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Passive and active acoustic monitoring of mulloway in the Swan River

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ABSTRACT

Passive acoustic monitoring is a standard tool to monitor vocal marine fauna. High-frequency multibeam echosounders have developed rapidly in recent years, with the number of applications for detecting and tracking biological targets expanding significantly. In the Swan River, Perth, mulloway (*Argyrosomus japonicus*) form aggregations each austral summer. Here, a Kongsberg MS1000 scanning sonar and a CMST Underwater Sound Recorder (USR) were deployed onto the riverbed in 12 m of water. The sonar scanned to ranges of 50 and 75 m (angular resolution, 0.45°), taking approximately 120 s for one full 360° scan. The USR sampled at 6 ksps for five of every fifteen minutes. The sonar detected fish travelling slowly (typically <0.5 ms^{-1}) within its range, while the passive recorder detected the development of an evening chorus, starting with individual calling fish. One example target remained within the field of view of the sonar for over an hour, detected 55 times as it moved ≈100 m. Simultaneously, the USR recorded mulloway vocalisations, with received levels approximating those predicted for a mulloway at the range detected by the sonar. This study outlines one of the first successes of matching passive and active acoustic tracking of vocal fish, as a precursor to using sonar techniques to verify estimates of calling numbers of fish from passive acoustic monitoring.

1 INTRODUCTION

Underwater acoustics (passive and active) has become acknowledged as one of the most promising tools for monitoring the marine environment (Koslow, 2009, Lammers et al, 2009, Trenkel et al., 2011) and provides a host of data sources for fauna that are predominantly sub-surface. Acoustic techniques can detect animals in conditions that limit other techniques, such as visual surveying in deep, dark or turbid waters. While not without their own limitations, the ability to autonomously acquire and store data for prolonged periods of time has particular advantages to long-term monitoring and for less accessible locations, reducing costs and some biases from snapshot sampling (Gastauer et al., 2017).

In fisheries (active) acoustics, traditional echosounder techniques have expanded to include multi-beam echosounders, increasing the resolution and volume of water that can be sampled in a given timeframe (Simmonds and MacLennan, 2005, Gerlotto et al., 1999, Parsons et al., 2013a). Forward-looking multi-beam echosounders are increasingly employed to detect fauna of varying size and range (Becker et al., 2011a, Lieber et al., 2014, Parsons et al., 2014), with particular benefit in shallow waters, and although species identification is highly limited, information on presence, behaviour, and relative numbers of fish of particular size classes can be gained (Hastie, 2012, Becker et al., 2011b, Becker et al., 2013). At close range (<10 m), estimates of length can be highly accurate (Becker et al., 2013); though accuracy decreases with distance as beam spreading reduces resolution across the swath.

Passive acoustic monitoring (PAM) of vocal fish can provide information on the location and timing of important life functions, spatio-temporal delineation of spawning grounds and other essential fish habitat, and a long-term record of calling fish numbers within the hydrophone detection range (Luczkovich et al., 1999, Rountree et al., 2006, Parsons et al., 2016). This is particularly advantageous for long-term monitoring at individual sites as in many conditions, the lower frequencies of fish calls (typically <2 kHz) can propagate 10s, if not 100s of m, dependent on source level and ambient noise (Parsons et al., 2012, 2013b). Many fish species aggregate to spawn and have an associated vocal repertoire to help facilitate individual or group success, such as courtship or lekking related calls and choruses, respectively (Luczkovich et al., 1999, Rountree et al., 2006, Engen and Folstad, 1999). Mulloway (*Argyrosomus japonicus*), are an example of such a species and produce calls of high source level at regular intervals, for periods of several hours during spawning (Ueng et al., 1999, Parsons et al., 2012, 2013c).

Previous studies of mulloway in the Swan River, Western Australia have shown the ability to gain significant information on the aggregation and its behaviour (Parsons, 2009, Parsons et al., 2009, 2012, 2013c, 2015). However, discriminating between individuals can be complex and verifying individual movements using PAM alone is labour intensive, particularly during periods of overlapping calls (Parsons, 2009). This study was designed to conduct a preliminary test into the utility of combining a scanning sonar with PAM as a means of cross-validating the detection, counting and behavioural observation of mulloway during spawning.

