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Avoidance behaviour of *Alosa fallax fallax* to pulsed ultrasound and its potential as a technique for monitoring clupeid spawning migration in a shallow river

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Abstract

A hydroacoustic monitoring technique to quantify and assess the ecological requirements for migration of the anadromous clupeid, *Alosa fallax fallax* (twaite shad) was developed, and its effectiveness studied, on the River Wye in Wales. The acoustic monitoring technique was a side aspect application, with two transducers fixed permanently to the riverbank and the acoustic beam from each aimed horizontally across the river towards the opposite bank, perpendicular to flow. Two split-beam echo sounders and transducers were deployed, each operating at different frequencies (200 and 420 kHz). Using a combination of these two frequencies it was possible to demonstrate that shad show strong avoidance behaviour to sound transmitted at 200 kHz and would not pass the monitoring site when sound was transmitted at this frequency. They remained unaffected by sound transmitted at 420 kHz and were observed migrating upstream in large, loosely aggregated shoals. From visual observations above and below the water, shoals were estimated to comprise of many hundreds of individuals, covering a size range of between 30 and 45 cm. Only a few individuals could be resolved by the acoustic system operating at 420 kHz, and it was therefore, not possible to obtain a count of fish by "target tracking" single shad. However, by transmitting 200 kHz sound pulses on a 50% duty cycle the seasonal and daily patterns of shad migration were derived from the analysis of data gathered by the acoustic system operating at 420 kHz.

Keywords: Fish behaviour; Split-beam; Shad

1. Introduction

It is clear from research into the sensitivity of fish to sound that some species of clupeiforms are unique amongst fish in being able to detect high frequencies.

Published sensitivities for other teleost fish range from 10 Hz to 1 kHz (Popper, 2000) with the odd exception like the Atlantic cod (*Gadus morhua*) demonstrating sensitivity up 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 has been found to detect frequencies within the 10–380 Hz range (Hawkins and Johnstone, 1978).

Studies conducted on the Alewife, *Alosa pseudoharengus* (Dunning et al., 1992; Ross et al., 1996), Blueback herring, *Alosa aesivalis* (Nestler et al., 2002) and American shad, *Alosa sapidissima* (Popper and Carlson, 1998) showed avoidance responses to sound at frequencies over 120 kHz. The highest frequency to solicit a response was 180 kHz for American shad.

More recent research has indicated that this ability to detect ultrasound may be limited to the alosids. Mann et al. (2001) used auditory brainstem response to show that the alosid gulf menhaden (*Brevoortia patronus*), detected frequencies over 100 kHz but the bay anchovy(*Anchoa mitchilli*), scaled sardine (*Harengula jaguana*) and Spanish sardine (*Sardinella aurita*) did not respond to frequencies over 4 kHz.

This study describes observations on the behaviour of a species of clupeid, the twaite shad (*Alosa fallax fallax*), when subjected to two frequencies of pulsed ultrasound, 200 and 420 kHz, as they migrate up the River Wye along the border between England and Wales. It discusses a potential technique that utilises this behaviour to discriminate and enumerate shoals of shad and assess the ecological requirements for the migration of twaite shad as they pass an acoustic fish

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counter deployed primarily to count salmon passage. The twaite shad is an anadromous species that enters freshwater to spawn between April and June.

This study is different from previous studies in that it describes empirical observations of fish behaviour to sound in a natural river environment rather than at an impoundment or a measured brainstem response. It is a study on a European species of anadromous fish and demonstrates an avoidance reaction to a higher frequency of sound (200 kHz) than previously published for any fish species.

It also illustrates a method of utilising this behaviour to discriminate alosid species from others and assess fish migration using a fixed location acoustic counter.

2. Methods

An acoustic echo sounder (HTI model 243) has been deployed on the lower reaches of the River Wye to monitor salmon migration since 1995. The split-beam transducer is aimed horizontally to the river bed and perpendicular to the river flow across the 30-m width. A second acoustic system and transducer operating at a frequency of 420 kHz was deployed next to the 200 kHz transducer, aimed in the same way.

