Evaluation of a multi-beam imaging sonar system (DIDSON) as Fisheries Monitoring Tool: Exploiting the Acoustic Advantage.

Technical Report

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Abstract

In March 2005, the Environment Agency began a full evaluation of a standard DIDSON unit and it's associated data-processing software, applied to a range of fisheries applications across England and Wales. These applications included:

1. Monitoring salmon smolt in small shallow streams- River Frome.
2. Counting fish at high passage rates - River Tywi sea trout and River Wye twaite shad.
3. Counting fish at low passage rates with high debris loads - Silver eels, River Dee smolt.
4. Behavioural studies: Using DIDSON as a surrogate for video - River Tyne Fish Deflection System; River Tyne fish counter; Benacre, Soham and Bourne Eau fish deflector systems.
5. Mobile applications 1: As an aid to interpretation of split-beam data.
6. Mobile applications 2: Resolution of small targets in shoals.
7. Fish stock assessment – Biomass estimates of Rochdale Canal.

DIDSON was found to be very simple to use. Its live output is in the form of images that can be easy to interpret and its 96 acoustic beams (in high frequency mode) combine to give it a wide overall beam angle without the disadvantages a split-beam system would incur in shallow water. It is very deployment friendly. The data gathered can be played back as if it were video which allows fish targets to be examined and behaviour studied by anyone with basic computer skills. However, there were applications where it was more difficult for an observer to identify fish targets.

The software to automate this process is relatively easy to implement. Its effectiveness comparing output to fish identified from a full image playback mode was found to vary considerably between applications and for many the associated lower target detection rate may not warrant the time saved by automation. This will have resource implications for potential medium to long term monitoring applications.

Introduction

Hydroacoustic 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 800 km of river length, enabling the status of fish populations to be monitored more efficiently and in situations that would be inappropriate for other methods. The same advantages can be said of fixed location applications. In the UK as a whole, adult salmon counting sites have operated on six rivers. However, "conventional", split-beam acoustic systems are technically complex to collect, interpret and analyse data. This has had an inhibiting effect on our ability to fully exploit the advantages of acoustic techniques for fisheries monitoring.

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. It works in lakes and rivers with rocky, uneven beds where other acoustic measurement products are generally ineffective and video too limited. High resolution, imaging sonar is being used increasingly in fisheries monitoring applications. In the USA, the DIDSON system is not only replacing existing split-beam operations, but also increasingly being used for a variety of fisheries monitoring roles that were unsuited to split-beam.

This Technical Report is a summary of the results and conclusions from an evaluation of the DIDSON system in the UK. The trials, evaluation methods and results in full are detailed in the Project Record titled 'Evaluation of a Multi-Beam Imaging Sonar System (DIDSON) as a Fisheries Monitoring Tool: Project Record', by Hateley, Gregory and Ingleby (2006).

Remit of Evaluation

As its name suggests, the system has two operating frequencies. A frequency of 1.8MHz is used for high-resolution images within a 10 metre range window. To operate out to ranges of about 40 metres, the system will switch to an operating frequency of 1.1MHz but as a consequence will compromise on target resolution and, indirectly, target detection. The only applications evaluated that utilised the low frequency capability for longer ranges was Counting Fish at High Passage Rates, on the Tywi and Wye, and Fish Behaviour Studies on the River Tyne. No attempt was made to validate or "ground truth" DIDSON on either frequency.

The data can be collected and stored either in full "real time" record mode or the system can be set to store a sequence of "frames" in two ways, both triggered by movement within the beam. Frames can be stored on a motion detection basis where a specified number of samples exceed a user configurable threshold (known as *n samples over threshold*, NSOT). Alternatively, frames can be stored that register a detection on the centre beam or centre 5 beams, based on user configurable parameters (termed *While Fish Are Detected*, WFAD). These two methods of reducing data storage and subsequent analysis were tested.

To obtain a count of fish targets passing through the DIDSON acoustic beam, there are two principal methods:

1. Playback all the frames stored to make a visual count, a method endearingly (or otherwise) referred to as "tallywhacking" and files that have been analysed in this way sometimes referred to as "tallywhacked".
2. Use the fish counting component of the DIDSON software to fully or partially automate the counting process.

Both of these methods were also tested under this evaluation.

Results

Operation

The overall performance of the DIDSON system varied by application. But in each case, DIDSON enabled the user to observe the target species to an extent beyond the capabilities of alternative techniques. As a surrogate for video images over ranges up to 12 metres and particularly on fish targets over 20 cms, it performed exceptionally, providing some startling images and insights into fish behaviour. Long term monitoring deployments proved to be more of a data analysis challenge.

