Assessment of Adaptive Resolution Imaging Sonar (ARIS) for fish counting and measurements of fish length and swim speed in the lower Fraser River, year two: *A final project report to the Southern Boundary Restoration and Enhancement Fund*

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ABSTRACT

The Adaptive Resolution Imaging Sonar (ARIS) is the newest iteration of imaging sonar technology from Sound Metrics Corporation, and will eventually replace the Dual Frequency Identification Sonar (DIDSON) that has been used by the Pacific Salmon Commission hydroacoustics program to monitor upstream salmon passage since 2009. To better understand any implications of adopting new technology for estimating lower Fraser River salmon escapement, we deployed an ARIS and DIDSON side-by-side on the right bank of the Mission hydroacoustics site. Using data collected from both systems from July 12 to August 2, 2016, we examined whether there were any differences in fish counts, fish lengths, salmon speeds, and salmon passage estimates produced from the two systems. We also deployed the ARIS, with a field-of-view of 14°x30°, alongside a 2°x10° split-beam sonar to compare estimates of salmon passage on the left bank of the Mission site. Comparisons between the DIDSON and ARIS on the right bank revealed significant differences in fish counts, lengths and speed measurements at close range (0-10m) and far ranges (20-30m), however, the salmon passage estimates across all ranges from 0-30m were not statistically different, with the ARIS estimating a total upstream passage of 13,030 salmon and the DIDSON estimating 12,600 salmon over the observation period. The observed differences in counts and lengths are attributed to different recording settings for frequency, focal point, sampling rate, and the number of imaging beams. The comparisons between the split-beam and ARIS resulted in statistically identical salmon passage estimates at intermediate ranges (10-30m) but not at close range (0-10m) or far ranges (30-50m), where the ARIS estimated approximately 40% lower salmon passage than the split-beam. We attribute these results to differences in the vertical beam-width between the two systems (14° vs 2°) combined with different sampling designs and estimation procedures. Overall, the results of our comparisons suggest that data from DIDSON or ARIS systems will generate similar estimates of salmon passage in nearshore areas, especially on the right bank where the nearshore bottom profile was concave.

INTRODUCTION

The Pacific Salmon Commission (PSC) hydroacoustics program has been enumerating salmon passage through the lower Fraser River at Mission since 1977. To improve the accuracy of salmon passage estimates, new technology is tested and adopted as part of the continued research and development of the program. This research and development led to the purchase of an Adaptive Resolution Imaging Sonar (ARIS), with funding from the Southern Boundary Restoration and Enhancement Fund, for estimation of upstream salmon passage.

ARIS is the newest imaging sonar system manufactured by Sound Metrics Corporation (SMC), the creators of the Dual Frequency Identification Sonar (DIDSON) that has been used by the PSC hydroacoustics program to monitor upstream salmon passage since 2009. Imaging sonars use multiple sound beams to generate a visual representation of underwater objects, allowing fish to be visually identified, counted and measured for determining abundance, size, and swimming behavior. DIDSONs are gradually being phased out by SMC, and the newer ARIS offers better image resolution for fish counting and measurements. Therefore, the PSC set out to test the new ARIS technology and compare its capabilities to other types of sonar technologies currently used at the Mission site.

Initial experiments with a leased ARIS 1800 unit were conducted during the 2015 field season to determine how the data it collected compared to a DIDSON and 2°x10° split-beam transducer deployed from the left bank of the Mission site. This comparison revealed that the ARIS produced similar counts to the DIDSON at close range on the left bank, but it was difficult to draw conclusions on other comparisons because the ARIS was deployed on a tripod and sampled a different portion of the water column (Lagasse et al 2016).

Given the limitations with 2015 comparisons and the importance of understanding any potential implications from adopting this new sonar system, over the summer of 2016 we set out to conduct additional experiments comparing the ARIS to the other sonar systems used at the Mission site. We deployed an ARIS and DIDSON adjacent to each other on the right bank of the Mission site to compare fish counts, as well as length and speed measurements taken from the two systems. We also deployed the ARIS adjacent to a split-beam sonar on the left bank to compare salmon passage estimates. The results from these comparisons are detailed in this report.

METHODS

Study site and sampling design

The PSC Mission hydroacoustic fish counting site (hereafter Mission site) is located 80 km upstream from the mouth of the Fraser River, where the maximum wetted-width of the river is approximately 450 metres and the maximum depth varies from 13 to 17 metres depending on discharge. The river at the site is highly turbid, preventing visual counting of fish passage. For additional details on the Mission site see Xie et al. 2005.

In 2016, the Mission site was operational during the main period of sockeye migration through the lower Fraser River, from July 8 to August 29. The sampling configuration for estimating fish passage consisted of a side-looking 2°×10° split-beam sonar deployed on the left bank (south side) of the river, a side-looking DIDSON deployed on the right bank (north side) of the river, and a mobile, downward looking 6° split-beam sonar deployed from a transecting vessel. Over the course of the sockeye migration period, we deployed an ARIS 1800 sonar system (henceforth referred to simply as ARIS) from both the left bank and right bank sites for comparison with the DIDSON and the 2°×10° split-beam sonar.

Right bank system deployment and sampling

From July 12 to August 2, an ARIS and DIDSON were deployed directly adjacent to each other to sample the nearshore area on the right bank of the Mission site. A DIDSON has been operated on the right bank since 2011 as part of the standardized sampling design to enumerate salmon passage. Both the ARIS and DIDSON systems were deployed towards the end of a fish deflecting weir to prevent fish from swimming behind or too close to the sonars. The systems were attached to the weir on a cross-bar using two separate pole-mounted brackets approximately one metre apart from each other (Figure 1). This deployment configuration allowed us to position the ARIS and DIDSON in close proximity using the same aim and bearing so that the two systems ensonified a nearly identical area of the river.

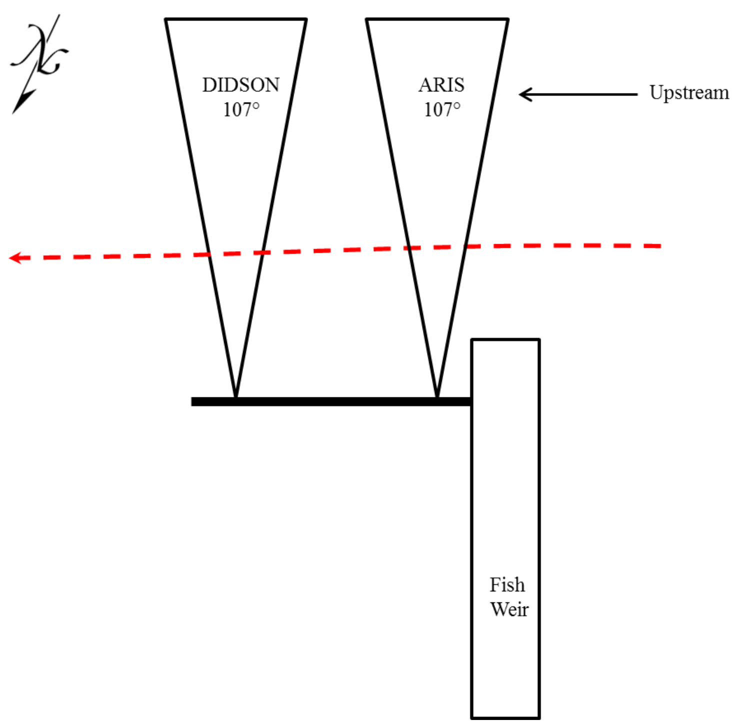


Figure 1. Deployment scheme and geometry of DIDSON and ARIS systems on the right bank of the Mission site. Bearings of the DIDSON and ARIS systems were 107°, respectively. The red, dashed line indicates the typical path of salmon travelling upstream through the beams.

The ARIS and DIDSON have a similar design with virtually identical fields-of-view of 14º vertical by 30º horizontal. This field-of-view is based on a composite image from 96 or 48 acoustic beams of approximately 0.3º or 0.5º horizontal width, with the wider beam width being used when sampling at lower frequency. The bottom profile offshore of the right bank closely matches the 14º vertical beam width of the imaging sonars, therefore only one aim was used to sample the entire water column within the near-shore area (Figure 2). Both systems were aimed at downward vertical angles between 4.5º and 5.0º from horizontal.

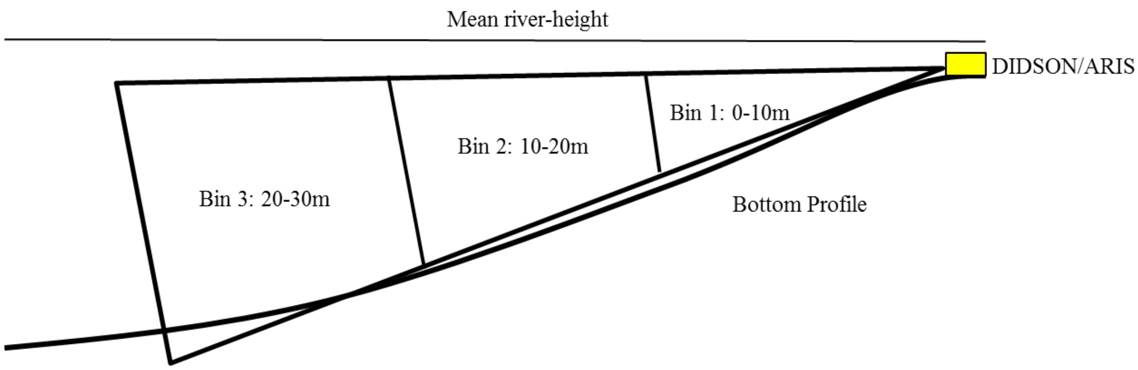


Figure 2. Schematic of the sampling configuration used by the ARIS and DIDSON systems on the right bank. The sampling area was stratified into three range bins of ten metres length each for fish counting, length and speed measurements.

