Assessment of a Dual-frequency Identification Sonar (DIDSON) for application in fish migration studies

Lee J. Baumgartner, Nathan Reynoldson, Leo Cameron and Justin Stanger

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April 2006

NSW Department of Primary Industries -
Fisheries Final Report Series
No. 84

ISSN 1449-9967

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Published By: NSW Department of Primary Industries
Postal Address: PO Box 21 Cronulla NSW 2230
Internet: www.dpi.nsw.gov.au

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ISSN 1449-9967

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ACKNOWLEDGEMENTS

NSW Department of Primary Industries and the Murray-Darling Basin Commission jointly funded this study.

The authors would like to the staff from Lock 8, Yarrawonga Weir and the Murray River Barrages for their support and assistance throughout the study. Peter Rose and his staff from Pacific Commercial Diving Supplies are thanked for arranging hire of the DIDSON and providing high quality technical support throughout the trial.

The staff at Narrandera Fisheries Centre are thanked for providing access to hatchery facilities and equipment necessary to undertake the ground-truthing experiments. Peter McLean is thanked for developing an extremely reliable and high-quality mounting system.

Bob Creese, Steve Kennelly and Ian Wooden are thanked for their helpful comments on early versions of the document.

The study was conducted under NSW Fisheries Animal care and ethics permit 99/15.

NON-TECHNICAL SUMMARY

Assessment of a Dual-frequency Identification Sonar (DIDSON) for application in fish migration studies

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OBJECTIVES:

- To undertake a field test of a DIDSON sonar for fisheries-based applications in Australian freshwater systems.
- To trial the DIDSON under a variety of experimental conditions including within fishways, in open river channels and hatchery ponds.
- To ground-truth the software to determine the efficiency of its automatic counting and measuring interfaces.

NON TECHNICAL SUMMARY:

Freshwater fish need to move within and among different habitats. Objects that obstruct migrations, such as dams and weirs, have led to worldwide declines in fish populations. Although the adoption of various management strategies (such as weir removal and fishway construction), has improved fish populations in many areas the success of any rehabilitation project relies heavily on a fundamental understanding of the biological requirements of fish. Such biological information is needed to ensure that any effects of human disturbance can be adequately ameliorated.

The ability to observe fish in their natural environment is often difficult to achieve, especially in turbid or low visibility conditions. Although many recent advances in technology have been developed, traditional methods generally require catching the fish in some way to obtain biological information. Whilst in some cases this is the only practical method to obtain data, it is largely unknown whether handling fish can alter their ‘natural’ behaviour.

Recently developed sonar systems are currently being assessed in North America and their non-invasive application to fish migration studies is very promising. One such device, the Dual-Frequency Identification Sonar (DIDSON), uses sound-distorting lenses to create high quality video images (Figure 1). When operating in high frequency mode, these features can define the outline, shape and even fins of target fish. In addition, DIDSON software can count and measure fish automatically. With such features, this technology can potentially allow the observation of fish behaviour such as spawning, feeding and migration. To date, no assessment of this technology for fisheries-based applications has ever been undertaken in Australia. Subsequently, this study was undertaken to provide the first assessment of a DIDSON unit in Australian systems.

The results indicated that the DIDSON is a powerful tool for observing freshwater fish populations. When used in conjunction with conventional trapping equipment, the DIDSON consistently provided additional data on fish behaviour that could not be otherwise determined. For example, at fishways on the Murray River, the DIDSON demonstrated that many more fish were approaching

and entering the fishways than were trapped as they passed through. In many cases, these fish were actively avoiding traps or displayed a behavioural impediment to entering the fishway. In addition, several fish actively migrated downstream through the fishway when no traps were in place. The DIDSON also provided useful observations of non-migratory activity and non-finfish fauna. In particular, predatory birds and fish were observed to use fishways to actively hunt prey. Such observations are not possible through conventional sampling, especially in turbid conditions.

A ground-truthing trial was also performed to determine the accuracy of the automatic counting and measuring interfaces of the operating software. In general, total fish numbers were frequently underestimated and estimated fish lengths were quite variable. Further development of the operating software could alleviate these problems.

Despite some limitations with its automated features, when operated manually, the DIDSON was a powerful tool that provided a viable alternative to traditional fish sampling techniques. Possible research applications of the technology to Australian systems include habitat mapping, fish-habitat associations, migration studies, bottom mapping, underwater survey and determination of sampling gear efficiency. The results of this study show that further use of a DIDSON unit would add substantial value to data collected from a number of research projects in Australia.

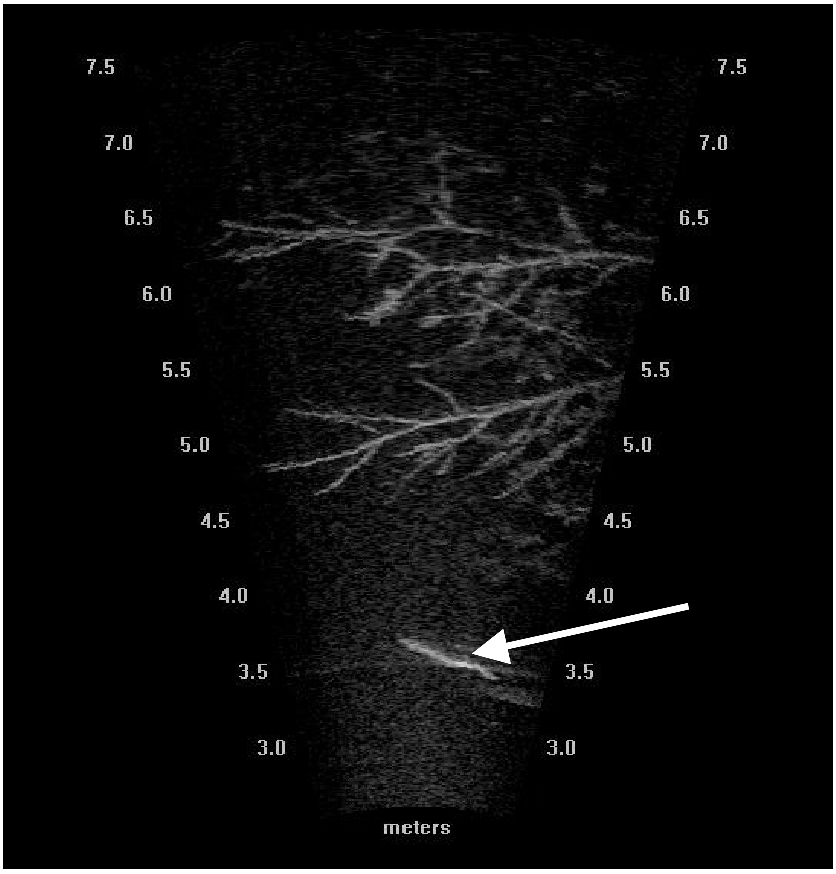


Figure 1. An example of a DIDSON generated image showing a longfinned eel (*Anguilla australis*) (arrowed) seeking refuge under a snag on the Williams River, NSW, Australia.

1. INTRODUCTION

The requirement for fish to move within and among different habitats is a well-established paradigm for many freshwater fish species (Lucas and Baras, 2001). Mechanisms that obstruct migrations, such as constructing dams and weirs, have led to worldwide declines in fish populations (Baxter, 1977; Cortes *et al*, 1998). Although the adoption of various management strategies has improved fish populations in many parts of the world (such as weir removal and fishway construction), the success of any rehabilitation project relies heavily on a fundamental understanding of the biological requirements of fish (Pitcher and Pauly, 1998). Such information is important to ensure that any effects of human disturbance can be adequately mitigated.

The ability to observe fish in their natural environment is often difficult to achieve, especially in turbid or low visibility situations (Tiffan and Rondorf, 2004). Although many recent advances in technology have been developed, traditional methods generally require biologists to interact with fish (e.g through trapping or handling) to obtain biological information. Whilst in some cases this is the only practical method to obtain data, it is largely unknown whether handling fish can alter their ‘natural’ behaviour; a phenomenon that is almost impossible to control for (Hubert, 1985).

Trapping or netting fish during upstream or downstream movements is commonly employed to obtain data during migration studies (See for example Mallen-Cooper, 1996; Mallen-Cooper, 1999; Fievet, 2000; Stuart and Mallen-Cooper, 2000; Stuart and Berghuis, 2002; Baumgartner 2005). In Australian systems, information on fish migration is usually collected from two sources; fishway trapping (Mallen-Cooper, 1996; Stuart and Berguis, 2002; Baumgartner 2005) or tag-recapture studies (Reynolds, 1983). Such studies provide important quantitative information on timing of migrations, distances traversed and species composition. However, fish are often trapped or recaptured in the process of migrating and little information can be deciphered about the ecological reasons behind observed migratory patterns (Pusey *et al*, 2004). Subsequently, little is known about fine-scale fish behaviour or even the proportion of migrating fish that are actually sampled.

