OBSERVING FISH BEHAVIOUR AT TIDAL FLOODGATES

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Introduction

Coastal floodplains provide essential nursery, feeding and spawning habitats for a wide range of fish species. In NSW, an extensive system of floodgates has been installed in many of these floodplain areas and recent studies by NSW Department of Primary Industries (NSW DPI) have shown that unmanaged floodgates act as barriers to fish.
In all of these studies, fish were netted at sites above and below floodgates as well as at ungated reference creeks. Pollard and Hannan (1994) found that fish passage through traditional floodgates on the Clarence River was very restricted. Although saline waters entered floodgated systems, they found that recruitment of fish upstream of floodgates was very limited. Fish assemblages above the floodgates were generally dominated by primarily freshwater species, while estuarine/marine species were found below the gates. Gibbs *et al* (1999) attempted to collect fish assemblage data before and after the Yarrahapinni floodgates were opened, however the gates were not opened during the study period due to delays in the EIS and associated approval process. They were able to compare Yarrahapinni Broadwater against managed/modified floodgates at Ironbark Creek and Rockdale Wetlands. This study showed similar results to Pollard and Hannan (1994) and was later supported by Kroon et al (2004), whereby upstream fish communities were dominated by freshwater species and recruitment of estuarine species to upstream areas was restricted.

Programs of active and passive floodgate management are now being widely implemented. In order to maximize fish access to wetlands through adaptive management of floodgates, information is needed about the temporal variability of fish passage and environmental factors that may restrict it. However, direct observation of fish behaviour is made difficult by the generally poor water visibility near floodgates. In August 2006, NSW DPI researchers had the opportunity to field test a new technology that provides high-definition video images of fish and other submerged objects in low visibility settings. The DIDSON (Dual-frequency IDentification SONar) is a multi-beam, acoustic lens, sonar capable of producing near video quality images of fish in turbid or low-light conditions. In addition to detecting fish in areas not visible to human observers, the DIDSON eliminates ambiguity in interpreting sonar signals. This is achieved by providing realistic, dynamic images of swimming fish, as opposed to the return pulses or intermittent “blips” of split-beam sonar, DIDSON enables researchers to distinguish between animals and moving debris.

In September 2006, the Commonwealth Department of Environment and Water Resources provided NHT funding to develop protocols for using the DIDSON acoustic camera to analyse fish movement behaviour above and below floodgate structures and at ungated reference areas. This study focused on sites in the Clarence and Hunter Rivers to assemble suitable equipment infrastructure and develop protocols for optimising the location, orientation, and camera settings at floodgate sites. Observations were also made at reference locations to determine whether movement patterns are related to tidal or diurnal cycles. Analysis of the video footage is not complete; however we have some interesting preliminary observations of fish moving through floodgates and aggregations of fish above and below floodgate structures. In this paper we will summarise our observations of fish aggregation and movement patterns and discuss some implications for active and passive management of tidal floodgates.

Methods

Study sites

Our study was conducted in the Clarence River floodplain, between Grafton and Yamba on the north coast of NSW (Fig 1) and in the Hunter River floodplain near Newcastle on the lower north coast (Fig 2). We focused our study on two drainage systems with floodgates that drain fresh to slightly brackish wetlands (Little Broadwater on the Clarence River and Ironbark Creek on the Hunter River). Three reference sites (Chaffin and Champion Creeks in the Clarence System and Cobans Creek in the Hunter System) were established in natural creek systems without floodgates that drained similar wetland systems. Sampling sites were selected on the basis of landholder permission to access study sites draining wetlands, availability of previous fish survey data and ease of access.

Little Broadwater is a backswamp-type wetland that covers an area of approximately 235 ha. and drains directly into Sportsman's Creek, 4 km upstream from its junction with the Clarence River (Fig. 1). The Little Broadwater drainage channel was dredged and then isolated from the main river system in the 1920s by the construction of a weir and floodgates across the main entrance to the wetland. This caused over-drainage of the wetland and resulted in the loss of fish and water bird habitat and the formation of acid sulphate soils in the area. A collaborative project involving Clarence Valley Floodplain Services, Department of Primary Industries, WetlandCare, the University of New England and local landowners resulted in the installation of tidally activated gates on the existing floodgates and an upstream "drop-board" water retention structure were installed in 2003.

The reference sites on the Clarence floodplain were located on creeks that flow into the Coldstream River approximately 10 km from its junction with the Clarence River. (Fig 1). Chaffins Creek is located 1.4 km north of the township of Tucabia and the one in Champions Creek is located approximately 3.4 km north east of Tucabia

