Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin

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NON-TECHNICAL SUMMARY

Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin

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OBJECTIVES:

- To perform a field assessment of an infrared fish counter in the Murray-Darling Basin.
- To determine if turbidity reduces the accuracy of an infrared fish counter.
- To determine how fish behave in relation to an infrared fish counter and fish trap.

NON TECHNICAL SUMMARY:

Fish communities of the Murray-Darling Basin are highly migratory, exhibiting movements in both upstream and downstream directions. Until recently, fish migration studies within the Murray-Darling Basin focused primarily on species of recreational or commercial importance. However, recent studies have also demonstrated that larval native fish also undertake substantial passive downstream movements and that many small-bodied species are also migratory. The ecology of migrations vary greatly between species but are usually in response to increases in water temperature or river flow. Fish movements are also highly seasonal, sometimes peaking during summer and autumn and, in some cases, individuals have traversed over 2,300km during flood conditions. Although migrations over such large scales are infrequent, many fish species are frequently observed to either negotiate fishways or accumulate downstream of obstructions.

Across the Murray-Darling Basin thousands of weirs obstruct the passage of fish and contribute to significant declines in many fish species. As part of a plan to rehabilitate native fish populations, the Murray-Darling Basin Authority (MDBA) is restoring fish passage along the Murray River from the sea upstream to the Hume Dam – a distance of 2,225 km. To monitor and assess the outcomes of the construction program, a team of freshwater scientists from the states of New South Wales, Victoria and South Australia were established. This tri-state research team is conducting a comprehensive research program that is monitoring fish as they approach, pass through, and leave the fishways. Four techniques are providing data on the effectiveness of the newly installed fishways: electrofishing accumulations; passive integrated transponder tagging to detect long distance movements, direct sampling of the fishways and developing long-term electronic monitoring tools.

Many fish within the Murray-Darling Basin are long-lived (> 10 years). This means that the benefits of a fishway construction program may not be immediate, and increases in fish numbers may take time. It is impossible to continuously trap fishways to gather information on migratory behaviour. The long-term deployment of an electronic monitoring unit to continuously monitor fish migrations is therefore an attractive alternative to manual trapping. If a system can be found which determines count and length information accurately, it could be used to determine long-term trends in fish passage and document increases in fish migration rates over time. This study aimed to perform a field study on the effectiveness of an infrared fish counter, the Vaki Riverwatcher in

anticipation of wider application throughout the Murray-Darling Basin. The limitations and advantages of the system were fully explored in both controlled and field environments.

Turbidity Trials

Infrared fish counters have gear-specific limitations which often limit application to specific sites or situations. The main limitations of infrared systems are beam distance and turbidity. Beam distance refers to the physical inability for red light to penetrate through water as it reduces to 50% intensity at a depth of 17.9cm in pure water. For this reason, the scanner unit can only be constructed to a particular width. Turbidity would therefore also influence beam strength by physically preventing light from penetrating to the optimal depth. Light emitted from one side of the scanner unit may therefore not be detected on the other site if the water contains a high concentration of suspended particles.

Laboratory trials were undertaken which aimed to determine the ability of the riverwatcher to cope with different turbidity and fish migration rates. Silver perch (*Bidyanus bidyanus*) were passed through the unit under a range of turbidity between 0 and 100 Nephelometric turbidity units (NTU). Results determined that the effect of turbidity was negligible because the unit had difficulty in coping with high numbers of fish. There were no differences in estimates counts whether passing single or multiple fish through the unit. This suggested that the unit was often underestimating fish numbers. When multiple fish passed through the counter at the same time, the software detected them as a single fish and led to overestimates of fish length. These issues were largely software-related, and could potentially overcome by better-defining the characteristic of Australian fish and incorporating these into subsequent programming.

Field trials

Traditional methods of fish capture, such as trapping or netting, provide estimates of fish abundance and size over a fixed time period. This information offers little information on how fish interact with the gear types and any potential avoidance issues. Electronic counting devices offer potential to help determine these aspects fish behaviour without a requirement for physically catch and handle fish. Previous studies with electronic gear largely focus on count or size data on fish that actually move through the unit. No information is provided on fish that failed to move through the unit, or behaved differently when approaching the gear. Such information is of importance because if the presence of a counting system influenced fish behaviour, the accuracy of resulting counts could be compromised.

An additional field study was subsequently performed to test the Vaki Riverwatcher system under river conditions. The unit was used in conjunction with other electronic monitoring gear, and also fish traps, to assess the ability of the riverwatcher to distinguish different species, count migrating fish, estimate the size of migratory fish and to assess fish behaviour in and around the unit. Results determined that the riverwatcher performed much better under field conditions than in the laboratory. Fish counts from the unit roughly corresponded with those caught from the fish trap. The unit tended to underestimate fish size and some fish actively avoided the unit.

When used in conjunction with sonar technology it became apparent that fish were behaving differently around the riverwatcher unit and trap. Many fish approached the units but failed to move through, indicating some degree of avoidance. Fish often made several attempts to migrate, and some returned downstream whilst others eventually continued upstream. This represented the first time that a suite of electronic monitoring gear was used to document fish behaviour in Australia and the trial was extremely successful.

Conclusion

It is recommended that the gear be refined for use in the Murray-Darling Basin and then be implemented at a key migration site over a longer time period, to determine if the gear is suitable for determining trends in fish movement over a long time period. Even though the unit underestimates counts, it could provide a useful tool to determine cues for migration and to investigate seasonality. A subsequent analysis of this information would determine the full utility of this system for wider, long-term, application at other sites in the Murray-Darling Basin.

KEYWORDS

Fish counter, Murray-Darling Basin, Hydroacoustics, DIDSON, Freshwater Fish, Fishways

1. GENERAL INTRODUCTION

1.1. The Sea to Hume program

Fish communities of the Murray-Darling Basin are highly migratory, exhibiting movements in both upstream (Reynolds, 1983; Mallen-Cooper, 1996) and downstream (Humphries and Lake, 2000; Gilligan and Schiller, 2004) directions. Until recently, fish migration studies within the Murray-Darling Basin focused primarily on species of recreational or commercial importance (Reynolds, 1983; Mallen-Cooper, 1996). However, recent studies have also demonstrated that larval native fish also undertake substantial downstream movements (Reynolds, 1983; Bigelow and Johnson, 1996; Humphries and Lake, 2000; Humphries *et al.*, 2002) and that many small-bodied species are also migratory (Baumgartner and Harris, 2007). The cues, nature and scale of migrations vary greatly between species but are usually in response to increases in water temperature or river flow (Mallen-Cooper, 1996). Fish movements are also highly seasonal, sometimes peaking during summer and autumn (Baumgartner, 2006) and, in some cases, individuals have traversed over 2,300km during flood conditions (Reynolds, 1983). Although migrations over such large scales are infrequent, many fish species are frequently observed to either negotiate fishways (Stuart *et al.*, 2008b) or accumulate downstream of obstructions (Baumgartner *et al.*, 2008).

Across the Murray-Darling Basin thousands of weirs obstruct the passage of fish and contribute to the significant declines in distribution and abundance suffered by many fish species (Reynolds, 1983; Walker, 1985; Thorncraft and Harris, 2000). As part of an ambitious plan to rehabilitate native fish populations, the Murray-Darling Basin Authority (MDBA) is restoring fish passage along the Murray River from the sea upstream to Hume Dam – a distance of 2,225 km. The program, instigated in 2001, is a multistate process involving engineers and fish biologists in the design, construction, testing and evaluation of fishways at 15 weirs and barrages along the main stem of the river (Barrett and Mallen-Cooper, 2006). The construction program includes the combined construction of vertical-slot fishways (large-bodied species) and fish locks (young and small-bodied species), to provide passage for a migratory fish community which comprises many species ranging in size from 40 – 1000mm.

To monitor and assess the outcomes of the construction program, a team of freshwater scientists from the states of New South Wales, Victoria and South Australia were established. This tri-state research team is conducting a comprehensive research program that is sampling fish populations in the river (before and after installation of the new fishways) and monitoring fish as they approach, pass through, and leave the fishways (Stuart *et al.*, 2008b). Four techniques are providing data on the effectiveness of the newly installed fishways (Barrett and Mallen-Cooper, 2006). Capture-dependent methods include electrofishing fish accumulations; passive integrated transponder tagging to detect long distance movements and direct sampling of the fishways. These techniques have limitations because fish must be caught to provide information and it is unknown to what extent this influences behaviour. Tagging also requires the maintenance of a population of tagged fish and only provides information on marked individuals. Electronic monitoring is a capture-independent tool which is also being assessed to obtain information on fish without the need to capture individuals. It is advantageous over other techniques as it allows the study of fish under more 'natural' circumstances but technological limitations can often reduce data quality. Despite these limitations, the adaptive approach to combine capture dependent and independent methods of assessment is providing multiple lines of evidence to support fishway success. Data generated from this monitoring program is being used to assist fisheries management throughout the Murray-Darling Basin.

1.2. Electronic monitoring of freshwater fish using hydroacoustics

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). Methods to study migratory fish generally require some degree of scientific interaction via trapping (Stuart and Mallen-Cooper, 1999; Baumgartner and Harris, 2007; Mallen-Cooper and Brand, 2007; Stuart *et al.*, 2007) or tagging (Hockersmith *et al.*, 2003; Zydlewski *et al.*, 2006; Cookingham and Ruetz Iii, 2008; Stuart *et al.*, 2008b). Whilst in some cases these techniques are the only practical way to obtain data, it is largely unknown whether handling fish can alter their 'natural' behaviour; a situation that is almost impossible to control or quantify (Hubert, 1985).

A method to overcome handling bias is to use remotely-operated electronic monitoring devices. With recent advances in technology, the number and types of electronic monitoring equipment have advanced greatly in recent years (Lucas and Baras, 2000). Techniques most applicable to fishway monitoring include multi-beam sonar (Suzanne and Gove, 2004), split-beam acoustics (Burwen *et al.*, 1995) or infrared counters (Beach, 1978). These techniques use various technologies to enumerate fish migrations without the need for human interaction. Although many techniques show promise, each has unique operating limitations and applications are limited to specific situations.

Hydroacoustic techniques use a wide variety of methods to convert sound waves into a visual representation of fish behaviour (Lucas and Baras, 2000). Transducers are used to direct sound beams vertically, horizontally or sidewards. Beams can also be emitted from a fixed station or mobile detection unit. Traditional techniques require regular calibration to establish reference signal strengths with objects of a known reflectance (such as a metal calibration ball) with unknown objects such as fish or debris (MacLennan and Simmonds, 1992). Single beam acoustic units provide information on the distance of a target from a transducer, but cannot provide information on directionality or orientations. Split-beam systems are slightly more advanced, and work by dividing the sound signal into sections. The sections are analysed separately to provide information on target strength, directionality and also length information. These techniques are useful for enumerating total fish size and numbers, but require physical capture of fish at some point to ascertain species compositions. As part of the Sea to Hume program, electronic monitoring assessments have formed an integral component of the monitoring program. Initial investigations comprised an assessment of split-beam hydroacoustic systems for counting fish (Berghuis and Matveev, 2004; Matveev, 2007; Berghuis, 2008). The results demonstrated that it is possible to estimate total abundance and size structure of fish in large rivers and at a large scale. It was also possible to count fish passing through fishways in both directions, estimate fish size and determine relative abundances.

