APPENDIX 6

UNLOCKING THE SEVERN

Report on the use of multi-beam sonar (*ARIS*) to monitor shad migration at Upper Lode Weir, River Severn.

18th May to 1st June 2017

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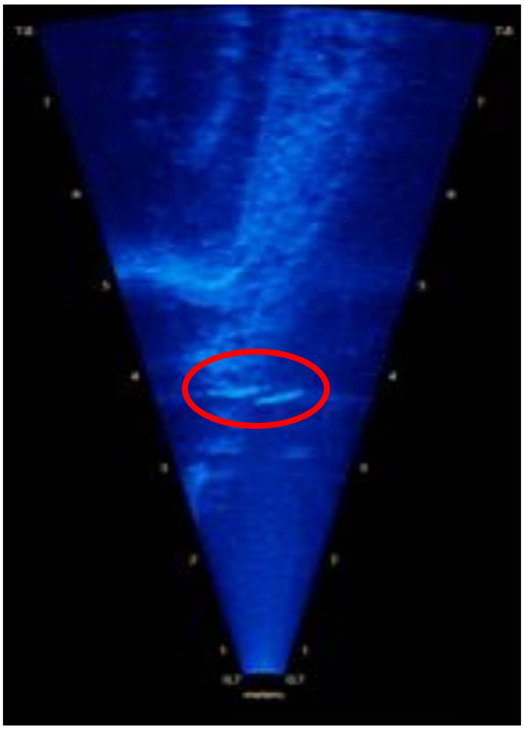

Monitoring Sub Group *LIFE15 NAT/UK/000291/HG-15-04573*

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1. Introduction

The Environment Agency and its partners, the Canal and Rivers Trust, Severn Rivers Trust and Natural England are investigating the potential of opening up the historic spawning area of shad on the River Severn. The ability to monitor fish in their natural environments is often difficult to accomplish in large lowland rivers, especially in low visibility or turbid conditions (Baumgartner *et al*. 2006). Recent advances in acoustics have led to the greater use of multi-beam acoustic systems to study fish. This equipment provides video quality images, allowing non-invasive monitoring.

Multi-beam acoustics contributes to a feasibility study to assess a number of monitoring methods and to determine their usefulness in understanding the current status and environmental influences on the migrating shad population in the River Severn.

2. Aim and Objectives

The overall aim of the study was to assess the practical and technical use of multi-beam acoustics to monitor, quantitatively, the migration of shad in the River Severn.

Three specific objectives were considered:

1. Assess the practical application and technical challenges of using multi-beam acoustics to enumerate and size migrating shad.

2. Provide suitable data on shad numbers, migration timing and size to validate the resistivity counter at Upper Lode Weir.

3. Provide suitable data on shad numbers and timing to validate Citizen Science observations at Upper Lode Weir.

3. Methods

2.1 DATA COLLECTION (ARIS)

A multi-beam sonar ARIS EXPLORER 1800 (*Sound Metrics Corporation*) operating at 1.8MHz was deployed at Upper Lode Weir between the 18th May and 1st June 2017. This was located immediately upstream of the notch (Figure 1) adjacent to the left bank. Deployment involved mounting the *ARIS* on a scaffold pole frame anchored into the river bank. The acoustic beam (28^0 x 14^0) was positioned to detect any fish moving through the notch. Beam range was 7.4m this providing coverage across the total notch width and part of the intact weir crest.

All equipment was housed in a metal strong box to provide a secure environment. Where required power was supplied by batteries charged from a methanol fuel cell.

Data was collected continuously at a frame rate of 6.3 per second and stored every 15 minutes into individual image files. A total of 1,330 image files were collected during the monitoring period.

2.2 DATA PROCESSING AND ANALYSIS (ARIS)

Four 24h monitoring dates (19th May; 20th May; 25th May; 26th May) were analysed. These data were chosen to cover two different flow events (*Source: Saxon Lode Gauging Station* NGR: SO8634939041) during the monitoring period. On the 19th May and 20th May freshwater river flow was at its highest whilst the 25th May and 26th May were during a "spring" tide event. Over these 8 days the river increased in temperature at the same location by 3.5 ^{0}C.

