Spawning sounds of the mulloway *(Argyrosomus japonicus)*

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ABSTRACT

In comparison with many complex mammal vocalisations, most fish sounds are relatively simple pulsed broad-band or tonal sounds where pulse rates and/or dominant frequencies are species-characteristic, resulting in several advantages and disadvantages for call classification. Mulloway *(Argyrosomus japonicus)* is a member of the sciaenid family, a group of fish containing several soniferous species. One suggested reason for vocalisation by the family is the attraction of female fish for the spawning process and that a spawning ground populated by 'chorusing' males increases the 'catchment' area of females in the vicinity. The location of one such area has been identified in the Swan River at Mosman Bay, Perth, Western Australia. Hydro-acoustic recordings of vocalisations in the bay, made by several individuals during reproductive periods, were taken and characteristic parameters analysed. Acoustic features of individual callers were discrete enough to distinguish between fish, whilst also comparable to suggest they were of the same species. The regularity of individual callers and their specific frequencies have also been analysed.

INTRODUCTION

Many species of fish aggregate to spawn in habitats where communication through visual stimuli is greatly inhibited by turbidity or lack of light (for example nocturnal spawning or feeding). Thus species have developed alternative methods to vision for communicating, in this case, acoustic communication.

Winn (1964) and Fine *et al.* (1977) summarised sounds produced by fish as associated with one of several categories including: aggressive encounters (commonly territorial), reproductive, echolocation, schooling, recognition, feeding, migration, exploration, distress, and not understood. Several species of fish are soniferous and are characterised by their specialisation in acoustic communication, such as the sciaenids (drums and croakers) (Fish and Mowbray, 1970), signified by their well-developed muscles associated with the swimbladder (Moulton, 1963), and utilise sound as part of their reproductive behaviour (Mok and Gilmore, 1983, Saucier and Baltz, 1993, McCauley, 2001).

Many fish sounds contain species-specific dominant frequencies, waveforms, pulse rates and signal repetition (Lobel and Macchi, 1995, Mann and Lobel, 1998), allowing the identification of a sound by simple parameters, such as duration, peak frequency, repetition frequency and bandwidth (Mann, 2002).

Calling detected close to spawning fish has been commonly reported (Mok and Gilmore, 1983) and recently, techniques employed to locate aggregations from these calls (Holt, 2002, Saucier and Baltz, 1993). However, the production of sound by aggregating fishes may serve several functions and requires identification. The male haddock *Melanogrammus aeglefinus*, for example, produces sounds of varying characteristics in the lead up to, and during courtship (Hawkins and Amorim, 2000). McCauley (2001) speculated these functions in Terapontidae and Sciaenidae may be one or more of: increasing the 'catchment area' of the aggregation; to 'prime' nearby fish for spawning; or to assist in mate selection and mediating gamete release. However, as spawning in these species is invariably in a dark environment after dusk, specific confirmation is difficult to obtain. By comparison, correlations have been shown between calls and spawning related events for several species which can be observed by diver and video, with simultaneous acoustic monitoring, either *in situ* (Lobel, 1992, Mann and Lobel, 1995, McCauley, 2001) or in aquaria (Allen and Demer, 2003).

In recent years anecdotal evidence has suggested aggregations of mulloway form in the lower regions of the Swan River, Western Australia, during summer months. Although previous extensive sampling of the Mosman Bay region of the Swan River did not reveal eggs and larvae of *A. japonicus* (Gaughan *et al.*, 1990), individuals at stage V and VI reproductive maturity (mature and spawning stages respectively) were caught between October and January (peaking in December) during a recent study (Farmer *et al.*, 2005), including females with ovaries containing hydrated oocytes, confirming spawning activity within Mosman Bay.

A. japonicus has sonic muscles in a narrow longitudinal band (one on each side) along the inside of the ventrolateral wall of the body cavity, which are not connected to the swimbladder, typical of some members of the sciaenid family (Griffiths, 1995). Confirmation of vocal behaviour of samples from local waters come from isolated *A. japonicus* at TAFE, Fremantle which are often heard vocalising prior to spawning (Jenkins, 2005, pers. comm.).

Previous passive acoustic recordings taken from Mosman Bay (McCauley, unpublished data) suggest that like other sciaenids *A. japonicus* vocalise over consecutive evenings for extended periods commencing prior to sunset and continuing for several hours into the night. It is the aim of this study to determine whether individual and aggregations of spawning *A. japonicus* can be detected and identified within the Mosman Bay region and the function of their calls determined by the use of passive acoustics.

