ARE TWAITE SHAD ABLE TO DETECT SOUND AT A HIGHER FREQUENCY THAN ANY OTHER FISH? RESULTS FROM A HIGH RESOLUTION IMAGING SONAR.

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ABSTRACT

This paper describes some unusual responses of riverine fish to a sonar system transmitting sound at 1.8MHz. It establishes that only twaite shad, *Alosa fallax fallax* were able to detect these transmissions and that these responses were not replicated in a "closed", captive environment. In 2005 and 2006, shad were monitored at two different sites on the River Wye in Wales, using an imaging sonar system (the Dual Frequency Identification Sonar or DIDSON) operating at both 1.1 and 1.8MHz. The data revealed that shad repeatedly and consistently swam away from the DIDSON transducer, changing direction as they moved upstream by between 45 and 90 degrees as they approached the centre beams. This is shown to be directly attributable to the DIDSON transmission. The behavioural characteristic observed could be described as mild avoidance rather than the startle and flee response observed during 200KHz transmission.

This paper presents data from those trials that clearly indicate twaite shad are capable of detecting a directional pulsed sound generated by an imaging sonar system operating at both 1.1MHz and 1.8MHz in a natural river environment.

To examine fish behaviour in a controlled environment, shad were captured and placed into a 5-metre diameter circular tank and their behaviour observed as they were subjected to sound transmitted by two different systems at 200KHz, 420KHz, 1.1MHz and 1.8MHz. The fish showed no discernible reaction to sound produced by the DIDSON system in either 1.1 or 1.8MHz frequency mode, despite their reaction under natural conditions in the river. As expected, the 420KHz transmission from the split-beam system also produced no reaction but the 200KHz produced an immediate flee response as they hit the sides of the tank so hard they were temporarily stunned. This reaction to 200KHz occurred, although with variable intensity, across a range of power and pulse rate combinations.

1 INTRODUCTION

The twaite shad, *Alosa fallax fallax*, has declined across its range and its threatened status is recognised under the Bern Convention and IUCN Red List. In the UK it is only known to successfully spawn in four rivers; the Usk, Tywi, Severn and Wye. The stability of those spawning populations is largely unknown due in part to the difficulty in monitoring the returning adult spawning stock.

Acoustic techniques are internationally established fisheries management tools. In England and Wales, the Environment Agency fishery monitoring programme consists of over 100 acoustic sites and represents 1000kms of river length, enabling the status of fish populations to be monitored more efficiently and in situations that would be inappropriate for other methods. However, "conventional" split-beam acoustic systems are technically complex to collect and analyse data. This has had an inhibiting effect on our ability to fully exploit the advantages of acoustic techniques for fisheries monitoring. For example, a 420KHz split-beam system has been used on the River Wye but the density of the shad shoals mean that individuals can not be resolved and this method is restricted to counting shoals of shad.

For management purposes, individual numbers are essential. In an attempt to overcome the resolution issues, trials were conducted with a high frequency imaging sonar. The development of high resolution imaging acoustic systems for fisheries applications appears to have the potential to more fully exploit the acoustic advantage. For riverine, shallow water applications, the multi-beam system produced by Sound Metrics and known by the acronym of DIDSON (Dual-frequency IDentification SONar), is the market leader. This device can produce high-resolution near-video quality images in low-visibility water. With very little training, practically anyone can use it to get impressive underwater images of fish from a few centimetres in length and be able to detect fish at ranges exceeding 40 metres.