Whilst equipment downtime events were experienced over the 15 days of monitoring no such events were recorded during the four dates used in this analysis.

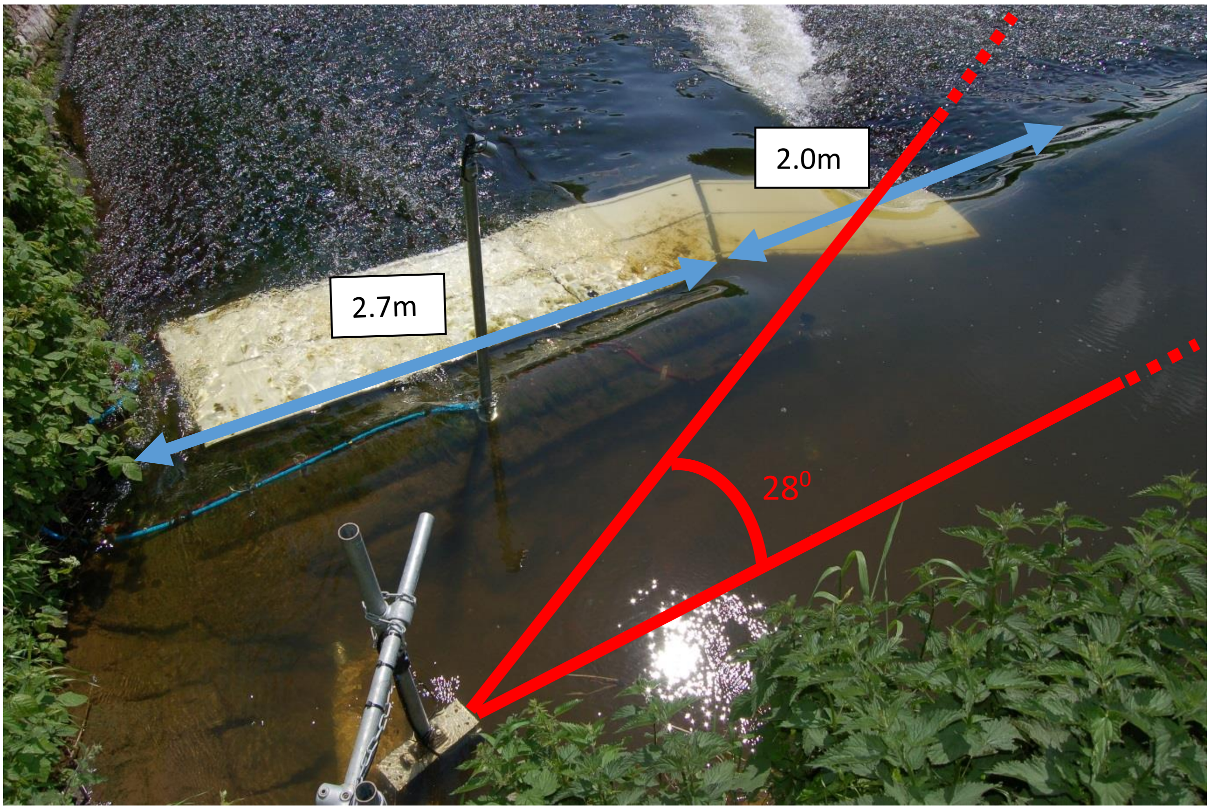

Figure 1. ARIS deployment at Upper Lode weir showing the approximate position of the acoustic beam.

None of the files were suitable for compression using *Continuous Sampling Over Threshold (CSOT)* analysis due to continuous movement from a combination of resident fish, flow and debris.

Data was reviewed at 30 frames per second using *ARISFish* software (*Sound Metrics Corporation*) with fish processed using the *Echogram* mode. An echogram is a visual representation of an entire image file. The echogram image displays fish tracks which represent the range location of the fish versus time as they swim across the beam. Tracks were identified where the acoustic signal intensity is greater than the background intensity (-80dB). When a fish was observed the footage was slowed and watched back. Where a number of fish were in close proximity this review was often conducted frame by frame.