Monitoring Fish at High and Low Passage Rates

Of the fixed location applications, it demonstrated a practical potential for counting adult salmonids in rivers and investigating aspects of fish behaviour. For example, on the River Tywi in Wales, DIDSON was able to identify and quantify two major issues with the split-beam salmon counter deployed there that had not been detected before in years of work with underwater video. At this site, even under target selection criteria optimised with hindsight, the split-beam system was detecting 30% of the upstream moving fish seen in the DIDSON for ranges up to 16 metres in both the low frequency and high frequency DIDSON modes (Griffiths and Davies, 2006). Furthermore, a significant amount of downstream movement was observed, which split-beam systems are unable to enumerate in the UK because the system can not distinguish downstream fish from downstream drifting weed and debris (Gregory et al, 2000). These results were contrary to the assumptions on which fish counting was based at this site and therefore vitally important. They could not have been revealed with any other technique. Fish behaviour at each of the other 3 remaining split-beam sites in the UK is being investigated with DIDSON and their continued operation reviewed.

Smolt counting proved more impractical in medium to large rivers, although the assessment was not helped by seemingly being about two days too late with our deployments at each of the Rivers Frome, Dee and North Esk. On the River Frome, in a 5 metre wide channel, smolt could be clearly resolved as individuals within a shoal (confirmed by bankside observations). However, on the Dee and North Esk in low density smolt movement, it was an arduous and sometimes impossible task to pick out the fish from the acoustic clutter.

Twaite shad monitoring was rendered practically impossible as adult fish clearly displayed a "mild' avoidance reaction to DIDSON (Gregory, Hateley and Lewis, in. pres.). There is therefore no method for enumerating individual adult shad migration. A method of monitoring shoals of shad on the River Wye has been devised (Gregory and Clabburn, 2003), but this is obtrusive to the fish. It may be timely to revisit echo integration techniques to solve this problem.

The downstream movement of silver eel was recorded by the DIDSON system as they entered a fixed trap. Eel could be identified despite heavy debris load. A high debris load has two possible effects. It can mask fish movement and lengthen analysis time as the operator has to playback the data at a slower speed. In this application analysis time was approximately one third of real time. DIDSON provided some unique insight into the subsequent escapement of eel from the trap, and therefore trap efficiency. Despite high debris loads, escapement and other milling or non-migratory behaviour, trap and DIDSON counts were remarkably consistent.

Mobile Survey Applications

Mixed results were recorded from the mobile applications. DIDSON was invaluable for assisting the interpretation of split-beam data from lakes with apparently low signal to noise ratios. At one such lake, Tatton Mere, the “noise” in the data gathered by the split-beam system was discovered to be aggregations of < 5cm long fish after observation with DIDSON. On Derwentwater and Ennerdale in the Lake District, DIDSON showed considerable promise for identifying and targeting spawning aggregations of vendace (*Coregonus albula)* and Arctic Charr (*Salvelinus alpinis*).. However, replicating the boat-mounted, mobile survey applications of the split-beam systems proved beyond the capabilities of the DIDSON. Using DIDSON to investigate fish aspect on mobile surveys was not encouraging. Measuring the orientation of small fish (< 15 cm) to the transducer was impossible as the targets themselves “disappeared” as they approached head and tail aspect. This does not only happen with small fish. Large, metre-long pike and mature sea trout have also been observed as they rotated through 90 degrees in the horizontal plane making them impossible to pick out when in a head or tail aspect with respect to the transducer.

Fish Behaviour

As mentioned previously, the DIDSON system enabled fish behaviour to be observed in a, until now, unique way. On the River Tyne at Riding Mill, a fish deflection system emitting a graduated electric field is periodically operated as a barrier to migration via any other route other than through a fish trap. The DIDSON provided invaluable information on the effectiveness of the deflection system. Fish behaviour as they approached the electric field was clearly observed and quantified. At one standard setting and at a relatively low and stable river flow, 93% of sea trout challenges made to the electric field of the fence were repelled. This efficiency exceeds the instalment specification of 80%. No other monitoring device could have shown this cost effectively.