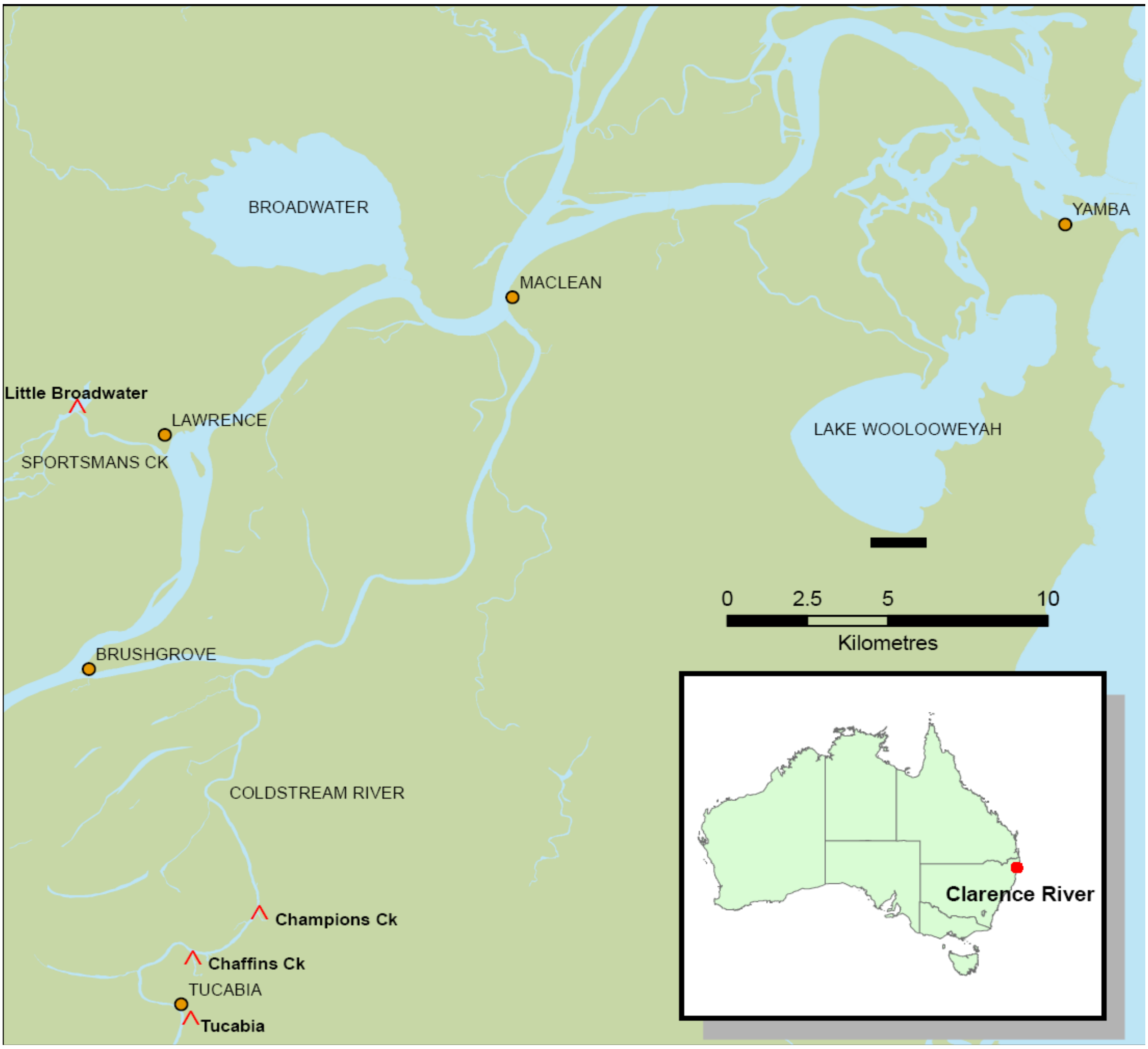

Figure 1 Location of DIDSON survey sites (^) in the Clarence River catchment.

Hexham swamp is the largest backswamp in NSW and covers approximately 2500 ha with Ironbark Creek draining the swamp directly into the Hunter River. Ironbark creek is approximately 12 kilometres upstream of Newcastle on the southern side of the Hunter River. A barrage of 8 floodgates was installed near the mouth of Ironbark Creek in 1972 for flood mitigation purposes.

A reference site on the Hunter River floodplain was established at Cobans Creek, which is located opposite Ironbark Creek on Kooragang Island 1.15 km downstream of the Kooragang Bridge that connects the Island to the mainland.

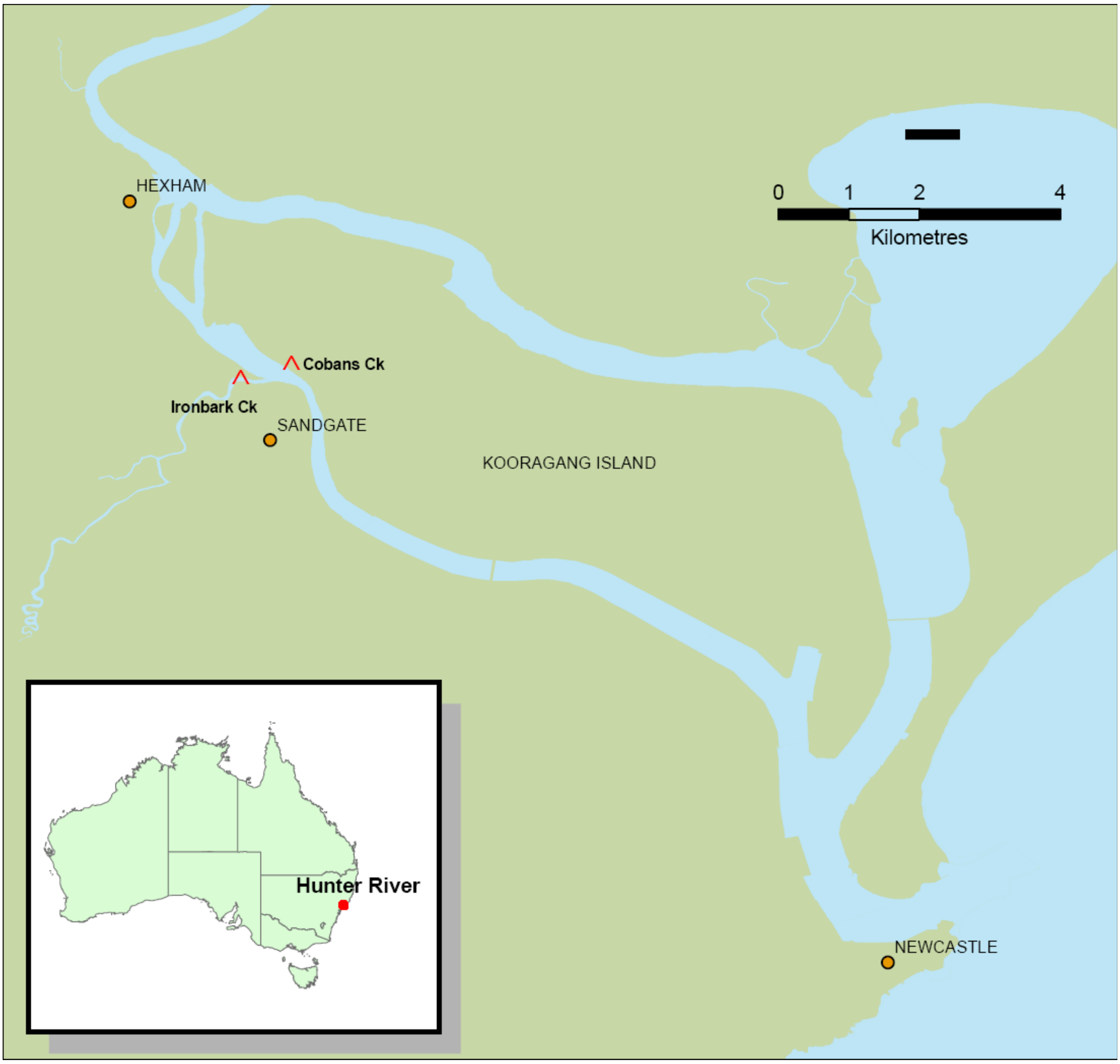

Figure 2 Location of DIDSON survey sites (^) on the Hunter River.

Floodgate Structures

Little Broadwater

The existing structure at Little Broadwater consists of two winch-type floodgates fitted with two 0.9 x 0.7m automatic tidal gates, a concrete weir with removable drop boards and reverse floodgates (fish-flap). The automatic tidal gates are primarily designed to open by means of a simple float mechanism (Fig 3). As the downstream water levels rise due to tide or floodwaters, a float rises and closes the gate, however the closing of the panel can be controlled by adjusting the operational level and weight of the float. Equally, as the downstream levels fall, the float drops and re-opens the panel, permitting water exchange and fish passage.

Figure 3 A typical tidally-activated gate fitted to a floodgate flap.

Approximately 10m upstream of the tidal gates, a concrete weir or water retention structure has been installed. Its main purpose is to maintain a suitable water level in the wetland to minimise potential acid sulphate soils and provide habitat for aquatic fauna. The original structure consisted of removable drop boards and a reverse floodgate fish flap. Recent changes to this structure include a gang-way over the concrete weir, a new 'under-shot' mechanism and a winch on the fish flap (Fig 4). The gang-way allows safer access to operators to make changes to the under-shot mechanism and fish flap. This also allows smaller incremental changes to the sill level of the weir hence better control of the water levels in the wetland.