METHODS

Study area

The Swan River, Mosman Bay estuary is approximately 300 m wide and comprises intertidal areas of up to 1 m depth and a 15 m deep channel with sand substrate and artificial reefs. Anecdotal evidence from fishermen suggests *A. japonicus* are present towards the western side of the river in this area, close to the steeply descending western side of the channel. Recreational fishers also target regions in the north of

the bay and downstream in the Blackwall Reach section of the river. Figure 1 displays the Mosman Bay region of the river and the area targeted during one day of acoustic recording (intertidal areas shaded in grey).

Data acquisition

Passive acoustic recordings were taken over several evenings between January and April 2006, ranging from 18:00, prior to sunset, to 23:00. These recordings were conducted by towing an omni-directional HTI hydrophone from a drifting 4 m vessel. Digital recordings were logged on Digital Audio Tapes (DAT) with a Sony D100 DAT recorder. Signals were sampled at a longplay frequency of 32 kHz. On each occasion grids of 5-8 minute transects were conducted repetitively throughout the evening, in a minimum of 3 m of water. Three sets of six transects conducted during the evening of the 17th January are shown in Figure 1. The same transects were conducted three times approximately an hour apart to obtain data concerning the change in detectable vocalisations from that location throughout the evening. Transects conducted during the evening of the 17th covered an area of approximately 100,000 m^2; however, prior and subsequent surveys were also conducted over a more extensive area.

Data processing

Recordings were transferred to digital files by means of a DP430-FFT Analyser (Data Physics Corporation). The data were processed using Matlab programs developed by the Centre for Marine Science and Technology (CMST), Curtin University, and passed through low (50Hz) and high (1000 Hz) pass filters to limit noise effects of hydrophone movement and shrimp. Analyses of data were then conducted from spectrograms and waveform plots, produced in Matlab. The combination of the digitising software and present Sony DAT recorder is currently uncalibrated and thus any quantitative response analysis must be considered relative. It should be noted that while spectrographic images shown within figures are based on the same scale, Power Spectral Density (PSD) values are relative.

RESULTS

Recordings acquired from Mosman Bay broadly illustrate the advantages and disadvantages of passive acoustics in the fine-scale study of spawning aggregations within a relatively enclosed, shallow environment accessible to human activity.
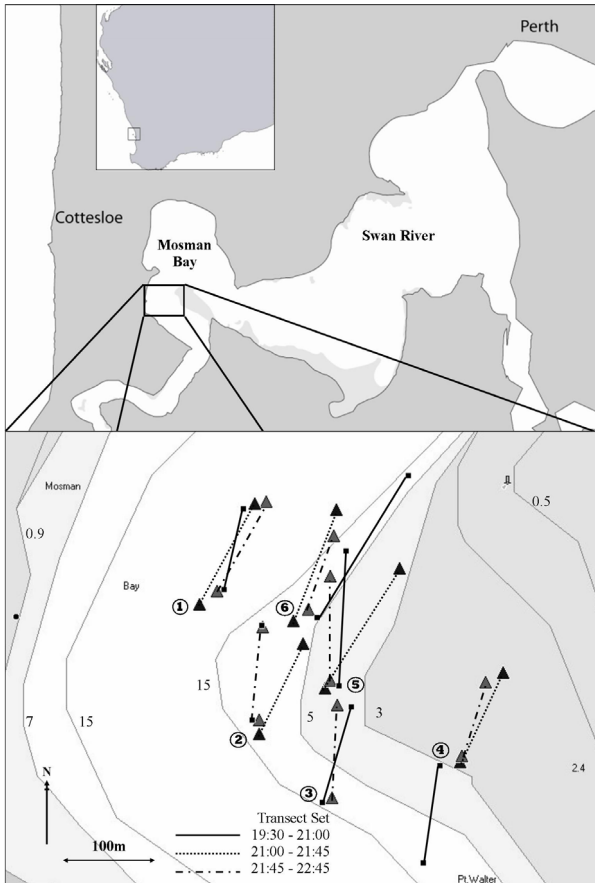