In more recent times, the development of electronic monitoring devices such as hydroacoustics (Johnson *et al* 1994; Steig and Iverson 1998; Frear 2002), infrared (Halfdanarson, 2000), sonar (Eggers, 1994; Eggers *et al*, 1995; Williams *et al*, 2003; Belcher and Matsuyama, 2003) and transponder (Castro-Santos *et al*, 1996; Zydlewski *et al*; 2001; Hockersmith *et al*, 2003) technology has greatly improved the ability of researchers to gather information beyond trapping and tagging studies. Such technologies allow fish to be observed with little or no interference.

Most recent research has focused on hydroacoustic technology (Berghuis and Matveev, 2004). Hydroacoustics is a term applied to the use of echo sounding, which detects and records the return signals of frequently transmitted ultrasound waves. The result is an integrated image known as an echogram, which can be interpreted into biological information by trained researchers (Berghuis and Matveev, 2004). This technology is widely used in North America for quantifying migrations of Atlantic salmon (*Salmo salar*) (Ransom *et al*, 1998; Thorne and Johnson, 1993; Yule, 2000) and shad (*Alosa* spp) (Schael *et al*, 1995; Vondracek and Degan, 1995; Guillard and Colon, 2000). In some cases, extremely accurate estimates of migrating fish numbers have been obtained (Ranson *et al*, 1998) and the technology is advancing rapidly. Hydroacoustic systems have had some application in Australia but its widespread use is limited by a high capital cost and impeded species recognition capability (Berghuis and Matveev, 2004).

The use of transponder technology has also increased rapidly in more recent times (Lucas and Baras, 2000). Passive Integrated Transponders (PIT) comprise a coil and an integrated circuit that is programmed to transmit a unique code to a remotely-stationed reader (Prentice *et al*, 1990). The tags are encapsulated in glass or plastic and implanted into the musculature or stomach cavity of the fish. It is important to note that PIT tags do not contain a battery. Therefore, once a tag has been implanted into a fish, it is theoretically tagged for life (Lucas and Baras, 2000). The two major disadvantages of PIT technology are that fish must be handled to implant the tag and the limited read-range of automated detection systems (often <1m). The strategic placement of detection systems, such as in fishways or migratory bottlenecks, can provide excellent point-source data on fish movements (Armstrong *et al*, 1996). However, detail on more generalised movements is difficult to determine because of physical limitations on the number of antennas that can be installed at automated detection sites.

Recently developed sonar systems are currently being assessed in North America and their application to fish migration studies is extremely promising (Eggers, 1994; Eggers *et al*, 1995; Williams *et al*, 2003). The Dual-frequency Identification Sonar (DIDSON; Figure 2) uses acoustic lenses to create high quality video images (See examples in Figure 1 and Moursund *et al*, 2003). When operating in high frequency mode, the DIDSON uses 96 acoustic beams that can define the outline, shape and even fins of target fish (Video 1). Importantly, the technology is particularly effective in dark or turbid conditions where visibility is otherwise poor. The software, which operates the unit, can also count and measure fish automatically. Therefore, this technology can potentially allow the observation of fish behaviour such as migration (Video 2) spawning and feeding (Video 3). However, no assessment of the applicability of this technology for fisheries-based applications has ever been undertaken in Australia.

Previous applications of DIDSON technology have primarily focused on quantifying migrations of commercially important species, such as Atlantic salmon (*Salmo salar*) (Eggers *et al*, 1995, Moursund *et al*, 2003; Maxwell and Gove, 2002). The purpose of our study was to investigate the feasibility of DIDSON to help address ecological issues that scientists have been unable to solve using conventional methods. A DIDSON was hired for a short time and deployed at three major sites on the Murray River to evaluate its potential to observe migratory fish within the Murray-Darling Basin (Figure 3).

Four specific field tests were undertaken. First, the DIDSON was used to quantify escape and trap avoidance within a fishway. Second, the unit was used at a coastal barrage to investigate the effect of altered entrance conditions on passage through a vertical slot fishway. Third, assessments of the entrance and exit efficiencies of a fishlift were investigated. Fourth, the automatic counting and measuring functions of the DIDSON software were assessed for accuracy under low and high-density fish situations.

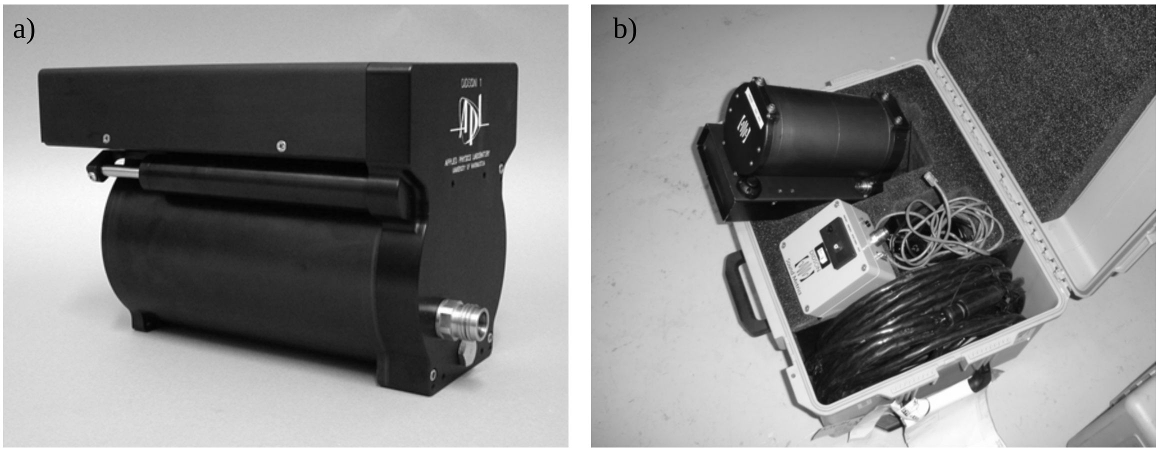


Figure 2. a) A standard unibody DIDSON transducer which weighs approximately 7kg and measures 171mm x 307 mm x 206 mm; b) A standard DIDSON accessory kit containing data cable, set-top box, Ethernet cables and the transducer. The operator additionally requires a laptop running DIDSON software to operate the unit.