For all four monitoring dates each upstream event was logged to provide a count for each file. In addition, all fish identified on the 25th May were measured using the *ARIS* sizing tool. Care was taken to ensure that size was taken when the full length of the fish was displayed. Image quality was variable and where head and tail not distinct no sizing was undertaken.

Using a combination of behaviour pattern, swimming form and echo track characteristics each trace was assigned into one of three fish categories:

i. Shad
ii. Anguilliform (eel and lamprey sp.)
iii. Other

Tracks from shad typically exhibit a characteristic form as shown in Figure 2. These tracks tended to be of higher intensity than for other fish species, indicating a strong returning echo. In most cases orientation of the track is near vertical, reflecting rapid movement across the beam.

The only other distinct fish group that was identified in this study was those with anguilliform characteristics, notably eel and lamprey. The remaining images were grouped into the 'Other' category. This category included images that were most likely salmon, principally due to the size and shape of the event on the echogram footage. For the purpose of this study these individuals were not specifically categorised. The remaining events in this category were included for two reasons. Firstly, the event did not exhibit clear characteristics of either shad or anguilliform. Alternatively the image quality was sufficiently poor, for example blurring, to clearly identify the image.

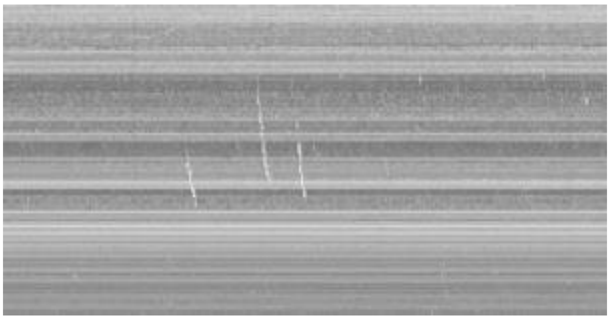

Figure 2. Typical echogram tracks from three shad passing upstream across the ARIS acoustic beam at Upper Lode Weir

2.3 STATISTICAL ANALYSIS

Statistical analyses were undertaking using *Minitab* and *MS Excel*. Linear regression analysis was used to examine the relationship between processing time and number of fish tracks. All graphical production was completed using *MS Excel*.

4. Results

3.1 COUNTS

A total count of 1,353 shad were recorded during the four days analysed with a significant bias towards the "spring" tide period (25th May and 26th May). Over these two days 84.6% of the total count was recorded.

Date	Shad $_{\text{total count}}$
19th May	108
20th May	101
25th May	462
26th May	682

Table 1. Total 24h counts for shad at Upper Lode Weir.

From the total count 1,329 (98.2%) shad moved upstream at a range (2.7-4.7m) approximate to the location of the notch. Of the remaining individuals migrating upstream, 11 shad were noted close (<2.7m) to the near bank and 13 shad at a greater range (>4.7m) than the notch.

3.2 TIMING

Shad appeared to use daylight passage (Figure 3), the period between 11:00h and 13:00h being the time of maximum upstream passage across the four dates analysed. A second, albeit with significantly fewer individuals, upstream passage occurred in the early evening between 18:00h and 19:30h. A few shad were noted passing upstream during the hours of darkness.