We collected ARIS and DIDSON data within thirty metres range from where the two systems were deployed. Since the DIDSON and ARIS operated at similar frequencies in close proximity, their acoustic beams interfered with each other when pinging simultaneously. To eliminate this cross-talk interference, a sampling scheme was implemented to perform active sampling at non-overlapping time periods within the hour. This sampling scheme also took advantage of the ARIS being able to record files over thirty metres range at the same or higher image resolution than the DIDSON. However, because of the non-overlapping sampling times, the two systems did not monitor the same fish targets.

The DIDSON collected hourly imaging data using a single aim over three 10m range strata or bins (Table 1). Image data from each 10m range bin was recorded over a ten-minute period per hour at different times within each hour. Image data from the first 0-10m bin was recorded at a high frequency of 1800 kHz, while data from the 10-20 m and 20-30 m range bins were recorded at a lower frequency of 1100 kHz. The ARIS collected imaging data also using just one aim, but data from the entire 30m range was recorded in a single file at a low frequency of 1100 kHz over a 15-minute period each hour (Table 1). To produce spatially comparable statistics between the two systems, we analyzed each 10m portion of the ARIS files by zooming into the corresponding range bin when viewing the ARIS data.

To investigate potential differences in data collected by the ARIS and DIDSON, we made statistical comparisons between the fish counts, fish lengths, salmon speeds, and salmon passage estimates. Data for these comparisons was collected over a total of 22 days, however, only 19 days were included in the statistical analysis because of gaps in data collection at the beginning and end of the sampling period,

Table 1. Summary of hourly sampling strata and reading effort of the data for comparisons between the DIDSON and the ARIS from July 12 to August 2, 2016.

DIDSON Sampling Strata:	Bin 1	Bin 2	Bin 3
Hourly Recording Time l (min)	16-26	27-37	38-48
Start and end ranges (metres)	0.8 - 10.8	10.8 - 20.8	20.8 - 30.8
File Reading Time (min)	5	5	5
Vertical Aim (° from horizontal)	-4.5°	-4.5°	-4.5°
Sampling Frequency (kHz)	1800	1100	1100
ARIS Sampling Strata:	Bin 1	Bin 2	Bin 3
Hourly Recording Time (min)	00-15	00-15	00-15
Zoomed-in reading start and end ranges (metres)	0.8 - 10.8	10.8 - 20.8	20.8 -30.8
File Reading Time (min)	5	5	5
Vertical Aim (° from horizontal)	-4.9°	-4.9°	-4.9°
Sampling Frequency (kHz)	1100	1100	1100

Left bank system deployment

From August 3 to August 29, the ARIS was operated from the left bank of the Mission site in parallel with a Hydroacoustic Technology Incorporated (HTI) split-beam sonar with an elliptical beam shape of 2°×10°. This stationary split-beam system has been used to enumerate salmon passage in the left bank nearshore area since 2004. Upstream salmon passage is typically the densest in this area compared to any other portion of the river at the Mission site.

The ARIS and split-beam systems were deployed towards the end of a fish deflecting weir and attached to a cross-bar approximately one metre apart from each other (Figure 3), similar to the deployment configuration on the right bank. The split-beam recorded data continuously for all 60 minutes of each hour and it was therefore not possible to avoid overlap of sampling times between the two systems. To minimize potential cross-talk interference, we aimed the ARIS approximately 15° upstream from the bearing of the split-beam sonar. The different operating frequencies of the sonars also minimized any interference; the split-beam system operates at a much lower frequency of 200 kHz compared to the ARIS operating frequency of 1100 kHz.

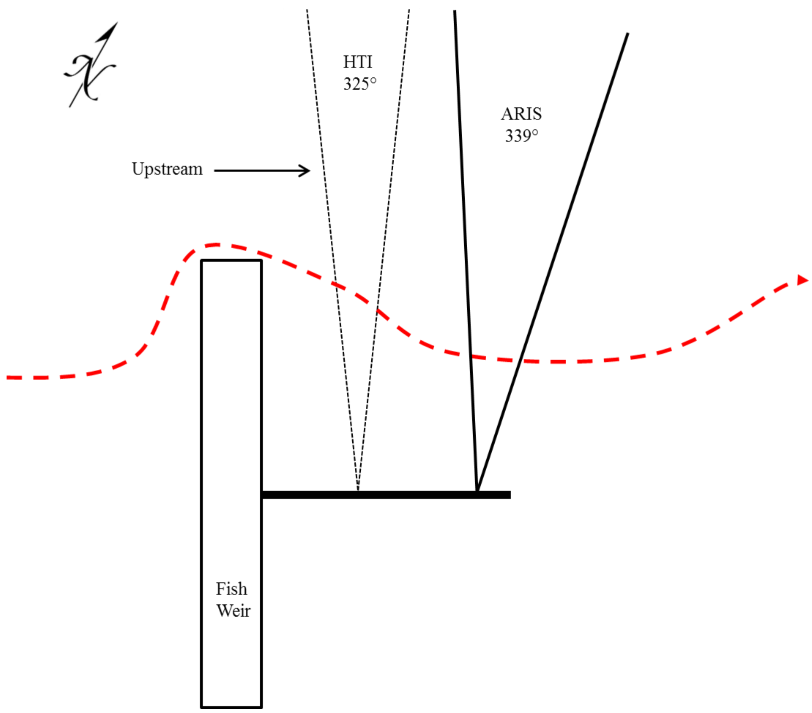


Figure 3. Deployment scheme and geometry of HTI split-beam and ARIS systems on the left bank of the Mission site. Bearings of the HTI and ARIS systems were 325° and 339°, respectively. The red, dashed line indicates the typical path of salmon travelling upstream through the beams.

For analysis purposes, we separated the comparisons between the ARIS and split-beam into two periods based on the sampling schemes of the ARIS system (Table 2). In the first sampling period from August 3 to 15, the ARIS sampled the water column up to 50 metres range using its full beam height of 14°. In the second sampling period from August 16 to 22, a concentrator lens was attached to the ARIS to narrow the beam height to 3° according to vendor specifications. The split-beam system maintained a virtually identical sampling scheme throughout the two sampling periods.

Left bank sampling with split-beam and 14° ARIS beam

The first left bank ARIS sampling period was from August 3 to 15 and used the full vertical beam width of 14°. The ARIS was deployed on a Sound Metrics AR2 dual-axis rotator, allowing the horizontal bearing and vertical tilt to be adjusted for sampling multiple aims each hour. We used three aims with different vertical tilts to sample the water column up to 50 metres range from the ARIS (Figure 4). All three aims were at the same approximate horizontal bearing of 339°, looking offshore from the left bank fish weir. The lowest aim (Aim1) was at a vertical angle of 12° below horizontal and sampled up to 20 metres range. The sampling over this 20 metres was divided into two range bins from 0-10 m and 10-20 m, with data collected in each bin recorded and counted separately for fish passage. The highest aim (Aim2) was at a vertical angle of 3° above horizontal to sample the area directly above Aim1 using the same two range bins of 0-10 m and 10-20 m. An intermediate height aim (Aim3) was used to sample further ranges from 20-50 m at a vertical angle of 6° below horizontal. Only a single aim was used for the ranges beyond 20 metres because the field-of-view could cover most of the water column. This aim was recorded in a single data file for each hour and divided into separate range bins for counting, with one bin from 20-30m and the final bin from 30-50m.

Table 2. Summary of hourly sampling schemes of the data for comparisons between the 2°x10° split-beam and ARIS for the three analysis time periods on the left bank at the Mission site.

2°x10° Split-beam August 3-22	S_1	S_2	S_3	S_4	S_5	S_6
Beam Range (metres from sonar)	45-50	45	35	45	45	40
Frequency (kHz)	200	200	200	200	200	200
Analysis Range (metres):						
First sampling period (Aug 3-15)	45	45	35	45	45	40
Second sampling period (Aug 16-22)	30	30	30	30	30	30
Vertical Aim (° from horizontal)	-4°	-2°	0°	-6°	-8°	-10°
Hourly Recording Time (min)	00-10	10-20	20-30	30-40	40-50	50-60
ARIS first sampling period (14°) August 3-15	Aim1	Aim1	Aim2	Aim2	Aim3	Aim3
Start and end ranges (metres)	0-10	10-20	0-10	10-20	20-30	30-50
Frequency (kHz)	1800	1100	1800	1100	1100	1100
File Reading Time (min)	5	5	5	5	5	5
Vertical Aim (° from horizontal)	-12°	-12°	2°	2°	-8°	-8°
Hourly Recording Time (min)	00-10	10-20	20-30	30-40	40-50	50-60
ARIS second sampling period (3° lens) August 16-22	Seq1	Seq2	Seq3	Seq4	Seq5	
Start and end ranges (metres)	0-30	0-30	0-30	0-30	0-30	
Frequency (kHz)	1100	1100	1100	1100	1100	
File Reading Time (min)	10	10	10	10	10	
Vertical Aim (° from horizontal)	-3°	0°	-6°	-9°	-12°	
Hourly Recording Time (min)	00-10	10-20	30-40	40-50	50-00	