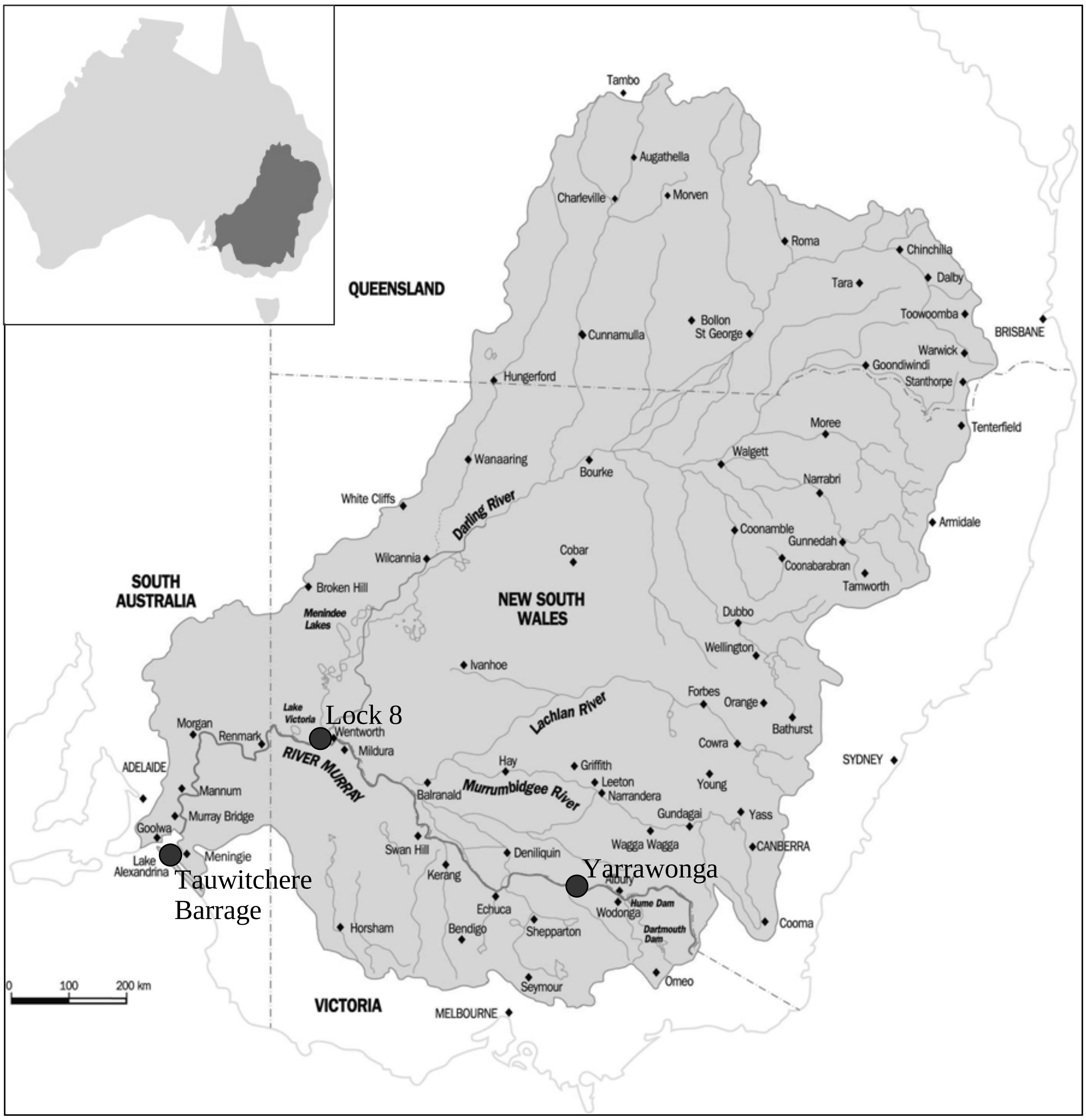


Figure 3. Map of the Murray Darling Basin highlighting the sampling sites (solid dots) investigated as part of this study (Modified from MDBC, 2003).

2. METHODS

2.1. DIDSON operation

Operation of the DIDSON unit is straightforward and requires minimal training. The DIDSON unit comprises the sonar, a set-top control box, a data cable, control software and an associated laptop computer (Figure 2). The DIDSON is directly connected to the set-top box, which is linked to the laptop via an ethernet connection. The image is transferred from the unit to the laptop via the control software, which displays the data as a streaming image. Image files can then be either directly viewed using the control software or saved onto a hard drive and reviewed manually at a later date.

The DIDSON operates in either high (1.8MHz) or low frequency (1.0MHz) modes (Table 1). In high frequency mode, image resolution is greatest but the unit cannot generate images from greater than 12m away. In low frequency mode, image resolution is compromised for a greater operational range (>40m). High frequency mode is considered the most useful for fisheries-based applications as image quality enables a much better determination of fish behaviour, including morphological features that could enable species recognition (Maxwell and Gove, 2002).

2.2. Fishway trials

A one-week trial was undertaken to assess the DIDSON’s ability to quantitatively assess the responses of fish to different trap configurations at the entrance of a vertical-slot fishway at Lock 8 on the Murray River. The DIDSON was installed to give the maximum field-of-view within the entrance chamber to detect any migrating fish (Figure 4). Three treatments were used with three temporal replicates (1.5hr duration) of each. Treatment one comprised, a standard cage trap (2m x 2.5m x 6mm mesh) containing a large entrance cone. Treatment two was an open-topped pop-net (5m x 2m x 6mm mesh). The third treatment was a control where no trap was present in the chamber but all fish were collected from a trap located within the second cell.

At the end of the predetermined sampling period, the traps were retrieved and all fish were identified, counted and measured prior to release. During each replicate, the DIDSON was used to record all fish movements within the entrance cell. Data were later extracted by manually observing the footage. Individual fish behaviour was quantified into one of six specific groups including fish that entered the fishway but exited (EE), fish that entered the fishway and proceeded through the first slot (ES), fish that entered the fishway and were caught in the trap (ET), fish that entered the trap but escaped (ETE), fish that entered the fishway cell and remained within it for the duration of the replicate (ESE) and fish that swam downstream through the slot (DSS).

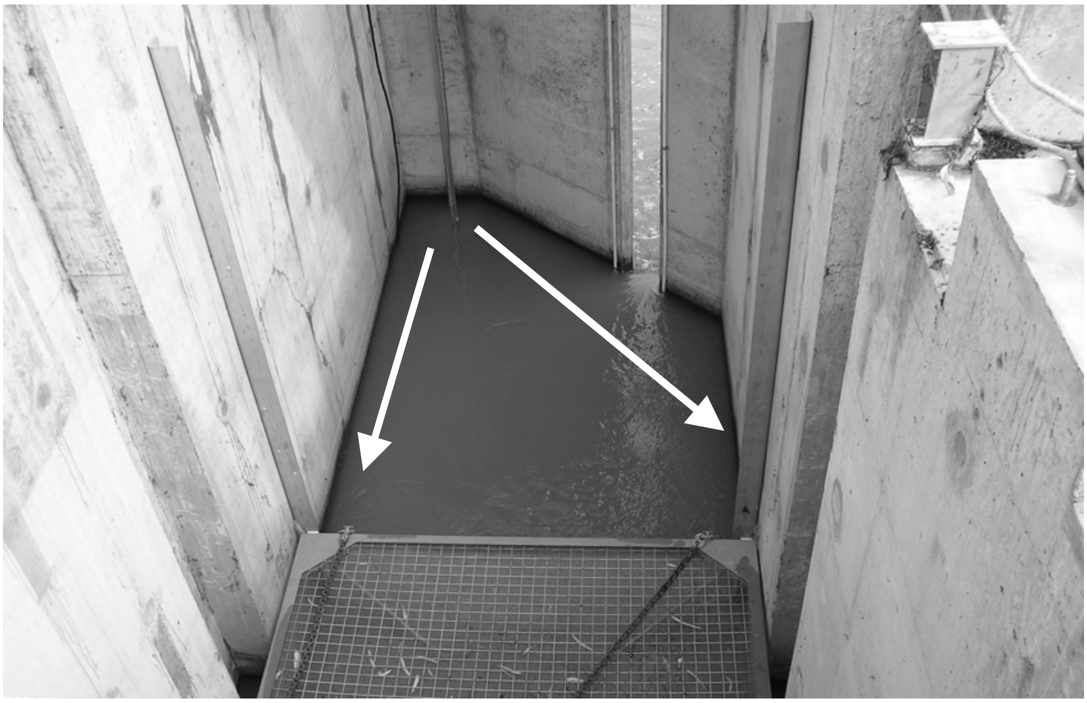


Figure 4. The DIDSON mounting system in the entrance of the Lock 8 fishway. The DIDSON transducer was mounted on the downstream side of the cell to monitor behaviour as fish approached each of the three different set-ups. The arrows depict the approximate range of the DIDSON beams.

