CHARACTERISATION OF MULLOWAY *ARGYROSOMUS JAPONICUS* ADVERTISEMENT SOUNDS

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Increasingly, fishes are reported as using acoustic variations in calls for different environmental and social contexts. However, to understand call functions and their associated behaviours it is first necessary to separate and characterise the species call types. During the Austral summer, mulloway (*Argyrosomus japonicus*), a vocal sciaenid, aggregates to spawn in the lower regions of the Swan River, Western Australia. *In situ A. japonicus* calls recorded here exhibited call spectral peak frequencies between 175 and 350 Hz and pulse repetition rate of 59 Hz. These swimbladder driven calls were categorised into; short grunts of 1-6 pulses ('Bup'), more predominant as the aggregation forms and separates; long grunts comprising 11-32 pulses ('Baarp'), most prominent in the hours after sunset; and a series of short calls comprising 1-5 pulses ('Thup') that increase sharply in call rate over a period of tens of seconds. This last category was observed only once or twice each evening. The second category was divided into several types of call where a single audible tone can also be broken into two or more parts, often preceded by one or more short 'Bups' (for example, 'Bup-bup-baarp').

INTRODUCTION

Many species of fish are soniferous, producing sound in a variety of contexts, most commonly spawning [1-3]. The waters of Western Australia are home to many types of fish calls and choruses, some of which may be associated with spawning [4-6]. Passive listening to a chorus of aggregating fish can greatly improve a biologist's ability to delimit spawning areas for conservation of essential fish habitat and identify movement patterns of the callers without creating behavioural bias [7-12]. However, to understand the timing and spatial extent of spawning behaviour, it is necessary to characterise the functions of calls produced during the reproductive period and identify the mobility of the fish over the calling period. This is because fish reproduction (and vocalisation) can comprise a complex array of behaviours that are associated with spawning, for example competition or courtship, but the may be spatially and/or temporally separated from the act itself [13-15].

Sciaenidae is a very vocal family of fish known as croakers or drummers [16,17]. Often only the males of the species possess the specialised 'sonic' muscles used to vibrate the swimbladder and produce sounds for which the family is renowned and in many cases competing males call repetitively, either individually or in a group, to attract a female with which they can spawn [18]. Mulloway (*Argyrosomus japonicus*) have been shown to produce sounds during spawning [19] and while both male and female *A. japonicus* possess sonic muscles, in previous studies the males produced almost all of the advertisement related sounds [20].

During the Austral summer, mature *A. japonicus* form spawning aggregations in Mosman Bay, Swan River (Figure 1), where catch data from studies during the 2004-5 and 2005-6 spawning seasons reported a mean total length of 101 cm [21]. Many of the fish captured in those studies were close to spawning maturity (discharged milt upon capture) or had very recently spawned, confirming times of spawning [22].

The aims of the study detailed here were to describe *in situ* vocalisations of *A. japonicus* in Mosman Bay, produced at times when spawning is known to occur in the area. The study also investigated whether different types of call and their occurrence throughout an evening spawning cycle could be discriminated by the observer.

METHODS

Passive acoustic recordings were taken in Mosman Bay over 37 evenings between November and March, during the 2006, 2007 and 2008 spawning seasons, from 17:00 hrs (prior to sunset) to 01:00 hrs. In Mosman Bay, the river banks descend rapidly to a 21 m deep channel comprising a sand/silt substrate of low acoustic reflectance (Figure 1) [23]. A few artificial reefs and several depressions are present, some of which reach 22 m depth at high tide. During recordings the water temperature in the bay ranged between 18 and 26° C.

Acoustic data were acquired using omni-directional HTI-90U (Hi-Tech Inc., MS, USA) hydrophones connected to Centre for Marine Science and Technology (CMST) – Defence Science and Technology Organisation (DSTO) developed sea-noise loggers located on the riverbed. Highpass (50 Hz) and lowpass (1500 Hz) filters were applied at various stages of data processing to remove noise. Spectrograms were produced using a 1024 or 2048 point Hanning window with 0.7 overlap. For analysis, the start of each call was taken as the first detected amplitude peak in the call pressure waveform and referred to as the Call Initiation Peak (CIP). The end of a call was noted as the point at which the final pulse decayed below background noise. The following characteristics of each call were recorded: call duration, pulse period, number of pulses in a call, pulse repetition rate (PRR) and spectral peak frequency. Where calls were speculated to originate from the same source the time between calls was noted.

