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Performance of a single frequency split-beam hydroacoustic system: an innovative fish counting technology

Andrew Berghuis

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Front cover photo: Lock 10 fishway exit with the split beam hydroacoustic mount in the foreground (Andrew Berghuis).

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Summary

Under the sea to Hume Dam fishway program, the Murray–Darling Basin Commission (MDBC) has provided funding for the construction of 14 new fishways on the Murray River. Research and monitoring of the new fishways has provided useful data on fish migration and optimum fishway designs. The purpose of the current project was to investigate a hydroacoustic method for counting fish migrating at the Murray River fishways.

A calibrated and tested 200 kHz split-beam hydroacoustic system was installed at the Lock 10 fishway in November 2007 to detect fish moving through the fishway exit channel. A dual-frequency identification sonar (DIDSON) acoustic sonar was also installed to provide video-quality images that could be used as a comparison with the split-beam acoustic data. Low rates of fish migration and reduced river levels precluded the ongoing collection of data.

The split-beam hydroacoustic system gave an automatic fish count of up to 3.96 fish per minute moving through the fishway exit channel. However, visual verification of the data with the DIDSON imaging over a one-hour portion of data found that 47.5% of fish were not detected.

Data from the DIDSON system was also analysed, and an automatic fish count of up to 1.09 fish per minute was established. Visual verification over the same one-hour portion as the split-beam data found that 26.25% of fish were not detected. Automatic fish length detection consistently underestimated fish length, most likely due to the poor orientation of fish to the acoustic beams.

Manual review of the acoustic data from both systems provided the opportunity to increase the accuracy of fish counts and identify schools of small fish. False fish track detections due to debris were also removed. Acoustic noise from rocks located at the fishway exit was considered partly responsible for the low accuracy rate of fish detections from both systems. The orientation of the DIDSON transducer compared to the direction of fish travel also reduced the detection of fish for that system. The acoustic target strength of fish detected with the split-beam acoustic system appeared to be indicative of fish size and may provide a method of classifying size classes of migrating fish. Manual measurement of fish targets in the DIDSON data appeared to be relatively accurate, and ongoing data collection and analysis may improve fish length estimates.

The DIDSON system appears to have several advantages over the split-beam system, but both systems have merit for fish counting. Recommendations to increase the accuracy of automatic fish counts and handling of data are provided. A continuation of fish counting trials using both systems, particularly during periods of high fish migration, is recommended.

1 Introduction

In 2001 the Murray–Darling Basin Commission made a commitment to restore fish passage through Murray River barrages and weirs from Hume Dam to the sea. To date Locks 1, 7, 8, 9 and 10 and the Goolwa and Tauwitcherie barrages have been retrofitted with fishways. Assessments of the fishways by a tri-state monitoring team have been completed on some fishways and are continuing on others (Barrett, 2008).

The Commission has made a major investment in fishways and monitoring programs, but trapping migrating fish within the fishway is the only method currently used to identify and count fish. Although trapping gives reliable results it is labour-intensive and fish are handled (potentially affecting behaviour), and some fish are known to avoid traps to some extent. The development of a reliable electronic system may overcome these problems and result in substantial long-term cost savings. Hydroacoustics has the potential to count and measure all fish entering and exiting the Murray fishways over long periods of time. Additionally the numbers of fish migrating at any point in time can be compared against environmental factors or manipulations to the operation of the fishway or weir.

In other countries hydroacoustic systems are routinely used to provide capture-independent data on fish abundance, distribution, size and behaviour at artificial structures such as weirs and fishways, and in natural systems in various habitats such as rivers and wetlands. In 2004 trials of a split-beam acoustic system to quantify fish migration through a vertical-slot fishway were undertaken for the Commission by the Queensland Department of Primary Industries and Fisheries (QDPIF) (Berghuis and Matveev, 2004). The potential for fish targets to be disguised by acoustic noise from objects in shallow water was raised, but off-the-shelf software was available that could assist in determining valid fish targets. The 2004 trials determined that split-beam hydroacoustics had the potential to provide useful information on fish migration on the Murray River fishways.

A Dual-frequency IDentification SONar (DIDSON) acoustic system provided by NSW DPI was employed in the 2004 trials to provide visual verification of the fish detections in the split-beam echograms. This system transmits multiple beams of ultrasound that reflect off objects in the water. The returning reflections are focused by a liquid lens and digitised to provide a low-resolution video image. Under optimal conditions, fish species can be identified by their outline and swimming behaviour. Extensive testing in some of the Murray River fishways and trials in tanks by Baumgartner et al. (2006) demonstrated that the DIDSON system had great potential for fish behaviour studies. However, a major disadvantage of the system is that it produces echograms with file sizes of approximately 1 Gb per hour, and such large file sizes are difficult to store and transmit from remote locations.

In the current project both a split-beam echosounder system and a DIDSON system were used. Analytical software was purchased and scripting was developed for automatic operation and analysis of split-beam acoustic echograms and transmission of analysed data.

2 Methods

2.1 Preparation, calibration and preliminary tests of the system

The hydroacoustic system used in the current study was a Simrad ES60 split-beam echosounder with a 200 kHz Simrad 200-7C circular transducer, 7º beam angle and 3dB step. This was operated using proprietary B1500 software provided by Simrad and installed on an Opentec RPC4-13 ruggedised notebook computer.

A Soundmetrics DIDSON system was also used. This system operates on two frequencies. In the low-frequency mode of 1.1 MHz it generates 48 beams with a two-way beam width of 0.5° horizontal by 13° vertical. In the high-frequency mode of 1.8 MHz the system generates 96 beams with a two-way beamwidth of 0.3° horizontal by 13° vertical. Echograms are recorded at a frame rate of 5–20 frames per second (depending on the target range) and a field of view of 29°.
Myriax Echoview software (versions 4.1 to 4.5) was used to perform the analysis of echograms associated with system calibration and fish-counting trials. Software for tracking fish using data from both the split-beam acoustic system was also purchased.

The split-beam system was calibrated in a freshwater reach of the Burnett River in Queensland where the sound speed was 1476.04 metres per second. A 13.7 mm diameter copper reference sphere with theoretical target strength of –45.1 dB ± 0.2 dB at 200 kHz was suspended by nylon monofilament at a distance of 4.5 m from the transducer face. The system was operated with a transmitted pulse length duration from 0.512 ms and power output of 800 W for a total of 1581 pings.

Using Echoview for single target detection, 822 valid single targets were identified and analysed. The average target strength value for the single targets was –45.7 dB, which varied from the theoretical target strength by 0.6 dB. A variation of 0.6 dB was therefore factored into all subsequent analyses where accurate target strength measurements were important.