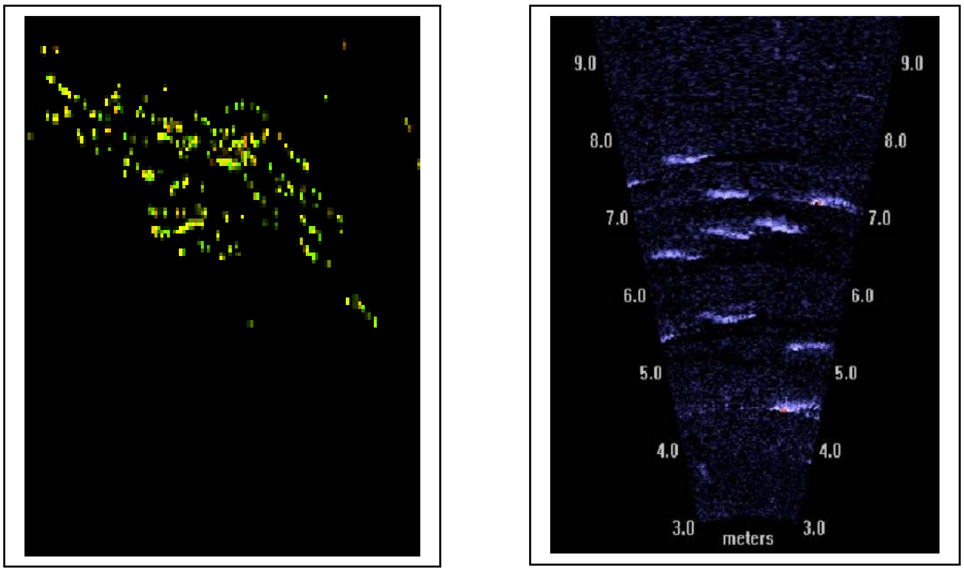

Figure 1. On the left, a shoal of fish from a 420kHz split-beam system. On the right, a shoal recorded from DIDSON revealing individual fish.

It is known that species of clupeid are sensitive to sound. Studies conducted on the Alewife, *Alosa pseudoharengus* (Ross et al, 1996) and Blueback herring, *Alosa aesivalis* (Nestler et al., 2002) showed avoidance responses to sound at frequencies over 120 kHz. American shad, *Alosa sapidissima* (Popper and Carlson, 1998) demonstrated a response to 180 kHz and Twaite shad, *Alosa fallax fallax* (Gregory and Clabburn, 2003) have responded to 200 kHz. Published sensitivities for other teleost fish range from 10Hz to 1 kHz (Popper, 2000). There are notable exceptions such as the Atlantic cod, *Gadus morhua* which demonstrates a sensitivity to 38 kHz (Astrup and Møhl, 1993). However, most fish detect a much lower range of frequencies, as typified by the anadromous Atlantic salmon, *Salmo salar*, which can detect frequencies in the 10 – 380 Hz range (Hawkins and Johnstone, 1978).

1.1 Objectives

The reason clupeids have developed a sensititvity to such high frequencies is unclear. But until their full sensitivity range is known it is important to establish that any sonar based monitoring technique does not impact on the behaviour of the migrating fish. Therefore the DIDSON trials on the River Wye had the following objectives:

1. To establish that pulsed sound at 200kHz repels twaite shad.
2. Use 200kHz as a barrier to shad movement for discrete time periods in an open river environment.
3. Continuously collect data with the DIDSON and categorise fish behaviour when this data was replayed as a surrogate for video.

2 METHODS

2.1 Establishing that 200kHz repels twaite shad

Twaite shad were captured on rod and line from the River Wye. The healthiest four were taken to the Environment Agency's fish hatchery at Cynrig, Brecon and introduced into a 5 metre diameter closed system re-circulation tank. One fish subsequently died. The fish were left to acclimatise to the tank environment for 18 hours, during which their behaviour was periodically observed both remotely via underwater cameras and an observer.

Introduced into the tank and activated individually were a 200kHz split-beam transducer, a 420kHz transducer and the DIDSON imaging transducer operating and 1.8MHz and 1.1MHz. Behaviour was observed from underwater via camera system and above water by observers. Following this, the fish were observed for a further week before being released back into the River Wye.

2.2 The in-river shad sound barrier

A 200 kHz split-beam transducer was deployed 8 km from the head of tide on the River Wye in both 2005 and 2006, aimed horizontally along the river bed, perpendicular to river flow. When active, this system transmitted a 0.2ms pulse at 20 pings per second at a source level of 221.8 dB (reference pressure 1 μPa at 1 m). The activity of the 200 kHz barrier is summarised in Table 1. During the studies, the system was active for one or two 15 minute periods of every hour and inactive for the remaining 15 minute periods, thereby allowing passage of shad.

In 2006, the DIDSON was aimed in the same direction as the split-beam system, immediately adjacent to the split-beam transducer, and operated for 2 days at 1.8MHz and 2 days at 1.1MHz. In 2005 it was deployed 250 metres upstream of the split-beam transducer. In both cases the DIDSON remained active for the entire hour.

Table 1. Operation of the 200 kHz sound barrier to twaite shad.