Figure 1. A map of the Swan River, Western Australia, including an outline of the study area with example transects recorded on the 17th January 2006 shown. Circled numbers display the order in which acoustic transects were conducted. Map courtesy of J. How, ECU.
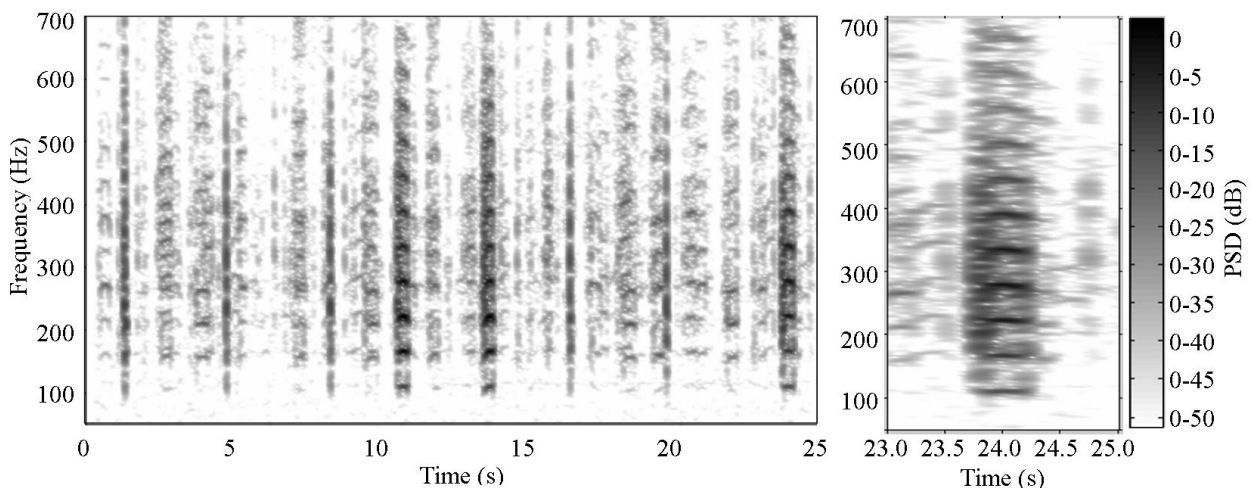

Figure 2. Spectrogram of signals recorded during the first 25 seconds of transect , 19:35:07 17th January in Mosman Bay, Swan River. The right image shows a close-up of a single call speculated to originate from *A. japonicus* between 23 and 25 seconds into recording.

Spectral Density

Figure 2 is a spectrographic display of 25 s recording taken at the beginning of transect 1, approximately in the middle of the channel (15 m depth). Darker areas show an increase in detected sound pressure levels at particular frequencies. Aural examination of the recordings suggest these data comprise predominantly fish calls, similar to those sounds produced by other sciaenids, and to a minor extent, shrimp clicks not removed by filtering. In this section, three calls stand out in particular at approximately 11, 14 and 24 s. Figure 2 displays spectral intensity at various frequencies and an estimation of the call length (though sample overlap in the production of this image results in an overestimate). To the right of Figure 2 is a magnified display of the 24 s call, highlighting sidebands of amplitude modulation of the signal (Watkins, 1967) discussed later, and providing an idea of the call structure, signified by the intense areas slightly below spectral lines at the start of the call (23.75 s). Typically spectrographic images displayed that call modulation frequencies of approximately 55 Hz were still visible as spectral lines from 50 Hz up to 1000 Hz, though tone burst carrier frequencies always remained between 250 and 300 Hz. Figure 2 also displays variation in the call types detected, for example the calls at approximately 1, 5, 9 and 16 s differ from those at 11, 14 and 24 s. This call variation will be discussed later.

The data also shows a large number of calls at differing spectral densities. If it is assumed that fish call at similar intensities over a short period of time this suggests that the calls of differing intensity are coming from varying distances from the hydrophone and probably from different fish. Anecdotal evidence from divers suggest that during the vocalising period *A. japonicus* 'nest' in the substrate for prolonged periods of time, possibly in the same way that weakfish form 'leks' (Gilmore, 2002) corroborating the assumption that calls originated from different sources.

Waveforms

Waveforms of the hydrophones' detected voltage provide significant data on amplitude and structure of each signal. Figure 3 illustrates the waveform produced from filtered data of 50 s recorded during transect 1, the first 25 s of which are displayed in the spectrogram in Figure 2. Calls mentioned above are visible with the highest response amplitudes in the first half of the top waveform. Sections of the waveform (bordered by dotted lines) have been expanded to demonstrate the structure of the individual call at 24 s (also magnified in the spectrogram of Figure 2). This figure highlights the tone bursts generated during the call, and below, the structure of a single burst. These features are characteristic of amplitude modulation (Watkins 1967) and typical of muscular modulation of a swimbladder. The call comprised 22 bursts over 39.80 ms, typical of a particular type of call discussed later. Signals with lower amplitudes, corresponding to calls from fish thought to be a greater distance from the hydrophone are also visible throughout Figure 3 (top image).