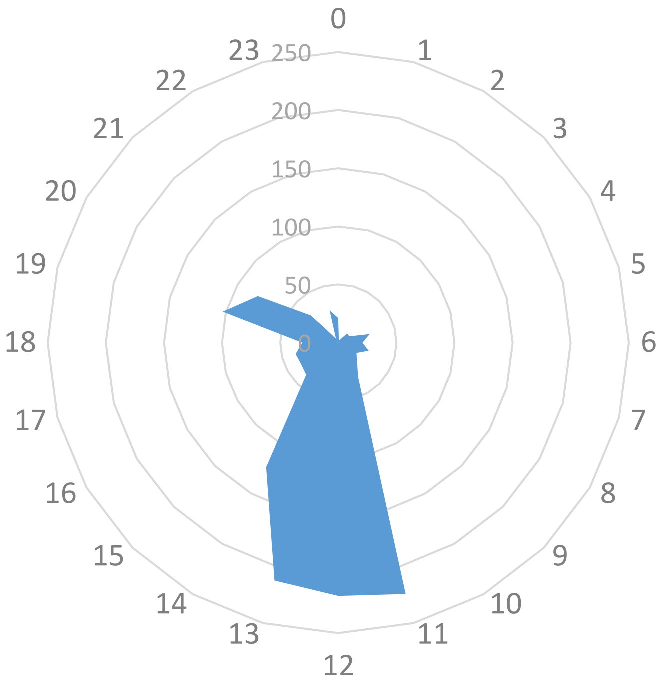

Figure 3. Distribution plot showing time against the combined number of shad recorded on the 19th May, 20th May, 25th May and 26th May at Upper Lode Weir

Timing, divided into four equal 6h intervals across a 24h period show a significant variation in shad upstream migration counts (Figure 4). The daytime intervals 06:00-11:59 and 12:00-17:59 reveal statistically significant greater counts than the intervals that cover night time (0:00-05:59 and 18:00-23:59).

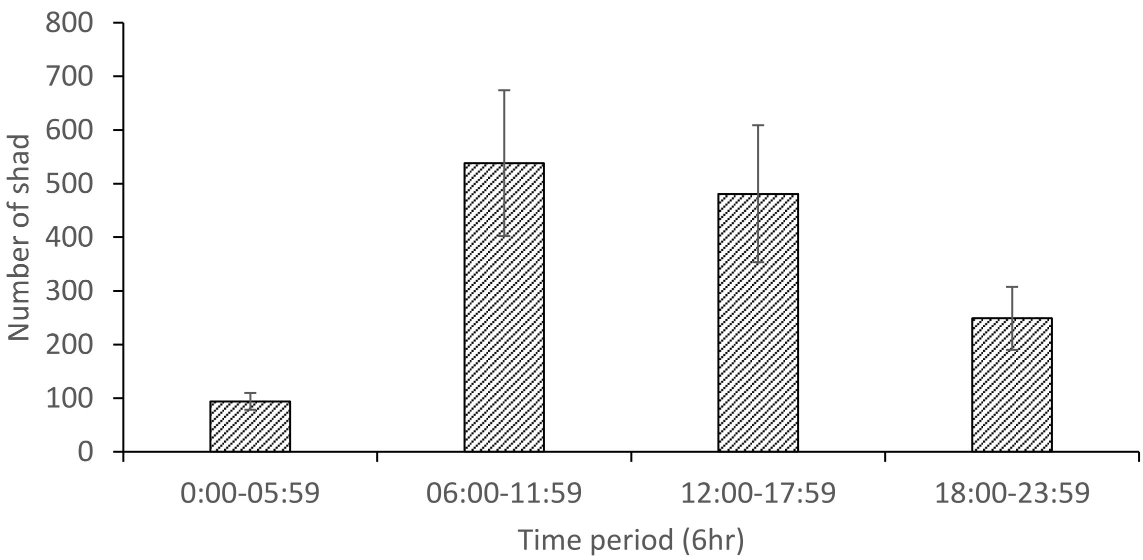

Figure 4. Distribution of shad upstream migration combined counts (with 95% CL error bars) across four time periods (0:00-05:59; 06:00-11:59; 12:00-17:59; 18:00-23:59) recorded on the 19th May, 20th May, 25th May and 26th May at Upper Lode Weir.

3.3 SIZING

Initial measurement of shad total body length from analysis of echogram footage for the 25th May resulted in an average body length of 43.11 cm. Applying a regression conversion ($L_{total} = L_{fork} * 1.1325 + 2.6556$) the average fork length of shad migrating upstream through the notch at Upper Lode Weir was 35.41cm. This value is close to a long-term (1979-1996) average of 34.9cm (n = 5,667) for *Allosa fallax* in the River Severn (*pers. com.* Miran Aprahamian).