	2005	2006
Survey dates	19th – 20th May	18th – 19th May 1st – 2nd June
Relative locations of split-beam and DIDSON transducers	200 kHz approximately 250 m downstream of DIDSON	200 kHz and DIDSON adjacent
Sampling periods (DIDSON 1.8 MHz = High Frequency DIDSON 1.1 MHz = Low Frequency)	DIDSON 1.8 MHz: 00 – 15 mins: 200 kHz ON 15 – 30 mins: 200 kHz ON 30 – 45 mins: 200 kHz ON 45 – 00 mins: 200 kHz OFF	DIDSON 1.8 MHz: 00 – 15 mins: 200 kHz ON 15 – 30 mins: 200 kHz ON 30 – 45 mins: 200 kHz ON 45 – 00 mins: 200 kHz OFF DIDSON 1.1 MHz: 00 – 15 mins: 200 kHz OFF 15 – 30 mins: 200 kHz ON 30 – 45 mins: 200 kHz OFF 45 – 00 mins: 200 kHz ON

Figure 2. Deployments on the River Wye in 2005 (left) and 2006 (right).

2.3 Data processing and fish behaviour characterisation

To examine fish behaviour and obtain a count of upstream and downstream moving fish targets passing through the DIDSON acoustic beam, all the frames were played back in Image mode (analogous to a video replay). Initial observations with the DIDSON revealed two types of fish behaviour.

1. Fish would enter the beam individually or in pairs, and pass more or less perpendicularly through the beam.
2. Fish were seen entering the beams of the DIDSON at right angles, parallel to the river bank. When about half a body length inside, the fish turned away from the DIDSON transducer, changing their direction of travel by 45 to 90 degrees.

The times and direction of travel of each fish that demonstrated this behaviour type were recorded.

2.4 Bank Side Observations

As shad shoals are easily identifiable by experienced personnel, fish behaviour was further investigated through bank side observations. Due to the conditions and distance of the fish from the bank only a limited number of visual observations were possible in 2005 and none in 2006.

3 RESULTS

3.1 Captive observations

On activation of the 200kHz transducer placed in the 5 metre tank, the three shad would instantly swim fast and hard into the sides of the tank, to an extent that they frequently appeared temporarily stunned and would float to the water surface. This reaction was observed, although possibly with a reduced intensity, when both ping rate and source level were decreased.

No reaction was observed when a transducer transmitting at 420kHz was deployed in the tank. Equally, no reaction could be discerned when the DIDSON unit was deployed in the tank, either at 1.8 or 1.1MHz.

3.2 River Observations

In 2005, after the DIDSON was deployed in the water but prior to it being activated, a shoal of about 6 shad were visually identified from the bank side
as they passed in front of the transducer and mount, seemingly undisturbed by its visual and physical presence. Once the DIDSON system was activated, no further visual observations of this behaviour were recorded.

On playback of the DIDSON data, distinctive and unusual fish behaviour was observed. Fish were seen entering the beams of the DIDSON at right angles, parallel to the river bank. When about half a body length inside, the fish turn away from the DIDSON transducer, changing their direction of travel by greater than 60 degrees.

This behaviour is illustrated in the sequence in Figure 3 taken from DIDSON playback mode and has not been noted during any other deployments of the DIDSON system on over ten UK rivers.