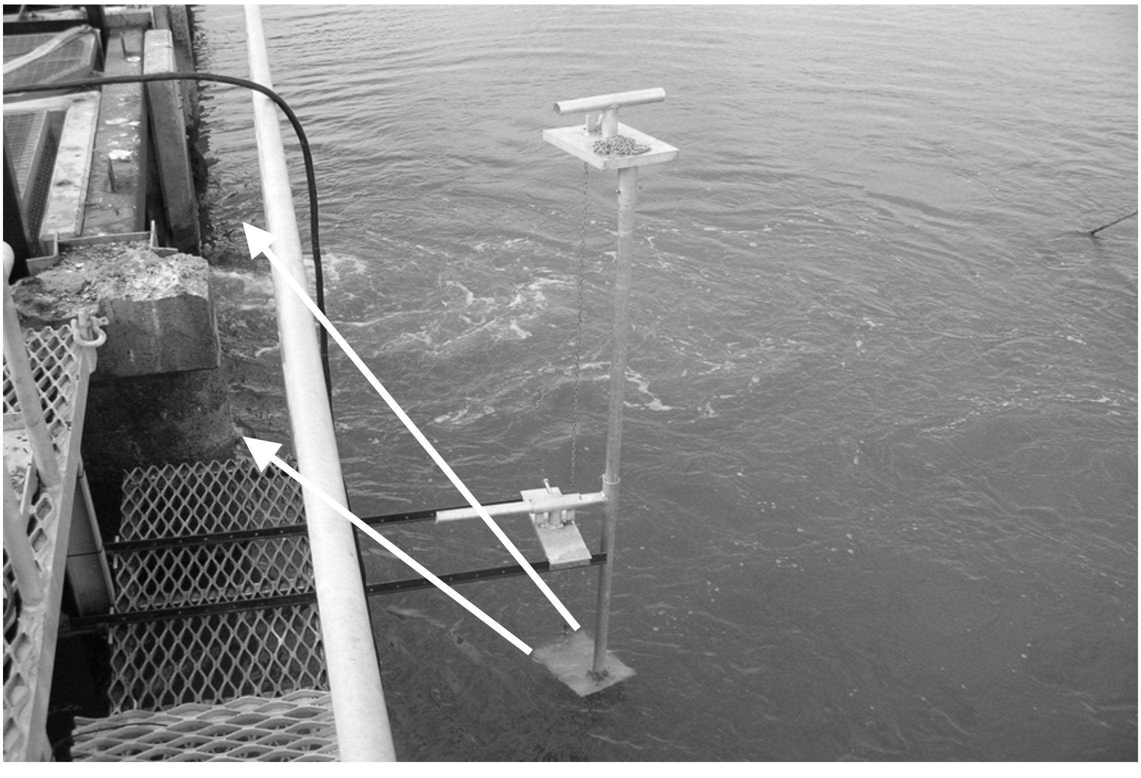


Figure 5. The DIDSON unit at the Murray mouth barrages. Arrows depict range of the beams. The unit was located to obtain an indication of fish behaviour outside the fishway entrance.

2.3. Murray Mouth Barrages trial

The final field trial of the DIDSON unit was undertaken over a week at a vertical-slot fishway on the Murray River at Tauwitchere barrage (See Figure 3). The DIDSON was installed to give the maximum field-of-view outside the entrance chamber (See Figure 5) to observe the behaviour of fish as they approached the fishway. The fishway was then operated under three different entrance headlosses (50mm, 150mm and 280mm), and any fish responses were recorded. To enable comparisons between DIDSON-determined data and actual fish passage rates, a large cage-trap was placed within the entrance cell. Three temporal replicates (of 1.5hr duration) were performed for each headloss treatment.

At the end of each replicate, the trap was retrieved and all fish were identified, counted and measured prior to release. During each replicate, the DIDSON was used to record all fish movements in the vicinity of the fishway entrance. Data was later extracted by manually observing the footage and individual fish behaviour was quantified into one of 5 specific groups including fish that approached the fishway but did not enter; fish that entered the field of view but did not approach the fishway; fish that entered the fishway and were caught in the trap; fish that entered the trap but escaped and fish which entered the field of view but remained there.

2.4. Yarrawonga fishlock trials

A one-week trial of the DIDSON's ability to quantify fish behaviour during migration through a fishlock was undertaken at Yarrawonga Weir (See Figure 3). Here, six replicates of two experimental treatments were performed. First, the DIDSON was mounted so that it pointed directly at the entrance slots and obtained an indication of all fish that were entering the fishway. Second, the unit was rotated so that it enabled a quantification of the number of fish entering the lock chamber (Figure 6).

Table 1. Technical specifications of the DIDSON unit (From Moursund *et al*, 2003).

High-frequency mode	
Operating frequency	1.8MHz
Beamwidth (two-way)	0.3° horizontal by 12° vertical profile
Number of beams	96
Low-frequency mode	
Operating frequency	1.0MHz
Beamwidth (two-way)	0.6° horizontal by 12° vertical profile
No. of beams	48
Both modes	
Field-of-view	29°
Power Consumption	30 W typical (24 volts)
Weight in air	7.0 kg
Weight in water	-0.61 kg
Dimensions	171mm x 307 mm x 206 mm

Fish behaviour was quantified into a number of discrete groups comprising fish than entered the field of view but exited downstream, fish that entered the field of view and continued upstream, fish that migrated upstream but returned to the field of view, fish that migrated upstream, returned and exited downstream and fish that entered the field of view but stayed there.

Thorncraft and Harris (1996) previously suggested that some fish successfully negotiating the fish lock might be subsequently drawn into a hydro facility located in close proximity to the exit race. To examine this hypothesis, a further trial was undertaken to assess the efficiency of the fish lock exit phase. To quantify the number of fish drawn into the hydro-plant, the DIDSON was mounted opposite the fish lock exit to enable the direction of exiting fish to be observed. As few fish were migrating at the time of the study, a total of 40 fish were collected downstream of Yarrawonga Weir using a Smith-Root 7.5 G/L boat-mounted electrofishing unit. The fish were transferred to the exit race of the fish lock and an exit phase was initiated. Any fish that exited the fishway was counted and recorded from DIDSON footage. Two replicates, each containing 20 fish, were performed.

2.5. Ground-truthing trials

Ground-truthing trials were undertaken in hatchery tanks at the Narrandera Fisheries Centre to determine the accuracy of the fish counting and measuring capabilities of the DIDSON unit. In auto mode, the DIDSON automatically estimates the size of a fish based on its signal strength and outline. In manual mode, the DIDSON provides a size estimate of the fish based on an outline drawn around the object by an operator. To test the accuracy of both operating modes, 50 fish of known size (166mm to 490mm) were used in the trial. Experimentation began when an individual fish was placed into a 600L hatchery tank and five independent length measurements were taken both automatically (i.e. by the DIDSON software), and then by an observer manually operating the software. These ten length estimates were recorded, the fish was replaced and the procedure repeated until 50 fish were measured.

Figure 6. The DIDSON setup in the Yarrawonga fishlift demonstrating the aspect of the sonar cone when pointed at a) the fishlift entrance and b) the lock chamber entrance.

The DIDSON also has a count feature, where a physical estimate of migrating fish numbers can be generated either automatically (via the DIDSON software) or manually (by an observer). To determine its accuracy, manual and auto estimates were obtained in 600L hatchery tanks containing different known numbers of fish (5, 10, 15, 20, 25, 30, 35, 40, 45 or 50) to simulate different fish migration rates past a specific point. Five replicates were completed for each ‘known’ abundance sample. Each replicate involved either the observer, or the software, counting all fish within the field of view for a total of two minutes. After two minutes the number of fish counted by each method was recorded and the number of fish increased by five. The entire procedure was then repeated.

2.6. Data analysis

All data were analysed using the S-Plus 2000 statistical analysis package (Insightful corporation, 2001). Comparisons between DIDSON counts and trap catches (Lock 8 and Murray mouth barrages) were done using Two-Way ANOVA with treatments and estimation method as factors. At Yarrawonga Weir, DIDSON counts among treatments were analysed using One-Way ANOVA using treatments as the factor. Data were log (x+1) transformed as Cochran’s tests determined non-homogeneity of variances.

General linear regression techniques were used to explore the accuracy of automated fish counting and measuring facilities of the DIDSON software. This procedure involves regressing automatic and manual estimates of fish abundance and length (generated from the operating software) against known values to determine the accuracy of DIDSON-generated data. Data were again log (x+1) transformed data as Cochran’s tests determined non-homogeneity of variances.

3. RESULTS AND DISCUSSION

3.1. Lock 8 trials

The DIDSON detected a total of 182 fish within the Lock 8 fishway but species identifications were only made for common carp (*Cyprinus carpio*), bony herring (*Nematalosa erebi*) and Murray cod (*Maccullochella peelii peelii*) because their body outline was noticeably apparent upon review of recorded footage (Table 2). In contrast, 6,718 fish from 9 species, were collected from all trapping treatments. Trap samples were dominated by smaller-bodied species such as fly-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), western carp gudgeon (*Hypseleotris* spp) and Australian smelt (*Retropinna semoni*) (Table 2). The increased abundance of these small species contributed to significant differences between DIDSON and trap samples (ANOVA: F=9.97, p<0.001) (Figure 7a). North American studies have highlighted that DIDSON is inefficient for fish less than 75mm (Eggers, 1994). When small species (<75mm at adulthood) were excluded from the analysis no significant differences in fish abundance were detected (ANOVA: F=2.69, p=0.120) (Figure 7b).

No significant differences in fish catches were detected among the three different treatments (all species ANOVA: F=0.24; p=0.78; no small fish ANOVA: F=0.09; p=0.90). This suggests that, when individual species were considered separately (Figure 8), trap design had little effect on the number of fish caught. Although, trap shyness is a phenomenon occasionally reported in fishway assessments (Stuart and Mallen-Cooper, 1999), the large number of fish trapped in this study initially determined that all methods of trapping were successful. However, it is important to note that trap catches were dominated by small-bodied fish (<75mm at adulthood).