Visual comparisons of individual calls often detected marked similarities between waveforms. Figure 4 illustrates the waveform of bursts from three different signals. Calls 1 and 2 are expanded waveforms from signals also shown in Figure 3 (31 and 36 s respectively), while Call 3 was recorded approximately half an hour later at a location approximately 250 m away. The similarities in structure between Calls 1, 2 and that displayed in Figure 3, combined with their proximity in time and location suggest that these calls originate from the same caller. It is estimated that minor changes in the waveform could be interference caused by variations in acoustic ray paths due to vessel drift. The marked difference

in burst structures shown in Figure 4, particularly the initial response amplitude where an extra cycle can be seen in the tone burst, imply that Call 3 originates from a different source.
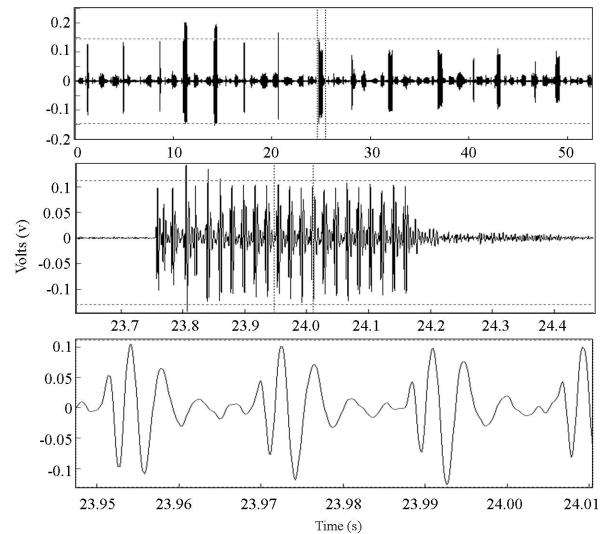

Figure 3. Waveforms from 50 s recording of transect 1 taken at 19:35 pm 17/01/06. Borders of magnified sections are highlighted by dotted lines in the prior image.

The waveforms of individual bursts within signals at 11, 14, 43 and 49 s were also similar to the structures of Calls 1 and 2, suggesting that all these calls originated from the same fish. The detected voltage amplitude over the course of these calls varied from a maximum of 0.35 v in the first call to a maximum of 0.0175 v in the last call, 38 s later. During this time the vessel had drifted 7.14 m.
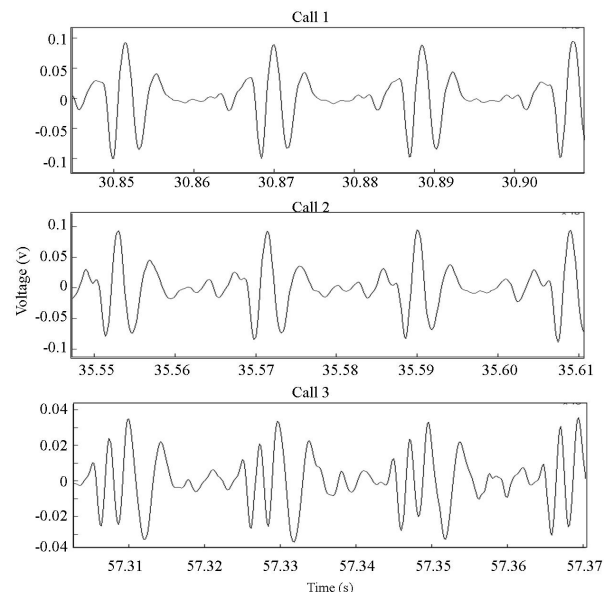

Figure 4. Waveforms from three individual calls recorded during the first two transects on 17/01/2006.

Further analysis of the three calls in Figure 4. showed that the modulation frequencies and the structure of the overall call displayed variations. Figure 5 shows spectrograms of the three calls. The structure of Calls 1 and 2 display similar carrier and modulation frequencies and also the same intensity at fractionally lower frequencies at the start of the call. Call 3 displays spectral lines lower than those of the other two calls and also less change in frequency over time.
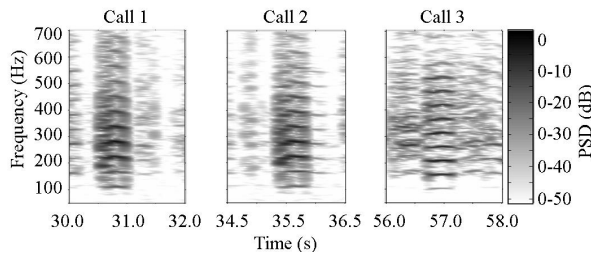
Figure 5. Spectrogram plots of the three recorded calls shown in Figure 4.