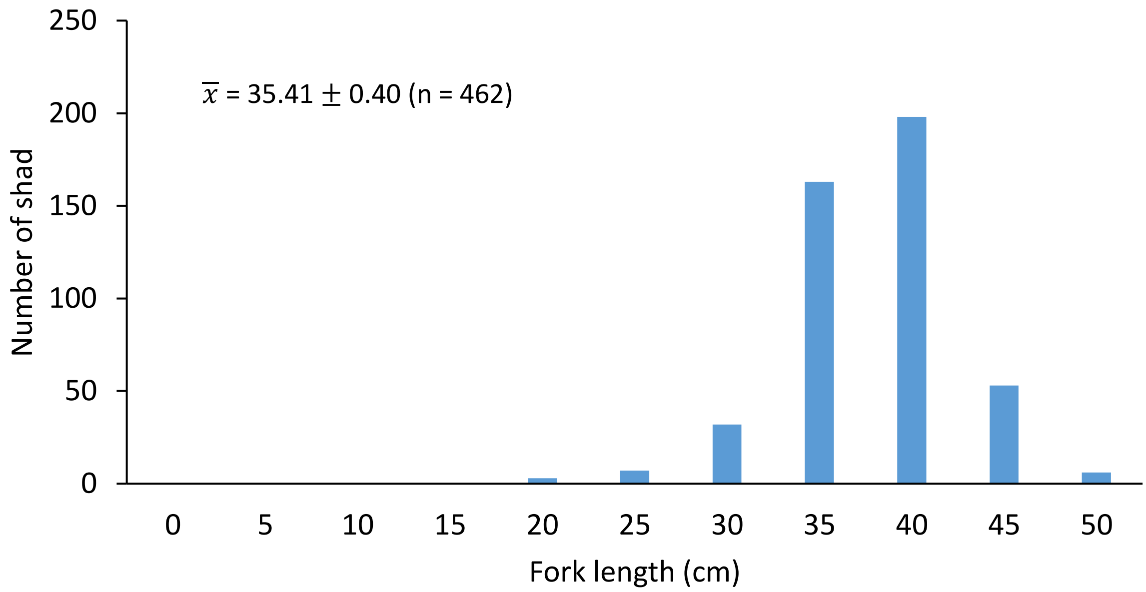

Figure 5. Frequency distribution for shad fork length (cm) at Upper Lode Weir on the 25th May 2017.

3.4 ENVIRONMENTAL DATA

Flow, tide and temperature data was used to determine which sampling periods were analysed from the multi-beam acoustic monitoring dataset. This information was used to ensure that sub-samples covered significant variation in environmental conditions experienced by the fish population (Figure 6). Increased river flow, “spring” tide events and a 3.5 ^{0}C increase in river temperature were recorded across the four days of data analysed.