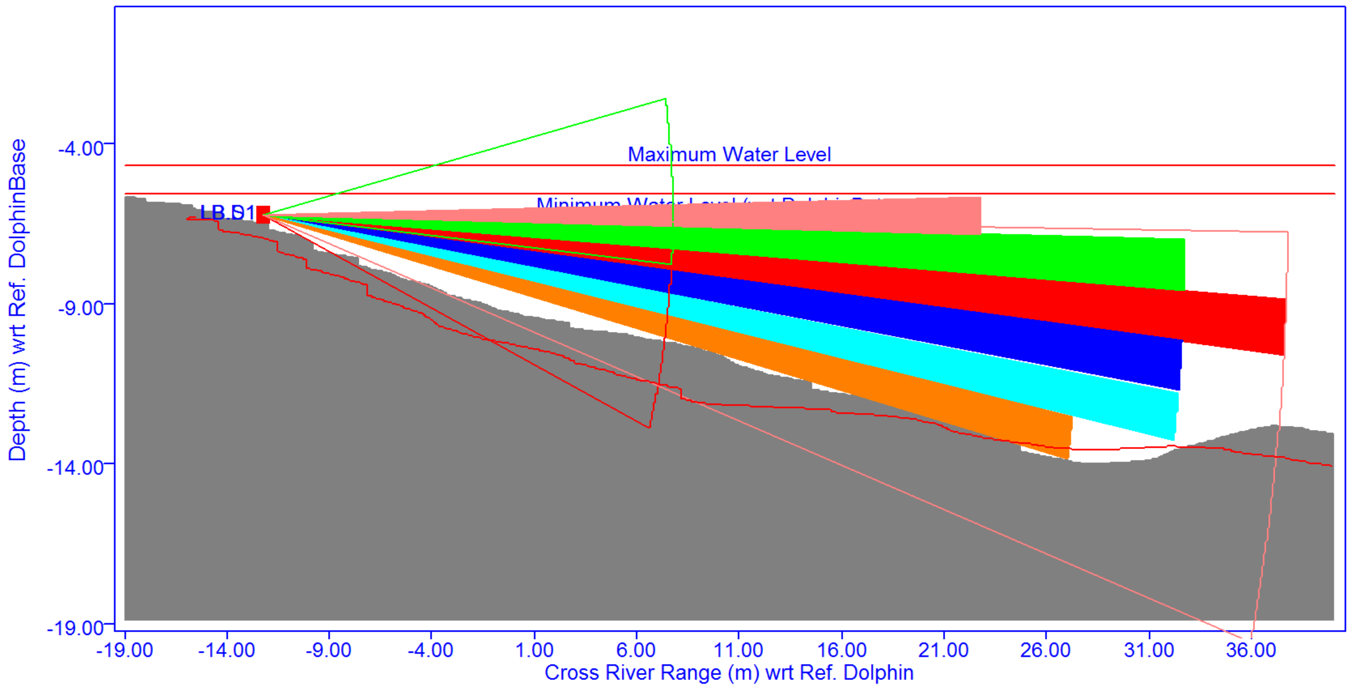


Figure 4. Side view schematic of the left bank sampling area for the first sampling period from August 3 to 15. The solid coloured triangles represent areas sampled by the 2°x10° split-beam. The areas sampled by the ARIS are outlined in red (Aim1), green (Aim2), and pink (Aim3) triangles.

The 2°×10° split-beam was attached to a SIDUS rotator that allowed it to sample multiple vertical aims each hour. The beam height of the split-beam is narrower than the ARIS so we used six vertical aims to sample the water column. Salmon targets observed by the split-beam are automatically tracked and distinguished from debris and small, resident fish using a discriminant function analysis based on swimming trajectories, traveling velocities, and target-strength readings (Xie et al, 2012). The salmon targets tracked within the six aims were added together to obtain the observed estimate of upstream salmon passage.

Due to the uneven bottom profile near the left bank and varying, tidal-influenced water heights, portions of the water column just below the surface and near the bottom cannot be sampled by the six aims of the split-beam. To account for salmon passage within these unsampled blind zones, a nearest neighbor extrapolation (Bowman and Azzalini, 1997) is applied to the observed salmon targets to obtain an estimate of salmon passage for the blind zone. This extrapolated salmon passage estimate is generated daily for the left bank and forms part of the official daily salmon passage estimate through the Mission site.

Left bank sampling with ARIS using 3° concentrator lens

From August 16 to 22, a 3° concentrator lens was attached to the ARIS sonar head for the second sampling period of its left bank deployment. According to specifications provided by SMC, the concentrator lens narrows the vertical beam width from 14° to 3°. The ARIS data collected by this setting were intended for a more direct comparison with the salmon passage estimates from the 2° vertical beam of the split-beam transducer. Five ARIS aims with the concentrator lens were used to sample approximately the same area as covered by the six aims of the 2° split-beam transducer, up to a range of 30 metres (Figure 5). The split-beam sampling design was unchanged from the first sampling period, except that the salmon target observations were truncated to 30 metres for comparison.

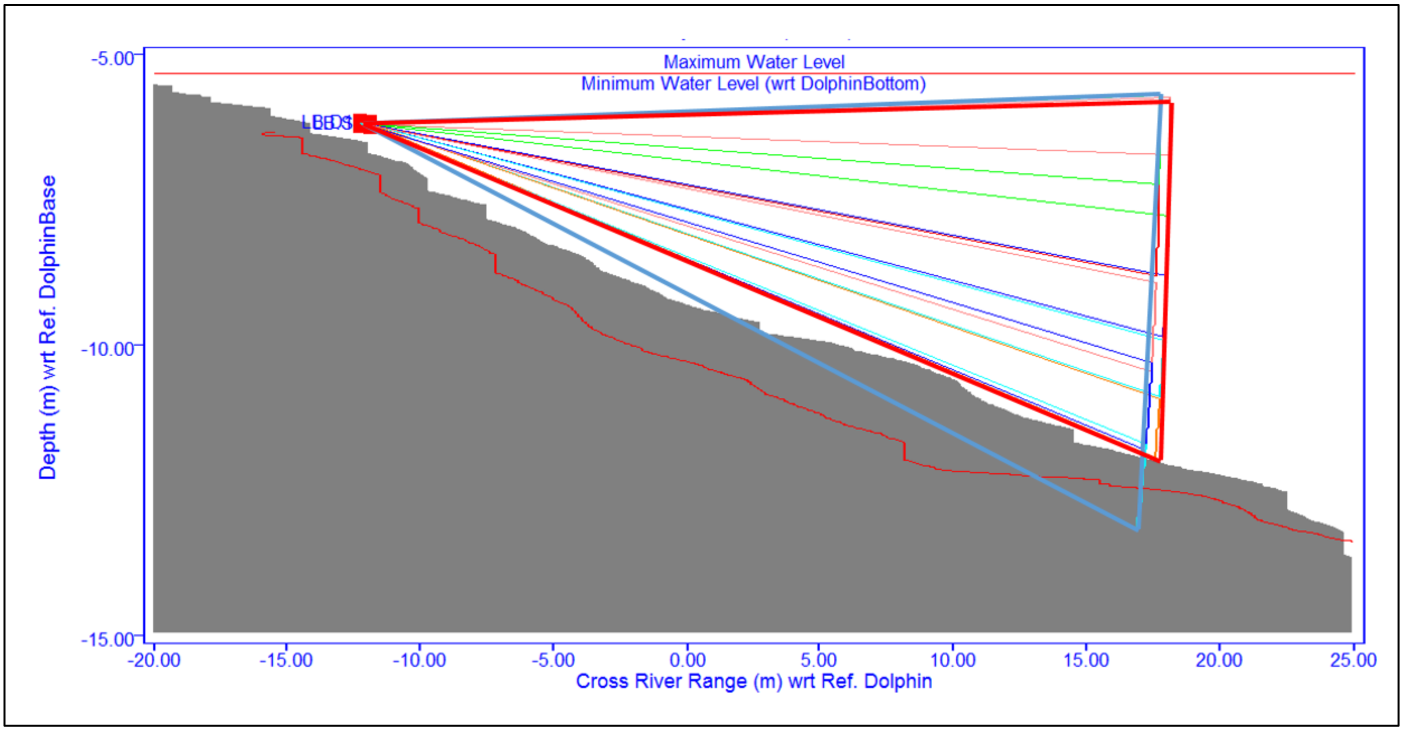


Figure 5. Side view schematic of the left bank sampling areas during the second sampling period from August 16 to 22. The triangle outlined in thick blue lines represents the total area sampled by the 5 aims of the ARIS with the 3° concentrator lens. The triangle outlined in thick red lines represents the total area sampled by the 6 aims of the split-beam system with a 2° beam height.

RESULTS

Comparison of fish counts near the right bank

We compared daily fish counts from the ARIS and DIDSON near the right bank of the Mission site among the three range bins from 0-30 metres (as defined in Figure 2 and Table 1). For each range bin, the number of upstream and downstream swimming fish were counted during the first five minutes of each hourly recording. All fish that travelled through the beam were counted, including fish targets apparently smaller than typical adult salmon. The daily net upstream fish count was then determined by subtracting downstream fish counts from upstream counts, multiplying the five-minute counts by 12 to represent the entire hour, then adding all hours in a day together. Incomplete days with less than 18 hours of observations were removed, yielding 19 days for comparison from July 12 to August 2.

Comparisons between ARIS and DIDSON counts for each range bin are summarized in Table 3 and Figure 6. Both systems detected similar temporal trends of fish counts in all 3 range bins, but on average counts were slightly higher for the DIDSON than the ARIS across all range bins, with the largest mean daily difference of 393 upstream fish in the 0-10 m range bin. Statistical comparisons of daily counts using a paired t-test found statistically significant differences between ARIS and DIDSON counts in bin 1 and bin 3, but not in bin 2 using an α-level of 0.05 (Table 3).

