images, which reduced viewer confidence.

Table 7. Numbers of adult Pacific lamprey tracks scored from DIDSON imagery at the Across and South_LPS deployments, with reviewer confidence scores for lamprey identification.

Deployment	Total events (*n*)	Scored events (*n*)	Identification confidence score Low	Medium	High
Across_bottom	298	295	3.1%	51.9%	45.1%
Across_top	133	133	4.5%	36.8%	58.6%
South_LPS	434	431	37.1%	41.3%	21.6%

Index of adult lamprey abundance near the UMTJ-LPS

The index of lamprey abundance (activity) derived from the first 2 min of each reviewed file was highest in July and declined through August and September, with similar activity in all three deployments (Figure 21). These patterns paralleled the adult Pacific lamprey counts at the WA-shore fishway and AWS-LPS (see Figure 7). Lamprey data from nighttime hours only were reviewed, and fish were most active in the middle of the night, with relatively few fish counted near dusk and dawn (Figure 22).

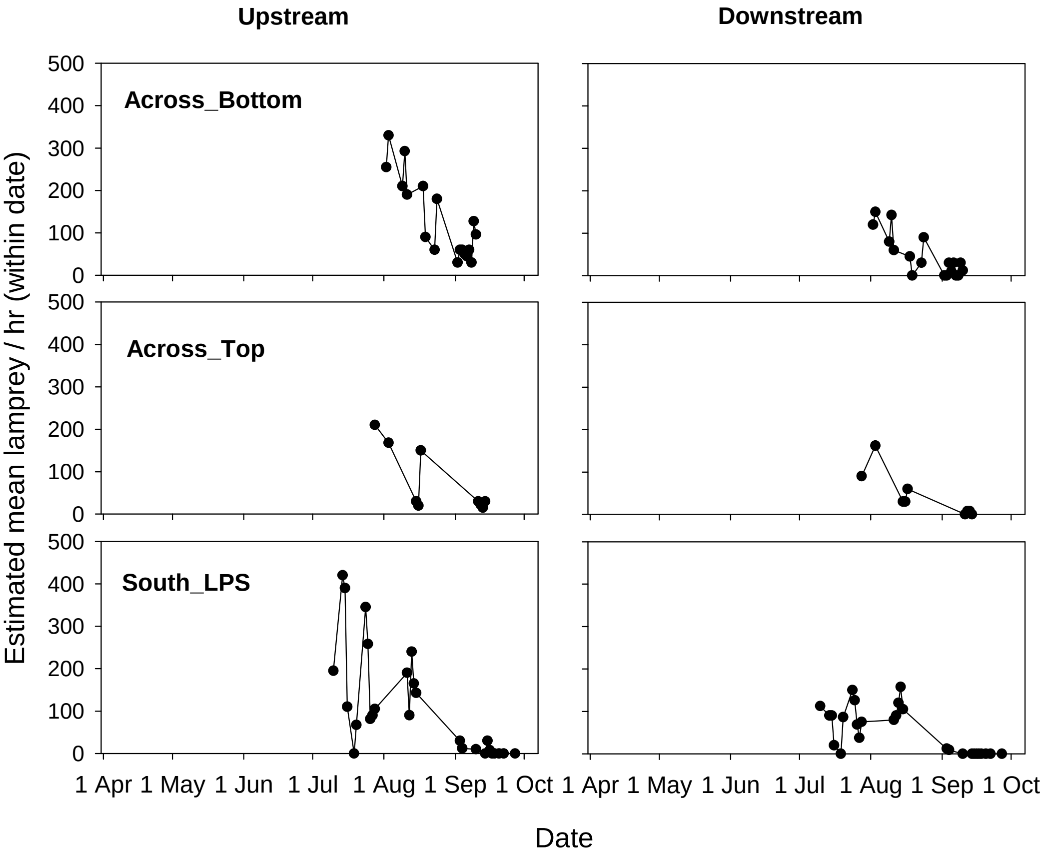

Figure 21. Expanded numbers of adult Pacific lamprey counted per hour in DIDSON files at the South_LPS and Across deployments near the UMTJ-LPS in 2017. Estimates were expanded from the first two minutes of each reviewed file to hourly fish/h for each day and included fish movements in all directions.