2.2 Development and assessment of automated fish counting software

Software scripting was developed by QDPIF and Myriax to automate a counting system using Echoview fish-tracking modules. The modules were developed from published algorithms for identifying fish in acoustic data and modified for use in software. Myriax Echosim software was used to constantly generate virtual echograms.
Fish targets were detected as they passed between two arbitrary lines that represented the exit of a fishway. Parameters were then developed to formulate an accurate count of fish targets that could be used as a template to automatically identify and count fish moving through the area of interest. The parameters were developed from the virtual echograms and refined using actual data from Lock 10 fishway. In the detection of single targets the Simrad LOBE beam compensation model was used with a maximum beam compensation of 12 dB and a maximum standard deviation of 0.6° for both minor and major axis angles. The target strength threshold was set at –50 dB or less to reduce the detection of targets that were not fish. The pulse length determination level was set at 6 dB and the accepted minimum and maximum normalised pulse lengths were 0.5 and 1.5 respectively.

The Echoview script was written so that all echogram files created were analysed at a predetermined time interval since the last time the script was run. The script loaded the fish-counting template, and echograms were analysed and a spreadsheet of fish counts generated. A spreadsheet of fish counts was then attached to an e-mail which was sent to a predetermined e-mail address for review. The automated fish counting and reporting system was run and tested over a two-week period.

2.3 Field trials of the acoustic system

The acoustic systems were installed at the fishway at Lock 10 near Wentworth NSW in October and November 2007. The transducer was located approximately 5 m upstream of the fishway exit, approximately 2 m from the river bank and 1 m below the water surface (Figure 1). The transducer beam was directed across the fishway exit and angled so that the fishway exit gate was visible in the echograms. Artificial targets were placed in the beam and moved through the fishway channel to verify the correct positioning of the transducer.

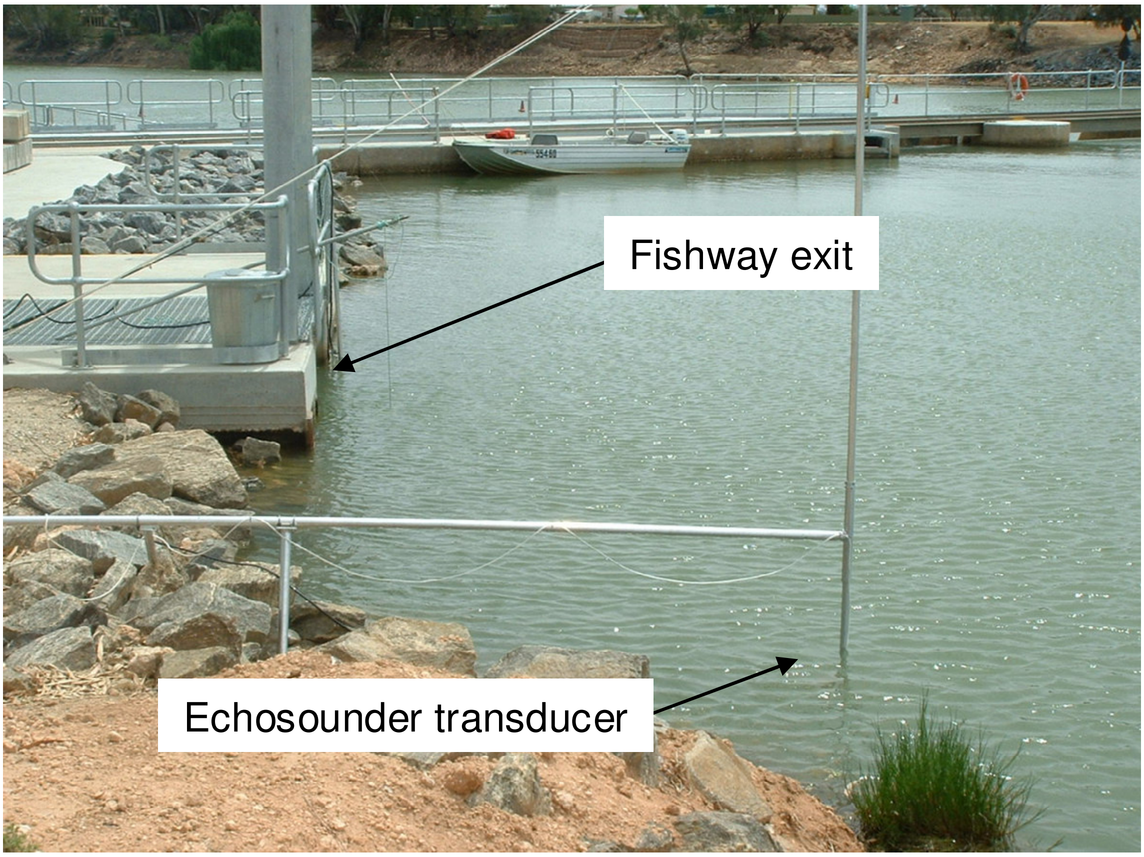

Figure 1. Location of the split-beam echosounder transducer at the Lock 10 fishway

The Soundmetrics DIDSON system was installed within the fishway exit channel to provide visual verification of fish detected by the split-beam system (Figure 2). The split-beam and DIDSON echograms were synchronised by including a date and time stamp in the filenames and also by placing an artificial target in both beams at the same time.

The DIDSON system provides echograms of low-resolution video image quality that can be used to visually identify objects underwater. In ideal conditions the size and shape of fish can permit large fish to be identified to species level. Soundmetrics provides software to adjust the system settings and capture echograms as well as count and measure fish. An evaluation of this software by Baumgartner et. al. (2006) found that manual counting and measuring of fish was accurate but that automated analysis had limitations.

Figure 2. Location of the DIDSON system in the fishway exit channel at Lock 10.

Over the 12 months since the current project commenced, the use of DIDSON systems for fish migration studies has increased, and the need to analyse DIDSON data has become more important. Echoview modules for DIDSON data analysis were developed very recently, so the opportunity to test the ability of this software was incorporated into the current study.

Trials were performed to test the ability of the DIDSON system to provide accurate counts and measurement of fish. During these trials the data was filtered to remove stationary objects and background noise that left only obvious fish targets. The fish target data was then converted to single targets that could be used to identify the track that each fish took through the beam and estimate the length of the fish that produced the track.

The DIDSON system was installed in a 5 m long parabolic tank and the beams were focused to concentrate on an area 1 m wide at the opposite end of the tank. Three Bony Herring *Nematolosa erebi* were placed within the tank and permitted to swim freely. Each pass through the beam was considered to represent a separate fish movement. The estimated lengths of each fish provided from the DIDSON data by the Echoview software were then compared to the known fish lengths.

Data from both the split-beam echosounder and DIDSON system were analysed using Echoview version 4.5 software. The split beam data was filtered to identify single targets that were grouped together as tracks representing individual fish. The location of the fish tracks could then be related to fish that had passed through the fishway exit in either an up or downstream direction. The DIDSON echograms were used to visually confirm that the fish track identified was indeed a fish.

The split-beam echosounder was installed at Lock 10 and tested over three days from 30 October to 1 November 2007. Routine collection of echogram files was carried out from 6 November until the 8 November, during daylight hours only. Low water levels during summer 2007–08 at Lock 10 and a perceived lack of migrating fish halted any further data collection. Due to the limited ability to collect data the automated scripting and reporting system was not installed at Lock 10. Echograms from both the split-beam and DIDSON system were analysed using Echoview 4.5 for both the automated fish counting parameters and the manual checking of data.