The carrier and modulation frequencies are also displayed more accurately as the spectral peaks in Figure 6. This spectral density plot against frequency is averaged over the length of each call. The call is considered to commence at the first detectable change in voltage amplitude and finish one burst period after the last burst has begun. Carrier and primary modulation frequencies in Calls 1 and 2 (223.8, 279.75 and 335.7 Hz), differ significantly from that of Call 3 (208.5 264.5 and 315.35 Hz) confirming that the Call comes from a different individual.
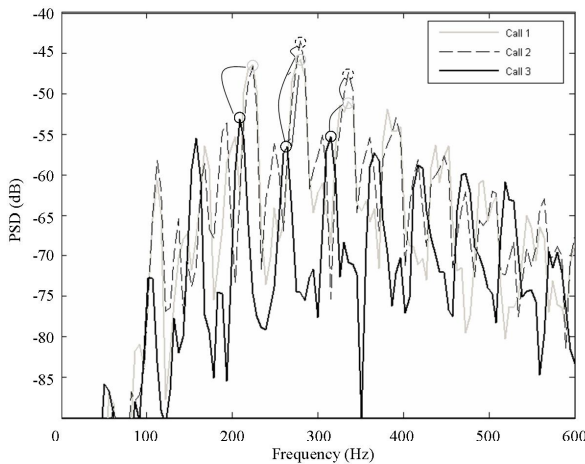

Figure 6. Power Spectral Density (PSD) against Frequency showing dominant spectral peak and modulation frequencies of Calls 1, 2 and 3 from the previous figures. Connected circles highlight the differences in spectral peaks for the calls.

Types of call

Preliminary analysis of individual calls throughout recordings resulted in general classification of identifiable fish calls into four types: Type 1 (Baaarp), a single audible signal consisting of many tone bursts in which the amplitude of the initial burst are lower than that of those succeeding them; Type 2 (Ba-baarp), comprising two (occasionally three) preliminary bursts followed by an interval equal to one burst and then many bursts of increased amplitude; Type 3 (Bup), a short signal consisting of two or three bursts, generally of lower amplitude than the longer calls; Type 4 (Bup), a short signal similar to Type 3 with an apparently prolonged impulse and period between pulses. Examples of waveforms for each of these call types can be see in Figure 7.

Variations in vocal behaviour throughout the evening calling cycles were apparent from the changes in call types heard. In late afternoon (sometimes several hours before sunset) calls have been recorded comprising predominantly of type 3. Typically, as the cycle proceeds these calls are replaced by types 1 and 2 with increased regularity and number of callers. Several hours after the cycle commenced calls of type 1 and 2 dwindle in number and those of type 4 become more prevalent. Some examples of call types and their properties from data recorded on 17th January are shown in Table 1.
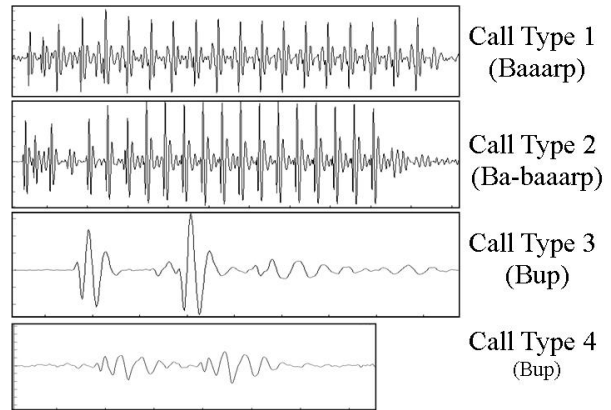

Figure 7. Waveforms of four classified types of detected fish calls thought to originate from mulloway.

Table 1. Mean values and standard deviations of example call characteristics of four identified types of call.

Call Type	Mean Peak Frequency (Hz)	Mean No. Bursts	Mean Burst Length (ms)	Mean Call Length (ms)
1	261.3 (± 42.82)	20.96 (± 3.36)	18.5 (± 1.44)	390.9 (± 61.2)
2	264.0 (± 41.76)	17.55 (± 2.98)	19.4 (± 1.32)	399.2 (± 54.6)
3	277.1 (± 52.89)	2.20 (± 0.41)	19.6 (± 3.67)	50.6 (± 15.4)
4	250.9 (± 27.56)	2.00 (±0.00)	28.2 (± 0.61)	56.4 (± 7.82)

Source: (Parsons *et al.*, 2006)

It should also be noted that during recordings there were also periods where comparatively few calls were detected. These periods tended to occur after the height of vocalisation while fish employed type four calls and lasted up to approximately a minute at a time. The extent and cause of these episodes are yet to be analysed.