High frequency multi-beam sonar is a recent adaption of this technology to convert sound into video images (also known as acoustic imaging). The technology works by transmitting many acoustic beams (up to 96 beam in high frequency mode at 0.3° spacing) and combining the acoustic data from each beam to produce a video image of the targets (Rose *et al.*, 2005). This is sufficient to show shapes and outlines of fish whilst also providing information on length and directionality. A major limitation of acoustic imaging is that processing software has a limited ability to combine acoustic and image data to provide automatic estimates of fish abundance, size and behaviour (Boswell *et al.*, 2008). A preliminary assessment of a dual-frequency identification sonar (DIDSON) system in the Murray-Darling Basin demonstrated substantial promise (Baumgartner *et al.*, 2006). Trials at Yarrawonga Weir, Lock 8 and the Murray mouth barrages revealed detailed aspects of fish behaviour at close range that has immediate implications for fishway design and for interpreting the results of monitoring. Additional applications of this technology to identify spawning sites, quantify interactions with irrigation offtakes and map critical habitats are also currently being explored.

1.3. Infrared technology – the Vaki Riverwatcher

The latest assessment of innovative fish counting technology involved assessment of technology developed in Iceland; the Vaki Riverwatcher. This technology is an electronic fish counter which measures the size, date and shapes of fish which pass through an infrared scanner. The system comprises of a scanner unit, display unit, storage cabinet and optional photo tunnel (Figure 1.1). The scanner unit generates an infrared net of light beams between two scanner plates (200mm x 600mm) inside a frame, ranging from 100 – 450mm apart. Inside the scanner, light diodes send infrared light beams to receivers on the other side. Fish need to move through the scanner unit (540mm x 215mm x 35mm) to break the infrared beams. The unit can detect migrations in either an upstream or downstream direction by the way a fish interacts with the infrared beams. A phototunnel can be attached to the scanner unit and contains a video camera and lighting system. When fish are detected on the scanner unit, the phototunnel is automatically activated and a five second video is recorded. An automated lighting system is integrated within the phototunnel which can allow video footage to be recorded at night, or in conditions of low light intensity.

The control unit receives and stores the information from the scanner and phototunnel via connection to a windows-based personal computer (Figure 1.1). Water temperature is measured at programmable intervals and the date and time of day that each fish passes the counter is also recorded. This allows fish movements to be correlated with environmental factors. Information generated by the scanner unit and phototunnel are then processed by the Winari control software. The Winari system is a specialised database which is designed to interpret data generated by the scanner unit and phototunnel. The Winari software collects information on fish size, time, date, swimming speed, water temperature and generates a silhouette outline of the migrating fish (Figure 1.2). This information is then processed and presented as a text and image summary of fish migrations whilst the unit is in activation.

The system can be installed in fishways, pools, traps or similar places where migratory fish can be directed. Riverwatcher systems are relatively energy efficient (power consumption; 210mA @ 12 volts) and can be used with mains power or solar panels with a deep cycle battery. The system can also be connected via a modem if automated remote operation is desired. The system is generally designed to detect migrations of fish greater than a minimum body depth of 40mm. This limitation is a potential disadvantage to using this technology but the actual limits of the unit are poorly reported in the scientific literature.

1.4. Study site

The Murray-Darling Basin is Australia's largest catchment covering over one million square kilometres and draining water from five separate states and territories. Its main constituent is the Murray River (2,560 km), which rises in the alpine regions of Southern NSW and meets the sea at the Coorong estuary in South Australia (Walker, 1985). The Darling River is the second largest drainage system in the Basin and rises as the Condamine River in Queensland and joins the Murray near Wentworth, approximately 700km from the sea. Although the Darling River is greater in length (2,740 km), it contributes much less total discharge than the Murray River (Walker, 1985).

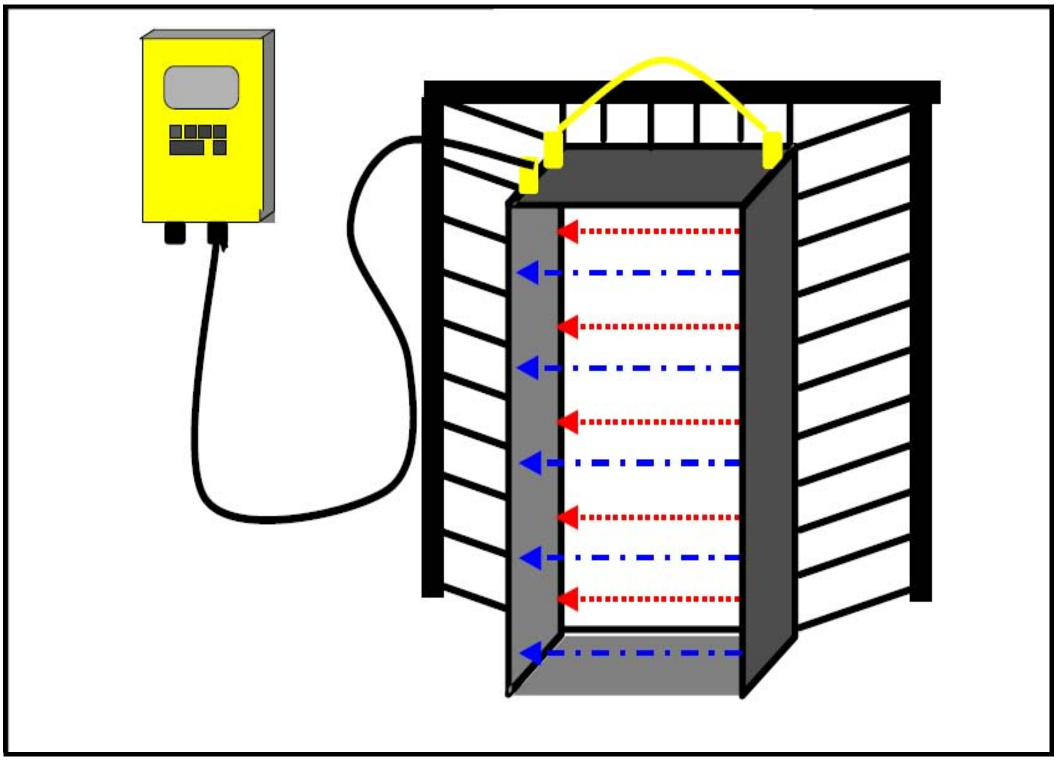

Figure 1.1. A schematic representation of the scanner unit demonstrating the connections to the control unit. An entrance cone guides fish through the scanner unit.

Figure 1.2. Example of output from the Winari control software. The software interprets information received from the scanner unit and presents individual fish detections as a silhouette. The output estimates the depth and calculated length of the fish based on how the fish interacts with the beams. The average ground speed is also detected. These images were obtained from a silver perch *Bidyanus bidyanus* used in this study.

Most of the Murray-Darling Basin represents a typical dryland river system which is located in semi-arid to arid climatic zones and receives low mean annual rainfall (430 mm) with high evaporation (King, 2002). Ninety-eight percent of the catchment contributes little or no run-off, and subsequently, the system has a relatively small annual discharge (12,200GL) (Crabb, 1997). Despite such relatively low discharge, the Murray-Darling Basin supports at least 40% of Australia's agricultural production (MDBC, 2003) and a population of over 2 million people (Jacobs, 1990). It is therefore an extremely important natural resource in Australia.

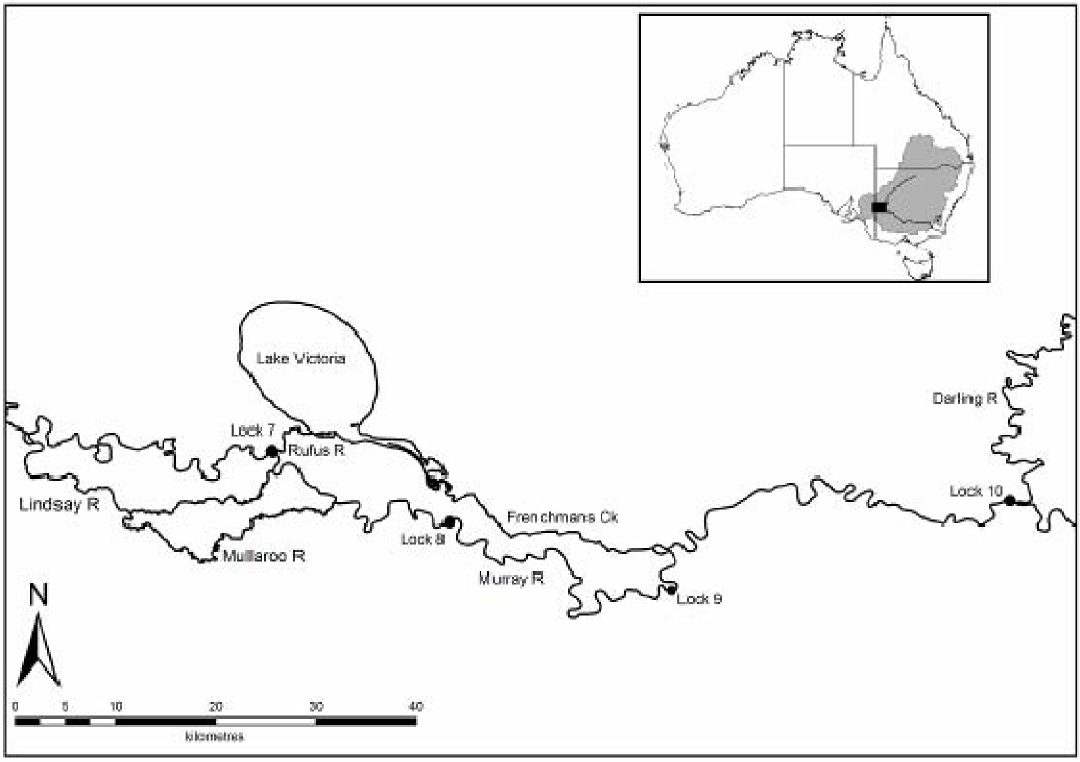

Figure 1.3. Map of the mid-Murray River showing the location of the Lock 10 study site where field trials were undertaken.

Lock 10 (Wentworth) is situated approximately 30 km west of Mildura on the Murray River. The low-level weir constructed in 1926 is located 726 km upstream from the river mouth (Figure 1.3). The weir is situated immediately downstream of the junction between the Murray and Darling Rivers and primarily operated to maintain navigability between Wentworth and Mildura. The Lock 10 weir was retro-fitted with a vertical slot fishway in 2006. The fishway was constructed on a 1:32 gradient (3.2%) with 3 metre long by 2 metre wide pools, the minimum operating depth is 1.5 m and the slot-widths are 0.3 m.

The fishway channel also contains five larger resting pools, each 3 m long by 4.4 m wide (Barrett and Mallen-Cooper, 2006). The head differential between pools is 0.1 m creating a maximum water velocity of 1.4 m s^{-1} and low turbulence of 40 W m^{-3} in the pools. The large pool size enables the passage of Murray cod, which grow > 1,000 mm TL, and the low water velocities and turbulence are intended to facilitate the passage of small fish (< 30 mm TL) with reduced swimming abilities. The fishways also have rocks glued to the floor to enhance the passage of crustaceans and a short Denil fishway (8 m length; 300 mm baffle width) was installed to provide fish passage during high river flows.

1.5. The purpose of this study

This study aimed to perform a field study on the effectiveness of the Vaki Riverwatcher and scope our potential for wider application throughout the Murray-Darling Basin. Firstly, the influence of turbidity and migration rates on the accuracy of riverwatcher units was investigated for slow swimming freshwater fish species. Experiments were conducted under controlled conditions where turbidity and migration rates were manipulated. Secondly, a field trial was undertaken where other electronic fish counting methods, such as DIDSON sonar and split-beam hydroacoustics, were used to validate observations made with the riverwatcher unit. Comparisons of Vaki Riverwatcher observations with passive trapping techniques were also performed to determine whether similar data was obtained using either technique.