3 Results

3.1 Automatic fish counting using the split-beam acoustic system

A total of 19 hours of split-beam echograms suitable for analysis were recorded during the field trials in November 2007. Only fish that were within the area delineated by the fishway exit channel gate were counted.

The number of fish detected by the split-beam acoustic system and identified by the Echoview software using the automatic detection parameters was divided by the duration of the echogram to obtain the number of fish per minute. The maximum number of fish passing through the fishway exit per minute ranged from 0.65 to 3.96 (Table 1).

Table 1. The number of fish detected (by the split beam system and estimated by the software) passing through the fishway exit during November 2007.

Date	Number of fish detected	Sample hours	Fish per minute
1 Nov 2007	201	3.5	3.96
6 Nov 2007	155	4	0.65
7 Nov 2007	279	6	0.78
8 Nov 2007	248	5.5	0.75

The quality of the data collected with the split-beam acoustic system varied somewhat between sample days. On 7 November the software automatically detected 5234 fish tracks. Visual inspection of the unprocessed echogram showed that the majority of these tracks were in fact detections of the rocks at the base of the fishway exit. In order to remove the effect of the rocks on fish track counts, the area surrounding the rocks was removed from the analysis.

Visual inspection of the data from the split-beam acoustic system identified two different types of single target patterns. The first pattern consisted of groups of closely spaced single targets travelling in a direction that indicated movement either into or out of the fishway exit. Comparison of these single target groupings with the DIDSON echogram for the same moment confirmed that they were detections of single fish (Figure 3). Generally these single target groupings were identified by the software as a fish track, as shown by the pink rhombus in Figure 3, and added to the count of fish passing through the fishway exit channel.

The second pattern of single targets consisted of dense rounded groups of multiple targets often emanating from the centre of the fishway channel. Comparison of these single-target groupings with the DIDSON echogram for the same moment confirmed that they were schools of fish (Figure 4). Depending on the density of the schools the software generally designated one or more fish tracks to the school.

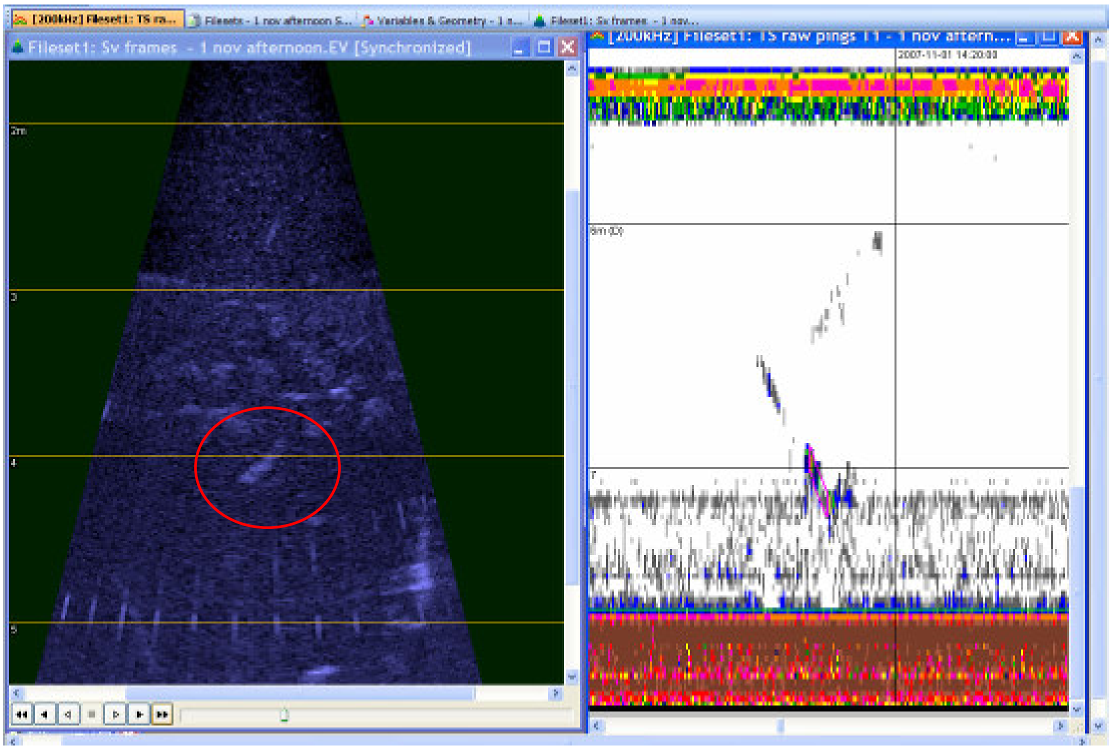

Figure 3. Echogram showing a fish (encircled in red) swimming out of the fishway exit channel at Lock 10 fishway and detected by the split-beam acoustic system (window on right) and DIDSON system (window on left). The pink rhombus around the single targets in the right-hand window indicates that the targets were selected as a fish track by the software.

3.1.1 Comparison of the split-beam system echogram data with DIDSON images

Rather than attempt to view all of the simultaneously recorded split-beam and DIDSON echograms, the footage was sub-sampled to simplify the analysis. Samples were randomly selected to represent a range of conditions at the fishway exit on the afternoon of 1 November. A one-hour sample from 13:58 to 14:58 hours was synchronised between both systems and manually viewed.

An analysis of the split-beam data for the one-hour period using the automatic fish detection parameters counted 42 fish tracks or 0.7 fish per minute. Playback of the DIDSON echogram alongside the split-beam echogram verified that the detected fish tracks were all indeed single fish or fish schools. Playback of the DIDSON echogram identified an additional 49 fish or schools that were not assigned fish tracks and so not counted.

Fish schools were detected as one single fish or groups of two or three fish but were not representative of the actual number of fish in the schools. Visual observation of the number of schools captured by the DIDSON echogram footage showed that 26 large schools of fish passed through the fishway exit during the one-hour period. Of the 26 schools observed, 11 were detected as fish tracks by the software. The fish track data from fish in schools were not noticeably different from those of individual fish.