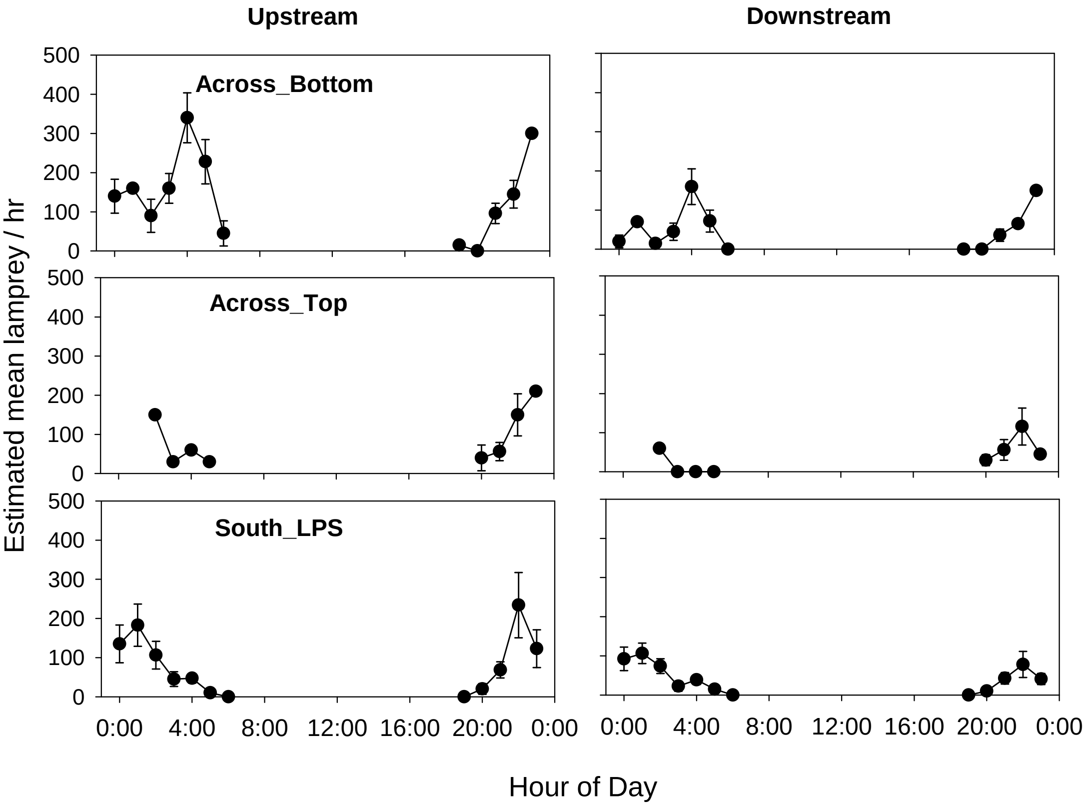

Figure 22. Expanded numbers (± SE) of adult Pacific lamprey counted per hour in DIDSON files at the Across and South_LPS deployments near the UMTJ-LPS in 2017 (nighttime only). Estimates were expanded from the first two minutes of each reviewed file to fish/h for each hour across all dates and included fish movements in all directions.

Adult lamprey orientation and turn-around near the UMTJ-LPS

A majority (~65-83%) of lamprey were oriented upstream for their entire track (Up-Up) in all three deployments (Table 8). Less than 1% of lamprey were initially moving upstream and then turned around during their track. About a quarter of the scored tracks were initially oriented downstream and remained oriented downstream (Down-Down); as with the salmonids, this result suggests that downstream-moving fish were more likely to be high in the water column relative to upstream-moving fish. Among the subset of fish tracks that started with upstream orientation (Table 9), from 0.0-3.2% turned around during the track and moved downstream. Ambiguous orientations at the end of a track (i.e., fish oriented laterally or moving out of the ensonified area) were more common in the South_LPS imagery than in the Across imagery, which was also consistent with the adult salmonid results.