Figure 4 Changes to the water retention structure can be seen in these photos. The photo above shows the new gang-way and winch for the new under-shot over-shot weir that is replacing the old manual drop boards and the winch for the vertical lifting of the fish-flap.

Hexham

The flood mitigation structure on Ironbark Creek consists of eight 2.13 x 2.13m box culverts each with a heavy, top-hinged floodgate. When water levels rise on the swamp side of the gates to a level higher than the Hunter River, the gates are forced open by this differential in hydrostatic pressure allowing water to flow out of Hexham Swamp. However, rising water levels on the river side, due to upper catchment floods or a rising tide, force the gates closed and prevent flow into Hexham swamp.

Figure 5 Eight floodgates located at Ironbark Creek draining Hexham Swamp.

The system was designed to allow each individual gate to be raised incrementally. This creates an opening at the base of the gate, allowing water to flow into the swamp on a rising tide. The floodgates were originally designed to remain shut at all times, however, it was suggested in 1972, shortly after construction of the floodgates, that one of the gates should remain open by one notch, an approximate height of 0.15m. This remained in place until July 2001, when this gate was raised an extra notch to an approximate height of 0.30m (wbm oceanics 2005). The raised gate remains in this position to-date. Significant changes in the distribution and extent of vegetation within Hexham swamp have occurred since the floodgates were installed (Morrison 2000). Estuarine wetlands have been largely replaced by freshwater wetlands. Mangrove and saltmarsh areas have decreased by approximately 40 and 99 percent, respectively, while *Phragmites* reed-swamp area has increased by a factor of 40.

Acting on a proposal in the Ironbark Creek Total Catchment Management Strategy (1996), the Hunter Central Rivers Catchment Management Authority (HCRCMA) is planning to modify floodgate operation by progressively opening the floodgate in order to ameliorate deteriorating ecological conditions within Hexam Swamp. After the completion of bunding works as well as hydrological and ecological studies, the floodgates will be progressively opened, starting with the gate that is already open, in early 2008.

DIDSON acoustic camera

The DIDSON (Fig 6) was developed for the US military by the Applied Physics Lab at the University of Washington for detecting underwater mines. It uses a set of liquid filled lenses to focus an array of 96 sonar beams (Fig. 7). This provides underwater video footage in zero visibility conditions, such as high turbidity or at night

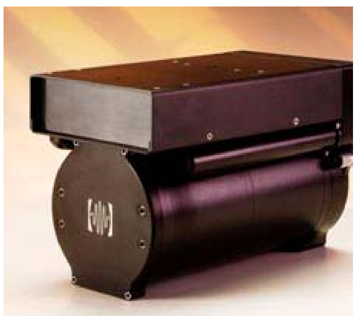

Figure 6 DIDSON camera

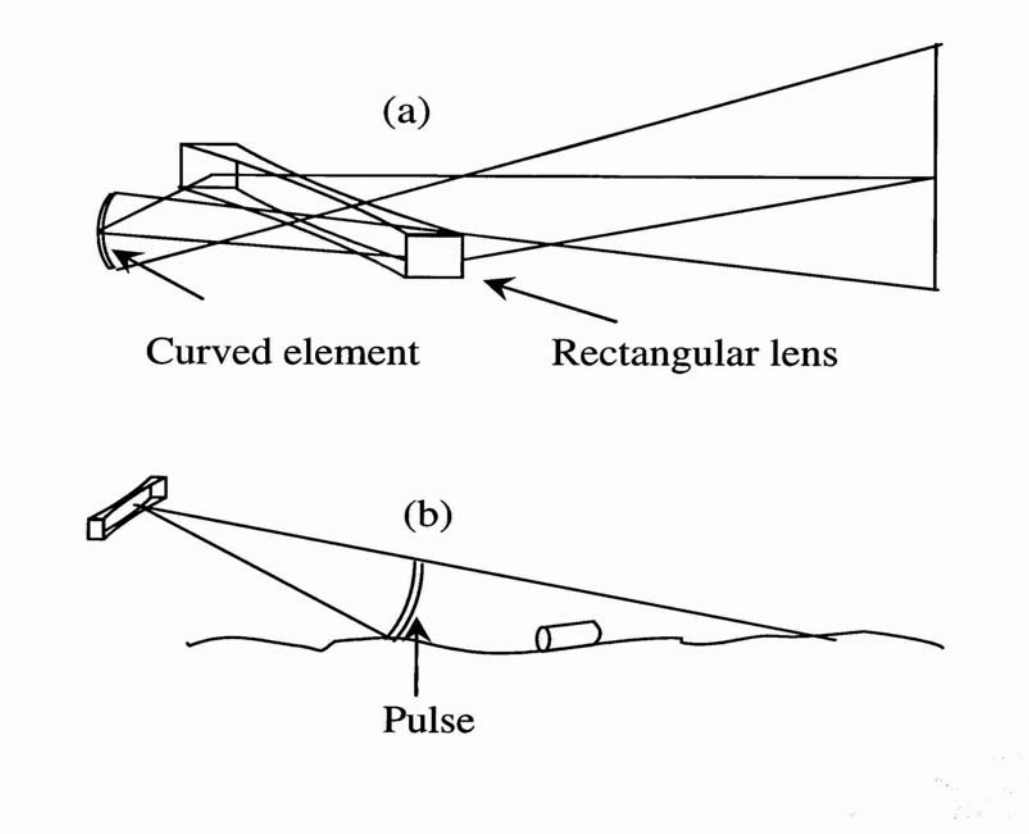

Figure 7 Object identification with acoustic lenses.Source: Edward Belcher, Bill Hanot, and Joe Burch, Applied Physics Laboratory (Sound Metrics 2007)

Low frequency mode detects objects with 48 beams spaced 0.6^o apart at ranges up to 40m. (1-MHz operation). High frequency mode detects objects with 96 beams spaced 0.3°apart at ranges up to 12 m. (1.8-MHz operation). Both modes have a 29 degree field of view and can record at 5-20 frames per second.

Two Gel type 12 volt automotive batteries were connected in series to supply 24 DC volts to the DIDSON through the “topside box”. Two deep-cycle (240 amp hours) 6 volt golf cart batteries were connected in series to supply 12 volts to the laptop data logger. The laptop controlled the DIDSON and recorded data through an Ethernet connection to the “topside” box.

Mounting bracket

Our DIDSON mounting bracket is based on a design used by the Canadian Fisheries and Ocean Sciences Branch (Enzenhofer. and Cronkite 2005), with major modifications to suit the variety of mounting platforms and conditions we found throughout the trial. This type of study requires a number of options, parts and hence combinations for the mounting bracket to secure the DIDSON in a range of fixed and mobile (boat) positions. For example all parts are required when the DIDSON is to be mounted on a concrete apron at floodgate structures, while only the transom bracket type mount is necessary for observation from boats. Our findings with regard to mounting bracket options are summarised and illustrated in the results section.