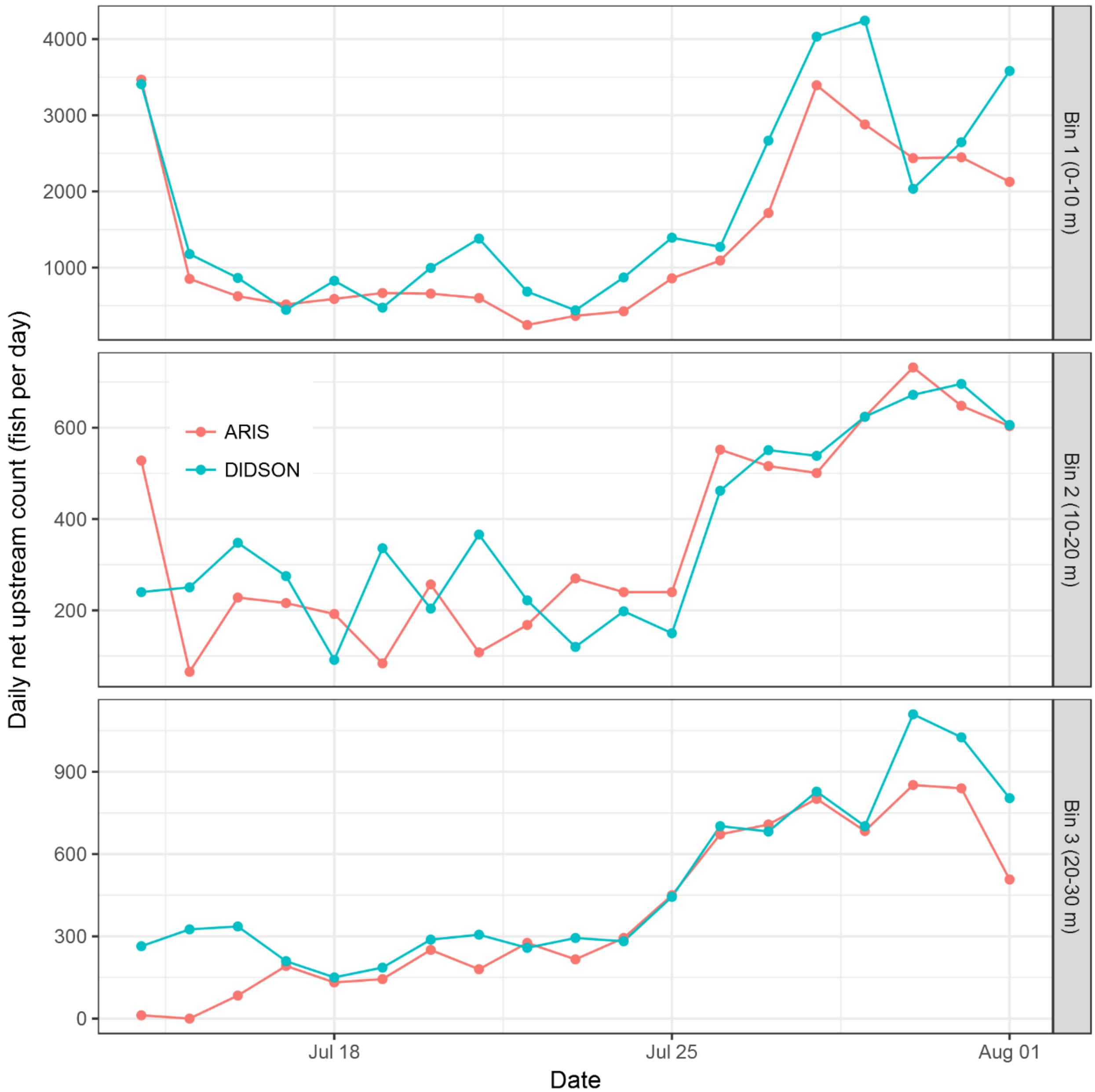


Figure 6. Comparison of daily net upstream fish counts for the three range bins of the ARIS (red) and DIDSON (blue) systems on the right bank at the Mission site from July 14 to August 1. The daily net count is based on a 5 minute downstream and upstream count sub-sample within each hour, then adding all 24 hours together for each day.

Table 3. Statistical comparisons of daily net upstream fish counts for ARIS and DIDSON systems on the right bank. The p-value shown is for a paired *t*-test on daily counts for ARIS vs DIDSON. There were 19 observations for comparison in each range bin over the study period from July 12 to August 2. Values marked with a * are significant at an α-level of 0.05.

	ARIS mean daily net upstream count	DIDSON mean daily net upstream count	Mean difference	% difference	p-value	df
Bin1 (0-10m)	1366	1759	-393	-22%	0.002*	18
Bin2 (10-20m)	356	366	-10	-3%	0.77	18
Bin3 (20-30m)	384	484	-100	-21%	0.002*	18

Comparison of fish length measurements near the right bank

Fish length measurements on images acquired by imaging sonar at the Mission site are used to determine the proportion of salmon-sized target counts from the total fish counts. By applying this proportion to the net upstream fish counts, we obtain the net upstream salmon passage observed by DIDSON and ARIS systems. We compared length measurements taken from July 13 to August 2 on the right bank between ARIS and DIDSON systems for the 0-10m, 10-20m and 20-30m range bins. More than 3000 individual fish images were measured in the 0-10m range bin, approximately 1300 images were measured in the 10-20m range bin and approximately 1000 images were measured in the 20-30m range bin.

Measurements were taken from the first 15 to 20 good quality fish images within DIDSON recordings for each range bin. Measurements from ARIS files were taken from good quality fish images over the entire 30 metre recording range. The measurements were then sorted into the three 10 metre range bins based on the location of measured fish to perform range-stratified comparisons between the DIDSON and ARIS systems. Only fish swimming in the upstream direction were measured. All measurements were taken using the sizing tools within the DIDSON and ARISFish software programs provided by SMC.

A comparison of the recorded images from the ARIS and DIDSON showed the two systems produced similar images of the water column from 10-20m range (Figure 7, C vs D). However, the nearest range bin, 0-10m, and furthest range bin, 20-30m, show visually different backgrounds between the two systems (Figure 7, E vs. F and A vs. B). From 0-10m the bottom features in the ARIS are not very clear in comparison to the DIDSON recordings. These differences are attributed to the recording settings used by the two systems to record data with DIDSON recording an individual file for each range bin and the ARIS recording one file for the entire sampling area. The focal range for DIDSON was the center of each range bin (5, 15 and 25 metres, respectively) while the ARIS focal range was 15 metres in all range bins. From 20-30m, the ARIS images are more detailed and less granular than the DIDSON. At this range, the DIDSON used 48 beams at low frequency while the ARIS used 96 beams at low frequency.

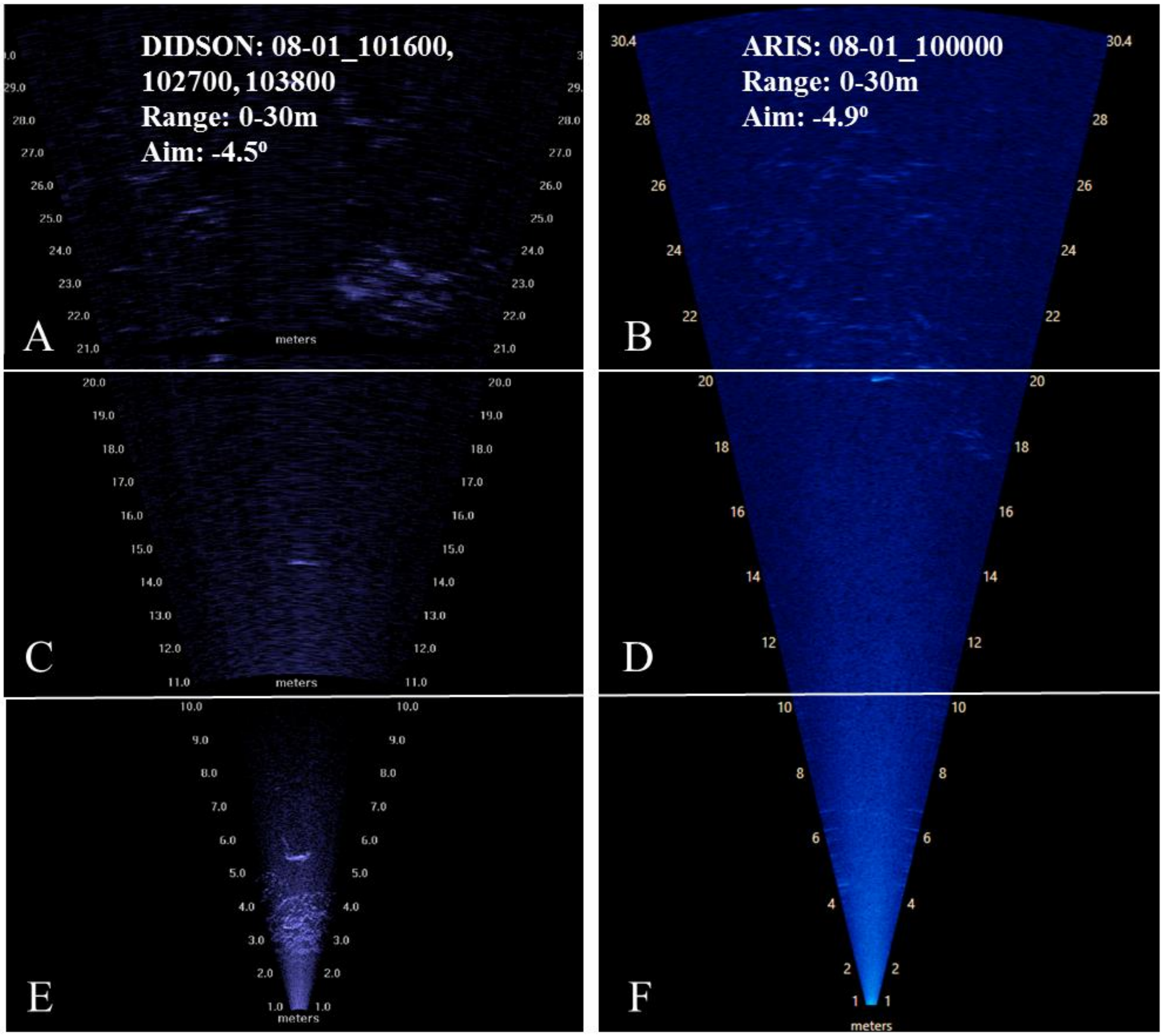


Figure 7. Background images acquired by DIDSON and ARIS in the 0-10m (E and F), 10-20m (C and D) and 20-30m (A and B) range bins at 10:00 on August 1, 2016.

Mean daily lengths were compared between the two systems from July 13 to August 2 (Figure 8). The nearest and furthest range bins, 0-10 m and 20-30m, had the largest mean difference with ARIS data showing higher length measurements in both cases. A paired *t*-test on daily mean values found statistically significant differences at an α-level of 0.05 for the closest and furthest range bins, but not for bin 2 from 10-20m (Table 4).