The 420 kHz system was operated continuously from April to July to cover the migration period for twaite shad into the River Wye. Data from the acoustic systems were collected and analysed during this period. The 200 kHz system was operated for 30 min every hour and deactivated for 30 min. Data were collected and analysed for the 30 min of operation each hour.

Observations on fish behaviour as they approached the acoustic beams were recorded on video cameras deployed from the bank in air and from underwater cameras deployed at various ranges across 26 m of the 30 m river width. Maximum water depth was around 2.5 m. The water clarity in the Wye enabled shoals of shad to be clearly identified from bank side observations as they swam upstream.

Observations on fish behaviour were made:

- During continuous operation of the 200 kHz system.
- Immediately following the disabling of the 200 kHz system.
- During the continuous operation of the 420 kHz system, with the 200 kHz system deactivated for 30 min of every hour.

Acoustic data were collected and analysed for all three periods.

2.1. Technical specifications of the two acoustic systems

The acoustic parameters of the sound pulse generated by the 200 and 420 kHz systems were standardised as much as possible. The major parameter settings used are shown in Table 1.

Table 1
Pulse transmission details for the two frequencies used

Parameter	Setting	
	420 kHz	200 kHz
Frequency (kHz)	420	200
Maximum processing range (m)	26	20
Source level (reference pressure 1 µPa at 1 m)	202 dB	2218 dB
Ping rate (s^{-1})	20	20
FM slide or CW pulse	CW	CW
Transmit pulse width (ms)	0.2	0.2
Transmit power (dB W)	18	24
Nominal transducer beam width (in degrees off axis of the –3 dB points of the beam)	2.8° vertical × 10° horizontal	2.8° vertical × 10° horizontal

3. Results

3.1. Shad behaviour under constant operation of the 200 kHz system

Shoals of shad migrating upstream were seen to abruptly reverse direction when they came within 5 m of the acoustic beam axis as it pointed towards the opposite river bank. Every shoal that approached the beam demonstrated this behaviour and returned downstream. It was not possible to tell how many different shoals approached the acoustic beam or how many approaches each shoal made. However, after several days under this operating regime, a very large “super” shoal of shad containing what looked like many thousands of individuals had formed downstream of the acoustic beam. This shoal circulated about 30 m downstream and made repeated approaches to the acoustic beam without passing through it. The underwater cameras recorded just two fish breaking away from the main shoal and passing through the acoustic beam.

During this operating regime, two changes to the transmit parameters of the acoustic system were made and the results observed. The parameters changed were transmit power and ping rate. Changing the transmitted pulse rate from 20 s^{-1} down to 1 s^{-1} made no observable difference to shoal behaviour. After lowering the transmit power to give a source level of 185 dB, the shad would swim much further upstream, and closer to the acoustic beam, before turning away and swimming downstream as before.

3.2. Shad behaviour on deactivation

On the deactivation of the 200 kHz system, approaching shad shoals passed upstream through the previously ensonified area without any apparent hesitation. If the 200 kHz system was activated when a shoal was within the beam of its transducer, the individual fish demonstrated an immediate “C” body shape startle response and scattered in different directions.