2 METHODS

Each austral summer, adult mulloway aggregate in areas of the Swan River in the evenings and form a chorus for hours, in association with spawning behaviour (Farmer et al., 2005). During one evening of the 2013 summer, a single underwater sound recorder (USR, McCauley et al., in press) and a Kongsberg MS1000 scanning sonar were deployed into 12 m of water, approximately 100 m off the Coombe Reserve in the Swan River, Western Australia (Figure 1), to detect mulloway. The two systems were located approximately 10 m from each other to provide confidence that caller ranges estimated from PAM would be for the same fish as targets detected by the MS1000. As the timing of the mulloway chorus is related to sunset (Parsons et al., 2013c), both systems were deployed at approximately 17:00, roughly two and a half hours before sunset and three hours before high tide, with the intention of detecting mulloway as they arrived and chorus levels increased.

Figure 1: Map of Australia (top left) with a white box highlighting location of Perth. Expansion of the Swan River (left image) highlighting the area around the Coombe Reserve in the Swan River, Western Australia. Expanded view of waters in front of the Coombe Reserve (right image) including a scan by the MS1000 and the location of the USR shown by the orange cross. Red circles identify increasing 20 m ranges from the MS1000. Boat moorings can be seen in the scan as large white marks.

The USR recorded at a sampling rate of 6000 ksps, for five of every fifteen minutes. Data for the evening was downloaded and processed using the purposed-designed Matlab graphic user interface, CHORUS (Gavrilov and Parsons, 2014). Spectrograms of recording periods and individual calls were generated using a 1024-point Hanning window over a 20-2000 Hz frequency band to include energy from mulloway calls and are presented with a colourbar from 60-120 dB re 1 μPa/Hz. Individual calls were extracted using CHORUS and analysed individually for received levels (RL, dB re 1 μPa), sound exposure levels (SEL, dB re 1 μPa^{2}s), peak-to-peak values (Pa), duration (s), number of pulses and call rate (s, time between signals attributed to an individual caller), similar to previous studies (Parsons et al., 2009, 2010, 2012, 2013a). Carrier frequencies were determined from the relationship between call duration and number of pulses (Parsons et al., 2017). In the PAM data, calls were attributed to one individual, based on similarity of RL, amplitude, regularity of calling, carrier frequency, call category, and where possible, range estimated from a single hydrophone, as per previous studies. Target detection from the scanning sonar was also included as a descriptor, to attribute calls to a particular individual, where possible. Coarse estimates of range of calls were conducted by comparing differences between RLs and species call source level with empirical transmission loss models previously determined in the area (Parsons et al., 2009, 2012).

The MS1000 single-beam scanning sonar was operated at 675 kHz and set to scan to ranges of 50 and 75 m, using a horizontal and vertical beam angles of 0.9° and 30°, respectively, and an angular resolution of 0.45° to ensure all targets were detected. These settings resulted in one full 360° scan taking approximately 120 s to complete and the entire water column was ensonified within 15-20 m horizontal range from the sonar head. Targets were detected by visual scrutiny of the backscatter intensity in each sonar scan. They were then manually confirmed as fish by their presence, position, orientation and strength in consecutive scans, i.e. if a target of high backscatter and less than one m in length entered the scanning range and continued to move in a direction and speed contrary to that of the current, it was considered a self-propelled target, likely a fish. Over time, these targets were monitored as they progressed across the area covered by the MS1000.

3 RESULTS

Both the USR and MS1000 successfully detected fish calls and targets, respectively, throughout the data between 18:00 and 20:00 (Figures 2 and 3). However, the most of the calls in the 18:00 sample were masked by passing vessels, and so while at least one fish was observed as present, analysis of the USR data commenced with the 18:15 sample. The MS1000 did detect targets prior to this sample, but as the masking prevented range estimates of calls, this paper reports on calls detected after 18:15. Spectrograms in Figure 2 illustrate example calls that occurred as the evening progressed and the chorus developed from a discontinuous to a continuous chorus. Discontinuous and continuous choruses are defined as an increase in ambient noise levels of >3 dB, as a result of biological sources, when averaged over a period of one min (McCauley, 2001), and one s (Cato, 1978), respectively.