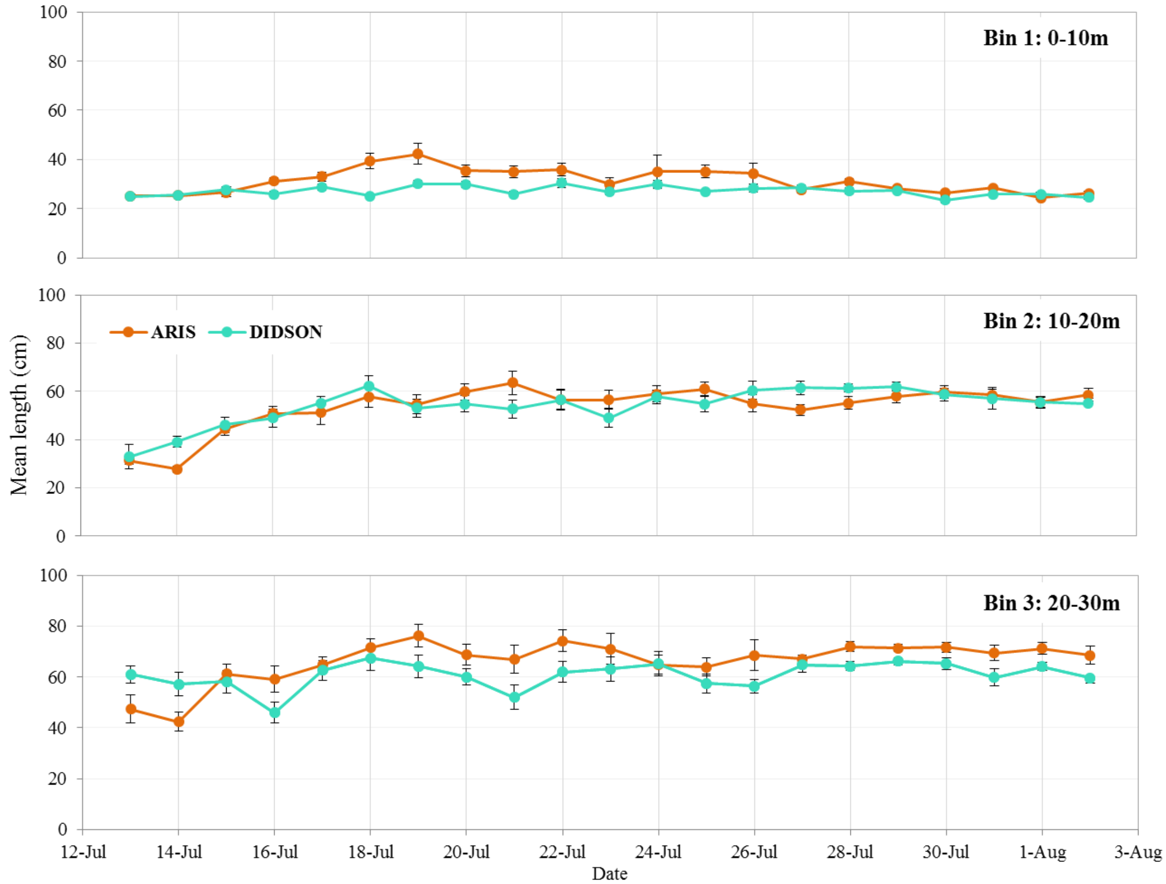


Figure 8. Daily mean lengths by range bin measured using ARIS (orange) and DIDSON (green) data from July 13 to August 2 on the right bank at the Mission site. The error bars represent ± 1 SE on the daily mean lengths.

Table 4. Comparison of mean lengths measured from ARIS and DIDSON data by range bin from July 13 to August 2 using a paired *t*-test on the daily values. Values marked with a * are significant at an α-level of 0.05.

	ARIS mean length (cm)	**DIDSON mean length (cm)**	**Mean difference (cm)**	**% difference**	**p-value**	**df**
Bin1 (0-10m)	31.26	27.07	4.19	13.4	0.0002*	20
Bin2 (10-20m)	53.64	54.02	-0.38	-0.7	0.7491	20
Bin3 (20-30m)	66.32	60.84	5.48	8.3	0.0036*	20

Comparisons of salmon speed measurements near the right bank

We compared speed measurements of salmon-sized targets from ARIS and DIDSON data to determine whether the two systems produced similar estimates of swimming speed. Speeds were measured according to the methods described in Xie et al. 2005. Since the ARIS and DIDSON systems operated at different times within each hour to avoid interference, we could not compare speed measurements on the same fish. Instead, we made unpaired comparisons of fish speeds using data from July 18, 27 and 28, representing relatively low, medium and high daily fish abundances on the right bank. Speeds were measured for approximately 300 individual fish each from the ARIS and DIDSON. Only salmon-sized fish swimming in the upstream direction were selected for speed measurements.

The mean speeds by bin for each day of measurements is shown in Figure 9. From 0-10m, the mean speed measured from ARIS data was 0.34 m/s while the mean speed from DIDSON data was 0.27 m/s (Table 5). From 10-20m, the mean speeds were 0.58 m/s and 0.64 m/s from the ARIS and DIDSON respectively, and from 20-30m the mean speeds were 0.77 m/s and 0.67 m/s respectively. An unpaired *t*-test was performed for each range bin to evaluate whether these differences were statistically significant at an α-level of 0.05. Statistically significant differences were obtained between ARIS and DIDSON speed measurements from 0-10m and 20-30m, but not from 10-20m.

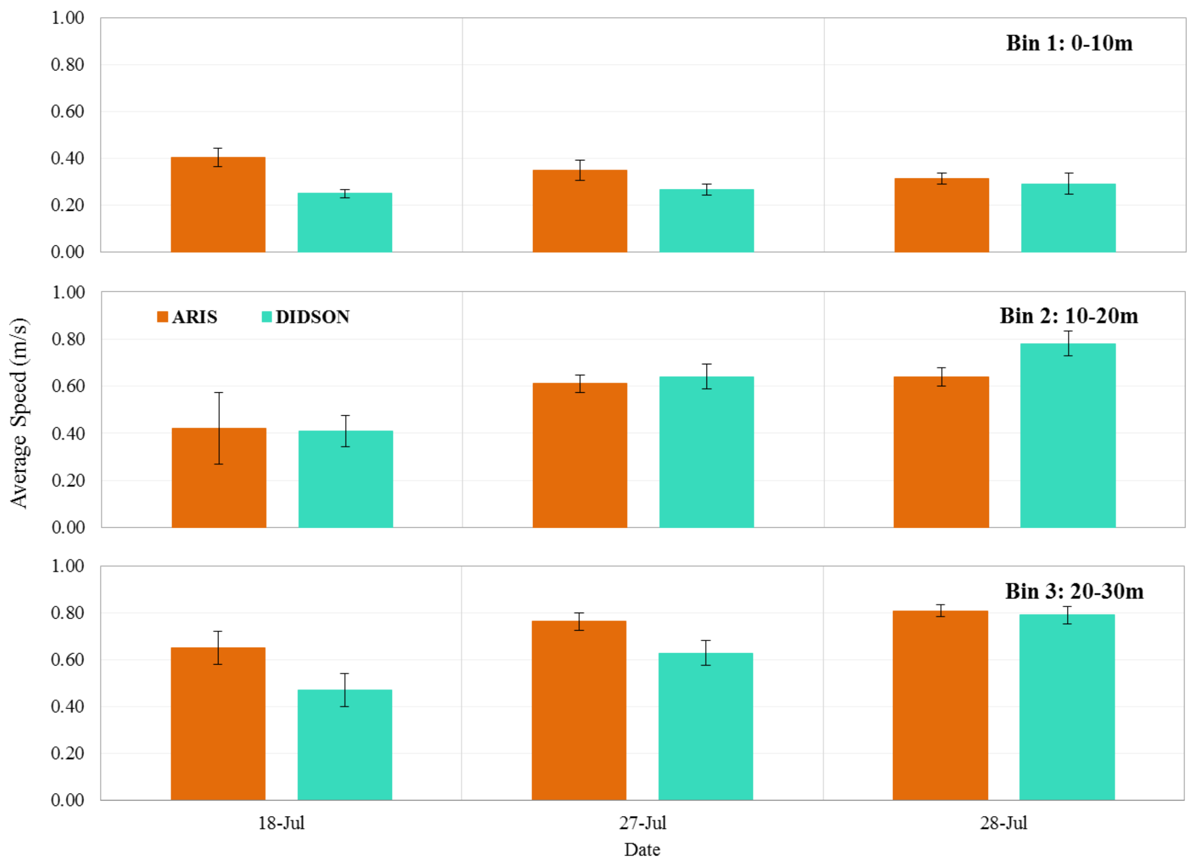


Figure 9. Comparison of mean daily speeds measured on salmon-sized targets by range bin from DIDSON (green) and ARIS (orange) data for July 18, 27 and 28 on the right bank at the Mission site. The error bars represent ± 1 SE on the daily mean speeds.

Table 5. Comparison of speed measurements on salmon-sized targets from ARIS and DIDSON data for July 18, 27 and 28, 2016. An unpaired *t*-test was used for comparing speeds in each of the 3 range bins. Values marked with a * are significant at an α-level of 0.05.

	ARIS speed (m/s)	DIDSON speed (m/s)	Mean difference (m/s)	% difference	p-value	df
Bin1 (0-10m)	0.34	0.27	0.07	20.6	0.0016*	175
Bin2 (10-20m)	0.58	0.64	-0.06	-9.4	0.1634	169
Bin3 (20-30m)	0.77	0.67	0.10	13.0	0.0075*	156

Comparisons of salmon passage estimates near the right bank

To produce estimates of upstream salmon passage from imaging sonar, daily fish counts are multiplied by the proportion of salmon-sized targets. This proportion is determined by importing measured lengths into a maximum likelihood mixture model that uses the distribution of length measurements within a day to estimate the proportions of salmon-sized fish and smaller-sized resident fish (see Xie et al. 2013, Appendix VII). We used the length measurement data described previously to produce daily estimates of proportions of salmon-sized fish for both the DIDSON and ARIS systems from July 14 to July 31. These proportion were then multiplied by the corresponding daily upstream fish counts to generate estimates of upstream salmon passage. These estimates were generated separately for each of the three range bins and compared using a paired *t*-test on the daily estimates within each bin.