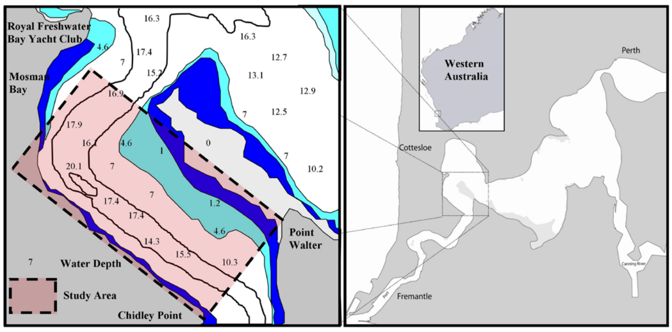

Figure 1. Map of the Mosman Bay study site and location within the Swan River, Western Australia

RESULTS

The light levels and turbidity at the time of *A. japonicus* calling restricts visibility to less than 2 m, thus video confirmation of calling was not possible. Lack of sexual dimorphism inhibited determination of sex of the calling fish. Anecdotal evidence from diver interactions with calling mulloway (including authors) confirmed them as the source of calls recorded in this study. Distress calls of *A. japonicus*, similar to the calls described here, have been reported anecdotally by fishers though they have not been recorded at this site.

Each evening, numerous *A. japonicus* calls were recorded with periods of low- and high-density calling. During low-density calling individual calls could be discriminated from each other and background noise (Figure 2). Calls were divided into three predominant categories, defined by the acoustic features and timing. Each call type comprised trains of swimbladder pulses of varying characteristics (Figure 2c, Table 1) and displayed sidebands of amplitude modulation typical of such sounds [24]. Between 19:30 and 23:00 many calls were masked by louder calls from other, closer fish and could not be counted. Due to interference, overlap between calls, or low signal-to-noise ratio, there were a number of calls where it

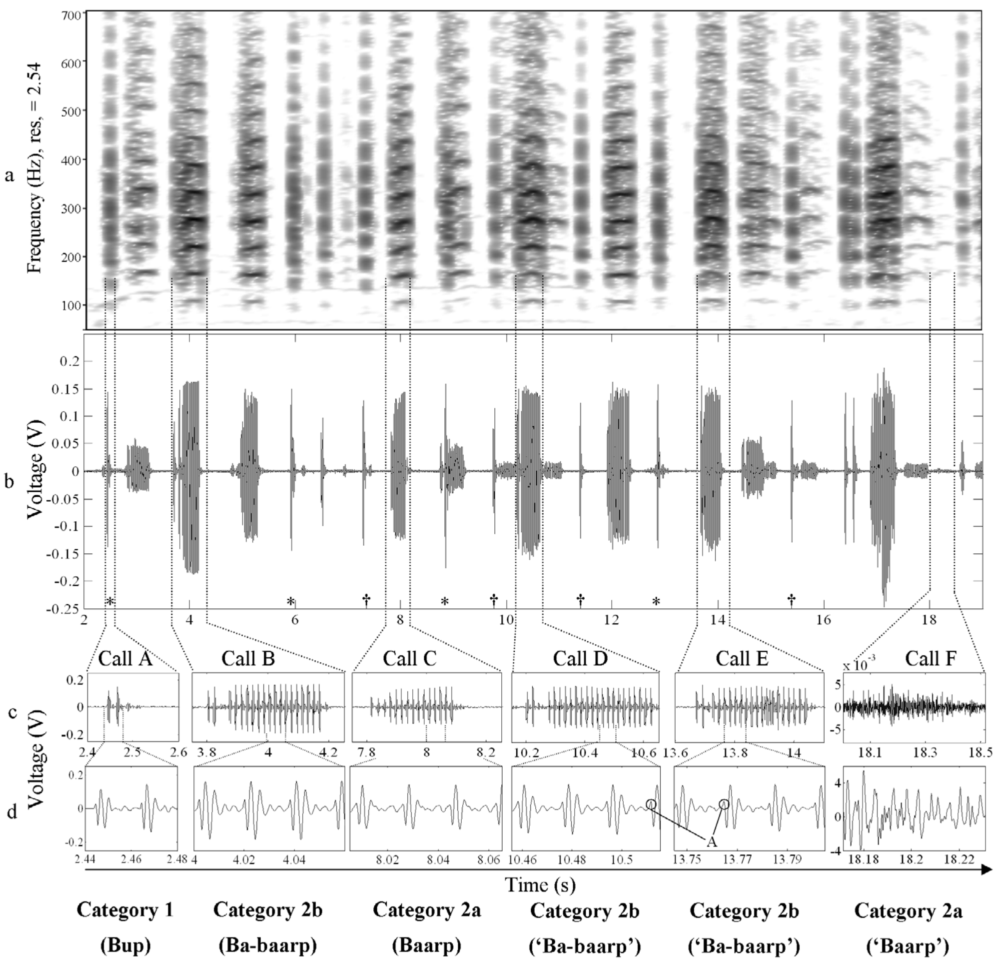

Figure 2. Spectrogram (a) and waveforms (b) from 17 seconds of Mosman Bay *A. japonicus* calling, recorded at 4 m depth in 19 m of flat water at 19:35, 17th January, 2007. Expansions of six selected call waveforms highlighting the entire calls (c) and sets of swimbladder pulses (d) are shown. Call F highlights an audible call of low signal-to-noise where waveform structure is distorted by noise. * and † denote examples of suspected repetitive Category 1 calls from individual fish.