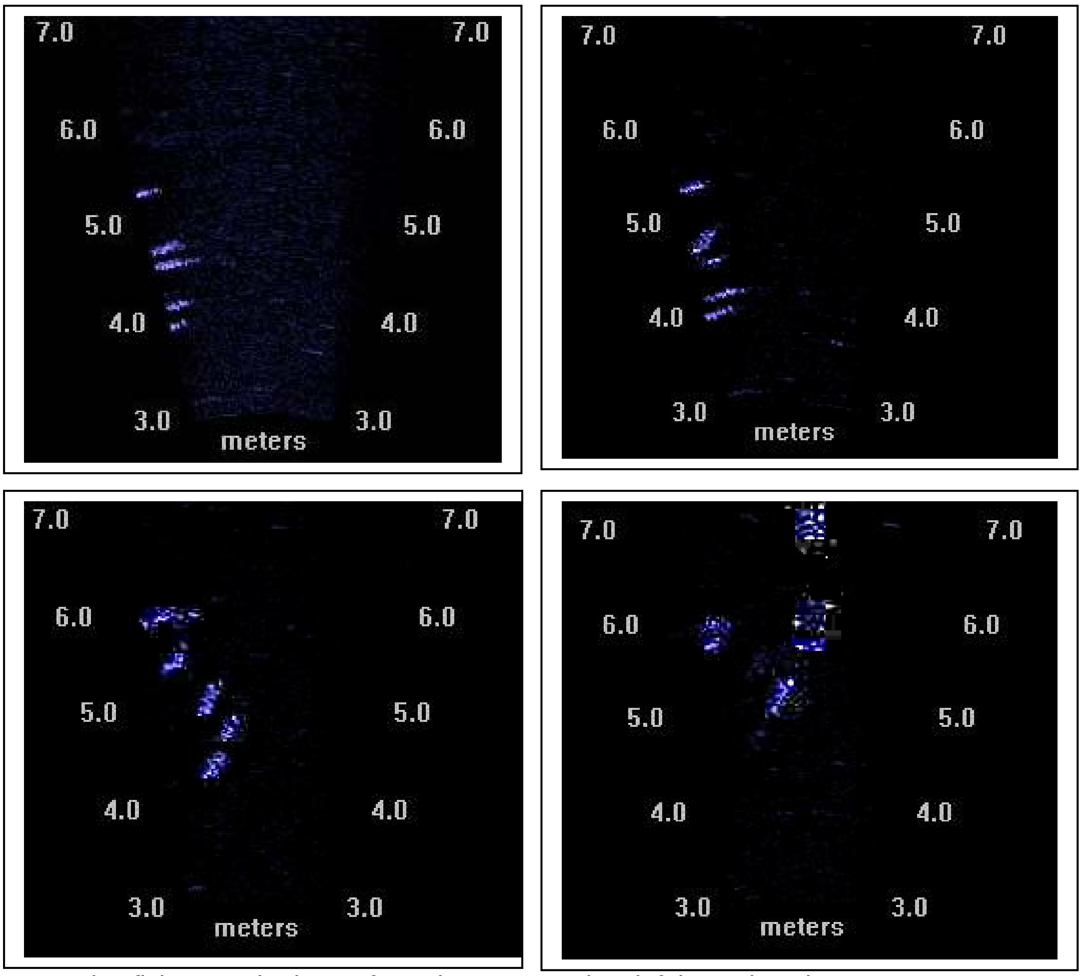

Figure 3. Five fish enter the beam from downstream (top left image) and start to turn away from the transducer (top right). They continue to turn and swim away from the transducer, but with a net upstream movement (lower two figures). This sequence represents less than 1 second of real time.

In 2005, 424 fish events were recorded displaying this behaviour using DIDSON operating at 1.8 MHz. The times of these events were not evenly distributed throughout the hour, and were biased in favour of the 15-minute period when the 200kHz system was inactive (Figure 4) and the following 15-minute period. Over 70 % of all upstream fish movements occurred during these two periods. During 2005, there was a 250-metre distance between the split-beam shad barrier and the DIDSON system.