The daily estimates of right bank salmon passage for DIDSON and ARIS are shown in Figure 10. Again, salmon passage estimates between the two systems show similar temporal trends in all three range bins. Salmon passage estimated using ARIS data was slightly higher than estimates from the DIDSON in bin 1 with a mean daily upstream passage of 190 salmon and 160 salmon respectively. In bin 2 the mean passage was very similar with 196 salmon versus 189 salmon from the ARIS and DIDSON respectively. In bin 3 the estimate from DIDSON data was slightly higher at 351 salmon versus 338 salmon from ARIS data. None of these differences were statistically significant using a paired *t*-test with α-level of 0.05 (Table 6). Over the entire observation period, the total estimate of upstream passage using ARIS data was 13,030 salmon in all 3 bins combined, while the estimate using DIDSON data was 12,600 salmon.

Table 6. Comparison of daily salmon passage estimates from the ARIS and DIDSON systems using data collected on the right bank from July 14 to July 31. The p-value shown is based on a paired *t*-test for daily salmon passage values in each range bin.

	ARIS mean daily salmon passage	DIDSON mean daily salmon passage	Mean difference	% difference	p-value	df
Bin1 (0-10m)	190	160	30	16%	0.19	17
Bin2 (10-20m)	196	189	7	4%	0.81	17
Bin3 (20-30m)	338	351	-13	-4%	0.53	17

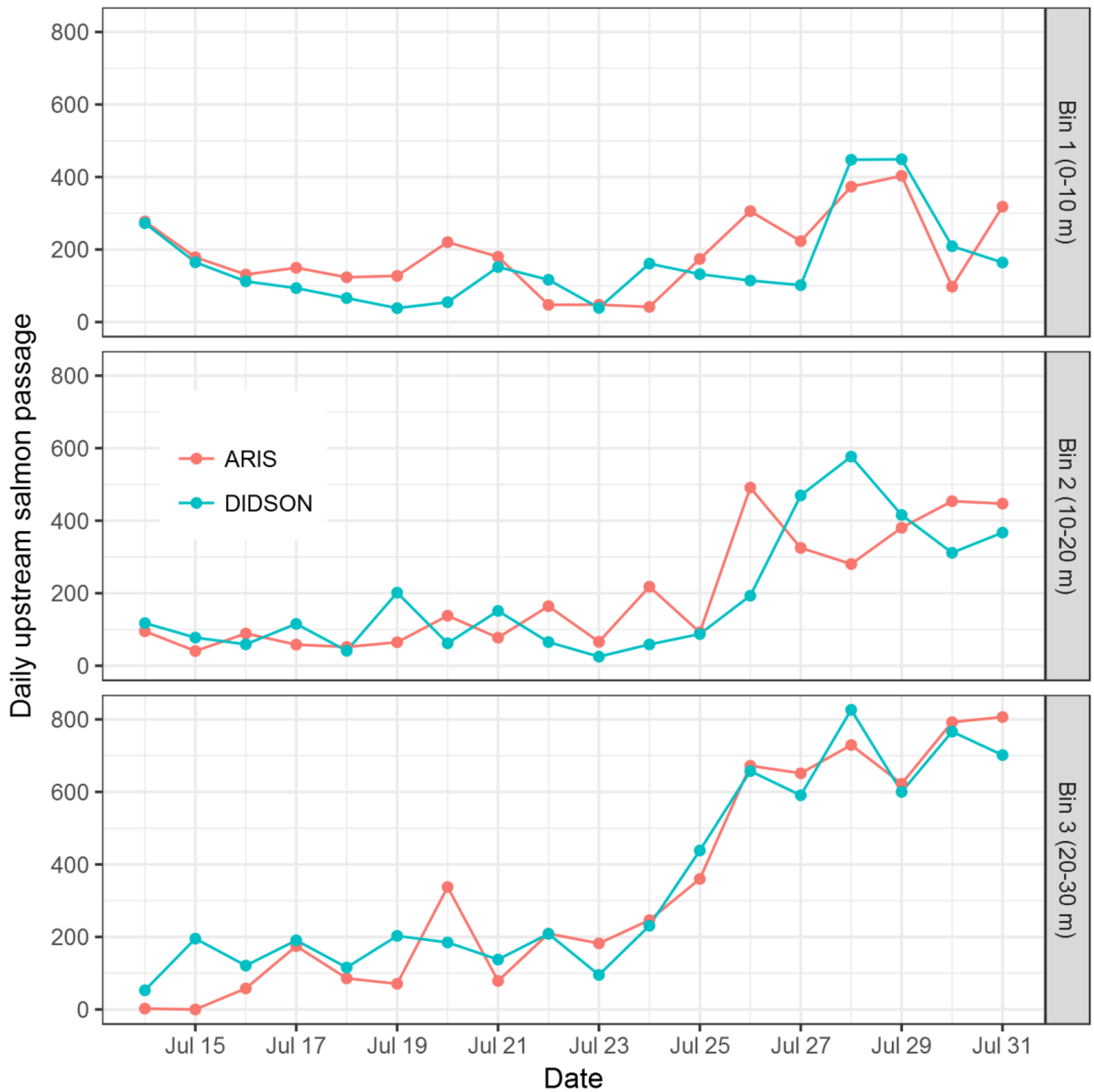


Figure 10. Daily salmon passage estimates by range bin from the ARIS (red) and DIDSON (blue) on the right bank from July 14 to July 31.

Comparisons of split-beam and ARIS with 14° beam near the left bank

We compared the salmon passage estimates near the left bank of the Mission site using data collected from August 3 to August 15 by the HTI 2°x10° split-beam transducer and the ARIS system with a full 14° beam width. Salmon passage using ARIS data was estimated using the same methodology as with the right bank data, except two vertical aims were used for bin 1 (0-10m) and bin 2 (10-20m) to sample the water column on the left bank. The salmon passage from each aim was then added together to get the total passage within bin 1 and bin 2. For bin 3 (20-30m) and bin 4 (30-50m) a single vertical aim was used.

In contrast, the split-beam used six vertical aims throughout the entire range from 0-50m and targets from all aims were added together to get the salmon passage within each range bin. Two split-beam estimates were used for comparison: the directly observed estimate of salmon passage, and the observed estimate plus extrapolated estimate in the blind zone (we call the sum of these two estimates "extrapolated estimate" hereafter). All estimates were summarized daily by adding all hourly observations within each day. Split-beam and ARIS estimates were compared using a paired *t*-test on the mean daily salmon passage.

Comparisons of the daily salmon passage estimates between the ARIS, observed split-beam, and extrapolated split-beam estimates are summarized in Figure 11 and Tables 7 and 8. The ARIS was statistically identical to the directly observed split-beam passage estimate from 20-30m, but for all other range bins the p-value suggests a significant difference between estimates (Table 7). Compared to the extrapolated split-beam estimate, the ARIS daily estimates were statistically identical from 10-20m and 20-30m where the mean daily difference between estimates was only 9 and 135 salmon, respectively (Table 8). For 0-10m and 30-50m, a significant difference was obtained with the ARIS estimate being lower than the extrapolated split-beam estimate. From 0-10m the ARIS estimate was on average higher than the observed split-beam estimate but lower than the extrapolated estimate.

Table 7. Comparisons of mean daily salmon passage by range bin for the ARIS with 14° beam and split-beam directly observed passage (without extrapolation). The *p*-value is calculated using a paired two tailed *t*-test with 13-day paired estimates. Values marked with a * are significant at an α-level of 0.05.

Range Bin (m)	ARIS mean daily passage	Observed split-beam mean daily passage	Mean difference	%Difference	*p*-value
Bin1 (0-10)	1433	775	658	85%	0.01*
Bin2 (10-20)	2340	1519	821	54%	0.001*
Bin3 (20-30)	2237	2215	22	1%	0.88
Bin4 (30-50)	2148	3146	-998	-32%	0.0001*

Table 8. Comparisons of mean daily salmon passage by range bin for the ARIS with 14° beam and split-beam extrapolated passage (directly observed plus projected passage in the blind zone). The *p*-value is calculated using a paired two tailed *t*-test with 13-day paired estimates. Values marked with a * are significant at an α-level of 0.05.

Range Bin (m)	ARIS mean daily passage	Extrapolated split-beam mean daily passage	Mean difference	%Difference	*p*-value
Bin1 (0-10)	1433	2534	-1101	-43%	0.005*
Bin2 (10-20)	2340	2331	9	0%	0.96
Bin3 (20-30)	2237	2371	-135	-6%	0.34
Bin4 (30-50)	2148	3535	-1387	-39%	0.0001*