Lamprey movement vectors (Figures 23-25) were broadly similar to those of adult salmonids. Lampreys moving upstream tended to favor routes close to the south fishway wall in the Across_top and South_LPS deployments and upstream movements were less direct in all deployments than were downstream movements. In the South_LPS tracks, many lamprey passed in close proximity (within ~1 m) to the south LPS ramp, but fish proceeded upstream past the ramp. We did not observe any lamprey definitively entering the UMTJ-LPS, but note that image quality may not have been sufficient to detect the behavior (see Figure 11).

Table 8. Numbers of Pacific lamprey tracks scored in the Across and South_LPS DIDSON deployments and the percentages of fish that were oriented upstream (Up) and downstream (Down) at the beginning and end of each track.

	Events	Fish orientation at start and end of event				
Deployment	(*n*)	Up-Up	Up-Down	Down-Down	Down-Up	Other[1]
Across_Bottom	298	83.2%	0.3%	13.8%	0.3%	2.3%
Across_Top	133	69.9%	0.8%	27.8%	0.0%	1.5%
South_LPS	434	64.7%	0.7%	27.0%	0.0%	7.6%

[1] Other = lateral or ambiguous orientation direction at start or end of track

Table 9. Monthly numbers of Pacific lamprey tracks scored in the Across and South_LPS DIDSON deployments where fish were initially oriented upstream and the percentages of fish that were oriented upstream (Up) and downstream (Down) at the beginning and end of each track.

		Events	Fish orientation at start and end of event		
Month	Deployment	(*n*)	Up-Up	Up-Down	Up-Other[1]
July	Across_Top	31	96.8%	3.2%	0.0%
	South_LPS	185	94.1%	0.5%	5.4%
August	Across_Bottom	171	100.0%	0.0%	0.0%
	Across_Top	41	100.0%	0.0%	0.0%
	South_LPS	73	91.8%	2.7%	5.5%
September	Across_Bottom	85	90.6%	1.2%	8.2%
	Across_Top	23	95.7%	0.0%	4.3%
	South_LPS	42	95.2%	0.0%	4.8%

[1] Other = lateral or ambiguous orientation direction at end of track

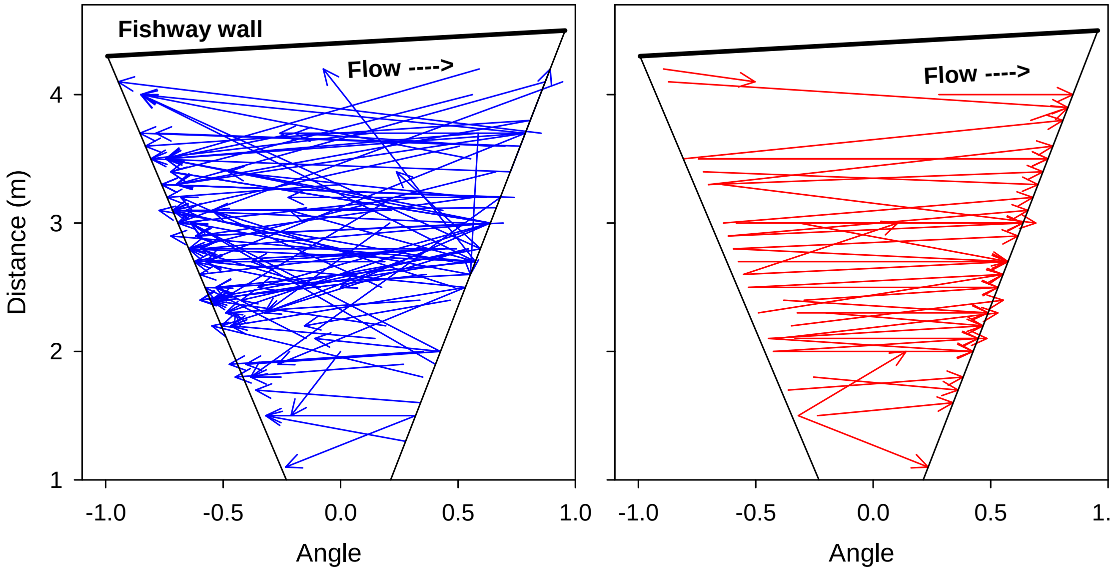

Figure 23. Straight-line vectors of randomly-selected Pacific lamprey tracks from the Across_bottom deployment where fish were initially oriented upstream (left, *n* = 100) or downstream (right, *n* = 42).