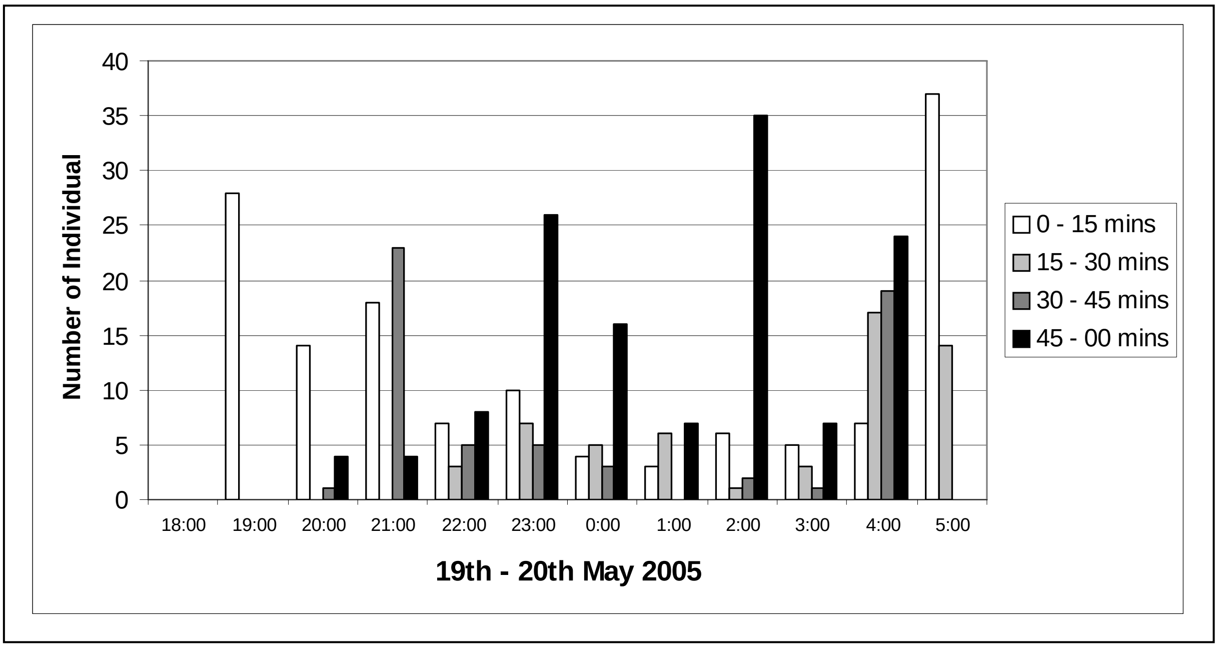

Figure 4. Number and time of fish displaying an avoidance reaction in 2005.

In 2006, 245 individual fish displaying this behaviour were observed and logged with the DIDSON operating at 1.8 MHz. Of these, 241 or 98.4%, occurred in the fourth quarter of each hour, during the 15 minutes that the 200kHz system was deactivated. See Figures 5 and 6.

With DIDSON operating at 1.1 MHz, the sound barrier was active for the first and third 15-minute period of each hour. 189 fish displayed the aversion behaviour, of which 188 (99.5%) passed through the beam when the barrier was inactive.

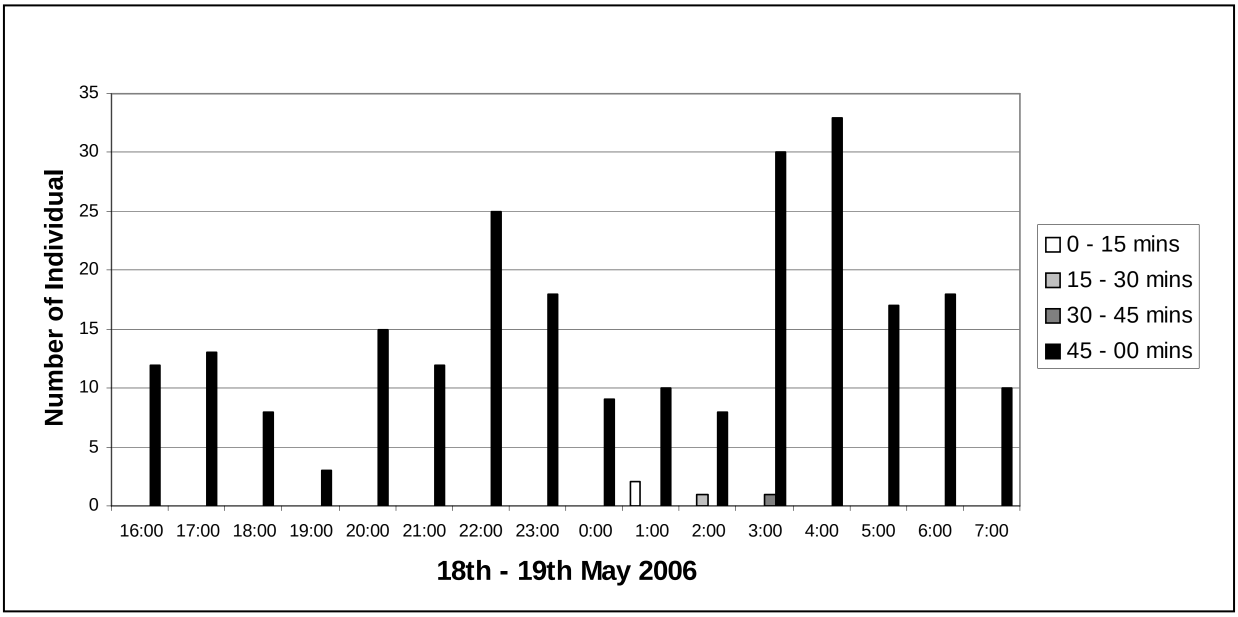

Figure 5. Avoidance reaction during 1.8MHz operation. The 200KHz sound barrier was active from 0 to 45 minutes each hour.