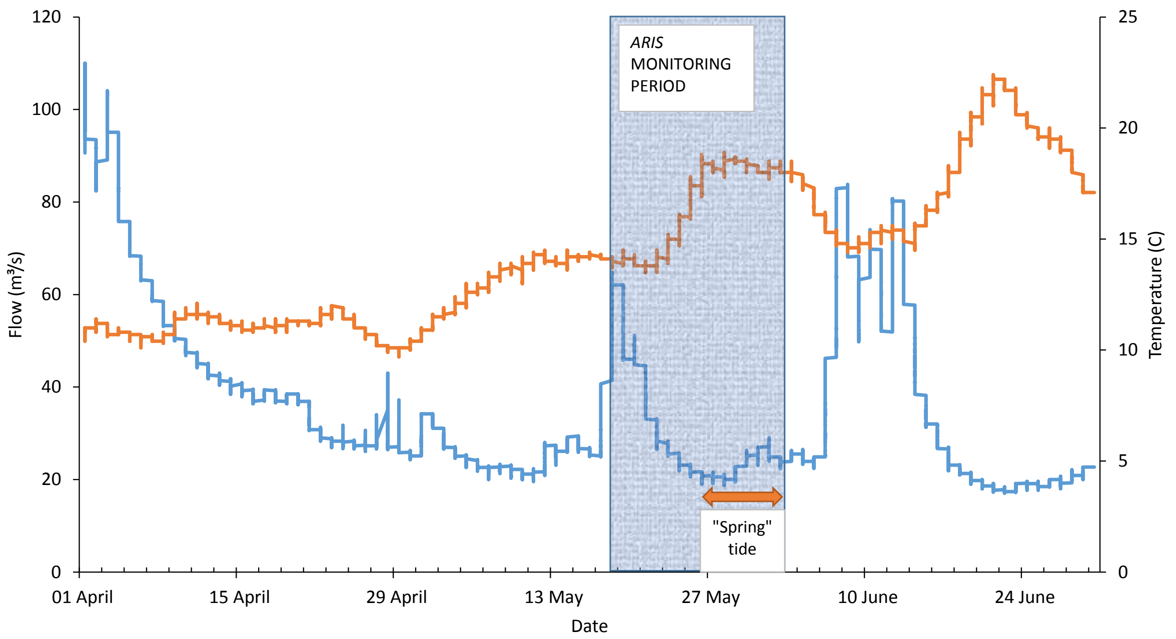

Figure 6. Flow and temperature data at 15 minute time intervals at Saxon Lode on the River Severn between 1st April and 30th June 2017.

3.5 RESOURCES

Acoustic monitoring, using multi-beam sonar, is a powerful survey tool in the fisheries scientists' armoury. However the gathering of these large data sets requires a significant resource to process and analyse the data to a point where it becomes valuable evidence to inform fisheries management decisions.

For data collected on the 25th May processing (fish count and individual sizing) time for recorded for each image file. Figure 7 describes a linear relationship between number of tracks and processing time. Using the mean value for all data it was established that on average it takes 19.1 minutes to analyse and process each file. With each being 15 minutes duration this represents a collection to processing ratio of 1:1.3. This ratio would reduce if the data is processed only for counts. Further resource savings could be made through adopting a sub-sampling approach to data processing and analysis. However the results clearly indicate that significant resource is required to provide a meaningful output.

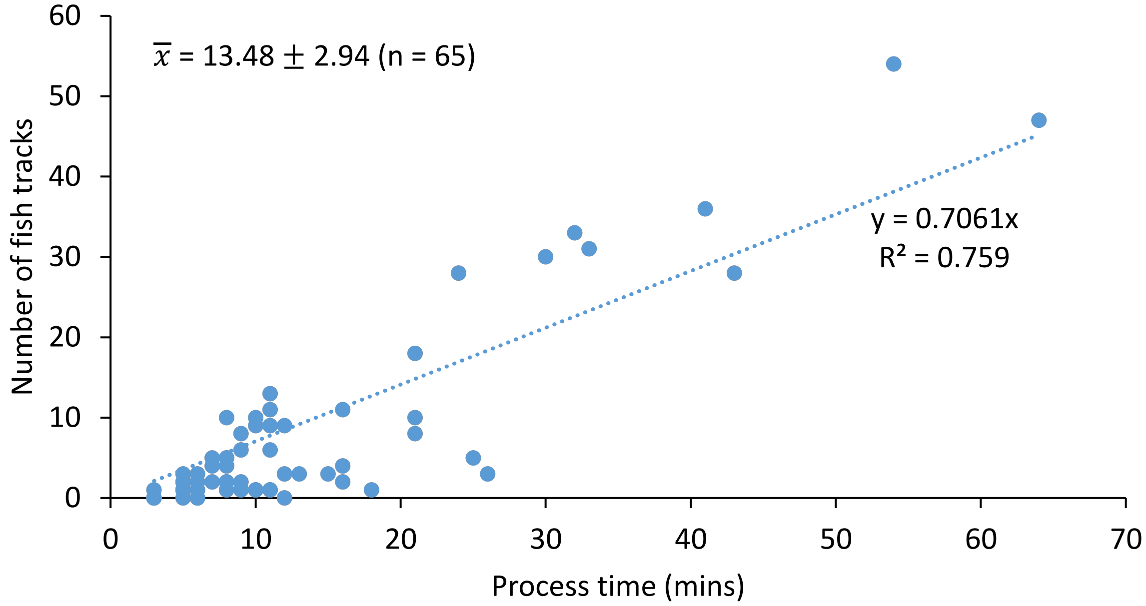

Figure 7. Graph showing the relationship for multi-beam (ARIS) data between process time and the number of fish tracks recorded.