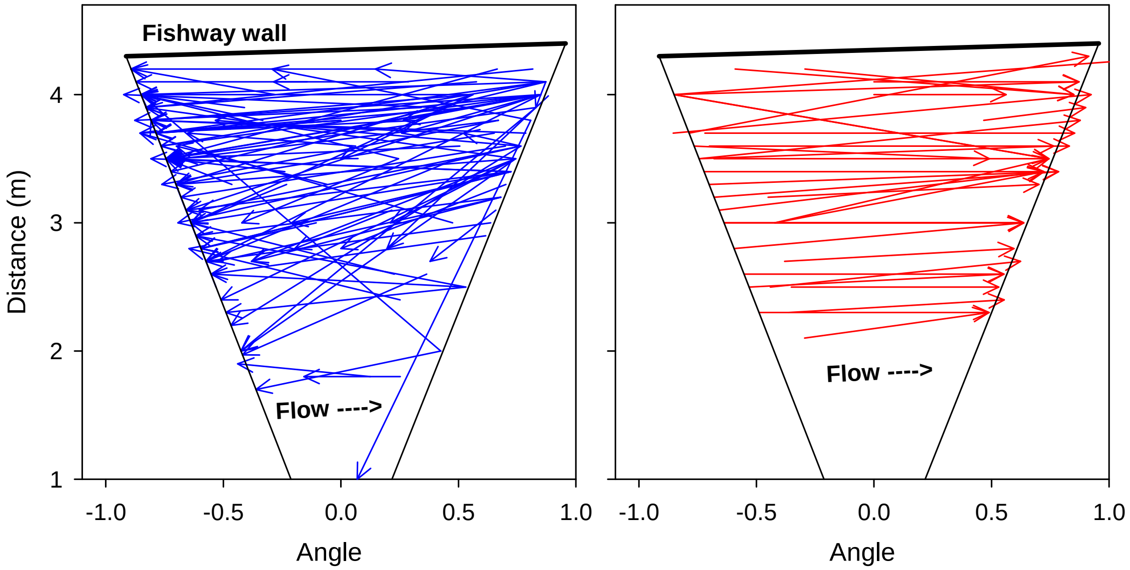

Figure 24. Straight-line vectors of randomly-selected Pacific lamprey tracks from the Across_top deployment where fish were initially oriented upstream (left, *n* = 95) or downstream (right, *n* = 34).