Fish behaviour above the electrodes of a resistivity counter channel on the River Tyne at Riding Mill, some 40 metres downstream from the deflection fence, was observed with the DIDSON system. The resistivity counter recorded 72% of the upstream moving fish observed by DIDSON and 48% of the downstream fish. Over 45% of the resistivity count was designated as “events” rather than “up” or “down” and half of this could be attributed to milling behaviour of fish immediately upstream of the electrodes. The DIDSON deployment further showed that genuine “ups” and “downs” were being downgraded to “events” during the counter verification process.
This further underlines the importance of detecting and counting downstream-moving fish for any fish counting system.

This comparison should not be confused with validation. To 'validate' a fish counter it is necessary to ground truth fish activity by providing a definite number of fish passage events. This can be obtained from visual (video) observations or to a lesser extent by a system with known errors that are independent from the errors of the system being validated. DIDSON data does not represent a "ground truth" as its errors are unknown, although likely to be independent from resistivity counter errors.

DIDSON was instrumental in observing patterns of fish behaviour and responses to fish deflecting devices at three pumping stations; Benacre, Soham and Bourne Eau. During winter months, tens of thousands of coarse fish leave the main rivers during daytime and seek refuge in the pump sumps. Acoustic (Benacre) and compressed air (Soham and Bourne Eau) scaring systems were therefore installed to expel fish from the sumps prior to pump start-up, and to prevent fish from entering the sumps during pump operation. DIDSON images from five trials clearly demonstrated that both acoustic and compressed air systems (in their installed configurations) were totally ineffective at expelling fish from the sumps prior to pump start-up. The acoustic system did, however, prevent fish from re-entering operational sumps at dawn. A battery of underwater cameras may have provided the same information as the single DIDSON used, but deployments would have comparatively complex and costly.

Data Storage
Using *N Samples over Threshold* function of the data collection software halved the file sizes for data collected at both high and low frequency without compromising the target detection rate. If the data is being analysed by visual playback (tallywhacking), a halving of data represents a decrease in analysis time. The *While Fish Are Detected* function reduced file sizes to up to a twentieth of its "real time" equivalent but missed targets. It did not work on data collected under low frequency mode as fluctuating background "noise" meant it was constantly recording and would not be appropriate for applications examining fish behaviour.

For complete accuracy and reduced file size in a relatively noise-free environment or set-up, applying NSOT during data logging is recommended. However, if a reasonably accurate count of larger fish and very small files in high frequency mode are required, WFAD may be adequate.

Data Analysis
A lot of work and painstaking analysis went into the following conclusion on the most efficient way of analysing the data. If you want accurate counts in the shortest possible time, tallywhack. Playback all the collected frames and count the fish. Target lengths and precise times of entry are achievable for all fish, but in high passage rates this will take time. Under these conditions, sub-sampling is practicable.

Conclusions

The DIDSON high resolution imaging acoustic system proved itself a powerful tool, enabling fish to be counted and their behaviour studied with minimal experience and cost, in ways inconceivable for any other technique. There are applications and circumstances better suited to the technique than others, and certain applications for which its use would be inappropriate or impractical. These are summarised in Table 1 below.

Table 1. DIDSON Application Summary Table.

	Application **Any details given here relate to the application tested and not intended to be interpreted as a limitation**	**Limitations**
DIDSON is great for:	1. Monitoring the migration of shoaling fish species of 30+ cms in length in an open river. Specifically, counting sea-trout & salmon in rivers.	Site selection critical. Need to resolve data storage issue. Lengthy post-processing. May require lengthy deployment periods. Reliability of DIDSON fish length estimates requires evaluation.
	2. Identifying and counting downstream moving fish of 30+ cms in a river with a high debris load over short ranges (under 7metres). Specifically, assessing downstream silver eel migration.	Site selection critical. Need to resolve data storage issue. Lengthy post-processing. May require lengthy deployment periods.
	3. Investigating fish behaviour (fixed location).	Site selection critical.
DIDSON has potential for:	1. Identifying fish aggregations.	Further work required testing for boat avoidance. Speed of survey boat. Shadows from substrate (e.g. cobbles)
	2. Impact of sediment bubbling on fish counts.	More data collection with split-beam required.
	3. Distribution and behaviour of fish (mobile).	Speed of survey boat. Orientation of fish to transducer.
DIDSON has problems:	1. Counting smolts	May only work on small rivers with relatively low flows.
	2. Counting twaite shad, *Alosa fallax fallax.*	Avoidance reaction of shad to the DIDSON renders this practically impossible. Isolation of the cause of this may help.
	3. Investigating fish aspect on mobile surveys.	Cannot discriminate head & tail aspect fish.
	4. Estimating fish biomass	Too many potential sources of error in DIDSON biomass estimation.

References

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