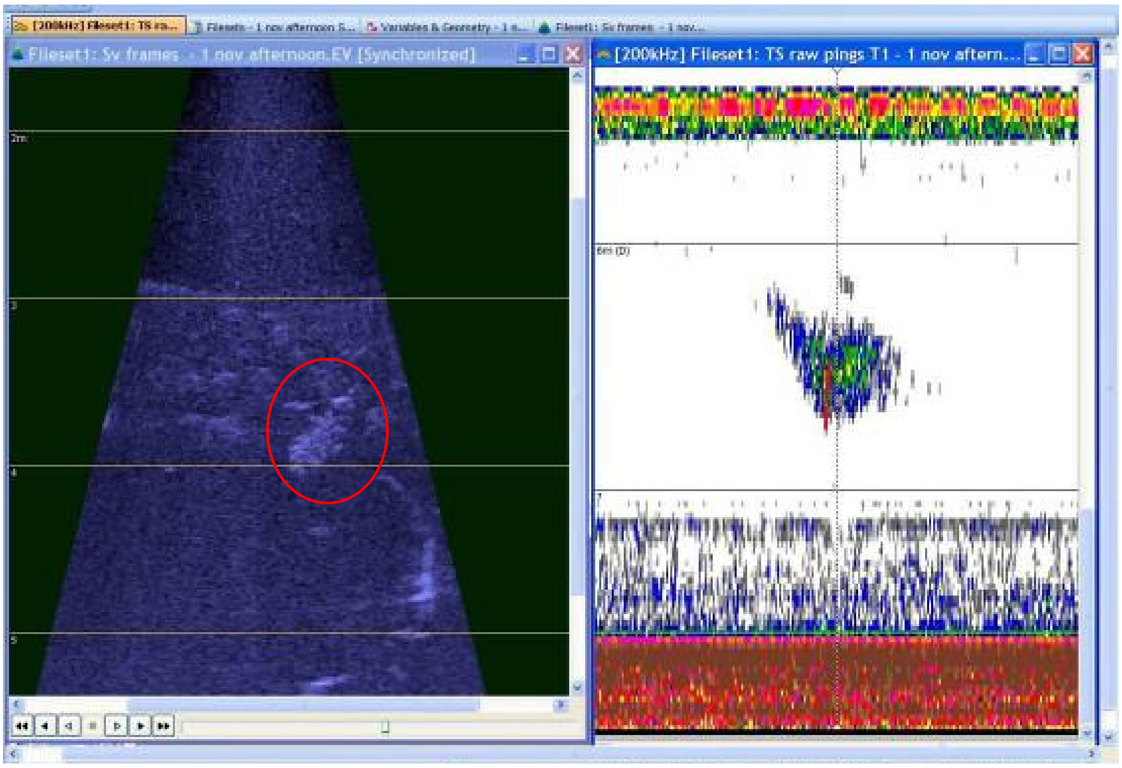

Figure 4. Echogram showing a school of fish (encircled in red) swimming out of the fishway exit channel at Lock 10 fishway and detected by the split-beam system (window on right) and the DIDSON system (window on left). The red shape around the selected single targets in the right-hand window shows that the targets were selected as a fish track by the software.

The actual count of fish that moved through the fishway exit channel in the selected period but were not in schools was therefore actually 80 (or 1.33 fish per minute), so the split-beam system failed to detect 47.5% of the fish passing through the fishway exit.

3.1.2 Manual analysis of the split-beam system echogram data

In addition to the automatic detection of fish tracks, the Echoview software can be used to manually add fish tracks. Single target groupings that are obvious detections of fish are assigned a track and added to the count. The split-beam data for the one-hour period was reviewed and fish tracks were assigned. A total of 15 fish detections were not automatically assigned a fish track; six of these were schools, so only nine additional non-schooling fish were detected and manually assigned fish tracks.

The analysis of the split-beam system data from the single targets in the fish tracks can provide information on the location of fish identified in the track. In the one-hour data from 1 November all of the fish tracks identified were no deeper than 0.7 m below the water surface.

The target strength of fish detected by the split-beam acoustic system can provide information on the size of the fish in the fish track. The target strength of all of the fish tracks had a mean value of –42.815 dB (0.799 s.e.) with a range of –52.481 dB to –31.586 dB. Using the DIDSON data and the measuring tool in the multibeam target detection variable the estimated lengths were 410 mm, 360 mm and 530 mm for the mean, minimum and maximum targets strengths respectively.

3.2 Automatic fish-counting using the DIDSON system

A total of 22.75 hours of DIDSON echograms suitable for analysis were recorded during the field trials in November 2007. As the DIDSON system was located in the fishway channel a 2 m long by 2m wide area at the end of the fishway channel extending out to the weirpool was selected for analysis. The number of fish detected by the DIDSON system and identified by the Echoview software using the default fish detection parameters was divided by the duration of the echogram to obtain the number of fish per minute. The maximum number of fish detected passing through the fishway exit per minute ranged from 0.53 to 1.09 (Table 2).

Table 2. The number of fish detected by the DIDSON system and estimated by the software that were passing through the fishway exit during November 2007.

Date	Number of fish detected	Sample hours	Fish per minute
1 Nov 2007	220	6	0.61
6 Nov 2007	244	4	1.02
7 Nov 2007	392	6	1.09
8 Nov 2007	215	6.75	0.53

The single-target detection data was derived from the DIDSON echogram images and so single target variables and DIDSON video were easily synchronised and fish or fish tracks verified by eye. As with the split-beam data, schools of fish and single fish were shown as single targets and either counted as fish tracks or not. In Figure 5 a school of small fish is shown in the video image and as two fish tracks (areas encircled in red).

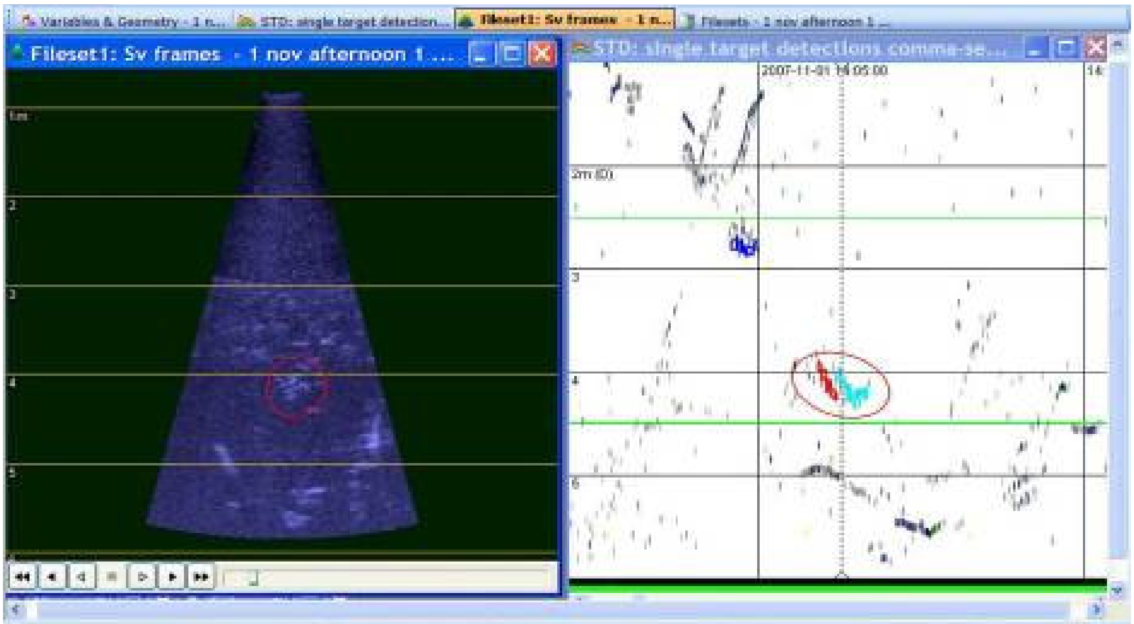

Figure 5. Echogram showing a school of fish detected swimming out of the fishway exit channel at Lock 10 fishway by the DIDSON system. The window on the left shows the acoustic system image the window on the right shows the single targets and two fish tracks (red and blue shapes around targets).