5. Discussion

Deployment of the ARIS in the current study was similar to a first trial (Crundwell *et al*. 2016) conducted in 2016 at the same site. Location of the equipment and orientation of the acoustic beam, to achieve best image quality, was based on a combination of theoretical knowledge on beam characteristics, site flow conditions, safe river access and the availability of suitable equipment fixing points. The nature of the site afforded laminar flow and a safe working environment. Minor modification to the 2016 installation was undertaken to achieve an increase in beam range from 5.3m to 7.4m. This increase resulted in additional information on fish passing across the weir crest instead of through the notch. Images of fish circulating or 'milling' were also captured, as in 2016, with the modified siting.

ARIS has shown to provide a suitable method to observe fish in their natural environment even under poor visibility conditions. The findings from this study concur with this assessment. At Upper Lode the site-specific arrangements, principally the presence of the weir notch affording an optimum migration path, created ideal conditions for multi-beam acoustics. Short (<10m) range and laminar flow allowed the use of a high frequency (1.8 mHz) beam option which afforded good image resolution.

The data was processed (30 frames sec^{-1}) at approximately five times the collection frame rate (6.3 frames sec^{-1}) by a single observer. Count errors were not assessed in this study and therefore no information on 'missed' fish is available. It should be expected that observations using this faster frame rate may incur some 'missed' fish particularly during periods of high passage activity.

This investigation demonstrates that fish counts using ARIS provide a good assessment of upstream passage by shad. Additional information on fish size and behaviour is also accrued. Outputs clearly show that suitable data was provided by this method that can be successfully deployed to verify counts obtained from other methods, for example, resistivity counters and Citizen Science observations. However, multi-beam sonar generates substantial amounts of data and whilst a powerful technique to detect fish, it is not suitable for routine applications. Table 2 describes the main advantages and disadvantages of multi-beam acoustics for fish monitoring.

Advantages	Disadvantages
High quality 'video' images.	Very large file size (TBytes)
Greater range of vision than traditional split-beam sonars	Data analysis requires significant resource and time.
Easy fish identification, in some cases to species level.	Restricted maximum (~15m) detection range at high (1.8 MHz) frequency.
Can be used at night	Requires laminar or no flow conditions. Not suitable for turbulent conditions.
Can be used in poor clarity water	Ideally needs perpendicular fish aspect to acoustic beam, particularly small targets.
Will run automatically during user-defined timings.	
Fish can be measured	
Fish behaviour can be observed	

Table 2. The pros and cons of using ARIS multi-beam acoustics

Previous studies with multi-beam acoustics (DIDSON) have shown that shad can pick up acoustic noise, possibly in the region of 200KHz and show avoidance behaviour. Whilst such behaviour cannot be discounted no evidence was found in this study that ARIS deployment impacts on the upstream migration of shad. Most upstream events showed shad moving straight through the beam, perpendicular to the acoustic beam. The remaining events followed various indirect migration routes across the beam as described by Crundwell *et al* (2016).

The results of this monitoring follows previous research from a range of studies that show upstream migration of shad is principally confined to daylight hours. Indeed, most of the observed upstream migration occurred within a two hour (11:00h – 13:00h) window. This information can be used to objectively construct an analysis regime that focuses resources towards times of maximum passage. With the same resource, such an approach would provide scope to analyse additional days within the monitoring period than covered in this report.