An absence of larger fish (>75mm at adulthood) from trap collections initially suggests a lack of migratory behaviour during the study period. However, examination of DIDSON footage confirmed the presence of larger-bodied fish and, more importantly, demonstrated that many individuals would not enter the trap. Overall, the proportion of large fish that were entrained into the trap systems was very low, at 12% (cage trap) and 8% (pop net) of all fish entering the fishway. Further, DIDSON revealed that over 80% of fish that entered the fishway exited without being caught (when a trap was present) or proceeded upstream through the slot (when no trap was present) (Figure 9; Video 4).

Table 2. Comparison of total fish numbers identified from DIDSON and trap surveys conducted within the Lock 8 fishway (all replicates pooled).

Species	**Cage net**		**Pop net**		**No trap**	
	DIDSON	**Trap**	**DIDSON**	**Trap**	**DIDSON**	**Trap**
Common carp	4	0	4	0	0	63
Flyspecked hardyhead	0	131	0	103	0	317
Gambusia	0	5	0	15	0	54
Gudgeon	0	248	0	220	0	722
Murray cod	0	0	0	0	12	0
Murray rainbowfish	0	14	0	0	0	2
Bony Herring	22	54	51	399	88	2
Flatheaded gudgeon	0	3	0	0	0	3
Australian Smelt	0	829	0	1,515	0	2,019
Unknown (>75mm)	0	0	1	0	0	0

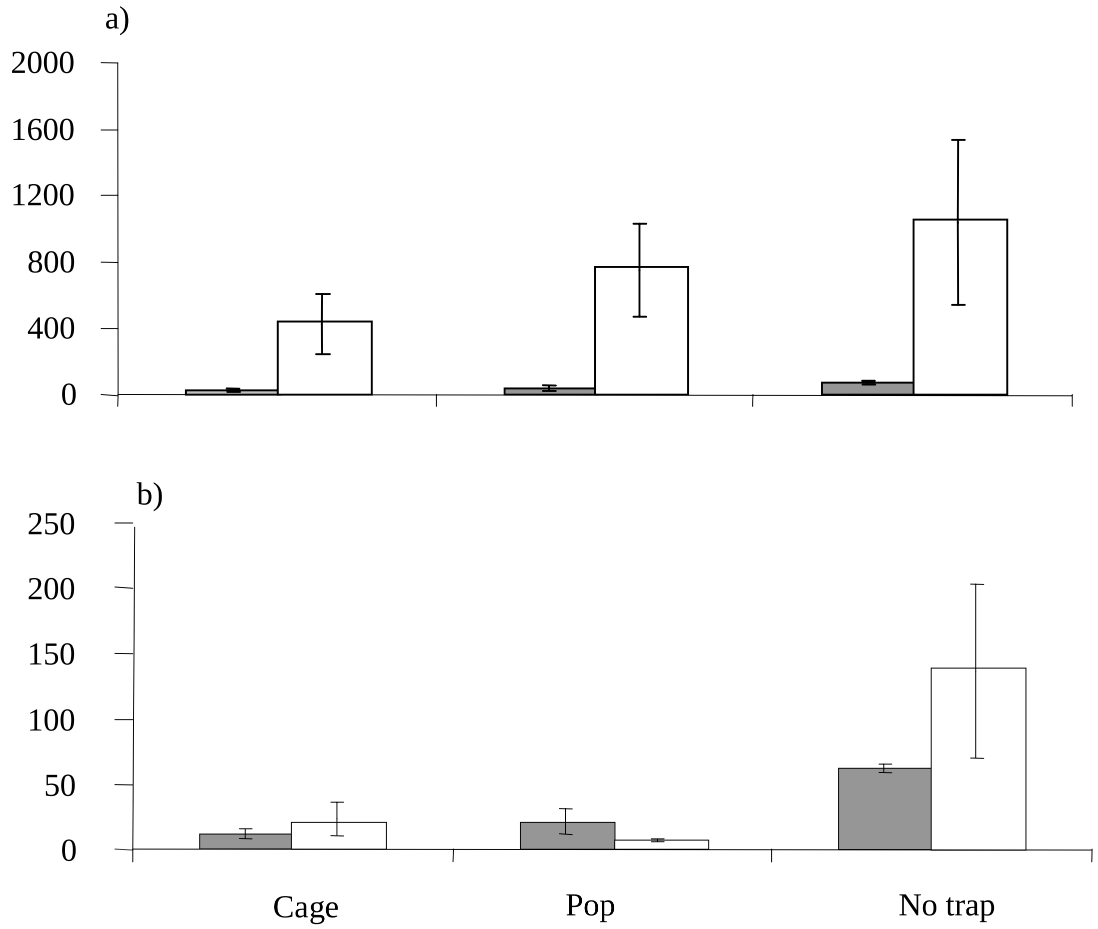


Figure 7. Comparison of mean numbers of fish identified by the DIDSON (shaded) and trapping (hollow) among the three treatments investigated at Lock 8. The two graphs represent data from (a) all fish pooled and (b) all large fish pooled (individuals >75mm).

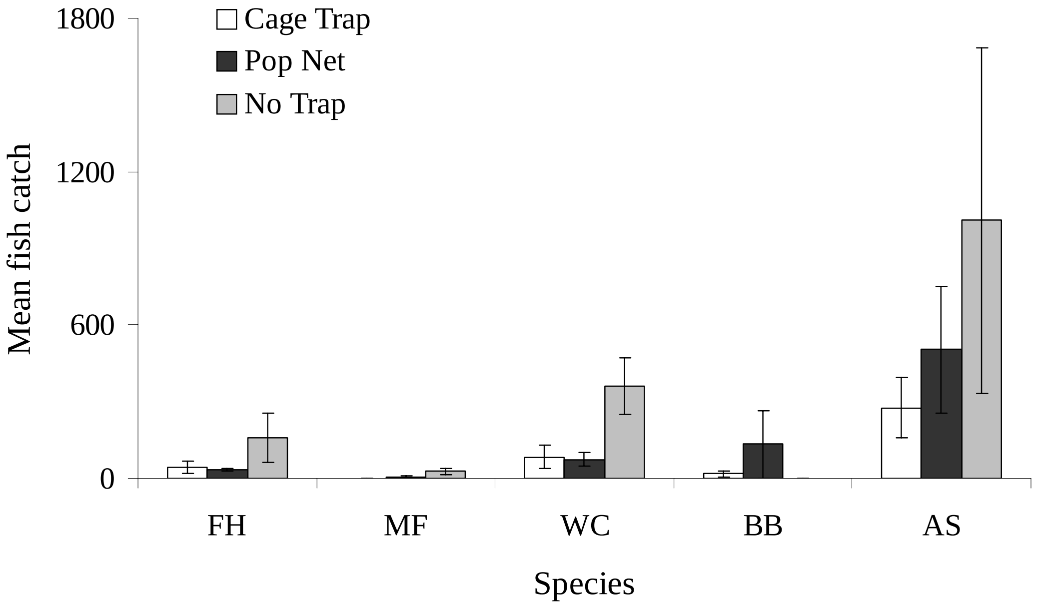
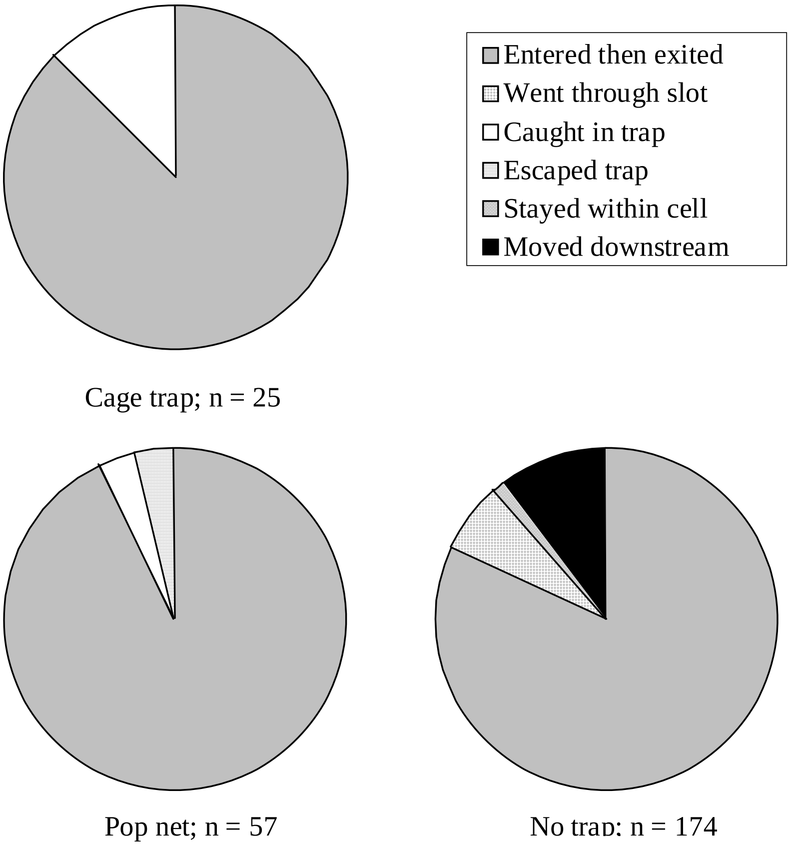


Figure 8. Mean catches of the five most abundant fish species caught in each of treatments investigated at Lock 8. Error bars represent one standard error; n=3 temporal replicates. Species are flyspecked hardyhead (FS); Murray rainbowfish (MF); Western carp gudgeon (WC); bony herring (BB) and Australian smelt (AS).