3.2.1 Verification of the automatic analysis

The analysis of the DIDSON system data for the same one-hour period on 1 November using the automatic fish detection parameters counted 59 fish tracks, or 0.98 fish per minute. Playback of the DIDSON echogram synchronised with the single target detections identified 29 fish or fish schools that were not assigned fish tracks and so were not counted.

As with the split-beam data, the Echoview software detected fish schools as one single fish or groups of two or three fish but did not provide an accurate count of the number of fish in the schools. Observation of the number of schools captured by the DIDSON echogram footage showed that 26 large schools of fish passed through the fishway exit during the one-hour period. Of the 26 schools observed, eight were detected as fish tracks by the software.

The actual count of fish that were not in schools and that moved through the fishway exit channel in the selected period was therefore 80 or 1.33 fish per minute, so The DIDSON system had failed to automatically detect 26.25% of the fish passing through the fishway exit.

Orientation of fish to the direction of the acoustic beam was imperative for accurate fish detection. The majority of fish that were missed in the automatic fish counting moved through the fishway in an almost parallel direction to the direction of the transmitted beams. Additionally fish that moved through the channel close to the rocks were often not detected. Fish that were grouped close together and moving parallel to the beam were sometimes detected as single fish track. For example, in the fish length trials three fish were shown in the DIDSON video image but were interpreted as a single fish track (Figure 6). As the three fish moved around at a 90° angle to the beam they were detected as three individual fish tracks (shown to the right of the shaded area).

3.2.2 Manual analysis of the DIDSON system echogram data

As with the split-beam data, fish echoes in the DIDSON echogram data are converted to single targets and analysed to assess whether they qualify as being fish tracks. However, with manual analysis of the DIDSON data the single targets can be viewed alongside a synchronised video image of the objects detected as single targets. The DIDSON echogram data for the one-hour period on the 1 November was reviewed manually. All 21 non-schooled fish that were not assigned fish tracks were shown in the single target variable and could be manually assigned fish tracks. To assess whether more fish track detections could automatically be assigned fish tracks, the detection parameters in Echoview were adjusted. However, the changes also resulted in fixed objects and debris being assigned fish tracks.

Schools of fish in the DIDSON echograms were not specifically recognised by Echoview in the automatic analysis. However visual inspection of the single targets produced from fish schools in the DIDSON data showed that in many cases the number of single targets in each one second ping grouping was the same as the number of small fish in the school. Therefore it may be possible to determine the number of fish in a school by outlining the single group in a similar way that an individual fish track can be identified and analysed.

Manual viewing of the single target groupings can also show the direction of fish travel through the fishway. The one-hour period on 1 November was reviewed, and the fish direction was assessed. Over the period 45 individual non-schooling fish moved into the fishway channel from the weirpool and 35 fish moved upstream and out of the fishway. Of the observed schools, 10 moved downstream into the fishway channel from the weirpool and 16 moved upstream and out of the fishway. Although it is difficult to verify, many of the fish observed going in both directions appeared to be the same individuals. In general, larger schools moved into the fishway channel than out of it.

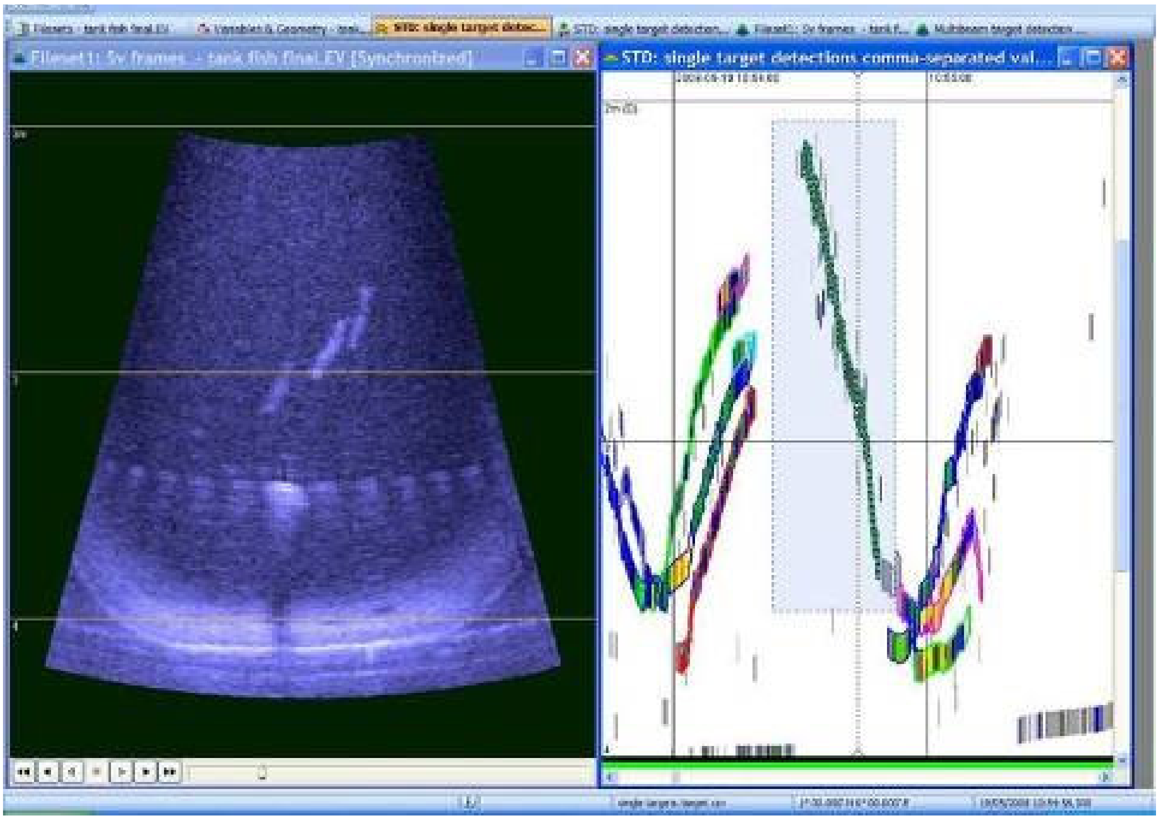

Figure 6. Echogram showing three fish detected swimming nearly parallel to the direction of the beam transmission from the DIDSON system. The window on the left shows the acoustic system image, and the window on the right shows the single targets and a single fish track (in pale blue rectangle) diverging out to three tracks.

3.2.3 Estimates of fish length using the DIDSON system echogram data

A new feature of Echoview version 4.5 is the ability of the software to estimate the length of fish tracks detected in the DIDSON echograms. The Bony Herring in tanks were counted and measured each time they passed through the acoustic beam. The actual total lengths of these fish were 232 mm, 260 mm and 265 mm. Exports of fish tracks that were visually verified as being from the Bony Herring were examined to gauge the accuracy of length estimates. The estimated average mean length of fish identified in the fish tracks ranged from 58 mm long to 508 mm.

Visual observation of fish tracks with the extremes of the range of length estimates indicated that underestimates were caused by fish swimming at a narrow angle to the acoustic beams and not presenting a full side aspect to the transducer. Overestimates of length were generally caused by more than one fish being detected as a single fish track, or by other objects being incorporated into the fish track.