Table 1. Example acoustic characteristics of all *A. japonicus* calls on the 5th March 2008 taken from the first minute of each hour between 17:30 and 23:31. Sunset occurred at 19:43

Time	Call Type	Number calls (no. analysed)	Call duration (s) x 10-1 (max, min)	Pulse number (max, min)	Modulation frequency (Hz) (max, min)	Spectral peak frequencies (Hz)
Total	1	509 (140)	0.56 ±0.25 (1.58, 0.26)	2.8 ±0.9 (6, 2)	52.6 ±10.9 (79.7, 36.2)	251
	2a	498 (170)	3.66 ±0.76 (5.27, 1.7)	21.6 ±4.5 (32, 9)	60.0 ±2.6 (63.8, 48.6)	250
	2b	81 (28)	3.94 ±0.68 (5.27, 2.68)	20.6 ±3.7 (30, 15)	52.4 ±3.9 (58.1, 43.00)	245
	2c	24 (12)	4.15 ±0.46 (4.54, 2.74)	22.75 ±4.0 (26, 18)	54.75 ±6.7 (62.6, 47.7)	275
	3	1 series (31)	0.22 ±0.12 (0.04, 0.09)	2.1 ± (4,1,1.09)	91.3 ±10.3 (114.2, 74.3) (22 measured)	260

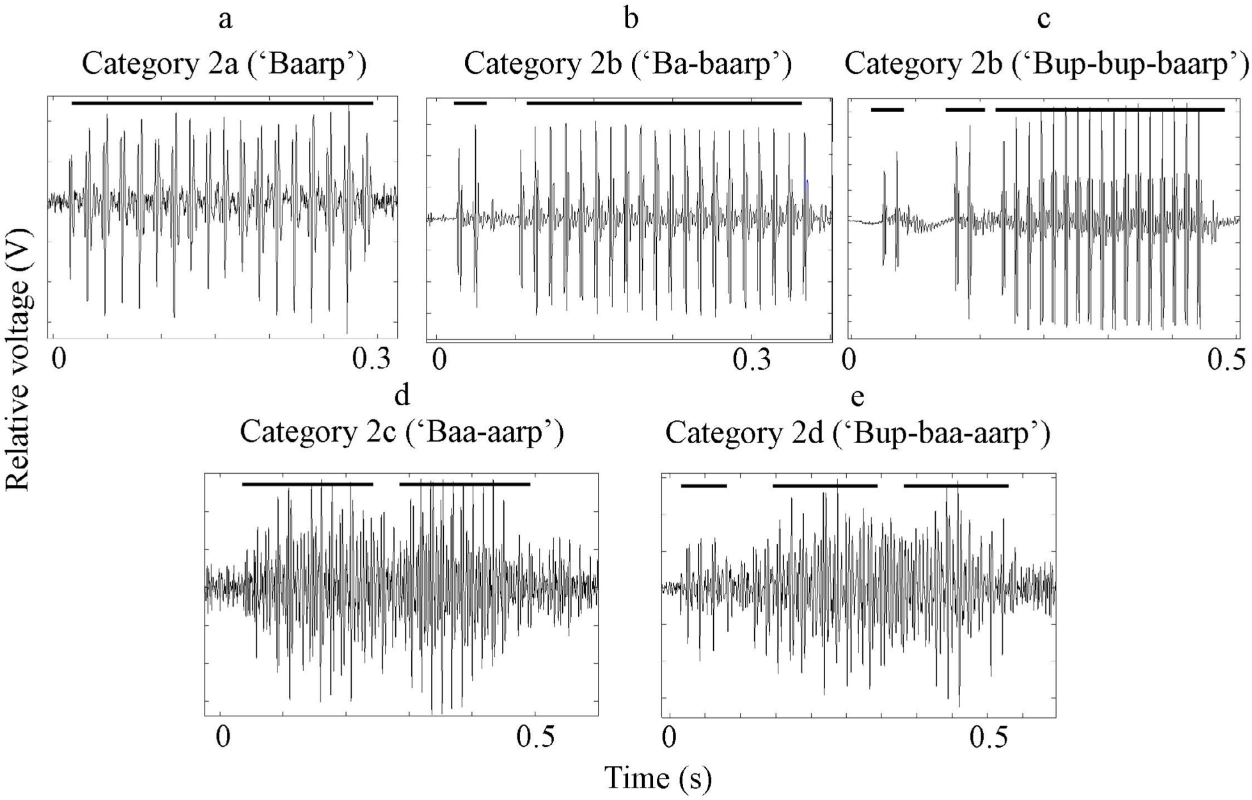

Figure 3. Waveforms of various detected Cat. 2 calls. Black lines shown above each waveform provide an impression of the audible periods of tone structure for each call type