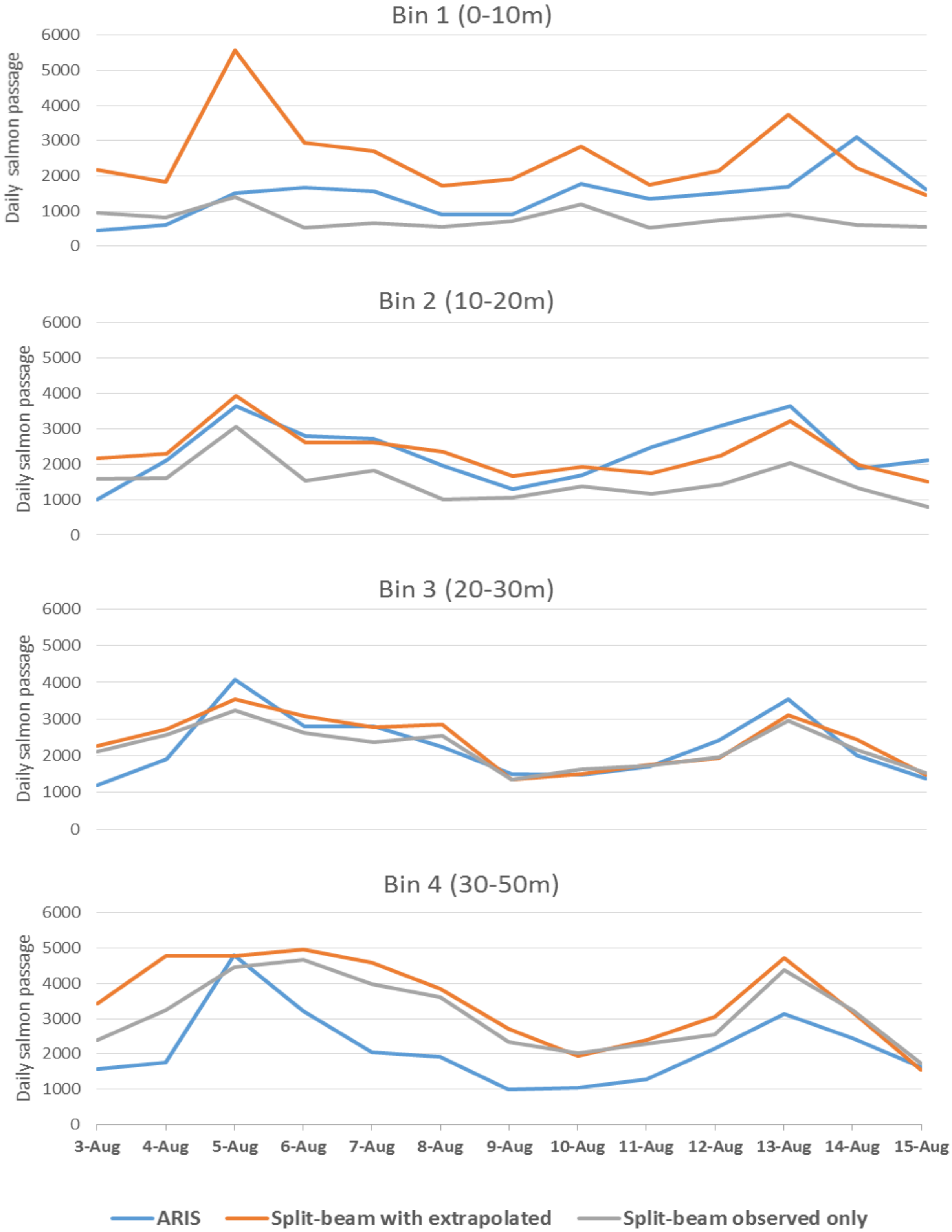


Figure 11. Comparison of daily upstream salmon passage estimates from the ARIS with 14° beam (blue), the split-beam directly observed salmon (gray), and the split-beam extrapolated estimate (orange, including projected passage in the blind zone).

Comparisons between the split-beam and ARIS using 3° concentrator lens

Salmon passage estimates from the ARIS with 3º concentrator lens were compared to estimates from the HTI 2°x10° split-beam between August 17 and August 22. We only examined the directly observed estimates from the split-beam and did not include extrapolations for a more consistent comparison by aim. Comparisons were made over a single range bin from 0-30m with five vertical aims for the ARIS and six vertical aims for the split-beam.

The ARIS with concentrator lens estimated a higher daily salmon passage within each aim and over all aims combined compared to the split-beam (Figure 12). The average daily passage estimate from August 17 to 22 was 3977 salmon summed over all six aims of the split-beam compared to 9312 salmon summed over the five aims of the ARIS. This yields an average passage per aim of 663 salmon for the split-beam versus 1862 salmon for the ARIS. The average passage observed by each aim of the ARIS with 3° concentrator lens was almost three times higher than the average passage observed by the 2° beam on the split-beam.

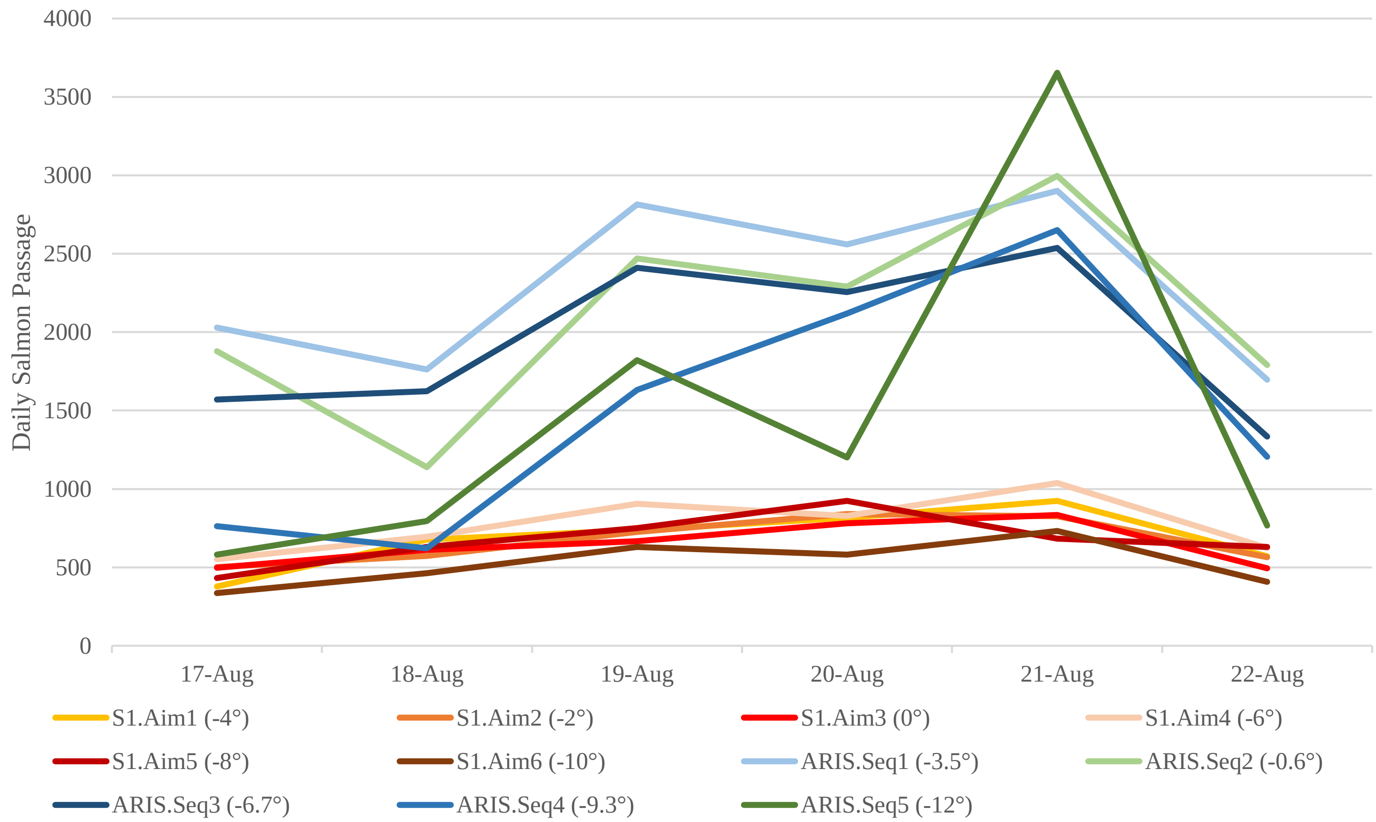
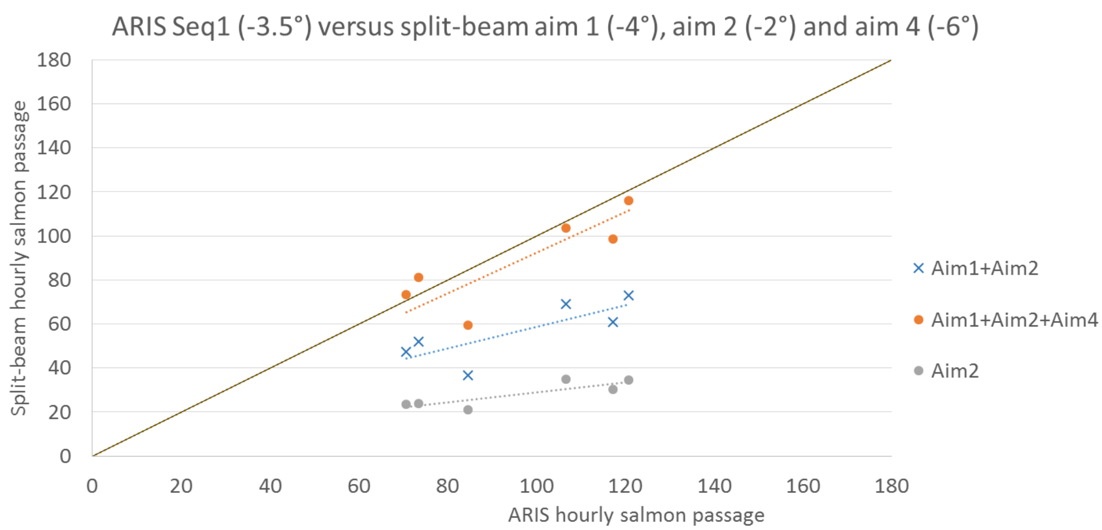


Figure 12. The daily salmon passage estimates for each vertical aim of the ARIS (blue and green lines) and split-beam (red and orange lines). The vertical angle of each aim relative to horizontal is shown in parentheses within the legend.

The observed large discrepancy in fish counts between the two systems led to the hypothesis that the effective vertical beam width of the ARIS with concentrator lens was greater than the 3º specified by the manufacturer. To test this hypothesis, we compared the aim-specific passage estimates of the ARIS to combined estimates from multiple aims of the split-beam system, as shown in Figure 13. The estimated salmon passage for each aim of the ARIS system generally corresponded with the combined salmon passage from 3 split-beam aims of 2°, rather than just a single aim. For example, the ARIS aim at -3.5° from horizontal estimated an average daily passage of 2294 salmon and the combined split-beam aims 1, 2 and 4 (at -4°, -2° and -6° respectively) estimated a similar daily passage of 2130 salmon.