Cage trap; n = 25

Pop net; n = 57

No trap; n = 174

Figure 9. A summary of six different fish behaviours as determined by DIDSON footage based on pooled data for each treatment. Behaviour is defined as fish that entered the fishway and exited, fish that entered the fishway and proceeded upstream through the slot, fish which entered the fishway and were caught in the trap (or secondary trap in the case of the control), fish that entered the trap but escaped, fish that entered the fishway and stayed within the cell and fish that swam downstream through the slot into the cell.

Trap avoidance is widely suspected in many species of salmonids (Todd, 1994; Pine *et* al, 2000; Iglesias *et al*, 2003) and cyprinids (Lilja *et al*, 2003). The present study has demonstrated that DIDSON can increase the accuracy of quantitative assessments of migration, when deployed *in-situ* with other sampling methods, by enabling an estimation of trap avoidance. Further trials investigating the extent of avoidance among different species would help improve the accuracy of migration rate determination. In the case of larger species, DIDSON could also aid the design of more efficient fish traps that account for the shyness of different species. Given the degree of avoidance detected by DIDSON, such a study is warranted.

When no trap was present, approximately 3% of fish moved into the entrance chamber and remained for the entire duration of the replicate (Figure 9). The DIDSON subsequently revealed these fish either foraged for, or actively hunted, prey within the structure. At least one fish was resident within the entrance chamber for 6 hours, and actively preyed upon smaller fish. Many studies report increased predation rates of accumulating fish outside fishway entrances (Svendsen *et al*, 2004; Baumgartner, 2005). However, few have been able to document predation within fishways or quantify its extent. The DIDSON provided a useful tool for monitoring such behaviour and has potential to further contribute to quantitative studies of fish predation rates at other sites where such behaviour is suspected.

3.2. Murray Mouth Barrages trial

The DIDSON permitted the observation of 246 fish at the Murray River barrages; but positive identification was only possible for one species (Black bream, *Acanthopagrus butcheri*) that was classified by body morphology from recorded footage. In comparison, 346 fish, from 6 species were trapped within the fishway during the week-long trial. Species sampled within the trap but not effectively detected by the DIDSON included small-bodied species (<75mm) such as yellow-eye mullet (*Aldrichetta forsteri*), small-mouthed hardyhead (*Atherina microstoma*), common galaxias (*Galaxias maculatus*), flatheaded gudgeon (*Phylipnodon grandiceps*), congolli (*Pseudaphritis urvilli*) and Australian smelt (*Retropinna semoni*) (Table 3). Significantly more fish were sampled from the fishway trap than were observed with the DIDSON (ANOVA: F=5.37; p=0.04). No significant differences in fish abundance were detected among entrance headlosses (ANOVA: F=3.41; p=0.07) (Figure 10).

No black bream were caught in entrance traps. Conversely, no fish sampled from the trap were detected with sufficient resolution to enable identification using DIDSON (Table 3, Figure 11). The observations highlight limitations of each technique for accurately describing the species composition of migratory fish communities. Interestingly, prior to this study it was largely unknown whether black bream were attempting to enter the fishway as previous studies also failed to detect their presence (Stuart *et al*, 2005).

Black Bream largely exhibited two different types of behaviour; they either entered the field of view then retreated without investigating the fishway or investigated the entrance slot but did not enter the trap. When the fishway was operated at a lower headloss (50mm) over 50% of fish investigated the entrance slot, but were not caught in the trap (Figure 11). In most instances, a small school of fish would approach the fishway and cautiously make their way to the entrance slot. After a brief investigation, which occasionally involved one or two fish swimming into the slot, the entire school would leave the area quickly (Video 5).

A number of explanations could account for this behaviour. Fish could be reluctant to swim through the fishway entrance because of insufficient width, some individuals could be trap shy (i.e. they noticed the trap and were reluctant to enter), freshwater discharging through the fishway could be acting as a behavioural impediment, or fish were simply not seeking upstream passage (i.e. they may have been simply foraging). Further experimentation, whilst controlling these parameters, could help to determine the causal factor. Such experimentation appears necessary to develop ways of improving black bream passage at this site.

Table 3. Comparison of total fish numbers identified from DIDSON and trap surveys conducted outside the barrage fishways over a range of entrance headlosses.

Species	**50mm**		**150mm**		**280mm**	
	DIDSON	**Trap**	**DIDSON**	**Trap**	**DIDSON**	**Trap**
Black bream	119	0	9	0	36	0
Lagoon Goby	0	0	0	1	0	0
Yellow-Eye Mullet	0	81	0	2	0	4
Small-mouthed hardyhead	0	10	0	0	0	1
Common galaxias	0	87	0	43	0	82
Flatheaded gudgeon	0	5	0	0	0	5
Congolli	0	10	0	5	0	6
Australian smelt	0	1	0	0	0	3
Unknown (>75mm)	10	0	0	0	7	0
Unknown (<75mm)	Abundant		Abundant		Abundant	

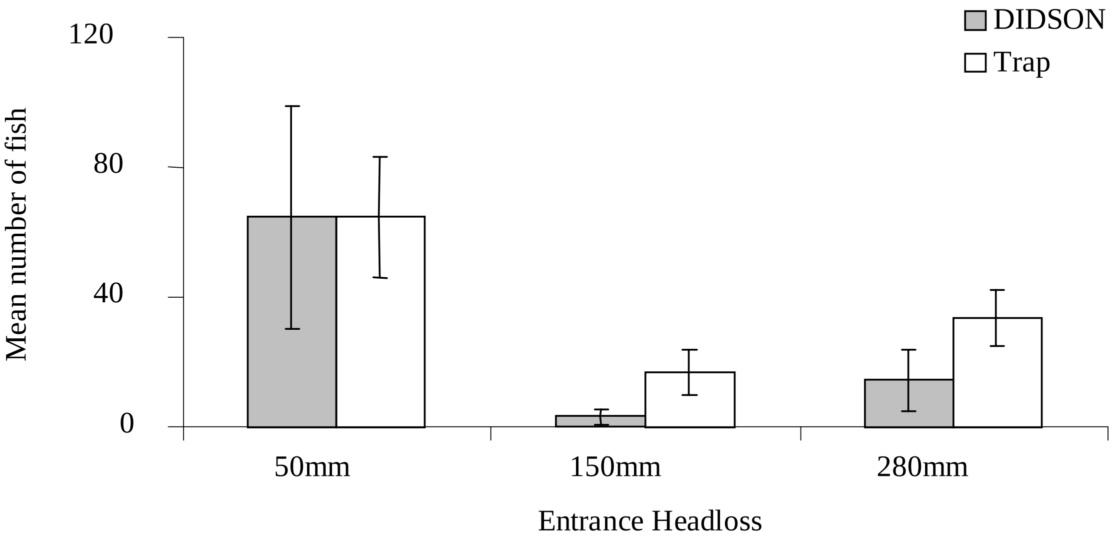


Figure 10. Mean numbers of fish (pooled for all species) identified by the DIDSON (shaded) and trapping (hollow) between the three treatments investigated at the Murray River barrages.

Figure 11. Fish behaviour as determined by DIDSON footage based on pooled data for each treatment undertaken at the Murray mouth barrages. Behaviour is defined as fish that entered the fishway and exited, fish that entered the fishway and proceeded upstream through the slot, fish which entered the fishway and were caught in the trap, fish that entered the trap but escaped, fish that entered the fishway and stayed within the cell and fish that swam downstream through the slot into the cell.