Temporal analysis of spectrograms and waveforms revealed that for some periods individuals repeated calls with regular intervals. Figure 8 illustrates some examples of this regularity with three callers exhibiting repetitive calls. It also displays areas where multiple callers result in a signal which cannot easily be split into individual contributions (dashed line). Callers 1 and 2 appeared to have approximately 4 s between calls. A third caller may have exhibited similar behaviour, however, at that point multiple vocalisations were recorded (approx. 35 s) and were difficult to confirm. Periods of repetitive calling by suspected individuals has been detected throughout the recordings, however, analysis of their occurrence has not yet been conducted.

Estimating call numbers

Table 1 shows it is possible to count individual calls from the majority of the detected signals. There were also a significant number of calls where signal amplitude and waveform were not clear enough to be classified as originating from a single source, possibly due to multiple sources (shown in Figure 8) or interference from multiple ray paths. Further analysis is required if these calls are to be classified.
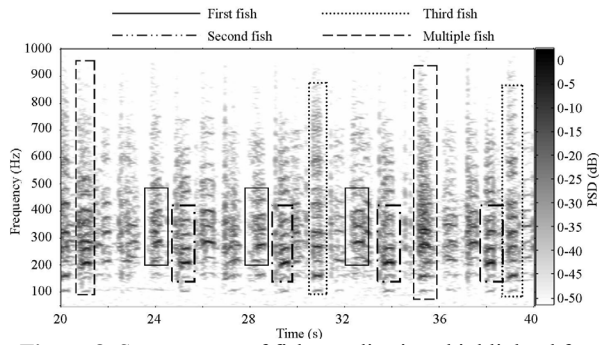
Figure 8. Spectrogram of fish vocalisations highlighted for periodicity of individual callers.

Biological noise

Evidence of biological noise unremoved by the filtering process was present throughout the recordings. Figure 9 illustrates some of this noise and the relationship with the fish calls. The shrimp click present at approximately 30.38 s contributes a large and easily discernible amplitude change in the wave form, however, as shown by the spectrogram, only a small proportion of that noise is present at frequencies relevant to the analysis of the fish calls. Two signals succeeding the shrimp click demonstrate the extent of the fish call frequencies. The signal detected at 31.13 s is currently of unknown origin, though the spectrogram shows that this signal extends into frequencies relevant to the analysis of speculated *A. japonicus* calls.

Vessel noise

Figure 10. displays the effects of noise created by a passing vessel, in this case at a distance of approximately 100 m. During this recording (probably due to the late stage in the vocalising period) the detected fish signals were weak. Vessel noise is visible in the spectrogram as horizontal dark lines, and in the waveform as increased background voltage amplitude in comparison with Figure 3. where no audible vessel noise was detected.
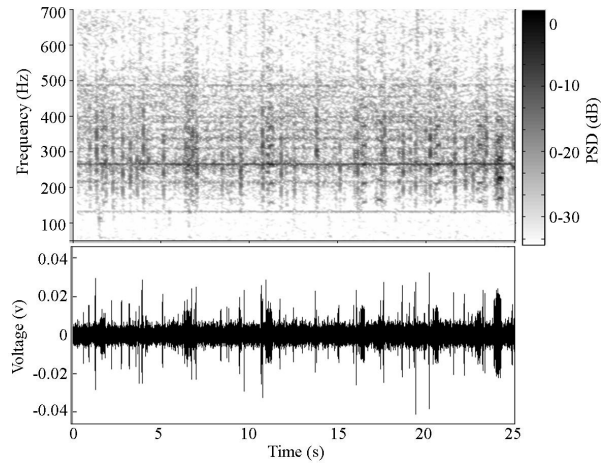
Figure 10. Spectrogram and waveform of a recording taken at approximately 21:30 illustrating the effects of contributing vessel noise at frequencies similar to that of the signals produced by fish. Horizontal dark lines in the spectrogram result from passing vessels.