2. THE INFLUENCE OF TURBIDITY AND MIGRATION RATE ON EFFICIENCY OF THE RIVERWATCHER SYSTEM

2.1. Introduction

Effective management of migratory fish communities requires a detailed knowledge of population size and understanding the seasonal aspects of fish movement (Beach, 1978). The major techniques used to determine these aspects can be divided into capture-dependent and capture independent methods (Lucas and Baras, 2000). Capture-dependent methods are often costly, and require the researcher to interact with fish in some capacity to obtain the required information. These studies are also intermittent in nature because it is virtually impossible to continuously trap migrating fish on an annual basis. Capture-independent studies generally have low ongoing operating costs, but can have a high capital outlay which requires some degree of specialist training. Techniques do not always perform equally well for addressing particular management questions or are applicable to all studies of spatial fish behaviour. The selected technique is often weighed by the need for accuracy of the required information, duration of the study, sample sizes needed and the availability of resources (Lucas and Baras, 2000).

Electronic monitoring techniques have gear-specific limitations which often preclude widespread applications. Main limitations of infrared systems include beam distance and turbidity. Beam distance is influenced by the physical inability for red light to penetrate through water. Intensity of red light reduces to 50% at a depth of 17.9cm in pure water (Beach, 1978). For this reason, there is a physical limitation to the width of the scanner unit. Turbidity would therefore also influence beam strength by physically preventing light to penetrate (Santos *et al.*, 2008). Light emitted from one side of the scanner unit may therefore not be detected on the other site if the water contains a high concentration of suspended particles. Despite this potential limitation, the critical thresholds of turbidity on the accuracy of Vaki Riverwatcher counts are yet to be determined.

Accuracy is also influenced by the passage rates of fish. Previous applications of infrared counting systems have reported accuracy up to 94% (Fewings, 1994). High accuracy however, has often been linked to low migration rates for arctic char *Salvelinus alpinus* (< 50 fish/d) and Atlantic salmon (*Salmo salar*) (Gudjonsson and Gudmundson, 1994). Field assessments of chum salmon *Onchorhynchus keta* migrations have further determined that accuracy is still relatively high (< 76%) during substantial migration events (< 1,500 fish/hr) but was problematic when counting more than one fish simultaneously (Shardlow and Hyatt, 2004). These studies focused on salmonids, few data exists on the critical migration rates influencing the accuracy of riverwatcher units for other species. Migration rates in the Murray-Daring Basin are variable, but generally lower. Migrations of golden perch (3,000 fish in a 24 hour period) was reported within at experimental fishway Euston Weir on the Murray River (Mallen-Cooper, 1996). Recent assessments of fish passage through vertical-slot fishways have also reported relatively low migration rates during low flow period (<200 fish.hr^{-1}) (Stuart *et al.*, 2008b). In comparison with North American observations, these data suggest migration rates of Australian fish are well-within previously-defined operating parameters of the Vaki Riverwatcher.

The purpose of this study was to investigate the influence of turbidity and migration rates on the accuracy of riverwatcher units for potamodromous freshwater fish species of the Murray-Darling Basin. Experiments were conducted under controlled conditions where turbidity and migration rates were manipulated. The ability of the unit to accurately enumerate fish counts and lengths was investigated over a five week period. The influence of variations in length-depth ratios is discussed.

2.2. Methods

2.2.1. Turbidity trials

Experimental trials took place at the Narrandera Fisheries Centre between October and November 2008. Riverwatcher limitations were trialled under controlled conditions to determine whether the system was able to maintain high levels of accuracy under different turbidity or migratory fish passage rates for slow-swimming freshwater species. The riverwatcher was initially set-up in a 2,000L tank and filled with river water. A temporary channel was established within the tank to guide fish into the riverwatcher during the trial. A pump was also installed within the tank which initiated a flow to encourage a rheotactive response from the fish.

Silver perch (*Bidyanus bidyanus*) sourced from a commercial hatchery were used in the study. Only mature fish (Mean FL 373 ± 29mm; Range: 345 – 498 mm; Depth: 88 – 131 mm) were used in the trials and all individuals were given 7 days to acclimatise to hatchery conditions before trials commenced. All fish were weighed and measured prior to the commencement of each experimental treatment and given 1 hour to acclimate to the experimental tank prior to commencement of experiments. Turbidity trials and migration rate trials were undertaken simultaneously. Turbidity in the tank was assessed at 0, 25, 50, 75, 100 Nephelometric Turbidity Units (NTU's). Turbidity was manipulated by gradually adding clay to the tank until the desired level was achieved. For logistical purposes, each experimental block began at 0 NTU then progressed in increments until the maximum level was reached. For each level of turbidity, a total of 1, 5 and 10 fish were passed through the riverwatcher unit which simulated migration rates of 12, 60 and 120 fish per hour respectively. These units are reported as 'actual counts' in subsequent analyses and were determined from previously reported data (Mallen-Cooper, 1996; Stuart *et al.*, 2008b) and aimed to represent of expected migration rates within fishways throughout the Murray-Darling Basin.

Each experiment used the same procedure and began when the predetermined number of fish were introduced into the tank and herded into the riverwatcher unit using a moving screen. Once inside the unit, the screen prevented experimental fish from exiting in a downstream direction. A mild flow was introduced through the riverwatcher unit and fish were given five minutes to migrate through the scanner and be recorded by the scanner and photo tunnel. Fish were then retrieved using a dip net and placed into a recovery tank. Each experiment was replicated 5 times at each level of turbidity among the three specified migration rates. Different fish were used in each trial. The Winari software recorded fish length, number of fish, direction of movement and swimming speed. The length (fork length), body depth (mm) and weight of each fish were manually measured at the end of each replicate.

2.2.2. Data analysis

Data were analysed using S-PLUS (Insightful Corporation, 2000). Significant differences in number of fish detected by the riverwatcher were investigated using a two-way ANOVA using turbidity and number of fish as factors. Cochran's tests identified heterogeneous variances within the data and a subsequent log (x+1) transformation was undertaken.

Two-tailed Kolmogorov-Smirnov tests (Sokal and Rohlf, 1996) were used to compare length estimates recorded by the riverwatcher, with actual lengths of fish used in the trials. For the purpose of the present study, length-frequency analysis revealed whether the empirical distribution functions for manual and riverwatcher size estimates were relatively similar. All statistical tests were considered significant at $p < 0.05$.

2.3. Results

2.3.1. Validation of fish counts

Of the 400 fish physically moved through the scanner unit, the riverwatcher successfully detected 129 fish; 115 moving in an upstream direction and 14 moving downstream. Vaki Riverwatcher counts significantly differed among migration rates (ANOVA: $df = 2$, $F = 11.91$; $p < 0.001$) but not among turbidity treatments (ANOVA: $df = 4$, $F = 2.39$, $p > 0.05$). Passing high numbers of fish through the riverwatcher produced the highest counts (Figure 2.1). Conversely, the low simulated migration rates always returned the lowest counts (Figure 2.1). The number of fish incorrectly interpreted as migrating downstream increased with higher turbidity (Table 2.1).

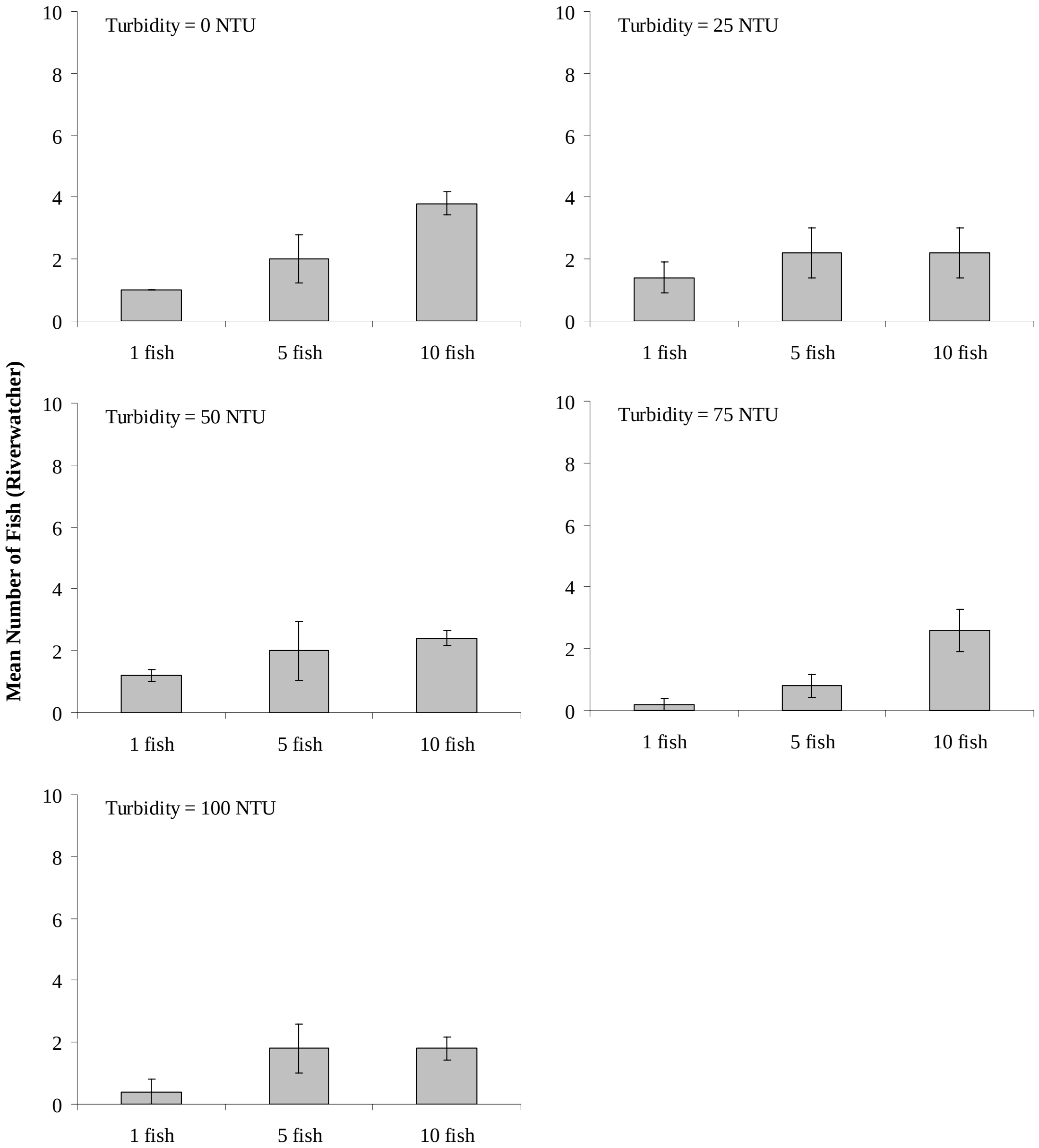

Figure 2.1. Mean number of fish from riverwatcher counts (y-axis) and actual counts (x-axis) for each level of turbidity assessed during the study.

Fish counts were estimated most accurately at low migration rates (1 fish/hr) in low turbidity but riverwatcher estimates rarely matched actual counts (Table 2.1). The unit generally overestimated fish counts during low turbidity (0 – 50 NTUs) but underestimated during high turbidity (50 – 100 NTU) (Table 2.1). Automated counts were underestimated during moderate migration rates (12 fish/hr) but accuracy neither improved nor deteriorated as turbidity increased. The degree of underestimation ranged between 56 and 84% (Table 2.1). At the highest migration rate (120 fish/hr) the riverwatcher underestimated actual counts by between 62 and 82%. Estimated counts also decreased as turbidity increased but the effect of turbidity was not significant (ANOVA: $df = 4$, $F = 2.39$, $p > 0.05$).