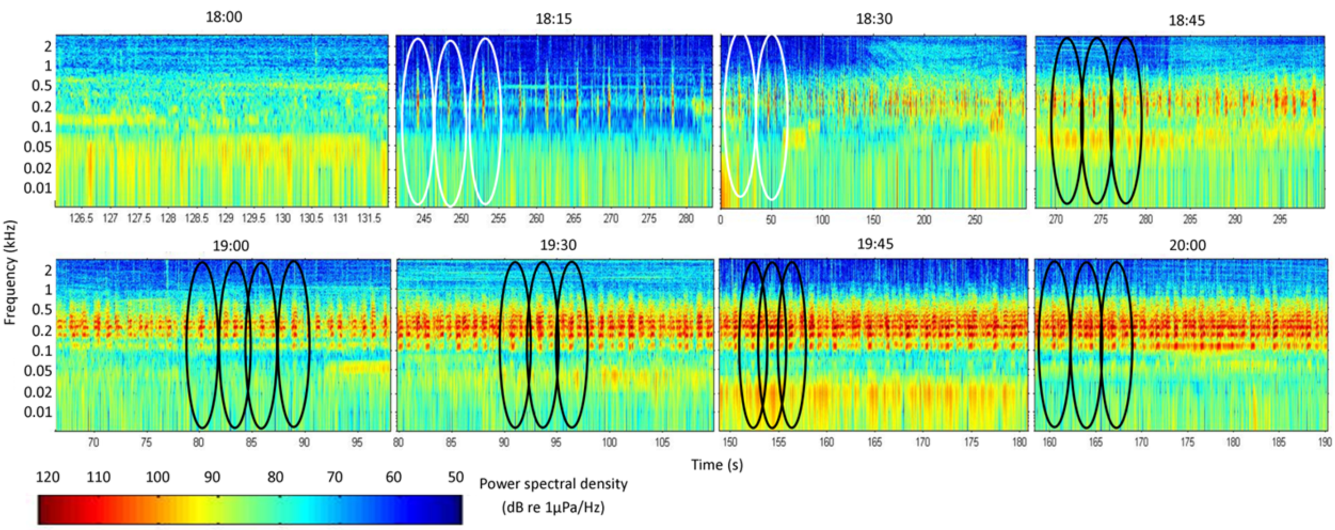

Figure 2: Example spectrograms from recordings taken by the USR as the evening mulloway chorus developed, with calls evident between 100 and 1000 Hz. Calls speculated to be from one individual including few pulses in the 18:00 and 18:15 recordings are highlighted by white ovals, while longer calls in subsequent recordings are highlighted by black ovals.

The most prominent example in the dataset was provided by one fish, first detected on the MS1000 at around 18:15, at a range of 27.4 m from the sonar (Figure 3a, yellow circles starting from the right hand side). Over the course of the following hour and a half the target moves approximately 100 m at an average rate of 0.03 ms^{-1}. It came within 15 m of the sonar, before passing and continuing along the same line of travel (Figure 3a). Over the same period, the USR recorded calls speculated to originate from the same fish, beginning at 18:15:08 and estimated to be at approximately 45-75 m range from the hydrophone, moving towards the USR to ranges of 10-20m. While off-duty periods of the USR preclude confirmation that the same source called in consecutive five minute samples, similarities in range and the on-going detections of the target by the sonar suggest that it was the same source.

While a single fish could be identified and tracked in the PAM data, the ranges of the single target, as detected by sonar and estimated from the USR data, were comparable (Figure 4a, 18:15 to 19:00). Other targets were also detected where ranges between the two techniques were similar (Figure 3, 4) and as caller numbers increased, identifying individual calls became problematic as they overlapped and masked each other, reducing confidence in values of RLs of individual calls. The closest caller, the fish consistently detected by the MS1000, however, was close enough for the signal-to-noise ratio to be sufficiently high for the background noise to have limited contribution to the RL in the USR data. However, at around 19:00 call densities on the USR became such that on-going identification of an individual was non-trivial (Figure 2) and at this time the closest caller to the hydrophone was closer than that of the sonar target (Figure 4a, 19:15 onwards). After this time the MS1000 also detected an increasing number of ‘fish-like’ targets, some quite close to the sonar (Figure 3, right hand images).