DISCUSSION

The data have shown that significant numbers of vocalisations from numerous individuals were present within the Mosman bay region of the Swan River during times where the presence of spawning *A. japonicus* have been confirmed by biological sampling. These calls have been detected throughout evenings with episodes commencing, on occasion, several hours before sunset and continuing into the night. Recorded vocalisations had significantly higher sound pressure levels than background noise allowing detailed analysis of individual calls. Detected vocal signals were very similar to those produced by other members of the sciaenid group suggesting that the recorded signals originate from spawning *A. japonicus*.

Analysis has shown that recorded vocalisations are discrete enough to count the majority of calls, although several occurrences of multiple callers and the effects of multiple ray paths resulted in many unclassified calls. From this analysis it has been shown that an individual fish may be monitored throughout the calling cycle of an evening.

Although mulloway sounds contribute the majority of the sound pressure levels between 50 and 1000 Hz the data has
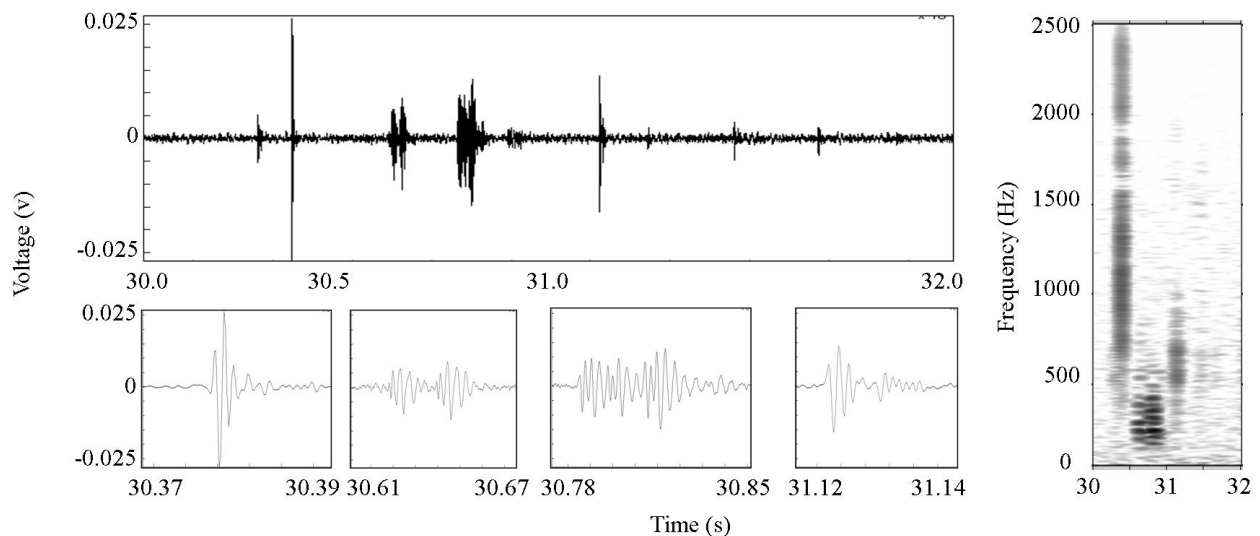
Figure 9. Waveforms (left) and spectrogram (right) from detected sounds of various sources. Expanded waveforms (left to right) illustrate a shrimp click, two Type 4 fish calls and a call of unknown source

detected several other sources of noise in the river. Filtered data still show evidence of shrimp clicks (though predominantly at frequencies above the range of mulloway calls), vessel noise and noise from unknown sources. Passing vessels, though sporadic, contribute a significant amount of noise to the data at frequencies similar to those of mulloway calls. Automated filtering of this noise is currently inadequate for the accurate analysis of spawning vocal behaviour. Other biological noise has so far only been detected to a minor extent and may, at this stage, be considered not to affect the overall results.

It has been possible to distinguish between individual callers by both the waveform and the dominant frequencies of a call. It is believed that there is a relationship between the swimbladder volume and the PSD/Frequency curve, although this is yet to be analysed. The eminence of carrier and modulation frequencies and waveforms to discriminate between fish implies that the swimbladder volume/frequency relationship has some bearing on the spawning activity, possibly mate selection.

If, as the anecdotal evidence suggests, the assumption that vocal fish remain stationary is correct it is possible to discriminate between individuals by the detected voltage amplitude of the signal. It is then possible infer a distance from hydrophone to source from the detected voltage amplitude and estimate locations of callers by variation in amplitude due to relative vessel movement.