Table 2.1. Summary of Riverwatcher detections for controlled tank trials undertaken at various turbidity levels and migration rates on Silver perch (*Bidyanus bidyanus*). Total counts give the pooled total number of detections for each level or turbidity and migration rate assessed. The overall mean is the mean number of fish (± one standard error) detected by the riverwatcher for each treatment combination of fish and turbidity. The percent accuracy column gives the overall level of underestimation or overestimation as a percentage difference of the mean riverwatcher counts from the actual number of fish used in each trial.

Turbidity (NTU)	**Total Counts** Downstream	**Total Counts** Upstream	**Overall Mean**	**Percent Accuracy**
1 Fish				
0	0	5	1.0 ± 0	0
25	0	7	1.4 ± 0.51	40
50	0	6	1.2 ± 0.20	20
75	0	1	0.2 ± 0.20	-80
100	2	7	0.4 ± 0.40	-60
5 Fish				
0	1	9	2.0 ± 0.77	-60
25	1	10	2.2 ± 0.80	-56
50	1	9	2.0 ± 0.95	-60
75	0	4	0.8 ± 0.37	-84
100	4	5	1.8 ± 0.80	-64
10 Fish				
0	2	17	3.8 ± 0.37	-62
25	0	11	2.2 ± 0.80	-78
50	0	12	2.4 ± 0.24	-76
75	3	10	2.6 ± 0.68	-74
100	2	7	1.8 ± 0.37	-82

2.3.2. Variation in length and depth estimates

Length-depth (l/d) ratios were calculated for four common species within the Murray-Darling Basin; golden perch *Macquaria ambigua* (*n* = 197; l/d ratio = 3.6), bony herring *Nematalosa erebi* (*n* = 74; l/d ratio = 3.48), redfin perch *Perca fluviatilis* (*n* = 34; l/d ratio = 3.13) and carp *Cyprinus carpio* (*n* = 464; l/d/ ratio = 3.62). A wide range of depths (8 – 208 mm) and lengths (34 – 724 mm) were used for all species (Table 2.2). These were pooled, averaged and then programmed into the Winari software to calculate length estimations. The overall ratio value used was 3.48 ± 0.18.

Actual and riverwatcher-estimated depths differed significantly (*KS* = 0.607, $p < 0.01$; Figure 2.2). Actual depths of fish used in the study were within a narrow range (88 – 131 mm) but the riverwatcher reported a wider range (60 – 220 mm) which largely contributed to the observed differences. In at least one instance, increases in depth could be attributed to simultaneous movement of two fish through the scanner unit. This led to an inflated estimation of depth (220 mm) rather than recording two individual depths.

Actual and riverwatcher-estimated lengths also differed significantly (*KS* = 0.731, $P < 0.001$; Figure 2.2). Actual lengths were again within a narrow range (340 – 520mm) but the riverwatcher recorded substantially greater variation (140 – 780 mm) with a high proportion of individuals being underestimated. The large estimates of length were associated with instances where multiple fish passed through the unit and overinflated the depth measurement.

Table 2.2. Length and depth statistics of species used to determine optimal length/depth ratios for programming into Winari software. *n*, denotes the total number of fish used; max, is the maximum measurement (mm); min, is the minimum measurement (mm).

Species	***n***	**max**	**min**	**Mean ± SD**
Length				
Golden perch	197	499	163	366 ± 69
Bony herring	74	350	43	155 ± 94
Redfin perch	34	351	176	251 ± 52
Carp	460	724	120	485 ± 92
Depth				
Golden perch	197	165	28	105 ± 24
Bony herring	74	112	8	49 ± 34
Redfin perch	34	100	48	69 ± 16
Carp	460	208	39	485 ± 92

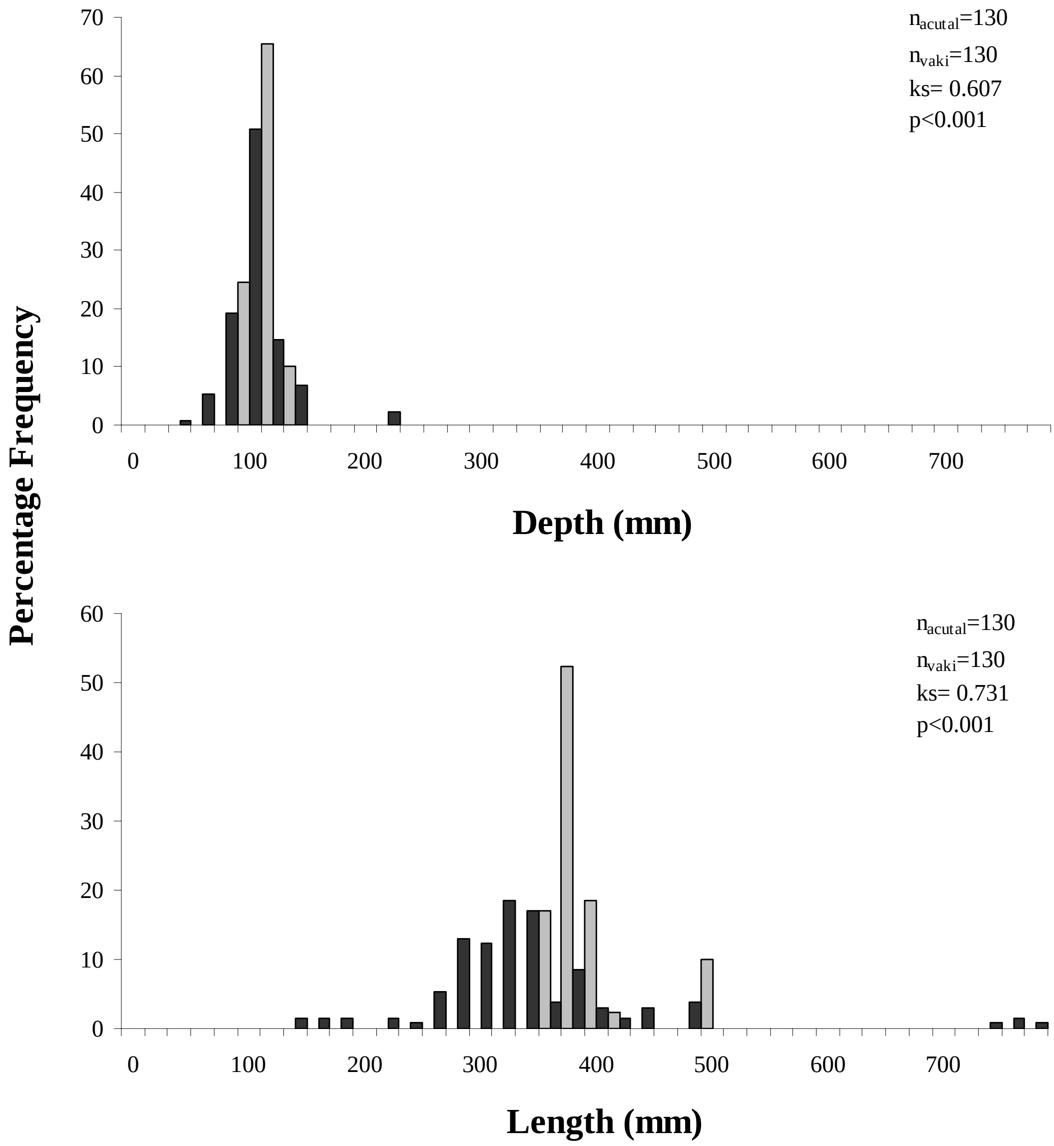

Figure 2.2. Frequency distributions comparing depth and length of riverwatcher estimates (dark) and actual fish (grey) used in the study. Sample numbers and Kolmogorov-Smirnov statistics are also given.

2.4. Discussion

The Vaki Riverwatcher successfully enumerated fish counts under controlled laboratory conditions albeit with some degree of error. The unit was able to generate summaries of estimated migration rates and also provided indications of fish length and depth. Fish counts, however, were generally underestimated and measurements of fish length and depth were variable. Underestimates of fish counts were likely due to the slow swimming speed of the fish and also confounded when two or more fish entered the scanner unit at the same time. In these circumstances, the unit only recorded a single fish rather than multiple targets. This factor was negligible at low rates of migration, but was problematic at increased movement rates. Similar decreases in accuracy were observed North America, particularly when passage rates were > 500 fish/hr (Shardlow and Hyatt, 2004).

Once inside the phototunnel, some fish were reluctant to leave the unit which created two additional problems. Firstly, any fish which repeatedly moved across the scanner unit were detected as both upstream and downstream migrants. Multiple counting of individual fish has been reported in studies of salmonid passage in Scotland (Chariskos, 2007). Secondly, instances where multiple fish were recorded in the scanner unit created incorrect depth profiles and resulted in erroneous length estimates. The Winari software relies on the user to enter a depth/length ratio based on information obtained from actual fish. The user calculates these parameters and manually enters a value into the software. When the scanner unit is deployed to measure the depth of fish, it then automatically calculates the length, based on this ratio. Even mild errors in the measurement of fish depth could therefore result in substantial variation in length estimates. Instances where multiple fish are recorded as a single target could also create errors.

Suspended particles disrupt infrared beams within the scanner unit and can adversely affect riverwatcher performance at higher turbidity (Chariskos, 2007; Santos *et al.*, 2008). The effect of turbidity however, was negligible during our study but was likely masked by the inability of the riverwatcher to enumerate fish at increased simulated migration rates. Even in the absence of turbidity (i.e., 0 NTU) the riverwatcher failed to accurately enumerate fish counts, except when migration rates were low. Fish also tended to accumulate within the phototunnel once the scanner unit had been negotiated. During high migration rates this limited the number of fish that could physically enter the structure. Fish therefore accumulated at the scanner unit and made repeat movement attempts. Some of these fish were recorded twice while others were incorrectly recorded as migrating downstream. The artificial nature of these trials could have influenced fish behaviour. Wild populations of fish would likely have a stronger migratory motivation which may reduce the number of false counts.

2.4.1. Conclusions

The riverwatcher unit provided a powerful mechanism to enumerate fish movement but often underestimated fish numbers and lengths often being underestimated which detracted from the quality of the hardware. If these limitations are overcome, or at least quantified, the unit would represent a cost effective mechanism to count and measure migrating fish (Shardlow and Hyatt, 2004; Santos *et al.*, 2008). In most instances the problems identified are post-processing issues which could be solved through improved software handling. False readings from multiple targets is often solved through target tracking techniques (Boswell *et al.*, 2008). These techniques recognise and track a target from first appearance until when it leaves the field of view. Application of this type of approach to post-detection processing may increase count and measurement accuracy. Further refinement to cope with changing depth/length ratios and increased migration rates would help to develop a reliable counting technology which can be a useful tool for fisheries management.

3. USING ELECTRONIC MONITORING TECHNIQUES TO DETERMINE ASPECTS OF MIGRATORY FISH BEHAVIOUR

3.1. Introduction

Assessments of the accuracy of fish counting systems generally involve the field deployment of a unit and monitoring its ability to enumerate migrating fish (Santos *et al.*, 2008). Ideally these studies should be undertaken under a range of environmental conditions and stock sizes but this is rarely practical (Thorley *et al.*, 2005). Accuracy has been previously determined by comparing automated estimates with visual counts (Andersen *et al.*, 2007), rod catches (Thorley *et al.*, 2005), underwater camera (Beach, 1978) or computer image analysis (Ruff *et al.*, 1995).