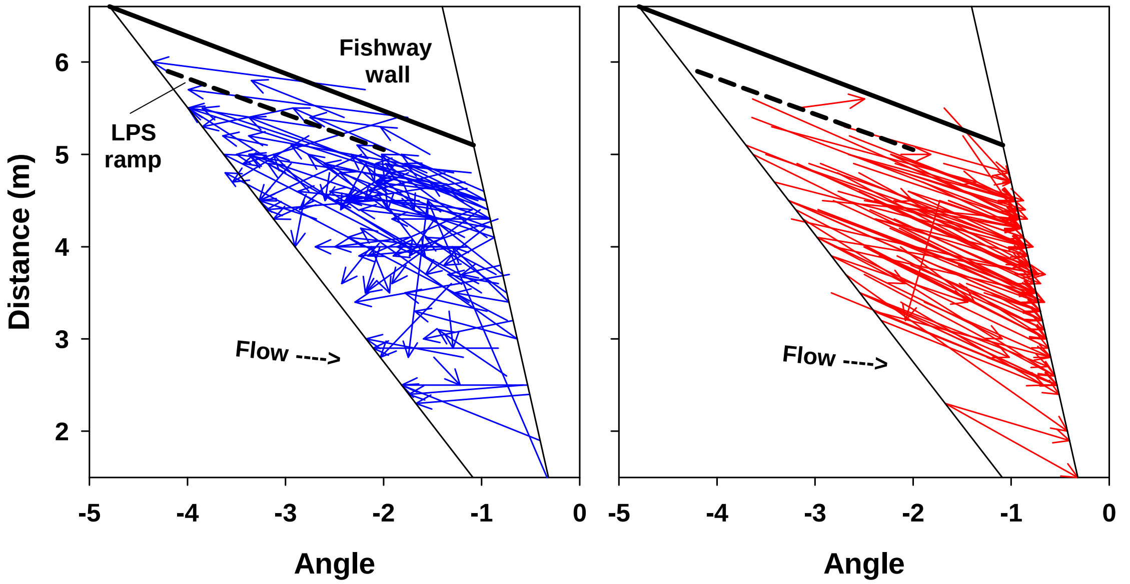

Figure 25. Straight-line vectors of randomly-selected Pacific lamprey tracks from the South_LPS deployment where fish were initially oriented upstream (left, *n* = 100) or downstream (right, *n* = 98). Dashed line represents the approximate location of the South_LPS ramp.

Adult lamprey track duration near the UMTJ-LPS

Track duration was similar across deployments for lampreys moving upstream and downstream and closely paralleled results for salmonids. The lamprey that were initially oriented upstream had average track durations ranging from 1.5-2.9 s (SD = 2.1-5.5 s) and very few tracks lasted >10 s (Figure 26). Fish that were initially oriented downstream moved faster than upstream-moving fish, with average downstream track durations ranging from 1.0-1.3 s (SD = 0.5-1.8 s).

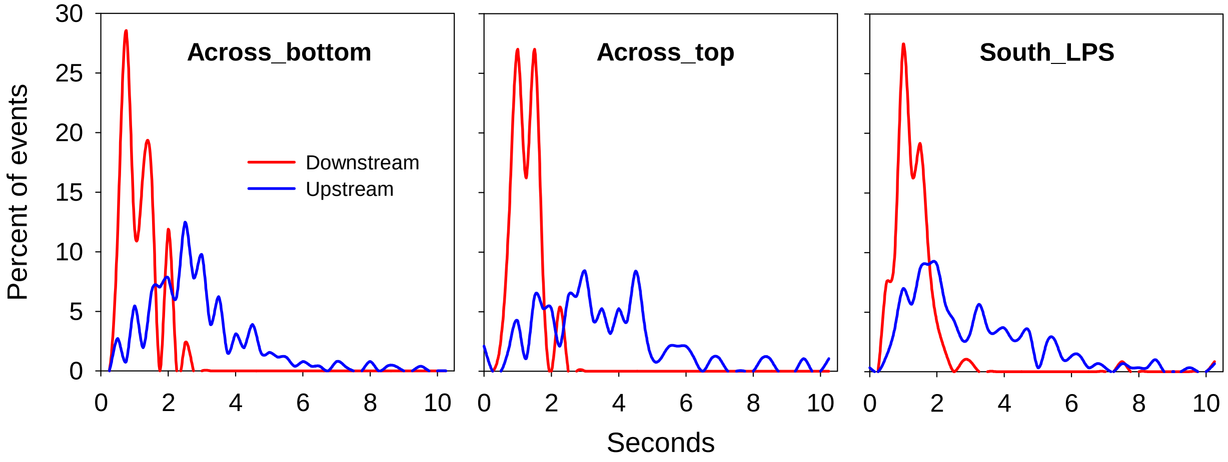

Figure 26. Histograms of the time (s) that adult Pacific lampreys were in the DIDSON field of view while moving upstream (blue) or downstream (red) in three deployments. Note that the ensonified area was larger and fish tracks were longer in the South_LPS deployment than for the Across deployments.

Optical video review of potential salmonid jumping near the UMTJ-LPS

We reviewed a total of 50 randomly-selected 10-min files (8.33 h) from the two optical camera deployments. Reviewed files were on all dates from 3 August to 15 August. No adult salmonids were observed jumping near the UMTJ-LPS ramp and none were observed jumping in the camera field of view in either deployment. A total of 5 presumed adult salmonids were observed swimming under the water surface, but their behaviors did not appear to be affected by the ramps. We also note that no adult salmonids were observed jumping near the ramps during frequent (several times per week) visits to the site by UI personnel for DIDSON maintenance from May to October.