Accurate sizing of fish using the ARIS measurement tool relies on good images for each event. Such images can be defined as those where a clear head and tail end are observed. Variability in image quality for shad was noted although most meet this criteria for at least one frame. Frames before and after the 'best' one can show additional acoustic reverberation that has the effect of lengthening and blurring the image. Measurement of images within these frames are likely prone to over-estimation. The average length of shad measured using the ARIS software was greater than that described by data collected between 1979 and 1996 for *Allosa fallax* in the River Severn (*pers. com.* Miran Aprahamian). These measurements were converted using linear regression ($L_{total} = L_{fork} * 1.1325 + 2.6556$) resulting in close agreement with the same long term data set. We tentatively conclude that acoustic measurement of shad from the echogram footage is most likely to reflect standard length. Further work on classification of image quality and measurement criteria is advised.

With the limited resources available only four days from the total monitoring period were processed and analysed. This study is not unique and the quantity of data accrued from multi-beam monitoring will necessitate a sub-sampling approach in future surveys. It is important that sub-samples reflected a range of those environmental conditions experienced by shad. River flow, tide state and temperature were considered those factors of greatest influence. Previous studies have clearly shown that shad movement is substantially driven by water temperature, 12^0 C the critical thermal cue to migration. Whilst water temperature during the entire monitoring period was greater than 12^0 C, a 3.5^0 C increase in river temperature was recorded across the four analysed days. Further analysis of the impact of this temperature change was beyond the scope of this study. Tide state and river flow were both variable within the monitoring period and selection of analysis days took account of this environmental change. In particular, the four days were divided equally, two covering "spring" tides and two elevated river flow.

Assessing the separate and combined influence of temperature, tide and river flow rise on shad upstream migration rate, are beyond the scope of this study. Our observations, however, do show that over four times as many shad migrated upstream during the "spring" tide period when compared to less tide height variation. Behavioural observations in many fish species have shown a willingness to exploit flow regimes that transport towards a location without the need to actively swim. Are shad in the River Severn also exhibiting this energy-saving strategy during their migration?

Multi-beam acoustics is a powerful tool that has a range of applications that will quantitatively inform fisheries management. However, as previously stated, its use should not been seen as a routine one not least because of the large amounts of data accrued and the subsequent significant time required to analyse. Its application in this study has shown it to be a suitable method for both counting and sizing shad at Upper Lode Weir notch.

As with previous new technology there can be a pressure, often driven by a management need, to see these as a 'universal panacea '. This approach often results in a poorly judged application of such technologies, significant resource expenditure and poor data outcomes.

This study illustrates the benefit of the targeted use of multi-beam acoustics to address specific data requirements.

6. Conclusions

- Multi-beam acoustics (ARIS) is an efficient and reliable method for counting, sizing and timing the upstream migration of shad at Upper Lode Weir notch on the River Severn.
- ARIS can be deployed reliably for at least two weeks with continuous data collection.
- Outputs are suitable for validation of resistivity counters and Citizen Science observations.
- The method is not suitable for routine monitoring due to significant resource required to process and analyse data.
- Prior identification of resource to analyse collected data is essential.
- Collection to processing ratio for counting and measurement of events is 1:1.3.
- Shad provide a clearly identified acoustic signal using ARIS at 1.8 MHz.
- Tide state is a likely influence on the upstream migration rate of shad.
- Most shad migrate during daylight hours.
- A total of 1,353 shad were counted passing upstream over a four day (24h) period.
- The ARIS measurement tool is accurate for shad where image quality is good.
- Average size of shad migrating upstream during the study period is 35cm.
- Frame rates up to 30 frames sec $^{-1}$ are suitable for analysis to identify and count shad.
- Lamprey sp., eel, salmon and coarse fish sp. were recorded during the monitoring period.
- Various fish behaviours were noted including: ‘milling’, spawning activity and shoaling.

7. Acknowledgements

Our thanks go to the following people for helping with this study and in the preparation of this report. Charles Crundwell, Darryl Clifton-Dey, Chris Bainger, Jon Hateley, Brecht Morris and Miran Aprahamian.

8. References

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