Accurately enumerating fish movement could have specific management applications, such as determining optimal delivery of environmental water. However, many electronic techniques are unable to collect additional information on size classes and species composition. This information is critical because many species within the Murray-Darling Basin migrate at different size classes and life history stages (Mallen-Cooper and Brand, 2007; Mallen-Cooper and Stuart, 2007; Stuart *et al.*, 2008a; Stuart *et al.*, 2008b). The Vaki Riverwatcher actually produces a silhouette of fish migrations, which in some instances has proved useful for species recognition (Santos *et al.*, 2008). Electronic monitoring tools which can gather information on different species and life history stages could be correlated with environmental parameters such as water quality to determine migratory cues. Accurately determining the size and species composition of seasonal migrations would be a useful mechanism to inform about movement patterns.

Traditional methods of fish capture, such as trapping or netting, provide estimates of fish abundance and size over a fixed time period. Whilst information is collected on fish that are captured, little can be learned about fish that are not effectively caught. It is therefore impossible to determine whether fish are not caught because they are locally rare, or because of potential gear selectivity. Electronic counting devices also offer enormous potential to quantify these aspects of fish behaviour without a requirement for physical interaction (Baumgartner *et al.*, 2006). Nevertheless, previous studies of electronic monitoring systems still largely focus solely on counts or sizes of targets that actually move through the unit or beam (Eggers, 1994; Fewings, 1994; Burwen *et al.*, 2000; Burwen *et al.*, 2003; Miller *et al.*, 2003; Berghuis and Matveev, 2004). These studies did not aim to acquire information on fish that failed to move through the unit or may have actively avoided the gear. Such information is of importance because the physical presence of a counting system may influence fish behaviour. If so, the accuracy of the results could be compromised.

The purpose of this study was to field-test the Vaki Riverwatcher system under field conditions. The unit was used in conjunction with other monitoring techniques (including manual trapping) to assess the ability of the riverwatcher to distinguish different species, enumerate migrating fish and estimate the size of migratory fish. Acoustic imaging was also used to assess fish behaviour in and around the unit to assess potential avoidance.

3.2. Methods

3.2.1. Experimental setup

A Vaki Riverwatcher unit was retrofitted on the upstream side of an exit baffle within the Lock 10 fishway (Figure 3.1). The riverwatcher relies on fish movement being directed through the scanner unit, so a metal guiding funnel (1,200mm high x 800mm wide x 700mm deep) was mounted to the downstream side of the unit (Figure 3.1). The riverwatcher unit was configured to continuously count, measure and determine the speed of migrating fish moving through the scanner unit. A 5 second time period was used to record video footage of migratory fish following detection by the scanner unit. Winari software recorded information on a control PC. A fishway trap (2,000mm x 2,000mm x 2,000mm; mesh size 6mm) was installed within the fishway channel upstream from the riverwatcher to catch any fish successfully gaining passage through the scanner unit. It was expected that any fish successfully negotiating the riverwatcher unit would be subsequently captured in the trap. This would permit a comparison of actual species counts and length frequencies with automated riverwatcher estimates. These comparisons would be used to provide a measurement of accuracy assuming that fish did not adversely interact with either unit in any way.

Comparing riverwatcher and trap catches provides a useful mechanism to compare the relative accuracy and efficiency of the two systems. However, it fails to provide information on individuals that may approach, but fail to enter the two systems. This information is critical because changes in behaviour attributable to the presence of either unit could potentially bias any subsequent comparisons between the two systems. Fish behaviour in the vicinity of the riverwatcher was therefore subsequently assessed via acoustic imaging using dual-frequency identification sonar (DIDSON). 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. The DIDSON unit generates echograms 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.

DIDSON units were installed upstream and downstream of the riverwatcher and fish trap to record fish that approached and entered the systems. Two DIDSON units were mounted within the fishway channel upstream and downstream of the riverwatcher unit (Figure 3.2). The downstream unit was used to record fish behaviour approaching the baffle. An upstream unit was also established to investigate aspects of fish behaviour after exiting the riverwatcher unit and approaching the fishway trap. Information collected from the DIDSON units would therefore provide an additional measurement of counting accuracy by determining if the presence of either a trap or riverwatcher unit actually influenced the movement behaviour of different fish species.

A replicated experimental design was established to investigate various aspects of fish behaviour in relation to the two units. Fish behavioural data from the two DIDSON units were quantified into different categories (Figure 3.2). These included fish which entered the field of view and either remained downstream of the respective gear type, entered and moved through the gear type, moved downstream through the gear type or exited immediately downstream to avoid interaction with the unit.

Four treatments were then applied to determine if fish reacted differently in response to either the Vaki or trap (Figure 3.3). Treatment one involved recording DIDSON data with neither the riverwatcher nor the trap present (Control). This acted as a control to quantify fish behaviour when both systems were absent. The second treatment involved assessing fish behaviour with the riverwatcher unit in place, but with no trap present. This sought to quantify fish behaviour in response to the riverwatcher. A third treatment involved establishing the trap but without the Vaki system. This would provide an understanding of how fish interact with trapping units within fishways. The final treatment was with both the trap and riverwatcher unit in place to determine if the presence of both systems invoked different behavioural responses.

Experiments were undertaken over a six week period in November and December 2008. Each treatment was replicated five times within experimental blocks during that time. Allocations of treatments within replicates for each block were based on a randomisation process. Once the treatment has been determined, it was configured within the fishway. All gear types for that treatment were then allowed to run for a four hour period. Data would then be processed and the next treatment would begin. This would continue until all possible treatments were completed within that particular block before repeating the process again. To eliminate any potential bias from diel changes in fish behaviour, replicates were only completed during daylight hours. Upon the completion of each replicate, all DIDSON and riverwatcher data was stored in individual files for later analysis. Trap data was processed immediately and all captured fish were identified, measured and counted for later comparison with electronic data.

a) b)

Figure 3.1. a) The guiding funnel mounted to the entrance of the scanner unit and b) the same unit deployed within the fishway.

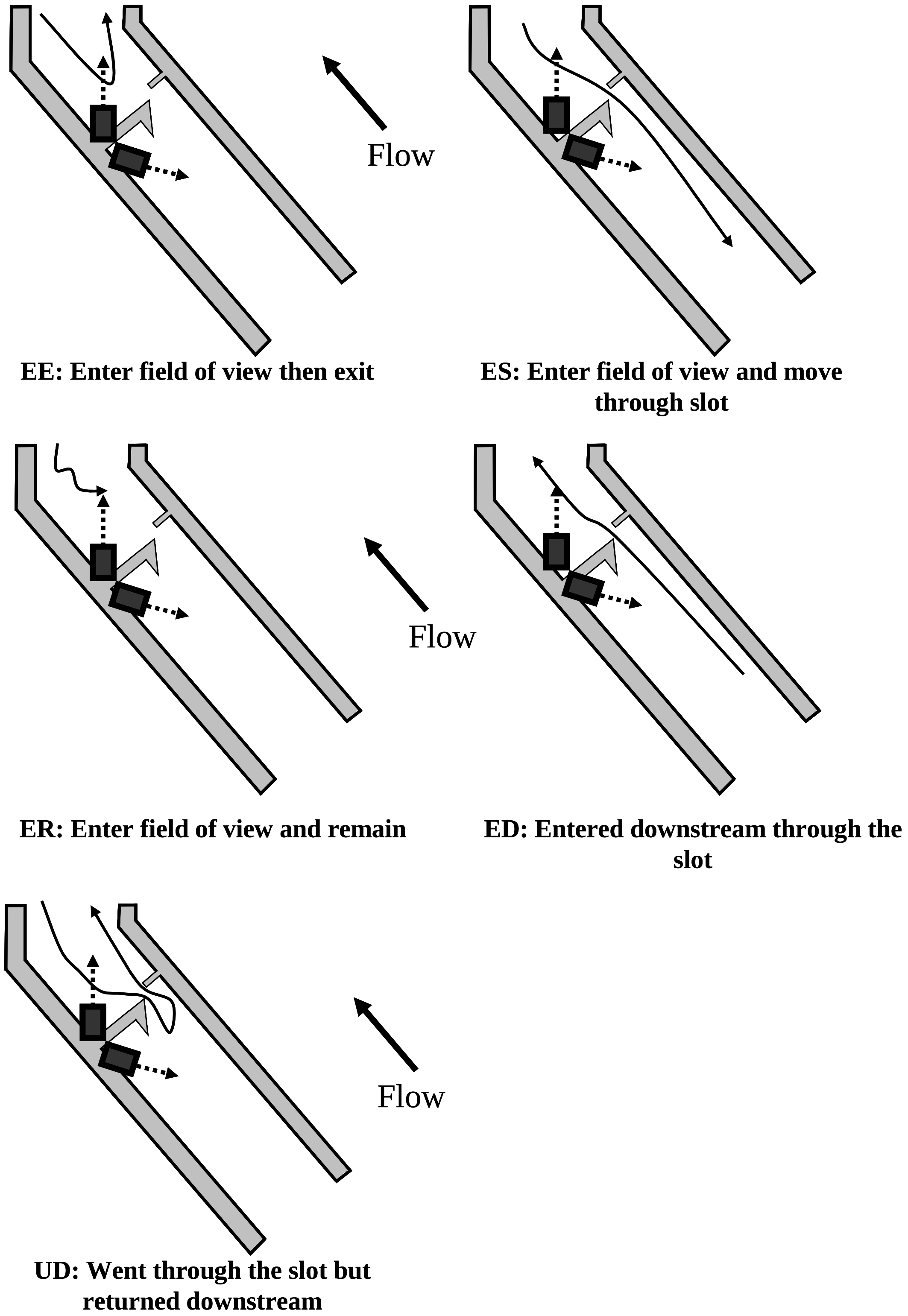

Figure 3.2. A plan view of the fishway exit channel demonstrating the deployment of DIDSON units in relation to the channel walls and fishway baffle. Each diagram summarises the five different fish movement behaviours identified by the DIDSON units. Fish which follow a similar pathway to the solid black arrows were grouped within that particular behaviour for analysis. The dotted black arrows demonstrate the orientation of the DIDSON lens when collecting this data. DIDSON 1 is oriented downstream and DIDSON 2 is oriented upstream.