Discussion

Adult salmonids

Installation and operation of any structure inside an adult fishway at a FCRPS dam has the potential to affect upstream passage of all fish species, including adult salmonids (*Oncorhynchus spp.*) protected under the U.S. Endangered Species Act. The primary rationale for this study was to evaluate whether passage of adult salmonids through the WA-shore fishway at Bonneville Dam was affected by the installation of the UMTJ-LPS. DIDSON was an effective, non-invasive tool for monitoring and evaluating the behaviors of adult salmonids and adult Pacific lamprey near the UMTJ-LPS, but only during the second half of the monitoring period. Unusually high turbidity during spring and early summer resulted in severely degraded DIDSON image quality for several weeks. These conditions precluded effective DIDSON sampling during the spring Chinook salmon run and early portions of the summer Chinook salmon and sockeye salmon runs at Bonneville Dam.

We found no compelling evidence that the UMTJ-LPS resulted in passage delays or substantively altered behaviors of adult salmonids from mid-July to the end of October, the period when good quality DIDSON imagery was collected. Salmonid activity in the DIDSON deployments paralleled the adult abundance estimates from the Washington-shore count station. Salmonids also consistently moved rapidly upstream past the UMTJ-LPS at all times of the day and we observed almost no clear ‘startle’ or aversive reactions by fish that passed in close proximity to the LPS ramps. Instead, almost all upstream-moving salmonids that passed close to the ramps simply moved around the ramps without slowing or stopping. We note that many salmonids were also recorded moving downstream, sometimes in large groups. The initiation of these downstream movements was clearly upstream from the UMTJ-LPS ramps, suggesting that fish may have turned around near the AWS picket lead or the adult count station. Some upstream-moving salmonids were also observed turning around in the South_LPS deployment field of view, but the percent of individuals with this behavior was low and was very similar to percentages in the quasi-control deployments located downstream. Furthermore, turn-arounds observed in the South_LPS deployment were distributed throughout the field of view and were not noticeably more frequent for fish that passed close to the LPS ramp.

One of the concerns before the DIDSON study was that the ramps would create hydraulic conditions that might attract some salmonids to hold position downstream from the structures. This did not occur, as we observed very little holding by adult salmonids near the UMTJ-LPS during the day. Some salmonids did slow or stop migration at night and held position in the field of view for longer periods in all of the DIDSON deployments. This behavior was expected based on previous radiotelemetry results showing greatly reduced adult salmonid activity inside fishways at night (Keefer et al. 2013c). We note that nighttime holding also did not appear to be associated with the UMTJ-LPS ramps as fish were distributed throughout the observed sections of the fishway channel, often with fish moving slowly upstream or downstream or repositioning in the field of view.

While we conclude that the UMTJ-LPS had no apparent negative effects on summer- and fall-migrating salmon and steelhead. It is possible that spring- and early summer-run migrants reacted differently. Colder water and much higher turbidity may have affected how the early runs moved past the ramps. However, we think large behavioral differences among seasonal runs were unlikely for several reasons. First, we observed nearly 900 individual salmonid tracks and several thousand additional salmonids passing the UMTJ-LPS during mid-summer and fall, including near dawn and dusk, and fish behaviors were remarkably consistent through time. This suggests that water temperature and low-light or reduced visibility did not strongly influence behaviors near the ramps. Second, the section of fishway between the UMT junction and the WA-shore count station is characterized by low-velocity, relatively laminar flow with limited hydraulic complexity compared to other areas of the fishway. We have not identified this section as challenging for either adult salmonids (Keefer et al. 2008) or adult lampreys (Clabough et al. 2011; Keefer et al. 2013b, 2014) in previous telemetry studies, and our observations in the 2017 study supported this conclusion. Our sampling design, monitoring duration, and number of observed events in the vicinity of the new structures were substantial (though seasonally limited) and the reported lack of negative responses was unlikely caused by a lack of statistical or sampling power to detect changes in behavior within the sample volume and monitoring period.