Acoustic surveys

A primary aim of the surveys was to develop protocols for programming and placement of the DIDSON acoustic camera in order to capture and quantify fish movement behaviour above and below modified floodgate structures. Three surveys, each one week in duration, were conducted at each site (Little Broadwater floodgates, Clarence River ungated reference sites, Hexham floodgates and Hunter River ungated reference site) during Spring 2006 and again in Autumn 2007 to determine the optimum location, orientation, and camera settings at each site.

Two locations were established at the Ironbark floodgate site (one above and one below the floodgates). At the Little Broadwater Floodgate site, data were collected in the middle section, between the main floodgates (creek side) and water retention structure, as well as above and below the entire structure. The camera was mounted inside the culvert looking downstream, at the inside of the tidal floodgates. At the ungated control sites the camera was mounted perpendicular to the bank so that the beam pointed across the channel.

The mounting arrangements generally consisted of positioning the DIDSON to capture and observe the tidal gate or fish flap opening and closing, in turn assessing how long the opening and closing periods were and observe the movement of fish in these times and correlate these findings with diurnal and tidal variation. Preliminary investigations showed that continuous 24 hr recording was preferable to hourly subsamples in order to ensure that events of short duration were captured.

These 24 hour recordings will be analysed with post-processing software techniques to establish optimal fish identification and counting protocols using sample time frames that adequately account for diel (day-night) and tidal variation through multiple 24 hr periods. Pilot work to establish initial protocols was completed by the end of December 2006 and further surveys were then conducted in 2007. The fish movement information will be analysed by summarising the numbers of fish that move upstream and downstream during 3 hourly phases of the tidal and diurnal cycle. Temporal movement patterns will be compared between the gated and ungated sites. The results of this analysis, in conjunction with existing information that the NSW Department of Primary Industries has already collected on fish communities within these wetland areas, will then be summarised to provide potential recommendations for management of the floodgate structures to optimize fish movement. The structures at these sites include traditional floodgates, tidally activated floodgates and submerged drop boards, thus allowing an assessment of strategies for managing each of the primary types of structures that are currently being used in coastal wetland rehabilitation programs. Analysis of the data collected during this study has not been completed, therefore only preliminary observations are reported in this paper.

Results

Equipment infrastructure

An important aspect of this project was the construction and assembly of equipment needed for operating the DIDSON in a wide range of remote floodplain environments. We have set up a mobile sampling unit in a tradesman’s trailer (Fig. 8) with flexibility to mount the DIDSON to a range of different structures at relatively short notice. The unit can be left in the field unattended but secure, due to the lock-up capability of the trailer unit. Recording periods of up to three full days are possible with the existing equipment, dependant on available hard disk storage capacity The continuous recording period could be extended further with the use of solar panels mounted on the trailer doors. The mobile unit provides researchers with an excellent non-destructive sampling unit that is robust, can be deployed at short notice and can be deployed in a wide range of field conditions.

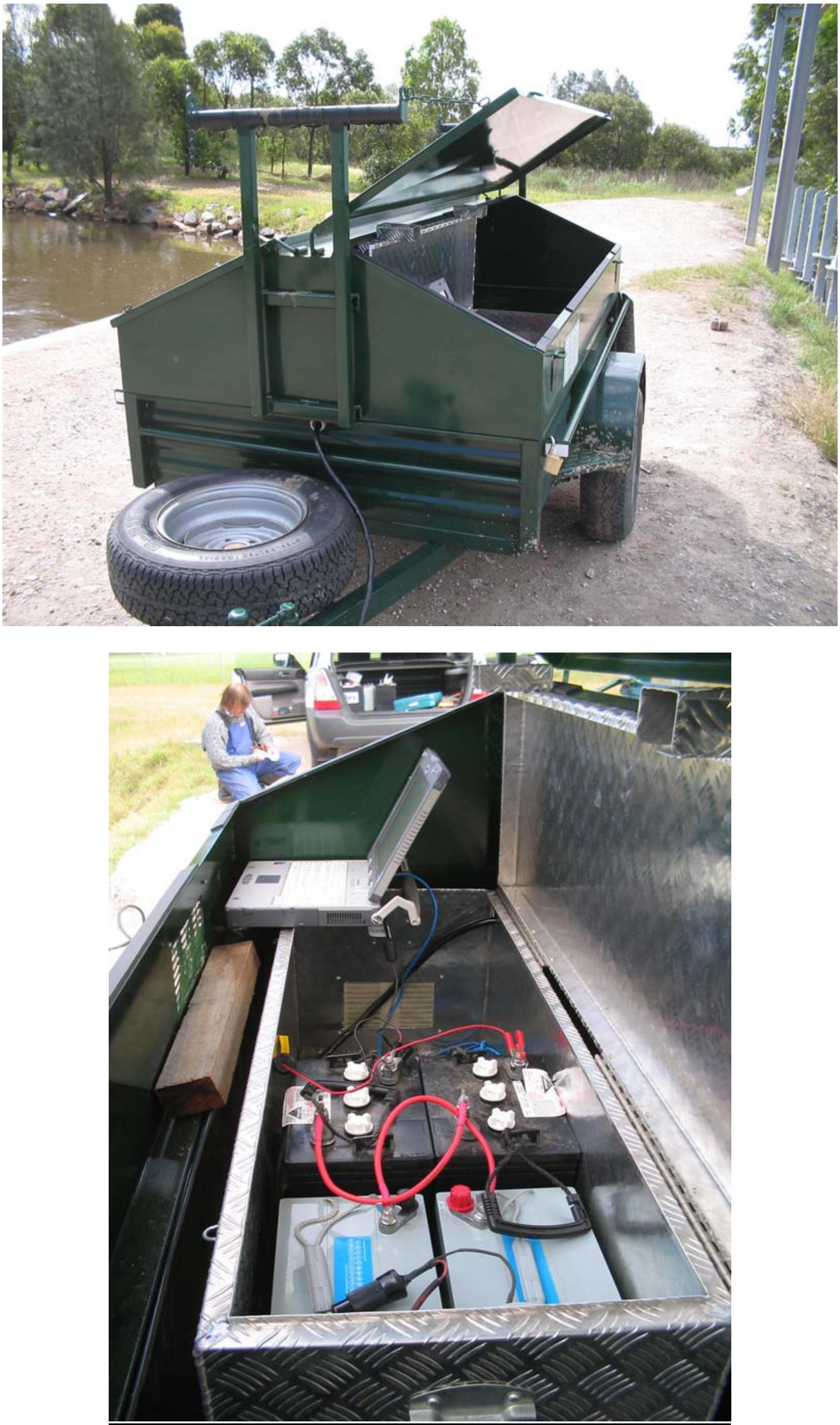

Figure 8 Mobile DIDSON trailer unit with lock-up capabilities. Trailer safely houses batteries and data storage unit and has recording capabilities of up to 48 + hrs, . dependant on data storage capacity.