The capture of many small fish within the fishway was a further demonstration that DIDSON is inefficient at dealing with smaller-bodied species. Size selectivity of other methods such as gill nets (Jackson and Noble, 1995), traps (Allen *et al*, 1999) and electrofishing (Divens *et al*, 1998) has been previously reported. However, it is important to note that without DIDSON, the presence of black bream at the fishway entrance could not be determined by trapping alone. Conversely, the sole use of DIDSON would have failed to enable species recognition for small fish.

A method to overcome such selectivity would be to use multiple methods that target specific size groups. Divens *et al* (1998) suggested that the use of multiple techniques provides the most accurate assessment of freshwater fish populations. In terms of fish migration assessments, the use of a DIDSON unit, combined with conventional fish traps would enable a more accurate assessment of fish migration and behaviour. This is especially true for individuals and species that are inefficiently caught by traps and nets. Should such a combined assessment facility be unavailable, then the relative efficiency of sampling techniques should be quantified so that catches can be adjusted to account for any potential underestimation arising from avoidance behaviour.

3.3. Yarrawonga trials

A total of 576 fish (5 species) were observed migrating through the Yarrawonga fishlift using the DIDSON. Footage was dominated by common carp (Video 6) and silver perch (*Bidyanus bidyanus*) (Table 4), which were manually identified on the basis of body shape from recorded footage. In general, more fish were observed near the fishlift entrance than at the entrance to the transfer chamber although no significant difference was detected (Figure 12; ANOVA: F=4.10, p=0.07).

Although no difference in abundance was identified, DIDSON again revealed important data regarding fish behaviour in lock chambers. Most interesting was the observation that 50% of fish that entered the fishlock subsequently exited without proceeding upstream (Figure 13). Surprisingly, only 8% of fish that entered the fishway actually continued upstream into the vicinity of the chamber. Despite this observation, many fish also entered the field of view from upstream, suggesting that they had entered the fishlock before the trial began.

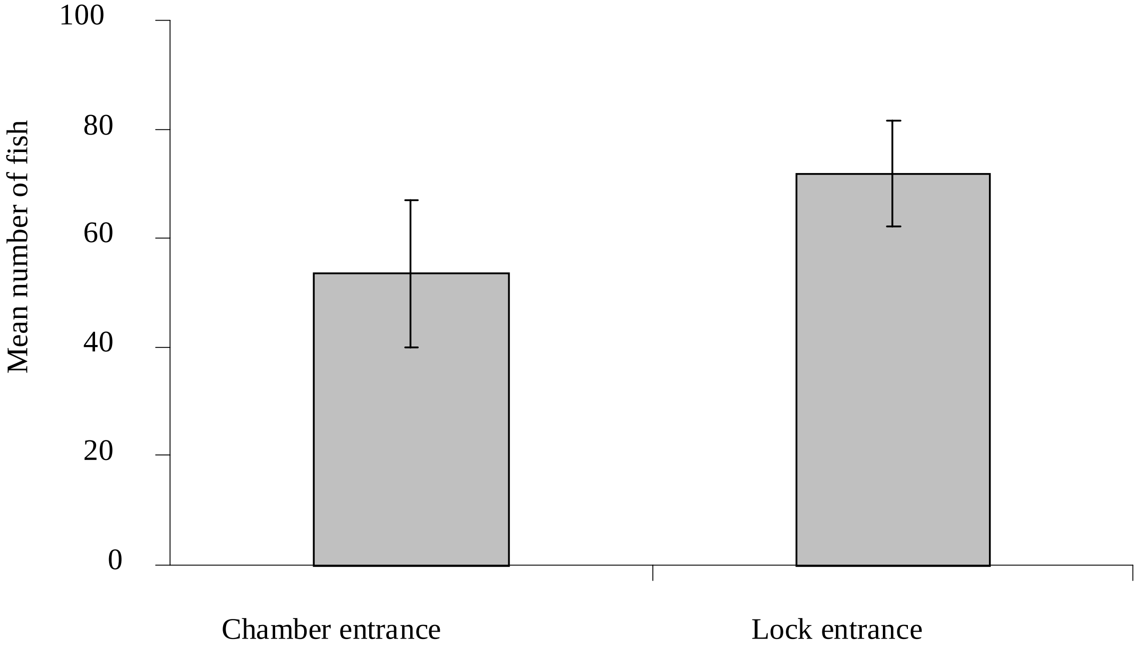


Figure 12. Comparison of mean numbers of fish (pooled for all species) identified by the DIDSON between the two treatments investigated at the Yarrawonga fishlift.

Figure 13. A summary of different fish behaviour as determined by DIDSON footage based on pooled data for each treatment undertaken at Yarrawonga fishlift. Behaviour is defined as fish that entered the fishway and exited, fish that entered the fishway and proceeded upstream, fish that proceeded upstream but did not return and fish that entered the field of view and remained.

Substantially different behaviour was observed when the camera was directed at the entrance of the lock chamber. Over 62% of fish that entered this section of the fishlock actually proceeded upstream (Figure 13). This observation indicated that most fish that proceeded to the vicinity of the lock chamber actually entered. However, DIDSON revealed most fish that entered the lock chamber actually exited before the end of each trial (Figure 13). Whilst most fish took some time to exit the structure, one silver perch was observed to enter the lock chamber but leave only 8 seconds later.

The silver perch example is a direct demonstration of how DIDSON has practical ecological applications, such as optimising fishlock cycle times. Optimal attraction times of fishlocks should be developed in accordance to the migratory requirements of individual species (Travade and Larinier, 2002). But few, if any, studies actually report on the justification for chosen cycle times, or if an optimisation was even attempted. No significant difference in fish passage among different cycle times was previously reported in a Deelder lock (Baumgartner, 2005) or during a previous study at Yarrawonga (Thorncraft and Harris, 1996). However, in both cases the attraction times tested were between 20 and 180 minutes. DIDSON data suggests that these cycle times may have been too long, as fish may leave the chamber in a matter of seconds, possibly explaining why these previous studies detected no differences. Subsequent trials with shorter attraction phases may be required to increase the probability of retaining fish in the lock chamber. Although optimising cycle time was not a direct objective of this study, DIDSON may provide a useful tool to optimise and improve fishlock operation in the future.

During the exit efficiency trial, none of the 40 fish that were placed in the exit race actually exited the structure. Subsequently, the test of whether fish were entrained into the hydroelectric plant, after exiting the fishway, was inconclusive. Recent trials using radio transmitters has partly addressed this issue by providing larger-scale movement data on large fish as they exit the fishway (Ivor Stuart, *pers. comm.*). The added benefit of a DIDSON is that data can be obtained from fish that have not been handled. Therefore, deploying a DIDSON during times of peak migration would supplement existing research by providing data on post-exit fish behaviour from a wider range of species and size classes.

3.4. Ground truthing

Manual fish counts were more accurate than software-generated counts (Figure 14). Although a significant relationship existed between manual counts and actual counts (GLR: $R^2=0.788$, $p<0.01$), accuracy decreased once the actual number of fish exceeded 20. The DIDSON generates relatively small beams (i.e. 96 across the field of view) which reduces the risk of multiple fish distorting an image (Maxwell and Gove, 2002). However, once the total number of fish in the tank was greater than 30, multiple readings increased and the ability of the observer to accurately count fish was compromised to some extent (Figure 14).

Automatic software-generated estimates were less accurate than manual counts. No significant regression was detected (GLR: $R^2=0.149$, $p<0.43$) and no estimate of fish numbers greater than 10 was recorded. In most cases, the mean number of fish estimated was less than 5 and, barely increased despite greater numbers of fish being added to the experimental tank (Figure 14). Auto counting has been previously recognised as a DIDSON limitation (Maxwell and Gove, 2002) and software to improve the auto count features of DIDSON is currently under development (Peter Rose, Pers. Comm.) If an acceptable error rate can be achieved, the unit would provide an excellent automated sampling tool for fish populations.

The experiments conducted in this study used arbitrary replicate times of two minutes to obtain the count. During manual counts, the observer was able to pause and replay frames during their assessment period, which likely accounted for greater accuracy than the automatic system. In Australian systems, expecting more than 50 large-bodied fish to migrate in a two-minute period (i.e. 1,000 fish per hour) is rare, especially considering 3,000 fish per day is the maximum published account of migrating through a fishway in the Murray-Darling Basin (Mallen-Cooper, 1996). Subsequently, lower accuracy during higher migration periods may represent an acceptable manual error rate for Australian systems as such a degree of fish movement only occurs in exceptional circumstances. Although time and labour intensive, excessive staff costs associated with manual counting could be overcome by deploying a random sub-sampling program, where a limited amount of footage (i.e. 10 minutes) is reviewed each hour (Maxwell and Gove, 2002). If migration rates were low, estimates could be considered acceptably accurate.