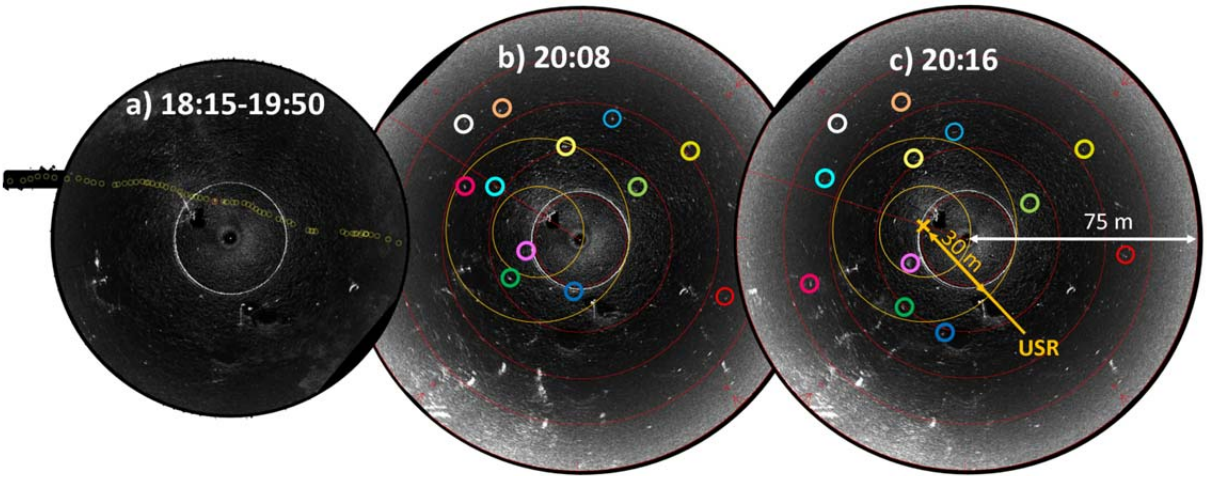

Figure 3: Example sonar scan of the area (50 m radius) surrounding the MS1000, with detected locations of one fish on scans between 18:15 and 19:50 overlaid in yellow circles (a). Scans taken out to 75 m range at 20:08 (b) and 20:16 (c, four scans later) including twelve targets speculated to be fish, marked as circles of different colours. Large red circles in b) and c) depict ranges increasing by 15 m from the sonar, while orange circles denote the same for the USR (location marked by the orange cross, similar to Figure 1).

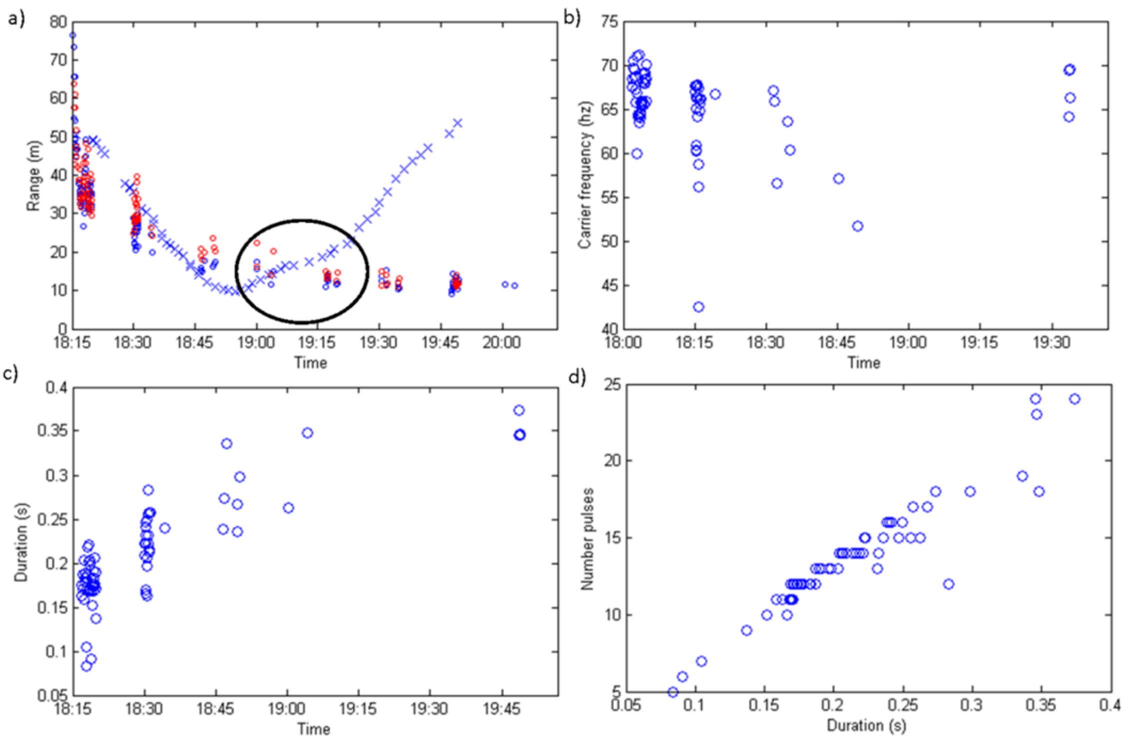

Figure 4: Plots of the relationships over time of range based on sonar (blue crosses), root mean square received levels (blue circles) and sound exposure levels (red circles), with each compared with their respective source levels for mulloway calls from Parsons et al., 2009, 2012 (a). The period of time where callers become present in increasing numbers and confidence in the identification of the specific individual reduces is shown by the black oval. Variations over the evening from the caller in carrier frequency (top right) and call duration (bottom left) and the relationship between call duration and the number of pulses (bottom right) are also shown.