Floodgate Apron Mount

The floodgate apron mount uses two builders clamps. This enables the operator to mount the DIDSON onto a floodgate apron wall.

Figure 9 *Typical DIDSON apron mount looking downstream from top of floodgate, Ironbark Creek, Hunter River, Newcastle and the downstream section at Little Broadwater floodgates, Clarence River.*

Boat Mount

To mount the DIDSON on a boat or mobile platform, a bracket that usually attaches the outboard motor to the transom was modified and attached to the DIDSON bracket to allow mounting on the transom.

Figure 10 Looking upstream at the tinnie from the culvert side with the water retention structure in the foreground and a larger boat mount on the stern transom. See DIDSON bracket bottom right hand corner on the larger boat.

Trailer Mount

A bracket was designed to mount directly to the trailer. A square metal tube was inserted into the trailers frame and extended over a culvert wall or similar. The Floodgate Apron wall mount was then attached to the metal tube. The secured camera literally hung over the edge of the structure into the water.

Figure 11 Mobile DIDSON trailer with lock up capabilities showing location of trailer mounting system.

Mounts with no structures

- **Pole or Pipe Frame Mount**

Figure 12 Pole or pipe frame mount on Cobans Creek, Hunter River, Newcastle, NSW

Wooden Frame Mount

Figure 13 Wooden frame mount on edge of floodgate apron, Little Broadwater and a wooden frame mount on edge of apron wall with full DIDSON extension bracket, Denny's Gully, Coldstream River.

Star-picket mount

Figure 14 Star-picket mount in Blaxlands Creek, Orara River, NSW and star-picket combined with wooden frame mount at Little Broadwater, Clarence River, NSW.

Protocol

Setting the frame/seconds rate is dependent on the amount of data storage capacity that is available in either the in-situ data logger or a portable hard drive. The frame rate can be set manually by the operator or calculated automatically by the computer. The minimum frame rate was determined to be 3 frames/sec. Anything below this will create an unsuitable stop-start image while the ideal maximum frame rate is between 12 – 24 frames/sec and possibly as high as 30 frames/sec. Greater frame rate than this will cause a flashing red square on the left of the screen and may result in the loss of some sections of an image. A frame rate of 6 frames/sec provides the best compromise.

The ideal recording and monitoring distance at the standard or horizontal orientation is between 5 – 12 metres, ensuring the ability to monitor behaviour and possibly identify to *genus* level. While in the 90^0 or vertical orientation, 2-5 metres is acceptable. At this optimal distance, identification to *species* level is possible. On low frequency the DIDSON operates on 1.1MHz so the operator can view further (up to 36m) but the ability to identify fish diminishes, while on high frequency the DIDSON operates on 1.8MHz to a distance of approximately 12m, subsequently making fish observation better.

If possible, recordings should be made in both the standard and 90 degree orientations. The standard view provides the best information for studying behaviour and counting fish because it provides a wider field of view compared to a narrow field of view offered by the 90^o view. The 90 degree view is very useful for identification of fish species, particularly if concurrent fish sampling methods are not used.

Observations

Little Broadwater

Our preliminary observations indicate that fish are moving through the automatic tidal gates at Little Broadwater. However, further analysis of video footage is needed to confirm the free movement of fish and other animals through these structures during all stages of the tidal and diurnal cycles.

Preliminary observations indicate that the fish flap at Little Broadwater does not remain open for an appropriate amount of time (Fig 15 & 16) to allow large numbers of fish to move through this structure into the wetland. Movement of middle to bottom dwelling commercial and/or recreational species such as dusky flathead (*Platycephalus fuscus*) and estuary perch (*Macquaria colonorum*), and non-commercial species such as the goby and gudgeon species may be particularly restricted. However, a number of species, such as sea mullet (*Mugil cephalus*), yellowfin bream (*Acanthopagrus australis*) and longfinned eels (*Anguilla reinhardtii*) have been regularly observed passing through the shallow water at the top of the drop boards.

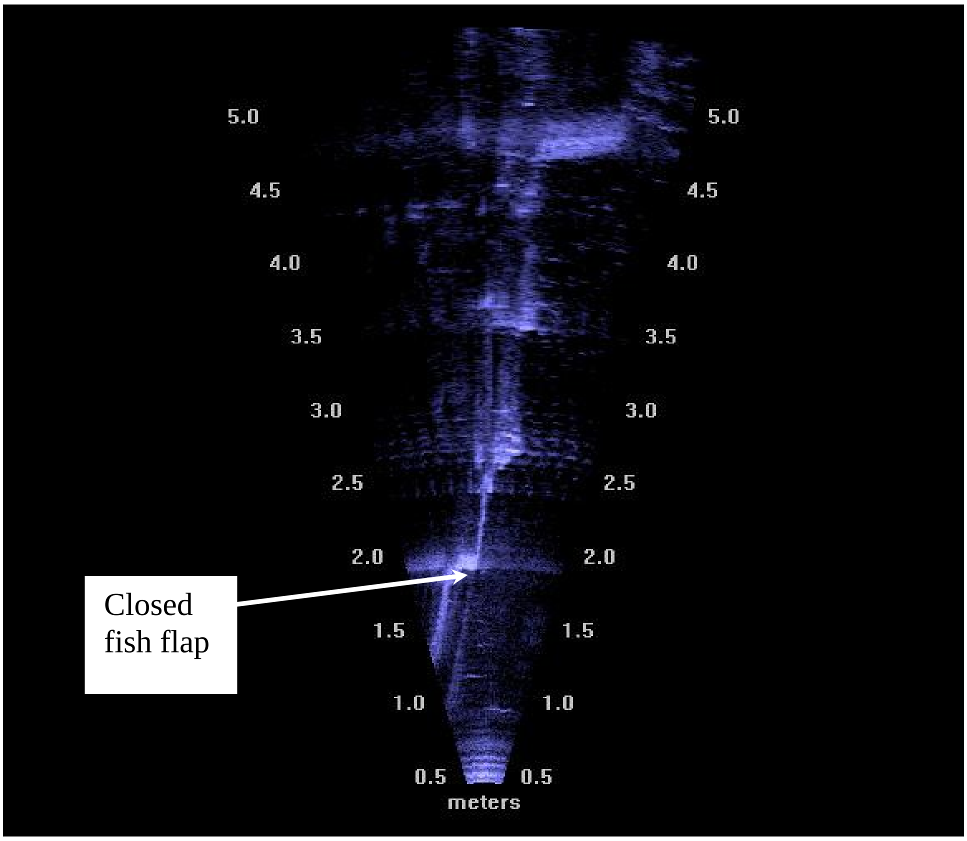

Figure 15 DIDSON still images of fish flap at Little Broadwater. Image shows when fish flap is closed. The fish flap remained closed for most of the incoming tidal cycle.