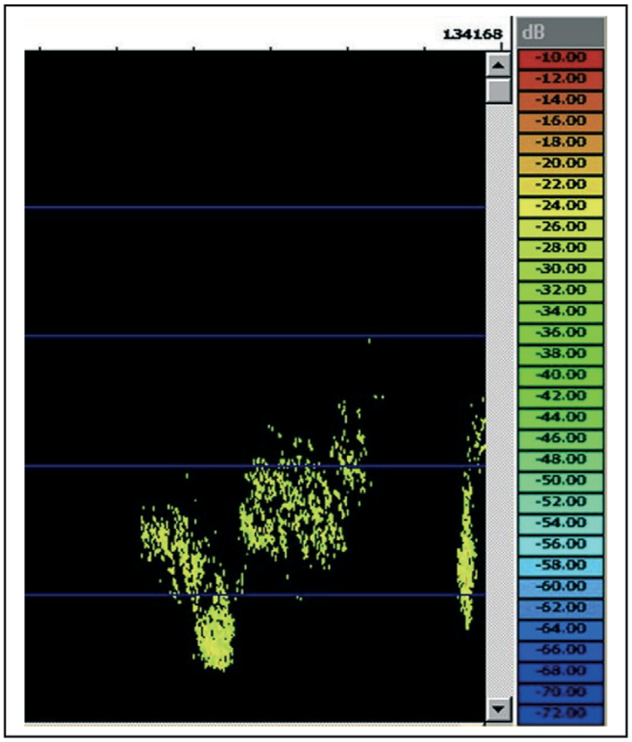

Fig. 1. Echogram display of shad shoals passing through the acoustic beam of the 420 kHz system. The horizontal lines are 5 m range intervals, representing a range of 0–25 from top to bottom. The echogram represents 4 min of data collection.

3.3. Shad behaviour during 60 min duty cycle of the 200 kHz system

During the 30 min each hour the 200 kHz system was deactivated, all shad shoal approaches observed resulted in unhindered passage. Estimations of the number of individual fish in the shoals ranged from 10 to many hundreds. The lengths of individual fish were estimated to range from 30 to 45 cm. All shad shoal approaches made during the 30 min of 200 kHz activation resulted in a failure to pass upstream.

4. Acoustic data results

The large aggregations of echoes on the echogram shown in Fig. 1 came from shoals of shad moving upstream. It was assumed that these are shad shoals because a corresponding echo pattern was not detected during activation of the 200 kHz system. These shoals were also confirmed by the underwater video camera array.

The fish were travelling too close to each other to resolve individual targets and it was not possible to obtain a count of fish by "target tracking" single shad. The fish migrated in large shoals from which only a very few individuals could be resolved by the acoustic system. However, shoals of shad could clearly be identified from the echogram and criteria developed to distinguish individual shoals so that the spatial and temporal migration patterns could be derived for shoal migration. A direction of travel for each shoal could be assigned by examining the average position of echoes in the horizontal plane. The change in average position over time as the shoal passed through the beam was used to determine positive (upstream) movement or negative (downstream) movement.

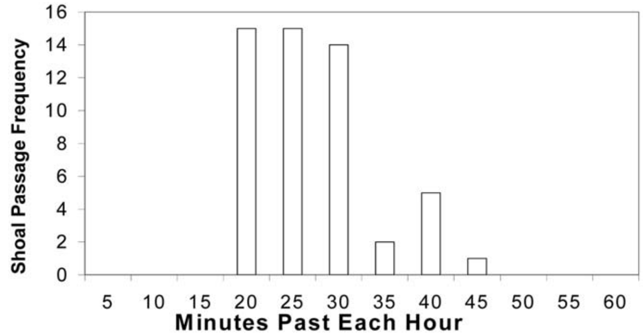

Fig. 2. Distribution of shoal passage within each hour for a 2-week period in May 2000. The 200 kHz system is active from 45 to 15 min.

The avoidance response of shad shoals to 200 kHz is clearly demonstrated in Fig. 2. The data displayed are from a 2-week sub-sample during the early part of the shad migration period. The 200 kHz system was active for half an hour from 45 min past each hour. All shoals passed the site when the 200 kHz system was deactivated, with one exception. This one exception passed upstream when the 200 kHz system was briefly shut down for maintenance.

The upstream spawning migration of twaite shad during 2000 is shown in Fig. 3, together with the subsequent downstream migration of post-spawning shoals. The river flow in cubic metres per second is also displayed.

Fig. 4 shows the diel distribution of upstream and downstream migrating shad shoals for 2000. Movement past the counter was much reduced from 21:00 to 03:00, with a peak in activity around dawn. This is a similar distribution to that found for allis shad (*Alosa alosa*) on the Dordogne in South West France by Travade et al. (1998).