Periods of regular repetitive calling by individuals have been detected within the data. Whether this is due to behavioural characteristics of the callers or instrumental characteristics such as the hydrophone only detecting nearby fish before the vessel drifts out of range is yet to be determined. Cause and frequency of repetitive calling periods requires further analysis as it will have significant impact on call counting and future estimation of fish numbers from data acquired with a single hydrophone.

Analysed data displayed call structure variation within call types not only between different callers, but also between calls speculated to originate from the same fish. The number of bursts in call type one speculated from one source, for instance, varied between 17 and 24 bursts and therefore call lengths of 311.04 and 436.22 ms respectively. Between fish this variation becomes 16 and 30 bursts, and 274.56 and 529.92 ms in call length. This suggests that fish calls are created with a mechanism in which the caller does not hold control at such precise levels, or some environmental factors affect each individual call.

The data have revealed a possible relationship between call structure (amplitude and interval variation between pre-clicks in call type 2 calls and the successive bursts) and PSD/frequency plots. After further analysis this relationship may aid in discriminating between fish.

Vocal behaviour of the spawning mulloway varies significantly throughout an evening's episode of calls. Calls detected in the afternoon were sparse in number and regularity, and also of a different structure by comparison with those at the height of the calling period in the hours around sunset. It is possible that these calls have a preparatory function before spawning activity commences. There was also significant change in calling behaviour later in the calling period where the call type changed again, though numbers and regularity remained high before diminishing at the end of the cycle. It is possible the various types of call originated from different species, or gender, which still requires confirmation, though

waveforms of all types of analysed calls were significantly similar to sciaenids.

Farmer (2005) concluded that spawning occurred with evening slack high tide thus egg and larvae could be quickly removed with the ebb tide, promoting survival. This behaviour would result in variation of calling period times throughout the month and provide a reason behind anecdotal evidence that calls have been heard in Mosman Bay as late as 3 am. Current analysis does not offer a sample of sufficient size to confirm whether this variation exists, although CMST have acquired datasets from sea-noise loggers, deployed in Mosman Bay throughout the 2004-5 and 2005-6 spawning period which should confirm or disprove this conclusion. Anecdotal evidence has also suggested a lunar cycle to the spawning of *A. japonicus* in Mosman Bay the authors have yet to analyse the long datasets held to check if call rates exhibit this pattern.

Once relationships between call patterns and behaviour have been determined it should be possible to calculate calling numbers, not only fish call counting, but also from callers' contribution to the overall Sound Pressure Level (SPL) in the detectable range of the hydrophone (Sprague and Luczkovich, 2002).

CONCLUSIONS

It has been possible to identify individual fish calls, originating from *A. japonicus*, in Mosman Bay against biological and anthropogenic noise. However, further data processing is still required to reduce remaining noise levels, in particular those originating from passing vessels.

Callers have been identified from characteristic waveforms, frequencies and call structures, though significant variation has been determined in an individual's call structure. Further analysis is required to determine cause and effect of this call variation. Discrimination has also been applied through variation in detected voltage amplitude which, once calibrated, may facilitate the estimation of source distance from the hydrophone.

Significant variations have been detected in the aggregation's vocal behaviour throughout the course of an evening calling cycle. Future ground truthing data are required to confirm that the use of different call types is employed by individual fish. More comprehensive datasets will reveal the extent and hopefully the cause of this behaviour.

Verification of the origins of signals detected in the Swan River remains an issue. Turbidity and nocturnal behaviour inhibit identification of signal sources as that of vocalising *A. japonicus*. Future plans to correlate calls are: recording signals produced by captive *A. japonicus* to compare waveforms with signals recorded in the river; underwater video to confirm 'nesting' behaviour of *A. japonicus* to compare with vocalisations at a known location; and the deployment of an array of hydrophones to accurately locate vocalising fish using differences in signal arrival times and compare with data acquired from a planned acoustic tagging program for locations of tagged fish with known vocal characteristics. Data acquired from a hydrophone array will also confirm calling strength of individual fish and density packing of the aggregation as a whole.

Deployment of a long term stationary sea-noise loggers, recording five minutes of every fifteen, continually throughout the spawning seasons provides comprehensive data on vocal behaviour of callers within the detectable range of the logger. Analysis of these datasets should reveal confirmation of an-

nual, lunar, diel and tidal aggregation formation, as well as mobility data of vocalising fish.

The discrimination of callers means that it will be possible to determine the number of vocalising fish within the range of the hydrophone by counting calls. Once calibrated, data from an array of hydrophones should be able to estimate numbers of fish in the Mosman Bay area not only from call counting, but also their contribution to the overall SPL.

ACKNOWLEDGEMENTS

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