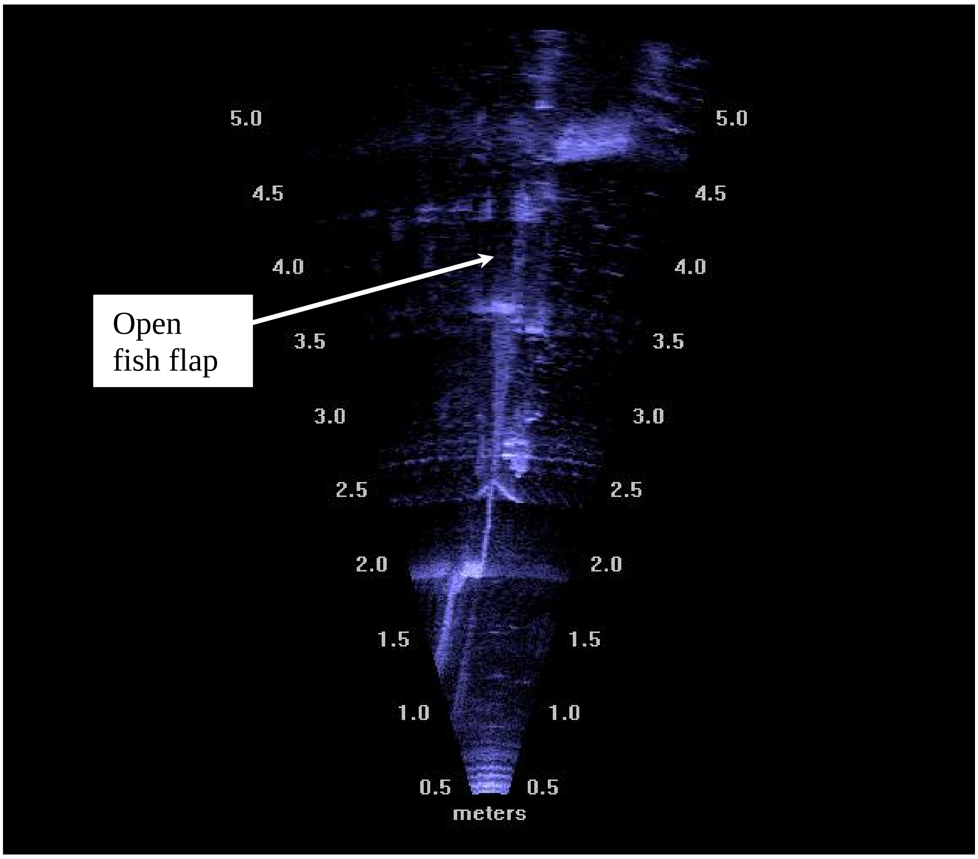

Figure 16 DIDSON still images of fish flap at Little Broadwater. Image shows when fish flap is opened. The fish flap remained open for 15 minutes during this incoming tidal cycle and another hour during the other part of the tidal cycle.

In a sense, the system has two structures that restrict water flow in and out of the wetland, the outer tidal gates and water retention structure. This creates a relatively confined space between the main floodgates and the water retention structure, where many species, such as mullet, gudgeons, glassy perchlets etc. aggregate during the day before moving into either the main river system or upstream into the wetland. Aggregations of large and small fish were often observed in this middle area as well as below the floodgates (Fig 17). These aggregations may be the result of a natural attraction to structures which provide shade and shelter. Further video observation is needed to determine whether the aggregation of fish is exacerbated by delays in passing through the complex structure.

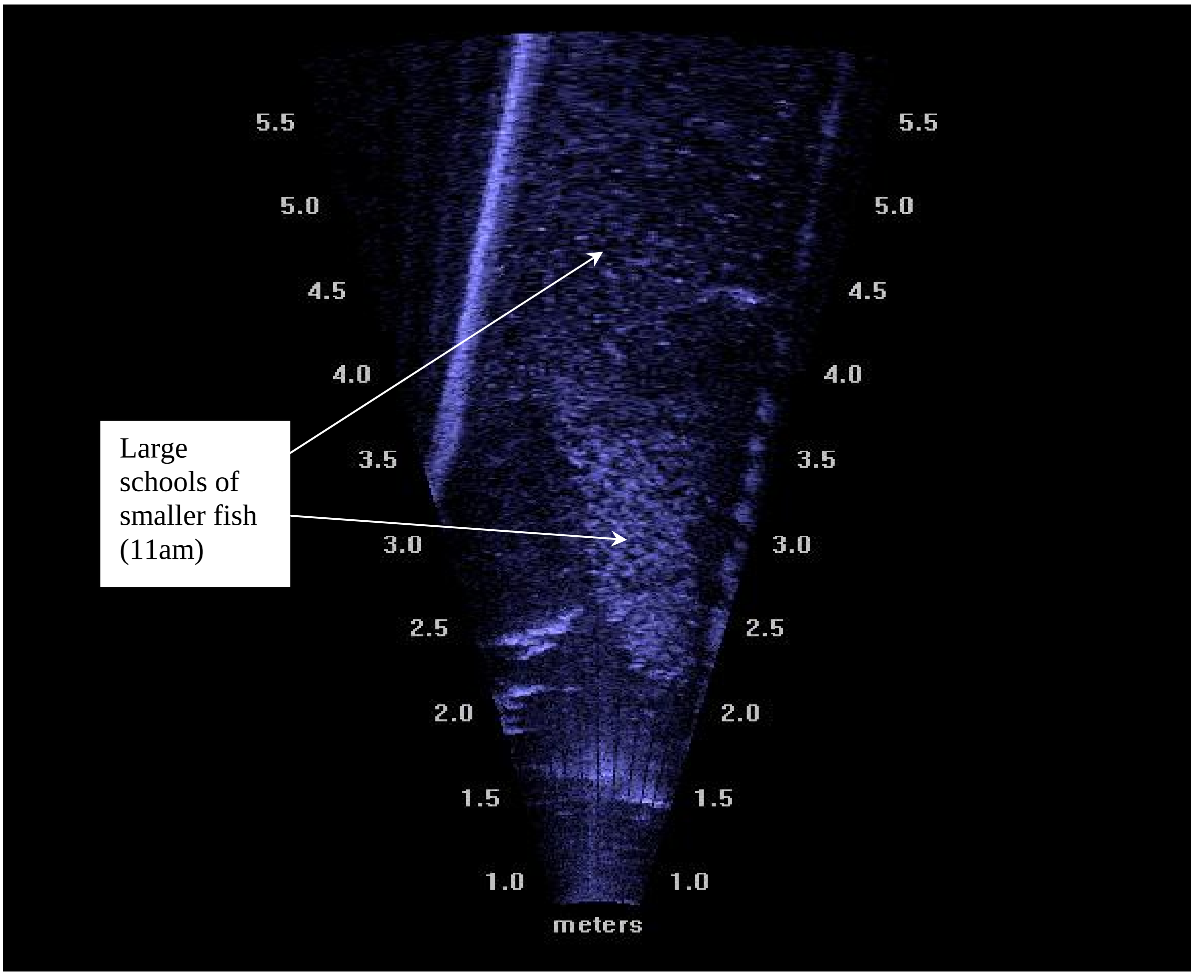

Figure 17 DIDSON still image looking downstream to the main floodgates / tidal gates from the water retention structure. The two lines depict the inner walls of one culvert. The second culvert is to the left of the central line. Footage recorded at 11am.