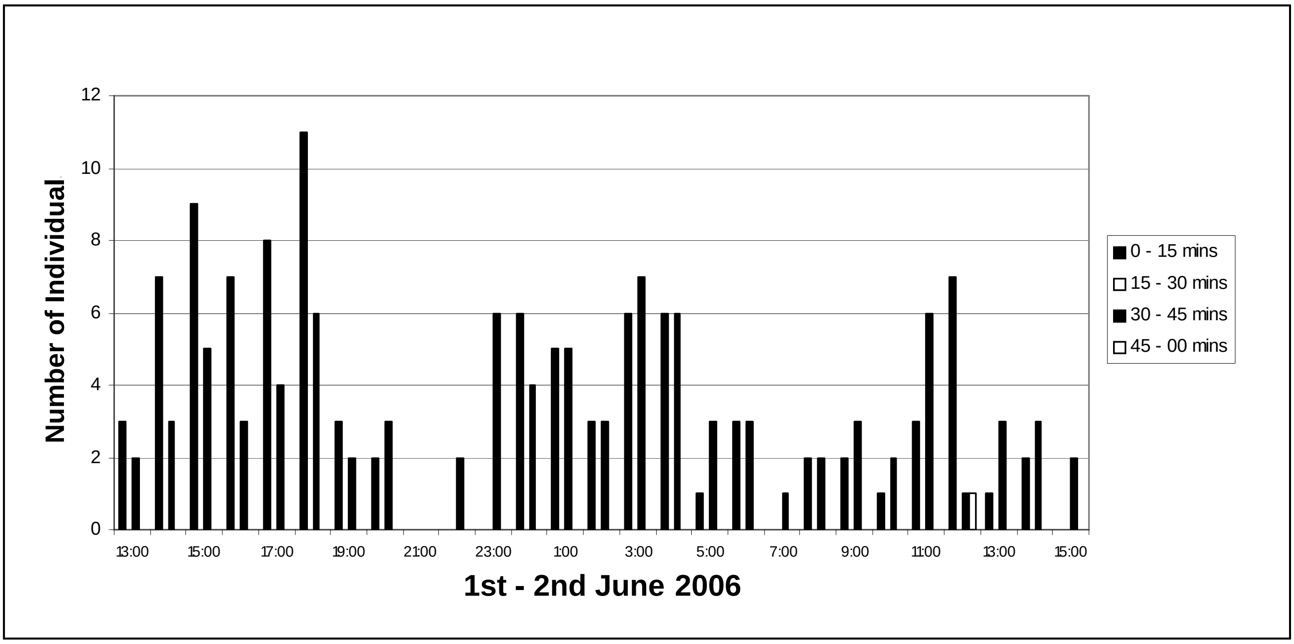

Figure 6. Avoidance reaction during 1.1MHz operation. The 200KHz sound barrier was active from 15 – 30 and 45 – 00 minutes each hour.

4 DISCUSSION

The results show unequivocally that twaite shad are able to detect sound transmitted at 200kHz and show a strong avoidance reaction to it. Pulsed sound transmitted at this frequency in an open river river would therefore act as a barrier to the movement of twaite shad, although the source level for detection and therefore the range of detection from the transducer is unknown. Shad did not respond to pulsed sound at 420kHz.

In an open river environment, the mild avoidance behaviour of fish to the DIDSON system operating at 1.1 and 1.8 MHz has not been recorded on any other river. Of the 10 in the UK where DIDSON has been deployed, and at the time of the deployment, it is likely that only the Wye would have had shad present in the river. The heavy bias towards the display of this type of behaviour in the period of 200kHz inactivity is the strongest indication that these fish are shad. The fact that it was recorded in two different years at different locations and the visual observation that shad swam in front of the system before it was activated, strongly indicate that they detect and avoid DIDSON sound transmissions.

The point at which the shad change from swimming parallel to the river bank to moving away from it can be observed using DIDSON system and occurs when the fish are about a body length into the beam, irrespective of the range from the transducer. This indicates that the sound source causing this avoidance behaviour is directional and related to the transmitted 1.8MHz sound pulses rather than a non-directional mechanical or electronic noise of the system.

Given the above, the lack of any discernible reaction by shad to the DIDSON system when placed in a 5 metre diameter tank is something of a mystery. It could be that there were so many other stimuli for the fish in this captive situation that these masked the impact of DIDSON. Or in a circular tank the sound lost its directivity.

A full sound spectrum analysis has never been carried out for the DIDSON system. Given that twaite shad show no reaction to 420kHz, it seems likely that the DIDSON system is transmitting a wide range of frequencies or harmonics around its 1.8 and 1.1MHz operating system, some of which are within the auditory range of the shad.

Shad are an ideal species to monitor with acoustic systems that have labour intensive analysis techniques. Their migration is usually over within a month of it starting and they all tend to travel upstream together rather than the circulating behaviour that makes salmon monitoring with acoustics so difficult. If the unwanted sound emitted by the DIDSON system can be identified, isolated and removed, then this could represent the only tool to monitor shad migration in an open river.

5 REFERENCES

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