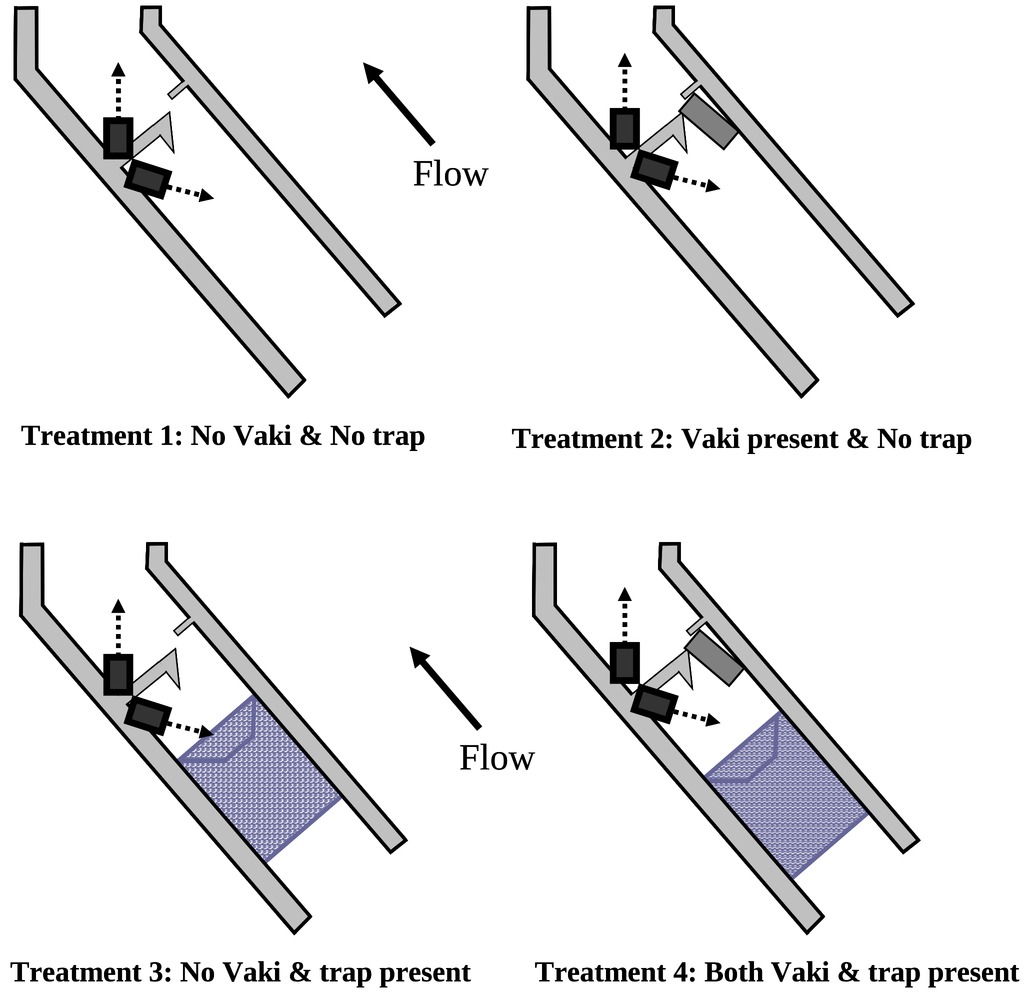

Figure 3.3. Plan view of the fishway exit channel showing the layout of each experimental treatment comprising the trap (large rectangle in channel), Vaki Riverwatcher (small rectangle in slot), DIDSON 1 (pointing downstream with the flow) and DIDSON 2 (pointing upstream against the flow).

3.2.2. Data analysis

Data were analysed using the S-PLUS (Version 6.1) statistical analysis program (Corporation, 2000). Fish counts among trap and riverwatcher information were compared using one-way ANOVA. Comparisons of length frequencies between riverwatcher estimates and trap counts were made using Kolmogorov-Smirnov tests. This analysis sought to determine if length estimates obtained by riverwater software generally corresponded with actual fish caught within the trap.

DIDSON observations were analysed using three-way ANOVA with treatment, behaviour and gear type (DIDSON 1 or 2) as factors. The analysis sought to determine if the behaviour of fish detected on each DIDSON unit was substantially influenced by the treatment being applied. The impact of treatment on fish behaviour may be used to determine whether DIDSON or trap observations were over or underestimated. The total number of fish observations were standardised to time for each behaviour identified. A log (x+1) transformation was applied to the data to stabilise variances and quantile-quantile plots confirmed normality.

3.3. Results

3.3.1. Trap vs riverwatcher comparison

A total of 6,391 fish were detected from all four gear types over the duration of the study. The greatest number of fish were detected by DIDSON1 (*n* = 4,474) and DIDSON2 (*n* = 1,475) (Figure 3.4). Fish detected by the riverwatcher (*n* = 266) and trap (*n* = 176) were relatively low by comparison. Trap catches yielded four species, silver perch (*n* = 5), carp (*n* = 7), golden perch (*n* = 141) and bony herring (*n* = 23). All species were caught from the trap both with and without the riverwatcher present. However, substantially more golden perch were caught from the trap when the riverwatcher was installed (*n* = 111) than when removed (*n* = 30). All catches in the trap were fish moving upstream. Of the 266 fish detected by the riverwatcher unit, some (24%) moved downstream.

Mean detections returned from the riverwatcher (22 ± 11 fish per replicate) and catches from the trap (21 ± 11 fish per replicate) were relatively similar during the study period. Regression demonstrated a strong linear relationship between riverwatcher detections and trap catches (R = 0.736; df = 1; F = 11.36, $P < 0.05$) (Figure 3.5). In cases of high trap catches, large counts were also reported by the riverwatcher. The maximum number of fish detected over a four hour period differed little between the trap (*n* = 76) or the riverwatcher (*n* = 71) suggesting that both techniques were recording similar abundances of fish.

Substantial differences in length frequency distributions were detected between the two methods (KS = 0.809; $P < 0.01$; Figure 3.6). The modal distributions of each gear type were similar, but riverwatcher-estimated lengths were substantially smaller than actual lengths of fish determined in the trap. No fish smaller than 250mm were collected in the trap, but large proportions (53%) of fish lengths estimated by the riverwatcher were smaller; with some fish as small as 120mm being detected.

Species recognition using the riverwatcher unit was difficult from silhouette images because outlines rarely resembled native fish. Identification to species level was therefore only possible from underwater camera footage recorded as fish entered the phototunnel. Successful identification was made for golden perch (*n* = 51) and bony herring (*n* = 1) but some fish could not be identified due to high turbidity (*n* = 12). The remaining detections recorded either no fish from video footage (*n* = 130) or the phototunnel did not activate when a fish was triggered on the scanner (*n* = 72).

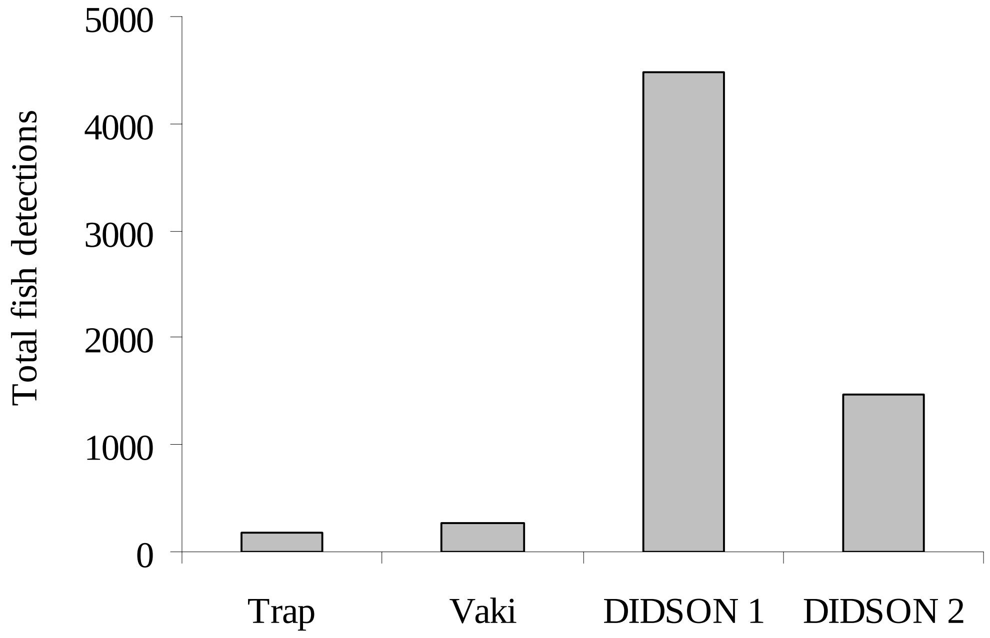

Figure 3.4. Total fish detections from each of the three gear types used during this study. Detections are pooled across all treatments. DIDSON 1 was directed downstream of the fishway baffle, and DIDSON 2 was directed upstream of the fishway baffle.

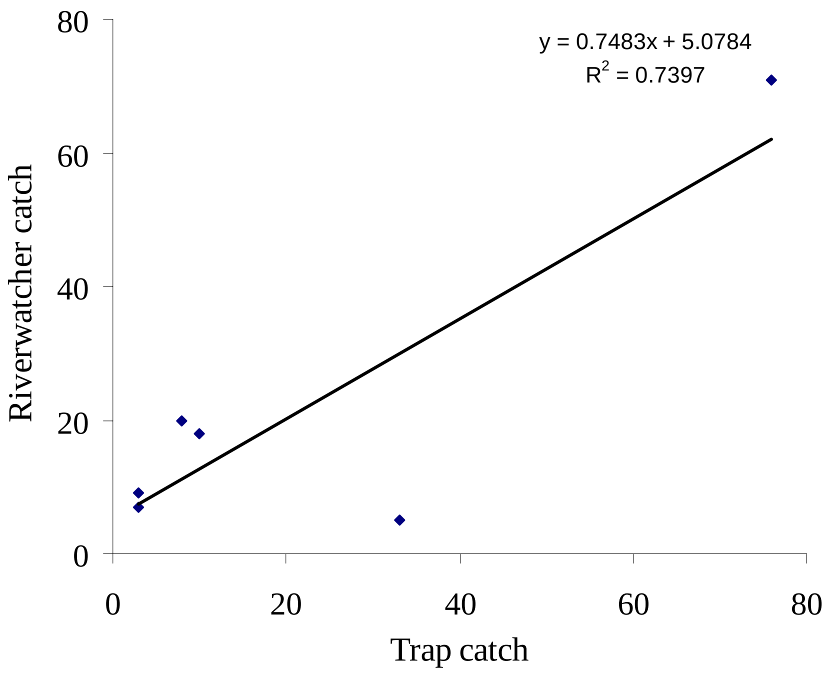

Figure 3.5. A scatterplot comparison of fish caught in the fishtrap (x-axis) against fish numbers estimated by the riverwatcher (y-axis).

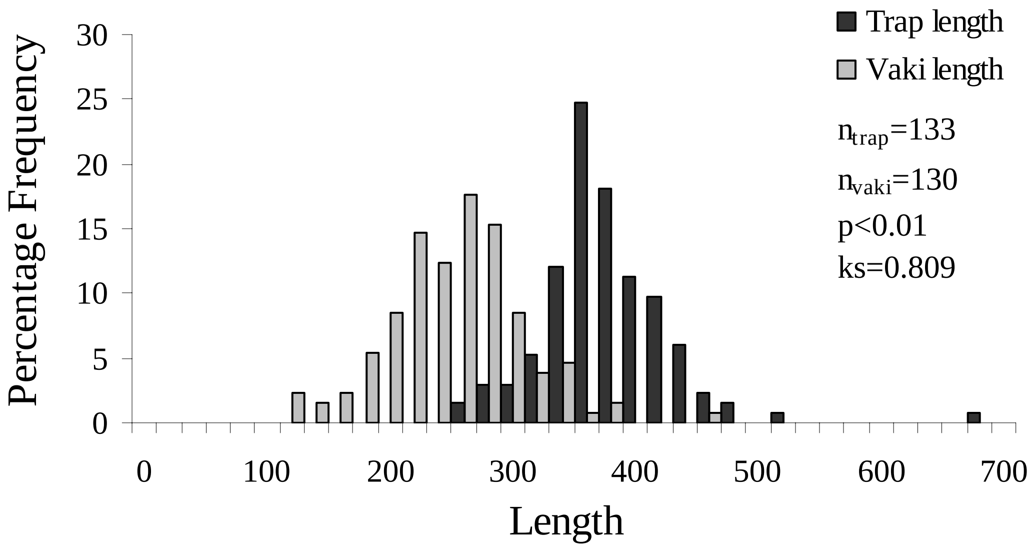

Figure 3.6. A comparison of riverwatcher-determined fish lengths and those of fish caught in the trap throughout the trial.