Manual selection of fish tracks that were separated from other objects and were more side-on to the beam direction provided more accurate length estimates, although lengths tended to be underestimated. The lengths of fish can be assessed manually using an inbuilt measuring tool in the software. In the analysis process Echoview develops a multibeam target detection variable that removes background noise from fish echoes. The DIDSON video image can then be synchronised with the multibeam target detection variable to find the most complete aspect of each fish target, and the measuring tool can be used to manually measure each fish. Manual measurement can be performed on any fish that is detected as a single target regardless of whether or not it is assigned a fish track.

In the tank test, echoes from three fish were selected for manual measurement (Figure 7). Manual measurement of the three fish gave with estimates of 230 mm, 270 mm and 240 mm from the fish at the top , middle and bottom of the screen respectively. The far right window shows the single target detection variable for the three fish and the fish tracks.

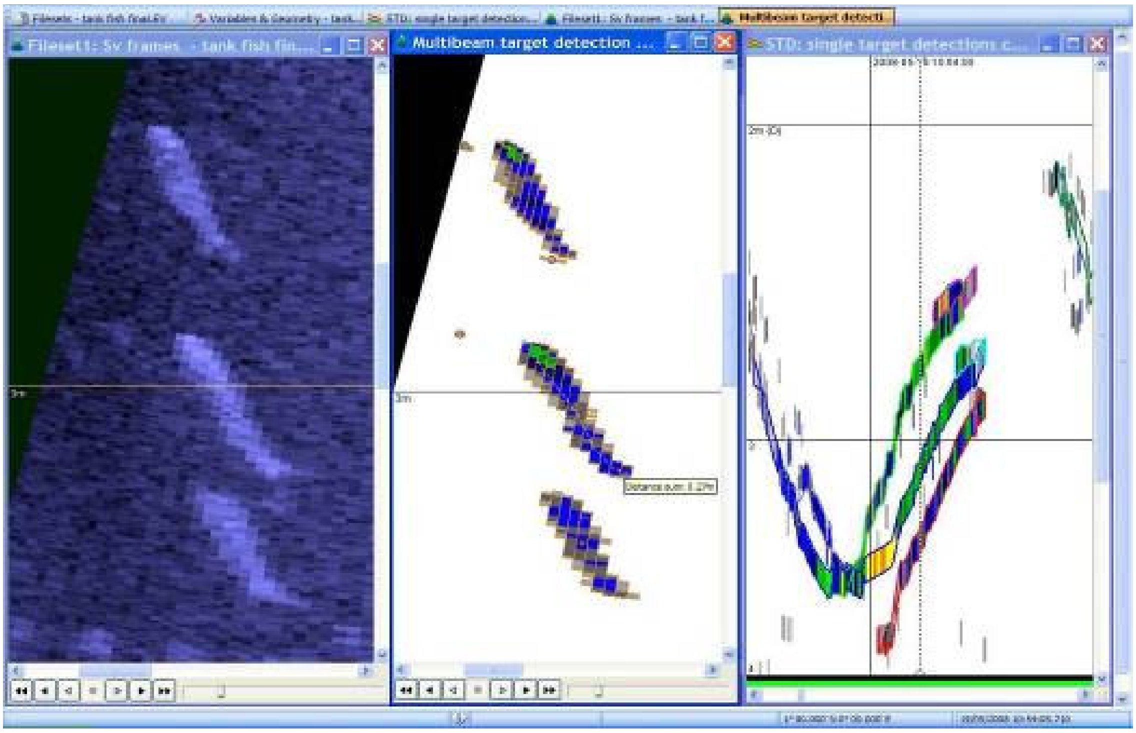

Figure 7. A DIDSON echogram showing the three tank fish detected swimming across the tank (left window) the fish extracted from background noise in the multibeam target detection variable with the central fish manually measured (centre window) and the single target detection variable with fish tracks (right window). The central window shows the multibeam target detection variable and the measurement of the second fish.

Automatically generated mean length estimates derived from the fish tracks were 193 mm, 263 mm and 164 mm from the fish at the top of the screen to the bottom of the screen respectively. Other fish echoes and tracks were similarly selected and measured, with similar results. In all cases the selection of suitable fish echoes and the use of the manual measuring tool was more accurate.

Several shrimp 80–100 mm long (rostrum tip to telson tip) were observed in the DIDSON video and retrieved when the tank was emptied. The outline of shrimp was obvious in the DIDSON echogram (Figure 8; left side window) and extracted in the multibeam target detection variable. The manual measurement tool estimated the length of the shrimp to be 90 mm long; the single target-derived ‘fish track’ estimated a length of 70 mm. The actual length of the shrimp could not be ascertained but it was likely to be somewhere between the two estimates. The outline of other shrimp that were detected was not as obvious but the mode of propulsion would enable differentiation from fish.

The data from the one-hour period on 1 November was reviewed to gauge whether reliable length data could be obtained. In the fish track export a fish with an estimated 27 mm mean length was actually a 410 mm long fish when gauged with the measuring tool. As with the tank fish, this fish was oriented parallel to the direction of the acoustic beams. Fish that were perpendicular to the acoustic beams were also measured and were generally 30% longer than the estimated mean length. The fish track with the highest fish track estimate (660 mm) was estimated to be 629 mm long on the measuring tool and oriented perpendicularly to the beams. Small fish that appeared to be in mid water could be identified and fish as small as 110 mm were able to be measured.