The tracking of one caller for such a prolonged period facilitated observations of call duration and the number of swimbladder pulses within each call as the evening progressed. For the callers where this could be monitored, the number of swimbladder pulses increased within each call, while the carrier frequency decreased (Figure 4b, c, and d). A qualitative observation by the author is that the vocalisations also changed in the call categories determined by Parsons et al. (2013b), as time passed. While the initial calls appeared to be the Category 1 ('short' 2-4 pulse) calls (full analysis could not be conducted as this occurred during the period when vessels masked calls), the caller then progressed to shortened versions of the Category 2a 'long' calls. The caller then included an additional gap between the first two pulses and the subsequent pulse train, as per Category 2b calls, varying the call further (Parsons et al., 2013b).

4 DISCUSSION

This study has shown the utility of matching PAM and scanning sonar as complementary data sources to validate results in the detection and tracking of vocal fish. The USR recorded the evening mulloway chorus from periods where individual callers could be identified and ranges estimated based on previously identified species call source levels and transmission losses (Parsons et al., 2009, 2012). The ranges of calling fish from the USR and MS1000 were in approximate agreement with each other and their speed tallied roughly with those observed previously (Parsons et al., 2009, 2010), i.e. very slow moving (<0.3 ms^{-1}).

The ability of the sonar to detect fish-like targets at range of >50 m shows potential to use this method to validate the number of callers within the area that are detected by the PAM. This is a useful step towards estimating abundance of vocal fish using PAM. The combined detection also provides evidence to use the two methods to define movements of individuals and potentially define fine-scale behaviours associated with calling. Other reports have shown how fauna in the mid-water, particularly megafauna can be detected and tracked in the water column using a combination of passive and active acoustic techniques (Williamson et al., 2014), though to the authors' knowledge this study was one of the first to do this for small (<1 m) targets positioned near the floor.

The anecdotal observations of individual fish changing call types are in line with a previous categorisation of mulloway call types (Parsons et al., 2013a), speculated to involve males using short calls in the lead up to the evening chorus. The observation that a caller then changed from Category 2a to 2b calls (a change in the internal structure of the call) is an interesting note and should be explored further. When considered together with the increase in pulse numbers in each call in the lead up to peak calling, it is suggested that this progression in call categories may be associated with preparation to the full calls that are believe to be advertisement calls of males attempting to attract females.

In the case of this study, the scanning sonar was useful in counting individual fish, at the beginning of the evening and during the dense calling part of the chorus. However, the scanning time of two mins, for the 75 m range, resulted in the potential for more mobile fish to move sufficient distances that confidence in targets detected in consecutive scans were the same fish was reduced. In the last few years, further advances in multi-beam technology have meant the ability to achieve faster update rates with greater ranges, potentially meaning swaths could ensonify broad ranges of water every few seconds, or possibly multiple times a second. Now that the species source level has been identified (Parsons et al., 2012), individual fish can be located and noted as being several m apart, and studies have shown that mulloway are present are multiple sites along the river simultaneously, the ability to map numbers of mulloway in sections of the river is getting closer.

5 FUTURE WORK

The next step in this research will be to verify caller numbers over a broader area to validate both the range and target density for which combined detection can be conducted and develop a better understanding of the relationship between caller numbers and received sound pressure levels in PAM. The ultimate goal of this activity would then be to provide estimates of caller numbers within the area that the aggregation and resulting chorus is known to form, as a method of long-term monitoring of the population. To convert these estimates to absolute abundance requires further understanding of the number of callers present to non-callers. Confirming this ratio requires answering the percentages of males and females that call and the percentages of adults that call and whether immature fish also contribute to the chorus. It will also help verify whether callers maintain a consistent calling pattern throughout the evening chorus. To facilitate answering some of these questions, a broader study, including multiple sound recording systems and sonar systems are to be deployed in the upcoming spawning season.

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