3.3.2. Combined gear analysis

The use of DIDSON technology permitted a detailed investigation of fish behaviour in relation to the riverwatcher and trap. A total of 5,949 targets were detected using both DIDSON units. Significant differences were detected among different fish behaviours ($df = 4$; $F = 27.32$; $p < 0.001$) but these observations were dominated by targets that entered the field of view and then exited downstream ($n = 3,221$) or which entered the field of view and then proceeded upstream through the fishway slot ($n = 1,237$) (Figure 3.7). There were no differences in the number of detections by DIDSON units among experimental treatments ($df = 3$, $F = 0.33$, $p > 0.05$) indicating the total number of detected targets were similar regardless of the presence/absence of the riverwatcher or trap. There were, however, significant differences in the number of detections by each DIDSON unit ($df = 2$, $F = 32.13$, $p < 0.001$) with a higher number of detections occurring on DIDSON 1. The highest number of detections on DIDSON2 was from treatments when the riverwatcher was absent (Figure 3.7).

3.3.3. No riverwatcher and no trap (Control)

Analyses among different treatments were used to determine changes in fish behaviour according to the presence or absence of the trap and riverwatcher unit. The first treatment assessed was when both the riverwatcher and the trap were absent. The expectation for this treatment was that fish would show no inhibition and move through the field of view on both DIDSON units. Actual detections from both DIDSON units determined that behaviour was dominated by targets which entered the field of view and then exited downstream (EE). Behaviour of this nature suggests a potential reluctance for some targets to exit the fishway. Some targets did however enter the field of view and proceeded upstream (ES), but the number of detections were few (Figure 3.7a). A moderate number of fish entered the fishway from the weir pool and migrated downstream (ED; DIDSON 2) (Figure 3.7a).

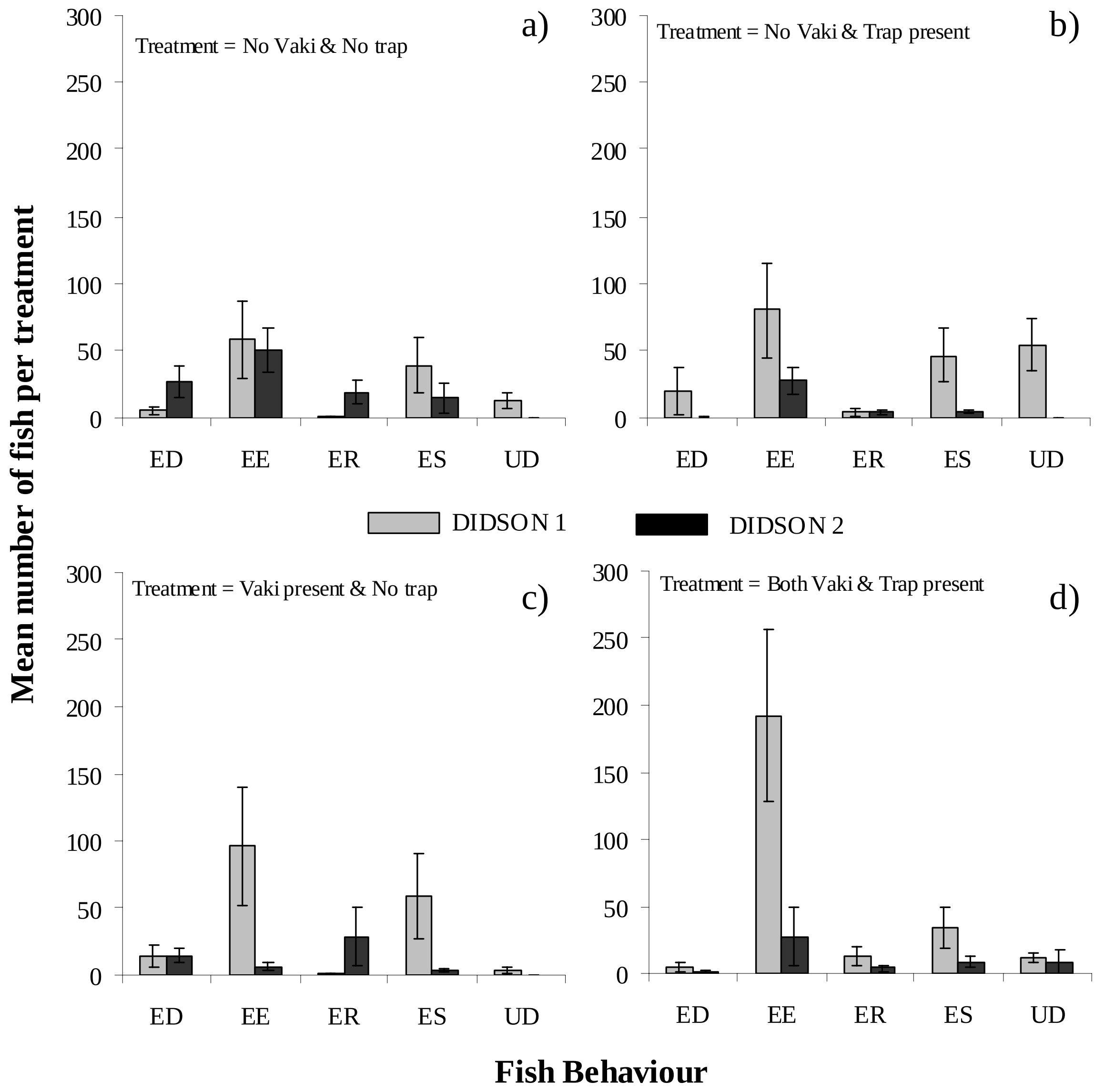

Figure 3.7. Summary of different fish behaviour recorded from DIDSON footage for each treatment. Behaviour is summarised as ED (fish which entered the field of view by migrating downstream through the slot), EE (fish which migrated upstream into the field of view, but then turned back downstream), ER (the number of fish which entered the field of view and remained), ES (fish that entered the field of view and migrated upstream through the slot) and UD (fish which migrated upstream through the slot, but immediately returned in a downstream direction).

3.3.4. No riverwatcher and trap present (Treatment 1)

The expectation for this treatment was that any fish inhibited by the presence of the riverwatcher would subsequently move upstream through the slot, and potentially into the trap. However, if fish were reluctant to enter the trap, the presence of DIDSON 2 would record any avoidance behaviour. Detections were greatest on DIDSON 1 and most targets entered the field of view then exited downstream without approaching the slot (EE; Figure 3.7b). DIDSON 2 also recorded this behaviour from targets that approached the trap but were reluctant to enter. These targets either remained in the field of view (ER) or exited downstream (EE). Many targets did not proceed entirely through the slot and some entered the slot, but hesitated and then immediately returned downstream (UD) and out of the field of view. Consistent with the suggested hypothesis, a third category of detections from DIDSON 1 were targets that entered the field of view and then proceeded upstream through the slot (ES) but this was not the dominant behaviour.

3.3.5. Riverwatcher present and no trap (Treatment 2)

This treatment sought to identify whether the presence of a trap influenced the number of fish moving through the riverwatcher unit. This treatment elicited two major behavioural responses from targets (Figure 3.7c). The dominant behaviour was targets that entered the field of view but exited (EE) indicating some avoidance of the riverwatcher. Many targets also moved through the riverwatcher (ES) but the majority remained in the exit channel (ER; DIDSON 2) whilst a smaller proportion exited upstream (ES; DIDSON 2; Figure 3.7c). Both DIDSON units also identified a small number of targets that entered the field of view and moved downstream (ED).

3.3.6. Both riverwatcher and trap present (Treatment 3)

The final treatment sought to quantify the behaviour of targets when both the riverwatcher and trap were present (Figure 3.4d). The expectation for this treatment was that the presence of both units would result in some degree of avoidance behaviour. Most detected targets entered the field of view and subsequently exited downstream (EE; DIDSON 1) or remained within this area within the field of view (ER; DIDSON 1). A small proportion of targets moved upstream through the riverwatcher unit (ES; DIDSON 1). Most of these targets then immediately exited downstream through the riverwatcher (EE; DIDSON 2). A much smaller number either remained within the space between the riverwatcher and the trap (ER; DIDSON 2), entered the trap (ES; DIDSON 2) or approached the trap funnel but did not enter (UD; DIDSON 2). A very small number of targets were observed to exit the trap through the funnel (ED; DIDSON 2).

3.4. Discussion

The combined use of DIDSON, riverwatcher and fish trap provided a comprehensive understanding of fish behaviour within the Vertical-Slot Fishway. Each unit provided complementary data which, once combined and interpreted, was able to provide accurate fish passage information and insights into fish behaviour. The DIDSON units were most powerful at inferring individual fish activity. In particular, determining how fish interacted with the riverwatcher and the fishtrap. The riverwatcher complemented this information by providing count and length estimates of fish that passed through the unit. The trap further added to the dataset by allowing identification of individual fish over a specific timeframe. Each unit had specific advantages and disadvantages and it is likely that the sole use of any item would have limited the ability to draw inferences from the data.

3.4.1. Effectiveness of the Vaki Riverwatcher unit

The riverwatcher generally performed better under field conditions than during laboratory trials. The unit successfully enumerated and measured migrating fish and also recorded video footage for a large proportion of detections. A significant relationship between numbers of fish detected by the fish trap and the riverwatcher suggests that either technique would be a reliable method of counting migrating fish. The trap, however, enabled fish to be physically caught and identified. This approach also enables the collection of biological information such as sex, maturity, length and weight but these variables are unable to be estimated using the riverwatcher. Passive collections using traps only permitted the collection of upstream migrating fish in this study. A major advantage of the riverwatcher system was a quantification of downstream migrants.

In general, the riverwatcher underestimated fish length. The actual length distributions of fish entering the trap suggested that the number of migrating fish was much larger by comparison.

Riverwatcher similarly underestimated body lengths during a similar assessment the River Zêzere (Portugal) (Santos *et al.*, 2008). Although length estimates differed between the two methods, the shape of the distributions patterns was remarkably similar. This suggests that the degree of underestimation was constant among size classes and could be corrected if correctly quantified.

The Winari software generally calculates length based on a user-specified length:depth ratio. The unit detects the depth of a fish and then estimates the length based on the ratio value. The ratio used in the current study was determined from a large database from migrating fish from a range of size classes. This overall ratio may have been incorrectly interpreted by the software because our calculations included ratios for small-bodied fish not effectively detected by the unit, which could have skewed subsequent length estimates. Future applications should attempt to use ratios that are more typical of the migratory fish community, rather than all size classes.

In low turbidity conditions the phototunnel provides clear and useful imaging of migrating fish and can help to reduce incidences of 'false counts' (Eatherley *et al.*, 2005). The phototunnel, and subsequent underwater camera, should be useful for validating counts through the scanner unit but the accuracy was low during our study (9.3%). The accuracy of images generated through the phototunnel was variable and often suffered from poor visibility due to fluctuating turbulence or due to fish failing to exit the unit prior to a new individual entering. The latter situation was common and could have resulted in species being misidentified. Images were generally acceptable when fish moved in close proximity to the camera lens but was poor in all other circumstances.

The unit has a range of potential applications including within fishways, at floodplain regulators, within supply channels or other points of suspected fish movement. The unit is flexible in terms of operation, but is limited by the restricted width of the scanner unit (Beach, 1978). Where width or depth is an issue, additional scanner units can be linked together to create an array which can give wider spatial coverage of the target area (Chariskos, 2007). Provided the site of application is a known point of fish movement, obtaining count and morphometric data on migrants would be possible and should be considered for a long-term deployment at a key site of fish migration in the Murray-Darling Basin.

3.4.2. Understanding fish behaviour

The use of DIDSON sonar greatly enhanced the understanding of fish behaviour in the vicinity of the riverwatcher unit and the trap. Substantially more targets were detected by DIDSON than were recorded in the trap or riverwatcher which suggested a large degree of avoidance behaviour. The categorisation of raw target data into specific behavioural attributes was successful in identifying potential sources of inhibition and also validating fish movement estimates determined by the riverwatcher and fish trap.