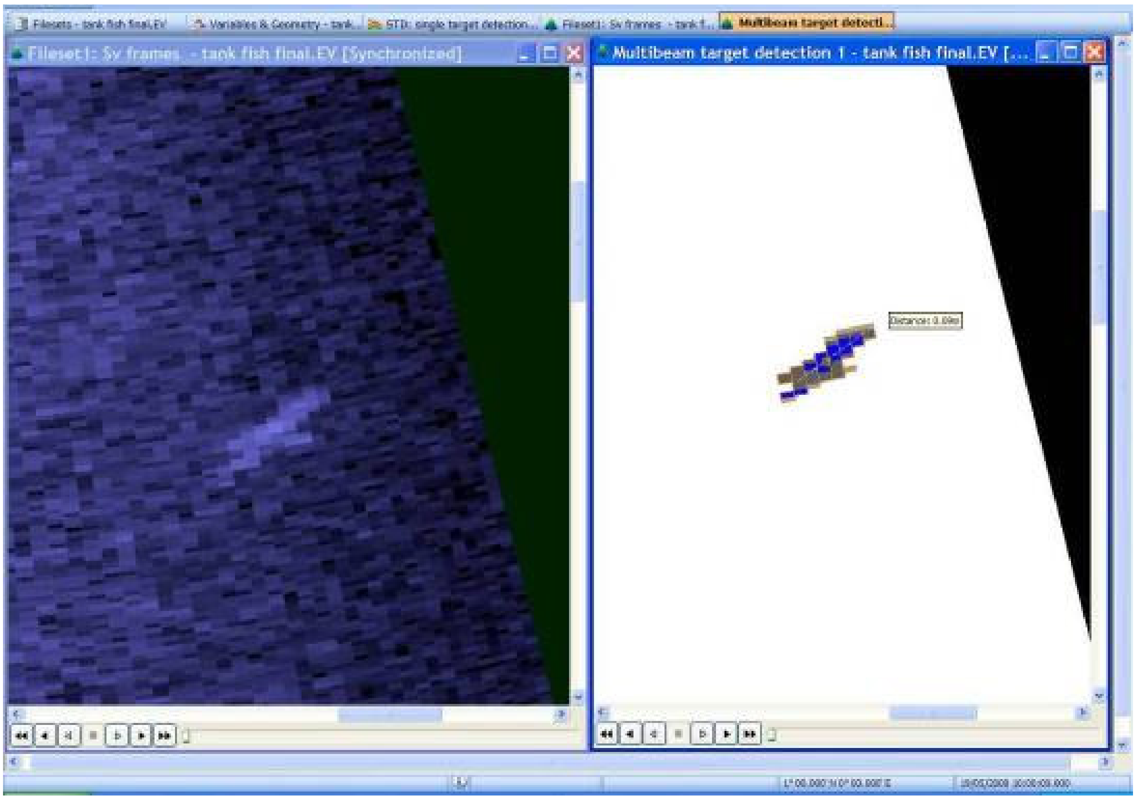

Figure 8. Echogram showing a shrimp detected using the DIDSON system and extracted from background noise in the multibeam target detection variable and manually measured.

4 Discussion

4.1 Review of the split-beam acoustic system

4.1.1 The split-beam acoustic system as a fish counter

The data collected by the split-beam acoustic system at Lock 10 has demonstrated that the system does indeed have the potential to provide an automated fish counting facility. However, certain limitations have been identified in this study that require consideration. In particular, automatic analysis of fish moving through the fishway exit detected less than half of the fish that actually moved through the field of view.

The most likely reason for a low fish detection rate was acoustic noise. The rocks at the fishway exit appear to mask some of the fish signals. The fact that no fish tracks were identified near the bottom of the fishway channel supports this assertion. During the testing and installation phase at Lock 10 various transducer angles and orientation angles were used. Trials using artificial targets confirmed that the location of the transducer was optimised for that location. However, as the data from 7 November showed, slight changes in transducer position could greatly increase acoustic noise.

An indication of the size of fish moving through the fishway was provided from the split-beam acoustic target strength data. Verification of fish track detections with high and low target strength using the measuring tool on the DIDSON multibeam target detection variable demonstrated the size range of fish detected. Apart from whole schools of fish, no small fish were detected with the split-beam acoustic system. The DIDSON video image showed numerous small fish that were missed in the split-beam acoustic data. Acoustic noise from the rocks surrounding the fishway exit is the most likely reason small fish were not detected.

To reduce the effects of acoustic noise a threshold on target strengths lower than a certain value is applied, but this reduces the potential to detect fish. An alternative method of reducing acoustic noise might be to keep fish away from the rocks by placing a 1–2 m long open flume on the fishway exit channel. The acoustic beam could be oriented to capture fish echoes as they exited the flume into deeper water. It is unknown whether fish behaviour would be affected by terminating the fishway in deeper water, so this may need to be assessed. Alternatively, the rocks immediately adjacent to the fishway exit could be removed.

4.1.2 Manual analysis of the split-beam data

The comparison of the DIDSON video image with the split-beam system was extremely useful. In previous trials with the split-beam acoustic system assumptions were made about whether a detected object was a fish, without any visual confirmation. The video image verified that many of these assumptions were correct, but it also demonstrated the limitations of the equipment, particularly for small fish in an acoustically noisy environment. The most likely object that could be falsely detected as a fish was an occasional piece of debris. However, at Lock 10 debris appeared to follow a fairly uniform, direct path in the water flow, fish rarely followed such a path. Even without the benefit of the DIDSON video image, manual checking of the split-beam acoustic data was beneficial. In the sample data only a small number of fish were added to the count as a result of manual checking, but false detections from rocks and debris were able to be removed from much of the data.

During the period of data collection it was considered that very few fish were migrating, although the counts of fish were relatively high. Fish and fish schools that moved into the fishway exit channel from the weirpool often appeared to exit shortly afterwards. The incidental counting of fish that moved through the fish detection zone but did not move entirely through the fishway may therefore be substantial. Using the limited data collected in the current study, it is difficult to quantify the number of non-migrating fish. During a period of high upstream fish migration it may be that the non-migrating fish can be identified easily by their behaviour, or that their numbers are insubstantial compared to strongly migrating fish. Alternatively it may be useful to perform some experiments in which fish movement into the fishway entrance is prevented and non-migratory fish that move through the exit channel are counted. It is likely that some of the fish detected were in fact migrating downstream. It may be necessary to place a trap at the downstream end of the fishway to attempt to count these fish.

Not all fish enter fishways during migration. For example, data from passive integrated transponder (PIT) tag readers on a fishway on the Burnett River in Queensland suggests that resident predatory fish use fishways to increase the opportunity to feed. Over five years one individual Blue Catfish *Arius graeffei* has been detected in the fishway on over 10 000 separate occasions (QDPIF, unpublished data). It is extremely likely that resident fish routinely move into and out of the Lock 10 fishway for the same purpose.

4.1.3 Remote counting using the split-beam acoustic system data

In summary, the split-beam acoustic system is capable of providing an indication of the number of fish using the fishway. However, as a tool for automatically detecting fish migrations the current level of accuracy would not be acceptable. The implementation of the recommendations in this report should increase the detection of fish, but unless acoustic noise can be dramatically reduced the detection of individual small fish may continue to be difficult.

The manual checking of raw split-beam acoustic data would improve the accuracy of counts and provide additional data that cannot be obtained automatically. It would not be necessary to review all of the split-beam acoustic data. Provided the system could be installed to obtain the optimum signal to noise ratio, a small snapshot of single-target data from each day or even weekly could be used to check automatic fish counts.

The project originally sought to e-mail processed fish track data for review and incorporation into a database. The quality of data from Lock 10 indicates that this approach would not be practical. The data files from the split-beam acoustic system (50 Mb per hour) are not as large as for the DIDSON system, but over a day the file volume would still be too large to e-mail. Rather than using raw split-beam echogram data, manual verification could be performed using single target export data e-mailed as a text file. The text file could be imported back into Echoview and analysed manually to assign fish tracks, identify fish schools and remove obvious detections of debris.

Unlike the DIDSON system, split-beam acoustic data cannot be used to estimate fish lengths. However, data from Lock 10 suggests that size classes could be inferred from target strength data. Further analyses using the target strength data from Lock 10 compared with manually estimated fish lengths from the DIDSON data may provide a target strength to length relationship.

4.2 Review of the DIDSON system

4.2.1 Ability of the DIDSON system to automatically count fish

In the original project concept the DIDSON system was to be used to substantiate the assumptions made using the split-beam acoustic data. However, the recent adaptation of multibeam software provided the opportunity to further test the suitability of the DIDSON system for fish counting.