Numerous large longfinned eels consistently appeared in the area between the floodgates and water retention structure in the early evening then swam around in the area (occasionally passing through the floodgates) throughout the night (Fig. 19). This species is known to be primarily piscivorous (Beumer 1979). Large, estuary perch (also thought to be piscivorous; McDowell 1996) were observed occasionally above and below the floodgates, as well as passing through the gates (Fig 18). Therefore, we assume that aggregations of fish near the structure are exposed to relatively high levels of predation.

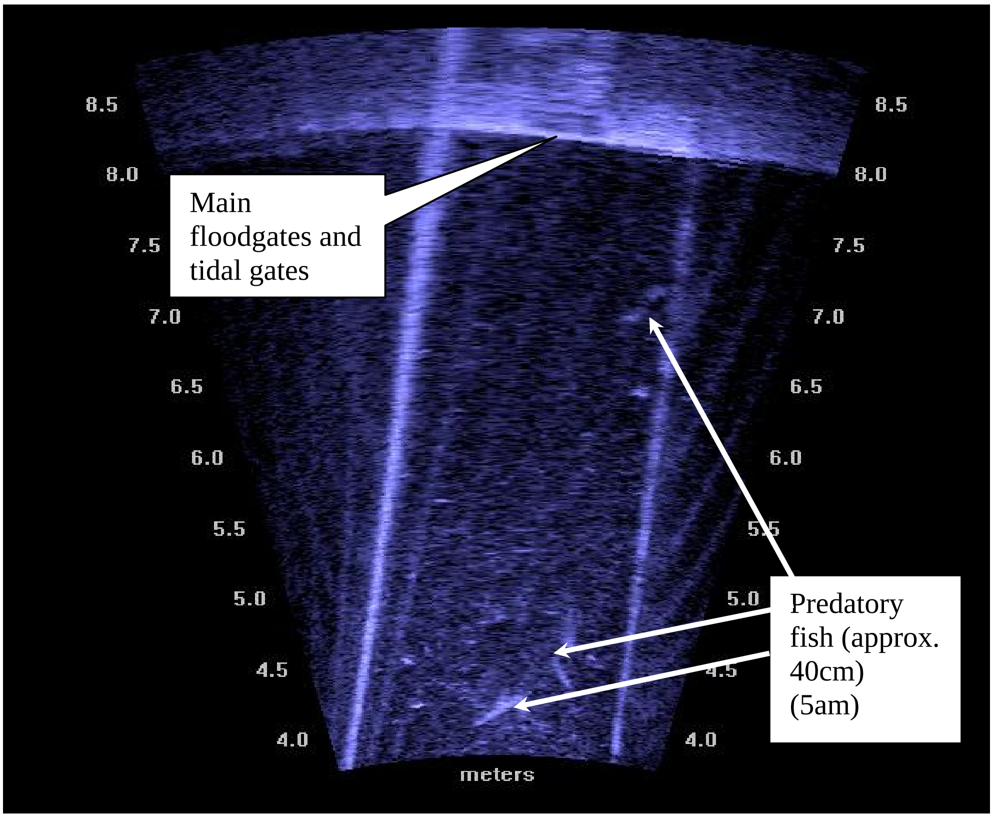

Figure 18 DIDSON still image orientated looking downstream to the main floodgates / tidal gates from the water retention structure. The two lines depict the inner walls of one culvert. The second culvert is to the left of the central line. Footage recorded at 5am.

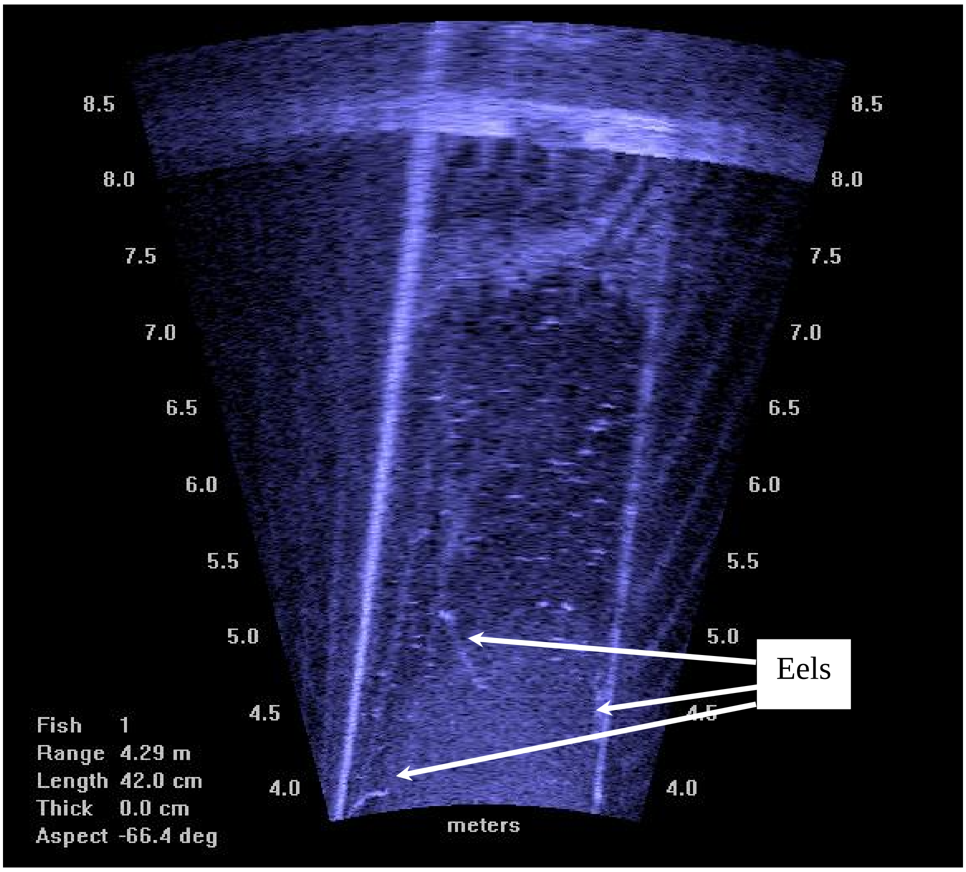

Figure 19 DIDSON still image orientated looking downstream to the main floodgates / tidal gates from the water retention structure. The two lines depict the inner walls of one culvert. The second culvert is to the left of the central line. Footage recorded at 12.30am.

Hexham – Ironbark Creek

Our preliminary observations indicate that fish are moving freely through the restricted opening (0.3 m) in the single floodgate in the barrage at Ironbark Creek (Fig 20). However, further analysis of video footage is needed to confirm the free movement of fish and other animals through these structures during all stages of the tidal and diurnal cycles. Turbulence at this site is often so extensive during high flows as the tide rises and falls, that the images are obscured by "snowy" interference.