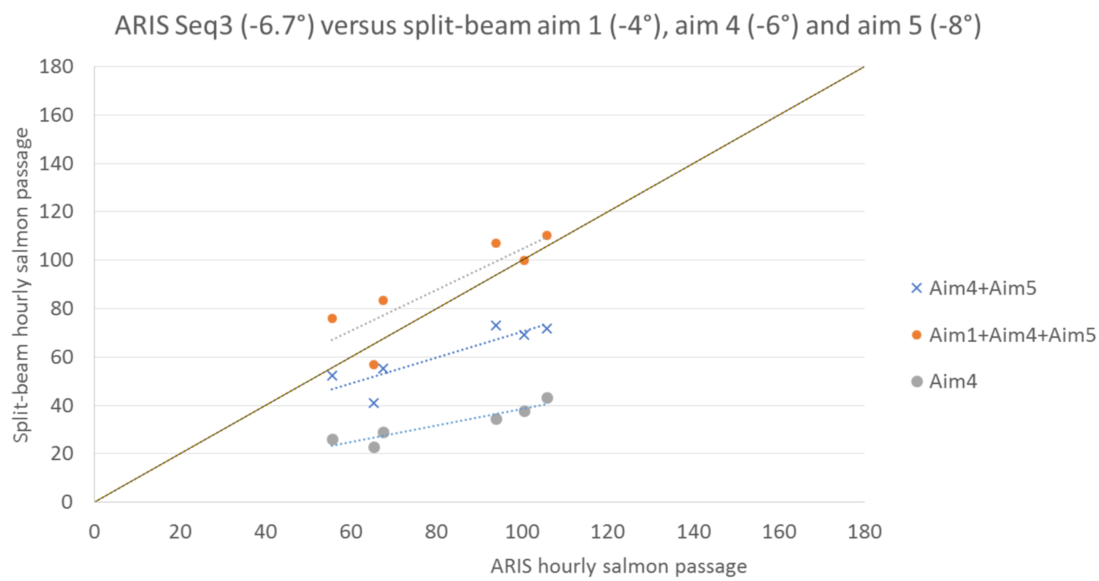


Figure 13. Estimated hourly salmon passage from the -3.5° aim (top pane) and -6.7° aim (bottom pane) of the ARIS with 3° concentrator lens compared to a single aim (grey circles), two aims (blue x symbol), and three aims (orange circle) combined salmon passage estimates from the split-beam. The black, solid line shows the 1:1 relationship between ARIS and split-beam passage estimates where the two systems would produce the same estimate of salmon passage.

DISCUSSION

ARIS and DIDSON comparisons

By deploying the DIDSON and ARIS systems directly adjacent to each other on the right bank of the Mission site, we were able to conduct direct comparisons of upstream fish passage, fish lengths, salmon speeds, and estimated salmon passage. Statistical comparisons between these estimates revealed differences between the fish counts, fish lengths and salmon speeds at closer (0-10m) and further (20-30m) ranges, but not at intermediate ranges (10-20m). However, when fish counts and fish lengths are combined to estimate salmon passage, there were no statistical differences in any of the range bins from 0-30m.

We attribute the differences in range-stratified fish counts, lengths and salmon speeds between the DIDSON and ARIS to the different recording settings being used by the two systems. The ARIS recorded the entire 30 metre range within a single file at low frequency (1100 kHz) using 96 beams and a focus point of 15 metres from the lens. By contrast, the DIDSON recorded each of the three 10 metre range bins in a separate file. From 0-10m, the DIDSON recorded at high frequency (1800 kHz) using 96 beams and a focus point of 5m from the lens. The higher frequency and more accurate focus point resulted in a clearer image that allowed more fish to be detected when counting and more precise measurements of length, likely resulting in higher fish counts and more accurate fish length measurements on average for this range bin compared to the ARIS. This finding seems surprising initially because the ARIS has the capability of recording at even higher resolution than the DIDSON, however, due to sampling time constraints we did not record at high resolution with the ARIS. We expect that if the ARIS recorded at high frequency with a more accurate focus point it would have resulted in counts and length measurements similar to the DIDSON.

At the furthest range from 20-30m, the ARIS and DIDSON both recorded at low frequency, however, the ARIS used 96 acoustic beams while the DIDSON can only use 48 beams. In low frequency, the horizontal width of each beam is 0.5° (versus 0.3° in high frequency) even if 96 beams are used. Since the full beam width of the ARIS is 30°, this means there will be overlap between adjacent beams, potentially resulting in images that are spatially smoothed for targets ensonified by two beams in the same area. This could be responsible for the higher average fish lengths and speeds measured with ARIS data compared to DIDSON data. However, the ARIS can also record at higher resolution at further ranges compared to the DIDSON, and this could have contributed to the differences by more accurately identifying targets and their edges. Further field testing would be helpful to evaluate if the 96-beam setting under low frequency mode produces more accurate length measurements than the 48-beam setting.

Despite the differences that we found in observed counts and lengths from the DIDSON and ARIS systems, the overall salmon passage estimates on the right bank over the observation period from July 14 – 31 were very close with the DIDSON estimating a total salmon passage of 12,600 and the ARIS estimating a total passage of 13,030. The difference in total salmon passage was only 430 or 3.4% of the total and there were no statistical differences in salmon passage estimates for any of the range bins. The salmon passage estimate on the right bank gets added to the offshore and left bank passage estimates to produce the official daily estimate of

Mission passage. Therefore, for management purposes it would have made no difference whether the DIDSON or ARIS systems were used during the experiment period.

ARIS and split-beam comparisons

Comparisons between the ARIS with full 14° beam and HTI split-beam suggest that the two systems produce similar estimates of salmon passage at intermediate ranges from 10-30m, but significantly different estimates at close range from 0-10m and further ranges from 30-50m. Estimates of salmon passage from the ARIS were about 40% lower for both close and far ranges compared to the split-beam with extrapolation.

The lower estimates of salmon passage from 30-50m using ARIS data compared to the split-beam is likely due to differences in the acoustic properties of the systems and interference from the convex bottom on the left bank. The ARIS operates at a much higher frequency than the split-beam (1100 or 1800 kHz vs 200 kHz) and higher frequency sound waves dissipate energy much more quickly due to absorption, therefore reducing the ability to detect acoustic targets at further ranges. In-situ measurements at the Mission site using a concrete fish showed that the target became faint and difficult to detect at further ranges with the ARIS, confirming that absorption with range can affect target detection. Previous experiments have also shown that convex bottom features on the left bank can shadow fish passage and prevent sound beams from seeing fish migrating behind the convex structures on the bottom (Xie et al. 2005). These blind zones likely also contributed to differences between the ARIS estimate and the split-beam estimates at further ranges.

At close range from 0-10m, we attribute the lower estimated salmon passage by the ARIS versus the split-beam with extrapolation to differences in sampling coverage of the water column. We used two overlapping aims each with approximately 14° beam height for the ARIS, while the split-beam used six aims of 2° beam height each combined with extrapolation of unsampled areas. Though the ARIS directly observed a higher passage of salmon compared to the split-beam without extrapolation, it could not sample the entire water column at such close range, and therefore produced a lower estimate than the split-beam with extrapolated flux. By contrast, the extrapolated portion of the split-beam estimate was much lower from 10-30m and the two systems produced estimates in this range that were not significantly different.

Using a 3° concentrator lens on the ARIS resulted in estimates that were more than double the split-beam estimates from 0-30 metres. Comparisons of individual ARIS aims to multiple split-beam aims showed that the salmon passage from a single ARIS aim using the 3° concentrator lens was comparable to 2 or 3 combined aims from the 2° split-beam. This suggests that the effective beam height of the ARIS with 3° concentrator lens is closer to 5° or 6° when counting salmon. In-situ measurements performed by raising and lowering a concrete fish within the ARIS beam produced similar estimates of the effective beam height. Therefore, if the concentration lens is to be used for any future estimates of salmon passage the sampling design must assume a larger beam height than 3°, otherwise the ARIS data will result in severely overestimated salmon passage.

Conclusion

An ARIS 1800 system was deployed at the Mission site in an experimental capacity during the 2015 and 2016 field seasons for comparison with the well-established DIDSON and split-beam systems. We found some differences in the fish counts, length measurements, and salmon estimates produced by the ARIS compared to the DIDSON, but they are likely attributable to the experimental design rather than any inherent difference in the systems themselves. In 2015 the ARIS was deployed in a different position than the DIDSON and sampled a different portion of the water column, while in 2016 the ARIS recorded with different settings at some ranges including the focus distance, frequency and number of beams. Despite the differences in the recording settings, the ARIS estimates of salmon passage on the right bank were statistically and functionally identical to the DIDSON estimates in 2016.

Overall, the results of our experiments give us confidence that either the DIDSON or ARIS systems can be used to produce comparable estimates of salmon passage in the right bank nearshore areas. The ARIS system offers the further advantage of being able to record at higher resolution and up to a further range than the DIDSON, though care should be taken when configuring the recording settings to ensure they will produce the most accurate counts and lengths measurements as possible within each range bin. Despite having the capability to record imaging data up to 50 metres range, the target detection ability of the ARIS may become degraded beyond 30 metres range, as revealed through comparisons with the split-beam system.

For 2017 and future years, the PSC hydroacoustics program intends to use data from the ARIS towards the estimation of daily salmon passage. Nonetheless, future experiments could help to further understand differences between the ARIS and split-beam systems, particularly at further sampling ranges and regarding behavioural information such as fish speeds. Further studies could also examine whether there is any potential for an imaging sonar to replace the mobile split-beam for offshore sampling of salmon passage.

ACKNOWLEDGEMENTS

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FINANCIAL STATEMENT

Pacific Salmon Commission

Evaluation of an Adaptive Resolution Imaging Sonar (ARIS) for Fish Counting in the Lower Fraser River SF-2016-I-15

Statement of Receipts and Expenditures

As at: **May 19, 2017**

	ACTUAL	BUDGET	Variance
Receipts			
Project Grant	$ 130,225.00	$ 144,692.00	$ 14,467.00
Total receipts	$ 130,225.00	$ 144,692.00	$ 14,467.00
Expenditures			
Capital Costs	$ 133,134.37	$ 137,364.00	$ 4,229.63
Shipping	$ 1,588.30	$ 860.00	(728.30)
Administration	6,468.00	6,468.00	-
Total Expenditures	141,190.67	144,692.00	3,501.33
Balance	$ (10,965.67)	$ -	$ 10,965.67

I certify the information given above is, to the best of my knowledge, correct and complete

Date: May 19, 2017 Signature: [signature] Witty Lam

Position: Senior Accountant