Avoidance behaviour within fishways has been previously suggested as an explanation for inconsistent fish movement data, but has been difficult to quantify (Stuart *et al.*, 2008b; Baumgartner *et al.*, In press). Most previous work on trap efficiency has largely focused on quantifying escape (Steinhorst *et al.*, 2004; Li *et al.*, 2006). DIDSON, however, provided a useful mechanism to document avoidance and provided a non-invasive mechanism to observe fish. Sonar footage determined that the presence of the riverwatcher, and to a lesser extend the fishway trap, elicited a behavioural avoidance response from migratory fish. When the riverwatcher was present, more targets approached and turned away from the unit than actually entered. Similarly when only the trap was present, many fish actively avoided capture. Those that were captured had previously made many unsuccessful attempts to enter the trap. Once caught, in some cases, DIDSON recorded subsequent escapes.

Detailed fish behavioural analyses are not possible using traditional passive techniques. Deployment of a trap or net only yields presence or absence information (Baumgartner *et al.*, 2007), it does not provide additional data on how captured fish interact with the gear. Correct identification of all species was difficult due to varying quality of DIDSON footage. Carp (*Cyprinus carpio*) however, have a very different body shape to Australian native fish and were easily indentified. This species showed a clear avoidance behaviour, especially to the fishtrap and may explain low trap catches in previous studies (Stuart *et al.*, 2008b). Although difficult to ascertain whether similar levels of avoidance in other species, the high number of targets identified by DIDSON were not reflected in trap or riverwatcher counts and suggest this was likely. The sole use of traps or riverwatcher units may therefore result in underestimates of catch data, particularly for large-bodied species. It is subsequently important that future migration studies using passive capture techniques attempt to quantify avoidance, especially if obtaining accurate fish counts is desirable.

Avoidance could be due to a number of factors. Fish could be intimidated by the physical presence of the riverwatcher (and the associated phototunnel) or the trap. Either gear type would act to substantially alter the natural hydraulics of fishway operation. Changes in hydraulics are known to facilitate avoidance behaviour at are a primary factor in the success of fish diversion screens (Lemasson *et al.*, 2008). However, a small number of fish also demonstrated avoidance behaviour when neither the trap nor the riverwatcher were present. This suggests that there may also be some degree of inhibition for fish to move through a fishway slot. Upstream migrating fish exhibit large differences in passage time when moving through fishways, with some completing movements much quickly than others (Barrett, 2008). This suggests that avoidance behaviour may vary among individuals within populations but also among species. This type of adaptive strategy is a known characteristic of many freshwater fish species and wild fish that are continuously exposed to dangers in their natural environment may adopt a conservative risk aversion strategies (Fuiman and Magurran, 1994). Under such circumstances, cautious species are more likely to be underestimated in the presence of artificial structure such as a trap or riverwatcher unit. These behavioural traits have been poorly defined for most species within the Murray-Darling Basin so it is difficult to identify species susceptible to underestimation by trap or riverwatcher presence.

Whilst both riverwatcher and trap data tended to underestimate movement rates, it is likely that DIDSON provided overestimates. Manual review of DIDSON data determined that target detection rates were generally low at the commencement of a treatment. Toward the end of a treatment, the number of target detections was much more frequent. These subsequent temporal increases in target detection arose because individual fish were frequently moving in and out of the field of view. Cyprinid species are known to exhibit ‘circling’ behaviour, where individuals swim around a fishway cell several times before proceeding upstream (Prchalova *et al.*, 2006). Similar behaviour likely resulted in DIDSON overestimates at Lock 10. Target tracking is a common technique employed to eliminate multiple esonifications of the same fish (Boswell *et al.*, 2008). But this technique is only effective for a single field of view at any given point in time, not when targets make multiple re-entries. It is therefore difficult to determine whether these are different fish, or in-fact the same fish making numerous attempts to negotiate the fishway.

The use of multiple techniques also allowed migration directionality to be quantified via both the riverwatcher and DIDSON. Fishways are often only assessed for upstream migration because many structures are designed for semelparous salmonids which migrate upstream to spawn and then die (Linløkken, 1993). Many fishways are now being designed for iteroparous potamodromous species which frequently perform bi-directional migrations for a variety of ecological reasons. Unless a trap has been specifically designed to catch downstream migrants, it is usually only set at a fishway exit so the degree of downstream migration through fishways is largely unknown. Both DIDSON and riverwatcher offer the capability to quantify the degree of downstream movements. Our brief study identified a number of downstream moving targets. This observation suggests that continuous deployment of this equipment over a long-term could provide useful management information on the cues and timing of these movements. Such information is of importance, especially for species which could be expected to migrate more than once.

3.4.3. Conclusions

The use of many electronic monitoring techniques proved useful at quantifying fish movement rates and behaviour. The system successfully counted, measured and generated reports regarding the direction and timing of fish migration within a fishway. There was some tendency for the equipment to underestimate both counts and size, but these issues can be resolved. Understanding the direction and magnitude of this bias can result in a subsequent correction which could act to improve the precision of the data. More concerning was the identification of fish actively avoiding passage through the unit. Identifying methods to reduce this avoidance behaviour is essential if accurate counts are required, such as if the unit was to be used for stock assessment purposes. Overall, the study successfully determined that electronic monitoring gear can be successfully used to determine aspects of fish behaviour that are poorly defined using passive capture techniques. These systems have potential for use on other fish behaviour studies and could be considered for wider application.

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APPENDIX 1: Future research suggestions

PROJECT: Permanent installation of a Vaki Riverwatcher at a key site in the Murray-Darling basin

Key Management Issue(s) (as identified in the Native Fish Strategy)

The following project relates to improved management of riverine structures (specifically section 3.10) which defines a need to develop cost-effective fish counting and monitoring techniques. The preliminary trials have suggested that (for large-bodied fish) results from an infrared counter are equivalent to information obtained from trapping. However, establishing a permanent monitoring site is the next step to determine how well the system can perform as a long-term monitoring tool.

Context, and how this addresses key management issue(s), strategies or policies

Fish communities of the Murray-Darling Basin are highly migratory, exhibiting movements in both upstream and downstream directions. Until recently, fish migration studies within the Murray-Darling Basin focused primarily on species of recreational or commercial importance. However, recent studies have also demonstrated that larval native fish also undertake substantial downstream movements and that many small-bodied species are also migratory. The cues, nature and scale of migrations vary greatly between species but are usually in response to increases in water temperature or river flow. Fish movements are also highly seasonal, sometimes peaking during summer and autumn and, in some cases, individuals have traversed over 2,300km during flood conditions. Although migrations over such large scales are rare, many fish species are frequently observed to either negotiate fishways or accumulate downstream of obstructions.

Across the Murray-Darling Basin thousands of weirs obstruct the passage of fish and have contributed to significant declines in distribution and abundance of many fish species. As part of an ambitious plan to rehabilitate native fish populations, the Murray-Darling Basin Authority (MDBA) is restoring fish passage along the Murray River from the sea upstream to Hume Dam – a distance of 2,225 km. To monitor and assess the outcomes of the construction program, a team of freshwater scientists from the states of New South Wales, Victoria and South Australia were established. This tri-state research team is conducting a comprehensive research program that is sampling fish populations in the river (before and after installation of the new fishways) and monitoring fish as they approach, pass through, and leave the fishways. Four techniques are providing data on the effectiveness of the newly installed fishways: electrofishing accumulations; passive integrated transponder tagging to detect long distance movements, direct sampling of the fishways and developing long-term electronic monitoring tools.

The majority of fish within the Murray-Darling Basin are long-lived (> 10 years) and therefore benefits of a fishway construction program may not be immediate, and increases in fish numbers may manifest over time. It is impossible to continuously trap fishways to gather information on migratory behavior. While site staff can assist in this regard, fish trapping can be time-consuming an impact upon other priority tasks. The long-term deployment of an electronic monitoring unit to continuously monitor fish migrations is therefore an attractive alternative to manual trapping. If it determines count and length information accurately, it could be used to determine long-term trends in fish passage and document increases in fish migration rates over time.

The Authority's need to fund this work

Quantifying fish migration rates and the benefits of fish passage rehabilitation is a basin wide issue. The large degree of investment under the Sea to Hume program necessitates an ongoing monitoring program to ensure that benefits to native fish populations can be adequately quantified. The Native

Fish Strategy provides a useful mechanism to benchmark fish migration rates through the innovative counting program. This program provides a framework to influence natural resource management on a whole-of-Basin scale by developing cost-effective techniques for continuous monitoring of fish migration. No other organization has the sufficient resources or ability to influence management on a scale that could facilitate large-scale improvements to existing practices. Incorporating the results of continuous monitoring would contribute to increased understanding of native fish migration and play a pivotal role in determining the long term benefits of increased fish migration.

Opportunities for linkage or collaboration

The work is listed as a research need under the native fish strategy and the work is planned to augment existing monitoring activities under the ‘Sea to Hume’ program. The work could be linked in with tri-state monitoring programs and site staff could contribute to ongoing operations and maintenance. The ‘real-time’ mode of operation would provide education and community involvement opportunities because actual counts of fish migration, and video footage, can be directly observed with the unit.

Project objectives

- To develop and install a long-term native fish monitoring system.
- To use the system to generate a long-term dataset on fish migration at a key site in the Murray-Darling Basin.
- To determine whether infrared counting is a feasible long term option to monitor fish movements within the Murray-Darling Basin.

Key tasks

- To purchase and retrofit remote controlling units to the existing Vaki unit.
- To purchase an retrofit a specific fishway-slot scanner unit for the Vaki unit.
- To install the unit at a key migration site (potentially Lock 10 or Torrumbarry).
- To monitor and collect data from the unit and generate reports for the MDBA.
- To maintain and ensure long-term operation.

Anticipated products

The major product will be a fully-automated infrared fish counting unit which has been permanently installed within the Murray-Darling Basin to document fish migrations. The project will also produce a dataset which contains continuous movement data (in both upstream and downstream directions). The data can be summarized ‘annually’ or as ‘event’ reports whenever a fish migration episode is detected.

Anticipated outcomes

The major outcome of this project will be the delivery of a fully-automated fish counting system that has been specifically tailored for long-term use in the Murray-Darling Basin. The project will also develop a dataset which can be interrogated by researchers or managers to determine annual, seasonal or daily trends in fish migration rates. If the installation is successful, it could be applied at other strategic sites to develop a holistic model of native fish movement.

Opportunities for end-user involvement

The opportunities for end-user involvement are huge because this is a highly-visual piece of equipment. Lock staff would be trained in the operation and maintenance of the gear via a demonstration from the commissioned agency.

Mechanisms for transfer and adoption

The products and outcomes of this specific project could be transferred to end-users via:

- The production of annual reports on fish migration for the site which will contain, numbers, direction and size classes. The use of a video tunnel may also allow species data to be collected.
- The production of ‘event’ reports, where large fish migration events are documented and reported.
- Presentations to interested community groups and also to a scientific audience via the annual Native Fish Strategy forum.
- The dissemination of the project products via the Native Fish Strategy Coordinators and members of the Native Fish Strategy Implementation Working Group.
- Engaging relevant media where possible (radio, TV and written press).
- Via the Murray-Darling Basin Commission website and through online mechanisms offered by other agencies.

Estimated cost and duration

The project could be carried out by a single agency or on a collaborative basis. However, after an initial capital purchase, ongoing operating costs will be minimal and limited to annual maintenance of the system and data analysis. The entire project would be ongoing, but the immediate capital expenditure (and installation) should cost between $25 – 100K and be delivered within 6 to 12 months depending on reporting requirements. Ongoing maintenance and data activities would cost less than $10K per year and may be able to be incorporated into lock staff duties.

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