Adult Pacific lamprey

Monitoring lamprey behavior was a secondary study objective, but our conclusions regarding lampreys were similar overall to those for salmonids. The lamprey activity metrics generated from the DIDSON imagery paralleled estimates of lamprey abundance from the adult WA-shore count station and the automatic counter at the terminus of the AWS-LPS. Individual lamprey tracks also indicated consistently rapid upstream movement near the UMTJ-LPS and in the quasi-control deployments, with more upstream-moving fish near the fishway floor and wall than higher in the water column. Turn-around rates were similar across deployments and were generally <5% of upstream-moving fish, which suggests that encountering the ramps did not result in frequent downstream movements by lampreys. In previous radiotelemetry studies, high proportions of lamprey have turned around in the serpentine-weir section of the WA-shore fishway relative to in the channel downstream from the adult count station and AWS picket lead (Keefer et al 2013b). Even though turn-around behaviors by radio-tagged fish were identified at a larger temporal and spatial scale, we would have expected to observe considerably higher turn-around behavior near the UMTJ-LPS if it was negatively affecting lamprey passage.

Unfortunately, acoustic imagery of both the north and south UMTJ-LPS ramps was of medium to low quality (see Figures 4, 5, and 9) and we were unable to observe lampreys using the ramps or entering the structure. In a large majority of the upstream-oriented lamprey tracks we scored in the South_LPS deployment, the fish moved upstream past the ramp and there were few conclusive images indicating that lampreys were attached to substrate or aggregating near the base of the ramp. That most of the observed movement was past the ramp was somewhat surprising because approximately 10,000 adult lamprey were estimated to have used the combined UMTJ-LPS ramps from May-September 2017 (‘corrected’ count provided by Nathan Zorich, USACE). Additional monitoring, including the planned tagging study in 2018, should provide considerably more information about lamprey behavior in the study area and their use of the structure.

Study caveats and limitations

We took several steps to ensure that our evaluations were unbiased. Specifically, we experimented with a variety of deployments to provide useful images and also reviewed randomly-selected DIDSON files from throughout the study period to ensure that visibility of structures and fish image quality was suitable for review and scoring. Once suitable files were identified, we used a modified random-block design so that data comparisons among deployments were as informative as possible. The random file selection within the day/night blocks and among deployments should have greatly reduced any temporal bias in either the activity metrics or the individual fish track scoring. Scoring individual fish at pre-set times within each 10-min file should have greatly reduced fish selection bias.

Three important limitations to using DIDSON were: (1) it was impossible to differentiate salmonid species due to extensive overlap in run timing and fish size; (2) it was impossible to differentiate among individuals, meaning some fish may have been counted more than once and estimates of fish activity may have been overestimates relative to abundance; and (3) reviewer confidence was lower for adult Pacific lamprey than for salmonids. We made no effort to differentiate salmonid species given size and migration timing overlap among sockeye salmon, jack and adult Chinook salmon, Coho salmon (*O. kisutch*), and steelhead. It was also possible that some scored salmonids were actually American shad, but experience of reviewers should have reduced this species identification error. Regardless, the overall variation in behavior of salmonids was low, suggesting any species-specific differences were small. Pacific lamprey identification was somewhat more challenging, especially in the South_LPS deployment where lamprey images were smaller and more likely to be foreshortened. This challenge was consistent with previous DIDSON studies that have reported higher reviewer confidence in species identification when fish were swimming perpendicular versus parallel to the camera (Pipal et al. 2012; Kirk et al. 2014; Keefer et al. 2017). The use of previously-established lamprey identification criteria (Kirk et al. 2015; Keefer et al. 2017) also likely reduced errors and inter-observer differences in scoring. Note that we included all scored lamprey in our analyses because there was little evidence that 'low' confidence tracks were different that those scored with higher reviewer confidence.

Lastly, we emphasize that the 2017 DIDSON study was purely observational and data from the quasi-control deployments were useful but not definitive for concluding limited effects of the UMTJ-LPS on upstream fish passage. There has not been any previous DIDSON or other video monitoring in the UMTJ-LPS section of the WA-shore fishway, so there is no possibility of direct before/after comparisons. We are also unaware of any quantitative evaluations of salmonid turn-around rates near the current UMTJ-LPS site so we do not know if turn-around rates observed for salmonids in 2017 were high or low relative to pre-installation conditions. Although the 2017 DIDSON data provide useful baseline information and we are reasonably confident in our assessment, we strongly recommend that 'before' data be collected prior to future LPS installations.

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