Figure 20 Floodgates at Ironbark Creek, Hunter River. Notice open floodgate at the current 0.3m level.

Accumulations of fish (primarily sea mullet and bream) were often observed above and below the floodgate structure. During low flow periods around high and low slack tides, most of the fish passage was through the single restricted opening. Large predators, such as longfinned eels and mulloway (*Argyrosomus japonicus*) are attracted to the small opening in the gates, as the tidal current starts to flow. At night, large longfinned eels cruise around and through the restricted area of upstream flow. During both the day and night, large mulloway often appear on the downstream side of the floodgate structure as the current starts to flow either in or out of the wetland, where they appear to spend most of their time near the single restricted opening in the floodgates (Fig 21). Therefore, it appears that predation on fish that pass through the floodgates is often concentrated on those passing through the single, small opening.

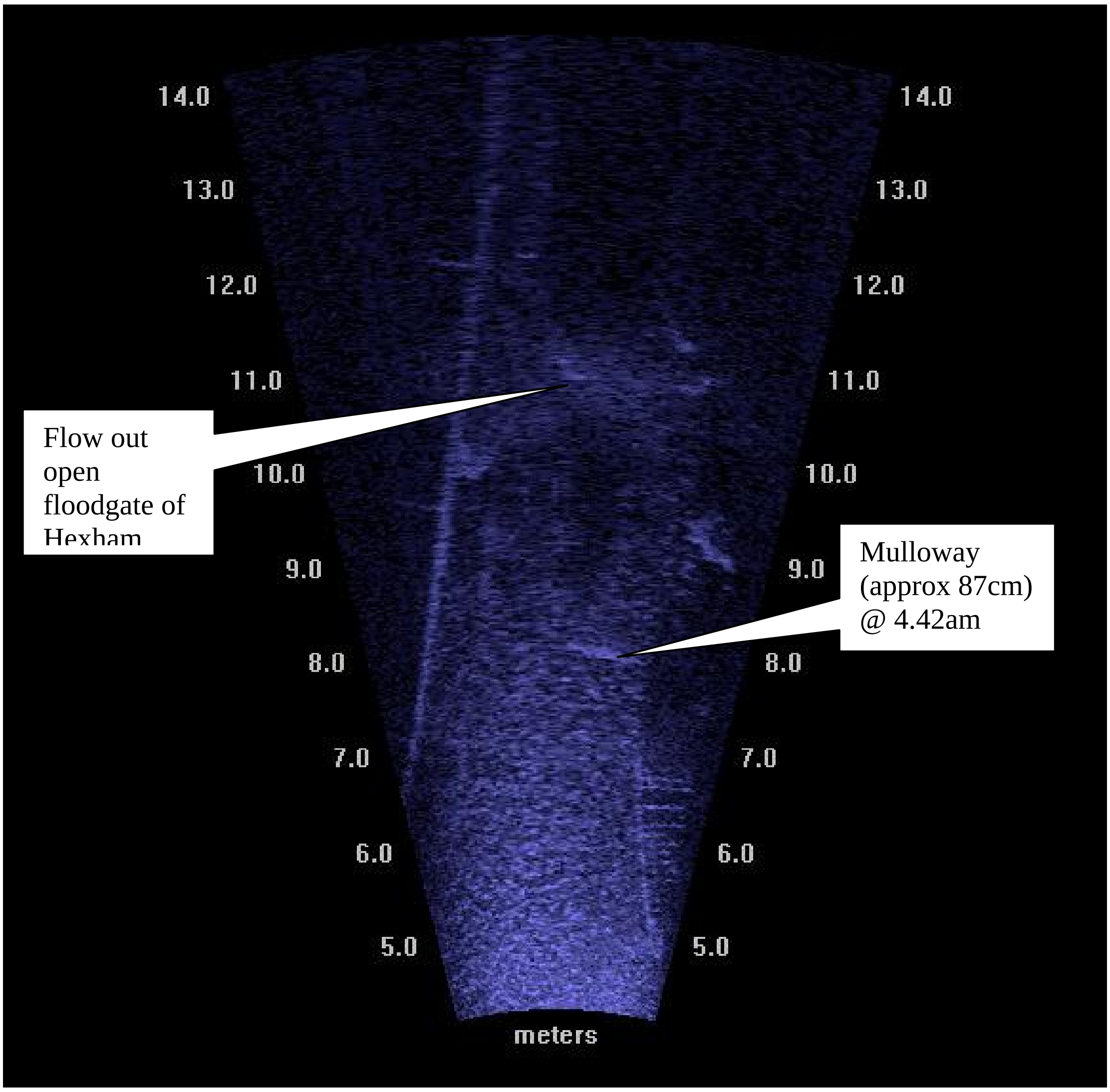

Figure 21 DIDSON still image of large (87cm) mulloway (*Argyrosomus japonicus*) on the downstream side of the Ironbark floodgates on an outgoing tide. Note flow coming out of Hexham swamp through the single restricted opening at 10-12m on side scale.

Conclusions

- Using the equipment infrastructure and protocols developed during this project, the DIDSON will provide a valuable tool for future adaptive management assessments of fish behaviour and passage at structures that have been modified for the rehabilitation of floodplain wetlands.
- The DIDSON also provides a valuable tool to determine the timing and duration of operation of tidally activated devices.
- Fish were observed to pass through both modified structures that were assessed during this study.
- A number of schooling fish species, including sea mullet, yellowfin bream and glassy perchlets were observed to accumulate at the structures.
- Predatory species such as longfinned eels, estuary perch and mulloway were often observed at the structures, indicating that predation rates may be relatively high where fish pass through tidal structures.
- Opening all eight floodgates by two notches, rather than raising the single, opened gate completely, may reduce predation on fish passing through the floodgates during the period of progressive floodgate opening by horizontally expanding the area of fish passage and reducing the focal concentration of predators such as longfinned eels and mulloway.
- Further analysis of the data collected at the floodgate structures and reference sites will help us delineate patterns of fish movement and aggregation in relation to tidal and diurnal cycles.

Acknowledgements

We gratefully acknowledge the Commonwealth Department of Environment and Water Resources for providing Natural Heritage Trust funding for this project. We wish to thank Nigel Blake for co-ordinating and administering the project through the Northern Rivers Catchment Management Committee. We would also like to thank the staff at Kooragang Wetland Centre, in particular Peggy Svoboda and Sharon Vernon, both of the Hunter Central Rivers Catchment Management Authority, for arranging access to both the Ironbark and Cobans Creek monitoring sites. Peter Wilson, Stuart Murphy and Matt Foley of Clarence Valley Floodplain Services provided valuable information and advise when it was required.

Our sincere thanks also go to the landholders at Little Broadwater, in particular Dale Vickery, for allowing us access to the Little Broadwater monitoring site, Ray Cornell and Alba Linklater for allowing us access to Chaffin Creek on the Coldstream and Lyle Chivers for access to monitoring sites on Champions Creek, Coldstream.

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