A ground-truthing trial of the auto-measuring facility provided similar results to the counting trial. Although significant regressions were identified by both methods, auto estimates (GLR: $R^2=0.313$, $p<0.01$) were far more variable, and overestimated length more frequently, than manual measurement (GLR: $R^2=0.667$, $p<0.01$) (Figure 15). A substantial factor influencing the accuracy of length estimates is the aspect of the esonified fish (Maxwell and Gove, 2002). When manually reviewing DIDSON footage, the observer can logically identify the direction the fish is swimming and hence obtain a head-to-tail measurement. Unfortunately, the software had limited capacity to identify aspect and lengths were frequently recorded when fish were ‘side’ or ‘head-on’ to the sonar.

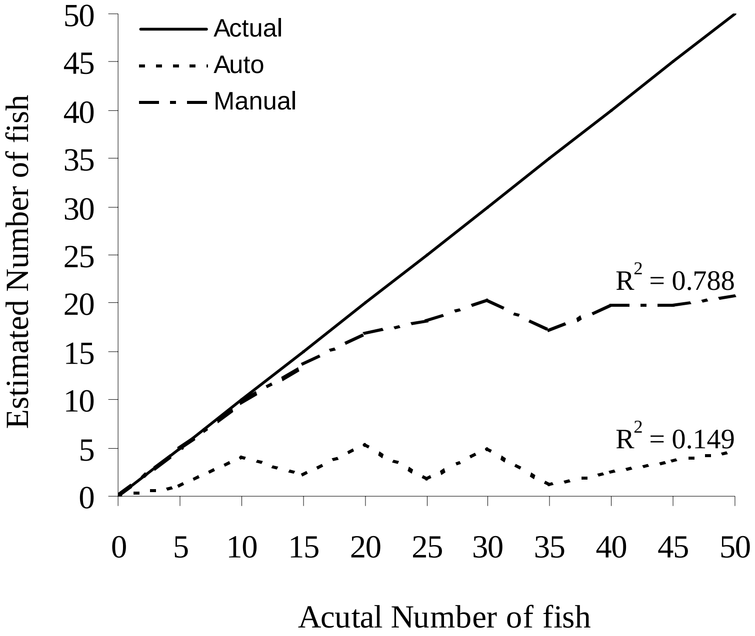


Figure 14. A comparison of actual, manual (mean) and automated (mean) counts of fish from a hatchery tank at Narrandera Fisheries Centre. The mean value was generated from 5 replicates undertaken for each actual number of fish tested (in increments of 5 between 0 and 50). Only golden perch and silver perch greater than 200mm in length were used in the trial.

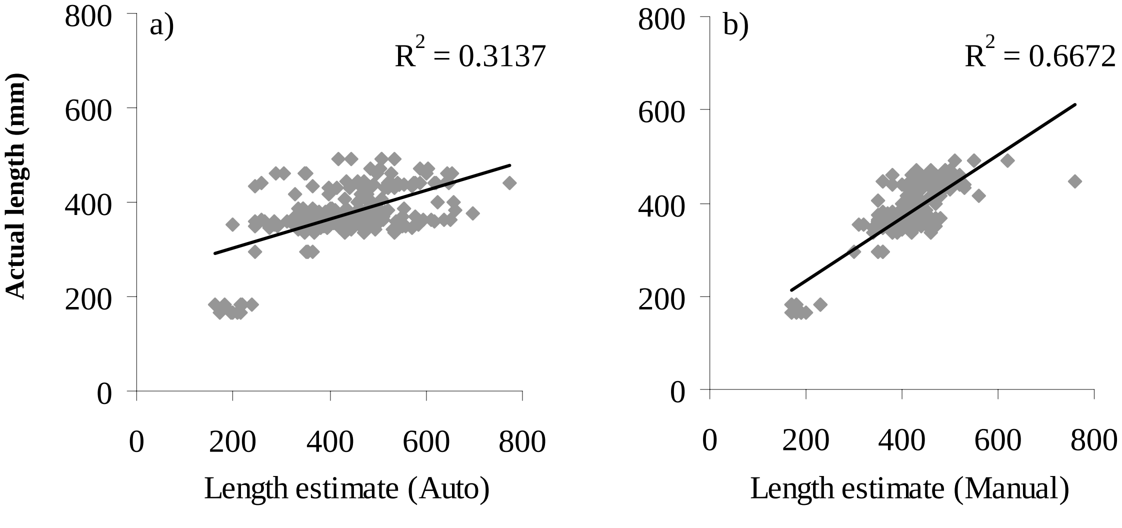


Figure 15. A comparison between a) the length of fish automatically determined by DIDSON software and b) the length of fish manually determined by an operator reviewing DIDSON footage. The lengths are based on individuals of golden perch, silver perch and goldfish (pooled for this analysis).

4. CONCLUSIONS AND RECOMMENDATIONS

The present study has demonstrated that DIDSON has enormous potential to improve scientific understanding of fish migrations and behaviour in Australian systems. In North America, DIDSON is now widely being used to replace existing hydroacoustic monitoring stations because of its increased capabilities and resolution (Maxwell and Gove, 2002; Table 4). Specifically, this study identified many favourable qualities of DIDSON that could enhance monitoring programs. These include directly observing behaviour, species identification, estimating sampling gear efficiency and permitting direct observation of fish in extremely turbid conditions.

The capacity for the DIDSON to contribute to increased ecological understanding was also demonstrated. The technology successfully permitted direct observations of fish behaviour in fishlocks, at fishway entrances and in the vicinity of fish traps. This newly generated information will lead to the development of new hypotheses necessary to improve the collective understanding of fish migrations and fishway efficiency. Based on data generated by this trial, NSW DPI are planning future DIDSON studies that aim to improve migration assessment methods and to optimise fishway design and construction. For example, researchers plan to investigate the efficiency of different trapping systems and use DIDSON-generated data to develop a design that maximises catches (by minimising avoidance and escape) for future fishway installations. In addition, the technology will also be applied to determine the optimal placement of fishway entrances by investigating areas of fish accumulation downstream of weirs.

Obviously, improving the ability of DIDSON to undertake accurate automatic counting and measuring would greatly enhance the value of the unit for biological assessments. If such modifications to the operating software are possible, the DIDSON could be potentially installed at any site to continuously record and interpret biological information with little interaction from the user. Australian systems are also characterised by large-scale migrations of small-bodied (<75mm) non-salmonid fish (Stuart and Mallen-Cooper, 1999; Stuart and Berghuis, 2002; Baumgartner, 2005). Therefore, enhancing the software to more accurately count and measure smaller fish would greatly contribute to biological assessments in Australian systems.

Upon the completion of this study, it is evident that an immediate remote deployment of a DIDSON to monitor fish migrations in Australian systems is feasible and could be used to supplement existing assessment programs. Although currently limited to larger-bodied fish (>75mm) the technology enables the continuous collection of data without physical interactions with target species. No other sampling technique can boast the same advantages and provide continuous data at such a high resolution. Based on these characteristics it is recommended that the capabilities of this technology should be further explored and developed to both enhance existing research programs and provide a new sampling tool for future projects.

Table 4. Advantages and disadvantages over other methods of DIDSON electronic monitoring based on the results of the present study and Maxwell and Gove (2002).

Task	**DIDSON attribute**
Advantages	
Imaging	The production of clear images that are easier to detect with a static background
Angle	A wide viewing angle (29°)
Depth	Good vertical coverage of the water column with few background noise issues
Operation	The unit is simple to aim and calibrate. Very little training is required.
Directionality	Upstream and downstream movement can be defined easily at ranges as close as 0.8m from transducer
Image Quality	High quality video images are produced (1,300 frames/sec) and a background substraction feature can eliminate unwanted noise
Fish length	The operator can manually determine approximate fish length up to 12m away from the unit in manual high frequency mode
Data	The unit is capable of revealing complex behavioural information with no interference of the researcher. Observations of feeding, spawning and migration are all possible.
Disadvantages	
Data handling	Large data files are produced which create storage concerns
Automated software	Improvement of automated counting and measuring capabilities are required for remote operation
Small fish	Presently unable to permit accurate assessments of fish under 75mm
Damage	Most electronics are deployed underwater and increase the probability of debris strike or vandalism

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