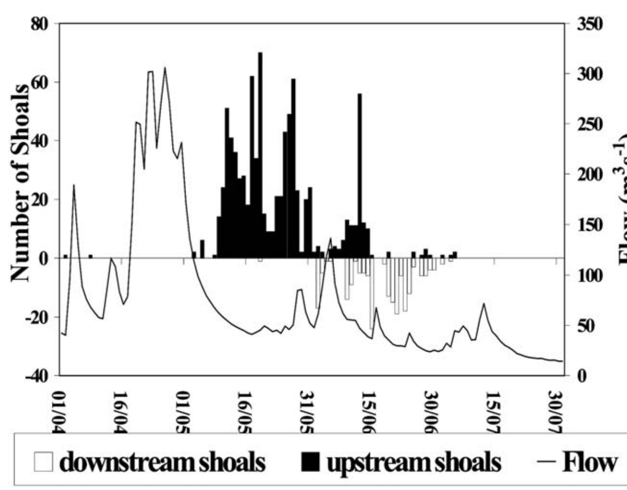

Fig. 3. The number of upstream and downstream migrating shad shoals detected by the 420 kHz acoustic system during 2000, in relation to river flow.

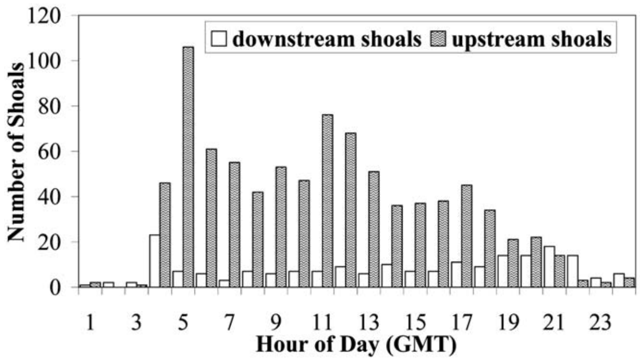

Fig. 4. Diel distribution of shoal migration.

5. Discussion

Twaite shad demonstrate a very strong avoidance reaction to a sound pulse transmitted at 200 kHz and would not pass upstream of a transducer aimed across a 30-m width of river. This behaviour remained unchanged on the variation of the ping rate. A lowering of the transmit power appeared to reduce the fishes sensitivity to the transmitted pulse. Only two fish were observed on the underwater video array to leave a shoal and pass upstream through the beam. It was not possible to tell from the video images whether these "break-away" fish were Twaite shad that may have become acclimatised to the sound or were the less abundant Allis shad, *A. alosa*, which are thought to be present in the Wye. Guillard and Colon (2000) monitored twaite shad with a 70 kHz acoustic system on the River Rhône in France with no reported avoidance reaction.

Twaite shad behaviour on the River Wye appeared unaffected by a sound pulse with similar characteristics transmitted at 420 kHz. Shoals of shad were observed passing through the acoustic beam without hesitation. This allowed them to be detected and enumerated by the acoustic system.

Although it was not possible to obtain a count of fish by "target tracking" single shad, shoals could be counted and spatial and temporal distribution patterns derived. On the Wye there were no other fish species shoaling at this time of year so species apportionment of these shoals was not an issue. However, it would be possible to apportion acoustic shoal or individual counts as either clupeid or not clupeid based on the difference in the number of events counted when the 200 kHz system was activated compared to periods of deactivation. In this way, the dual frequency technique could be used to distinguish and enumerate clupeids sensitive to ultrasound in situations where other shoaling fish species are present.

Although two shoals of shad were first recorded migrating upstream in early April, the main run did not begin until the 10th May when flows had dropped to 50 $m^3 s^{-1}$. When river flows increased to over 100 $m^3 s^{-1}$, there was a marked decrease in upstream migration. Although water temperatures were not recorded, they would have been rising during May as the river flow dropped. Boisneau et al. (1985) and Guillard and Colon (2000) have reported positive correlation of shad migration with water temperature for *A. alosa*. Downstream migration was first recorded on 1st June, with the last shoal being detected on 4th July. Upstream migrating shoals continued to be detected into early July.

Very little upstream migration occurred during the hours of darkness (22:00–03:00), although the peak in downstream movement corresponded to decreasing light levels in the evening. Similar patterns of movement have been reported for the American shad, *A. sapidissima*, from observations made by underwater video cameras (Haro and Kynard, 1997).

Echo integration, as used in the marine environment to estimate shoal densities, was not considered applicable to data collected from a shallow river using a horizontally aimed transducer as many of the key assumptions required for the echo integration technique do not appear to hold true under these circumstances. However, enumeration of shoals and assessment of their run timing characteristics is possible.

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