Although the automatic analysis of the DIDSON data provided a greater level of accuracy than the split-beam data, it did not detect a large proportion of fish, and fish schools were not recognised as such. As with the split-beam data, acoustic noise was responsible for some of the missing fish detections. In Echoview the filtering of DIDSON echograms is more sophisticated than simply setting a threshold limit. A sample section of the echogram that does not contain fish is used to develop background noise levels, which are then subtracted from the rest of the echogram. Fish that moved over the rocks placed at the fishway exit appear to be disguised until they entered open water. To reduce the effect of the rocks the fish detection zone was extended into the fishway channel and also out to the weirpool. However, as recommended for the split-beam system, attaching an open flume to the end of the fishway channel or removing the rocks is likely to improve fish detection with the DIDSON system.

The orientation of fish in the acoustic beams was a major factor in whether a fish was detected. Many of the fish that were not automatically detected appeared to move through the fishway parallel to the channel walls and therefore nearly parallel to the acoustic beams. Quite often fish that were parallel to the direction of the acoustic beam were not visible at all in the acoustic video image until they turned at an angle to the beam. A possible improvement would be to place the DIDSON transducer out into the weirpool looking sideways across the fishway channel. A flume to guide fish over the rocks as suggested above would be of further benefit with such a side-looking application.

The inability of the software to automatically provide accurate length estimates of fish detected using the DIDSON system was disappointing. However, fish orientation was again the most likely major cause of the inaccuracy. In the tank test the estimated mean length was always less than the actual length, sometimes by a substantial amount. If a fish swam side-on to the beam or if sections of fish tracks that only included a direct side on aspect were selected, the accuracy of the length estimate was increased. As suggested above, positioning the DIDSON transducer in side-looking aspect should improve fish length estimates. The use of mean target lengths appears to be responsible for the erroneous length estimates. Further development of the Echoview software to provide a more rigorous methodology for length estimates should also improve the accuracy of automatic fish length estimates.

4.2.2 Manual analysis of the DIDSON system

The major advantage of the DIDSON system is that it produces video-quality images that can be manually checked against the fish detection data. A review of the video images from Lock 10 found 29 additional fish or fish schools that were not detected automatically. As mentioned above, the most likely reasons for low detection was the orientation of the transducer to the direction of fish movement and the high acoustic noise. A side-looking transducer orientation and the installation of a flume should increase the number of automatic fish detections. Improved definition of fish may also increase the opportunity to visually identify them to species level.

Manual verification of the DIDSON data would give a higher level of accuracy of fish counts and enable false detections to be eliminated. The Echoview software produces variables that filter and select fish targets. Each variable can be synchronised and viewed in real time at high speed or frame by frame. Although manual verification would be time-consuming it would not be necessary to view all footage, as a snapshot of a portion of each day could be reviewed to check the automatic fish detection data.

Fish schools were not detected automatically by Echoview but were very easily distinguished in the single-target data. A manual review of the single-target data, even without the video image for verification, would enable fish schools moving through the fishway to be detected. The Echoview software is constantly being upgraded and improved, so the ongoing collection and interpretation of data from fish schools and liaison with the software developer Myriax may result in an improved ability to automatically detect fish schools.

Manual measurements of fish detected in the multibeam target detection variable appeared to provide more accurate estimates of fish length. However, only fish that presented at least a partial side-on aspect to the transducer during some part of their movement through the beam could be accurately measured. The detection and measurement of the shrimp in the fish tank trials suggests that, under ideal conditions, the DIDSON system can provide very detailed data. At Lock 10 individual small fish were not detected, probably because of the acoustic noise from the rocks. However fish in small schools that appeared to be in mid water were detected and measured, although in more dense schools this may not be possible. Relocating the DIDSON transducer to increase the number of fish that pass side-on to the acoustic beams would also increase the number of fish that can be measured manually.

4.2.3 Remote counting using the DIDSON system

In summary, the DIDSON system appears to provide substantial benefits over the split-beam system for automatic fish counting. Although the DIDSON system was installed in a disadvantageous location it managed to detect 73.5% of the medium to large fish that moved through the fishway. If the transducer is located in a more suitable orientation and acoustic noise is reduced, the automatic count rate should increase.

Automatic estimates of fish length were inaccurate but could be used as a guide to the size classes of fish migrating. Ongoing collection of DIDSON data in conjunction with further development of analytical software should improve fish length estimates.

Manual analysis of the data would improve fish counting and fish length measurements. A major disadvantage of the DIDSON system is the size of the files that are created. At Lock 10 an hour of echogram created a file of about 1 Gb, which necessitated the use of high-capacity external hard drives for data storage. During data analysis with Echoview the size of the files also created problems with extended processing and handling time. To reduce handling time, processed single-target data could be exported as a text file and imported back into Echoview as a stand-alone file. The same process could be employed at remote sites on the Murray River fishways. The single-target data could periodically be e-mailed to the group responsible for data analysis and management. If visual verification of raw DIDSON echograms was considered necessary, files could be written to an external hard drive and periodically e-mailed to the same group or to a file storage facility.

5 Conclusion

Both the split-beam system and the DIDSON system provided automatic counts of fish moving through the Lock 10 fishway. However, because of the limited data collected in the current study the counts are only rough estimates. The split-beam system severely underestimated the number of fish exiting the fishway channel at Lock 10. Despite poor transducer placement, the DIDSON system counted fish more accurately. Both systems were affected by acoustic noise at the fishway exit, but with minor modifications their accuracy is likely to improve. The DIDSON system appears capable of providing accurate fish length estimates whereas the split-beam system can only provide indications of fish size classes based on target strength. Only the DIDSON system records video-quality images that can be visually verified and might be used to identify fish species.

Manual review of the data from both systems can increase valid detections of fish moving through the fishway exit and filter false detections from debris. Both acoustic systems generate raw data files that are too large to transmit at present, particularly in remote areas. The transmission of partially processed data for analyses would be a practical solution to the file size problem. However, a commitment to manually review the data, at least in the shorter term, would be necessary.

If fish counting accuracy can be improved, the split-beam system may also be suitable. Given that the Murray–Darling Basin Commission has already purchased both systems, further testing should be undertaken before a final decision is made on which to use.

Recommendations

The following actions for further testing of both fish-counting systems at Lock 10 are recommended, and should be carried out in the order shown:

1. With Myriax, review existing Lock 10 data to identify opportunities to improve data collection and analysis with Echoview software.
2. Fabricate and install a flume at the fishway exit that will guide fish away from the exit channel rocks, or remove adjacent rocks.
3. Fabricate a bracket that orients the transducer side-on to the end of the flume and 3 to 5 m away from the flume exit.
4. Operate both systems once a month at Lock 10 from September to January and collect continuous data for 3–4 days at a time. Monitor fish numbers observed using the fishway to ensure that some periods of high fish migration are included in the data. Undertake experiments to determine the number of non-migrating fish.
5. Continue to investigate improving the accuracy of automatic fish length estimates with the DIDSON system using data from Lock 10 and fish of known length.
6. Decide on which acoustic system to employ in the long term, and modify the existing Echoview script to suit. Install telemetry to permit the transmission of data files for manual verification and analysis.

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