was not possible to discern some acoustic characteristics (such as number of pulses or pulse duration) despite the call being distinguishable to the human ear. Across all call types spectral peak frequencies between approximately 175 and 350 Hz were observed, with sidebands of amplitude modulation at regular intervals (55.1 ±9.87 Hz, n = 350).

The majority of calls recorded were classified into two significantly different categories (Welch's t-test), depending on the number of pulses and duration of the call. To the ear Cat. 1 short calls (Figure 2c, Call A) sounded like a "Bup" and comprised 2.8 ± 0.92, n =140 pulses at a mean PRR of 52.6 Hz (Table 1). These signals were classed as an individual call if no further call, deemed to be from the same individual, followed within a second.

Cat. 2 calls were significantly longer than Cat. 1, comprising between 9 and 32 pulses (Table 1; Figure 2, Calls B-F). This category of calls comprised successive swimbladder pulses at sufficient PRR to be discerned by the listener a single audible tone (*pers. obs.*). However, this tone was often broken into constituent parts by a short cessation of pulses within the train (Figure 3, where the audible part of each call is marked with a black line). The gap in the acoustic tone most commonly occurred after the initial two swimbladder pulses and lasted between one and three pulse periods (Figure 3b). However, the position of this gap within the pulse train was found to vary. As a result, Cat. 2 calls were classified into five different types. Cat. 2a was a single audible tone, unbroken by pulse cessation ('Baarp'; Figure 2c Call C and Figure 3a). If the tone was preceded by one or more of the two pulse 'Bups' it was classed as Cat. 2b ('Bup-baarp' or 'Bup-bup-baarp'; Figure 2c

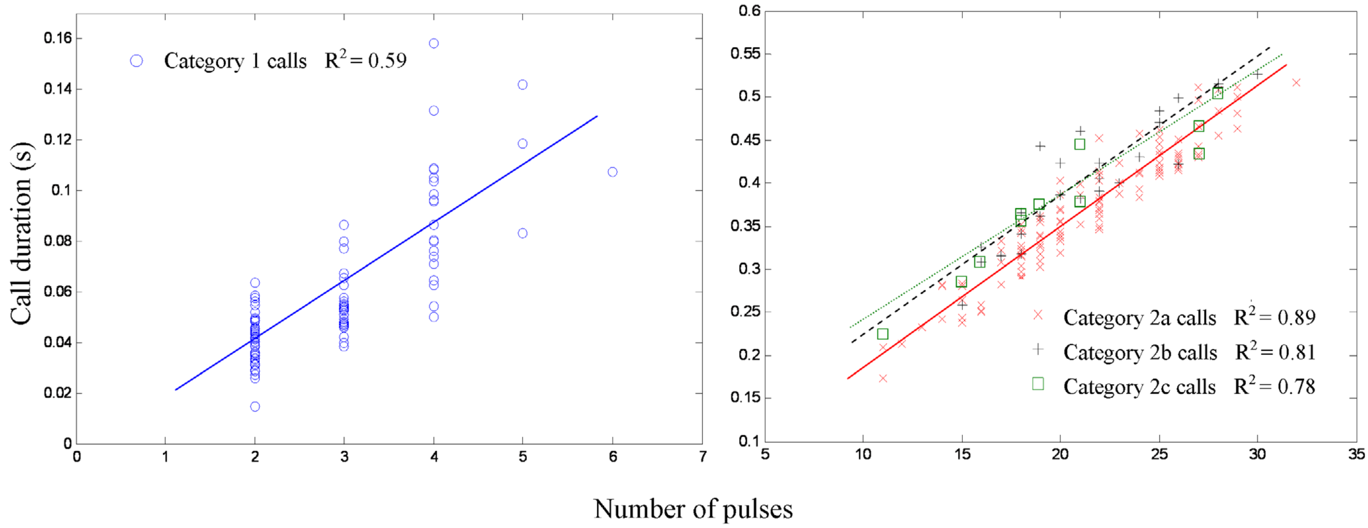

Figure 4. Distribution of calls as a function of numbers of pulses within the call (a), together with the relationship between the number of pulses and the duration of the call for Cat. 1 (b) and Cat. 2 (c) calls. Correlation coefficients of Cat. 1(○), 2a (x), 2b (+) and 2c (□) calls were r^2=0.59, 0.81, 0.81, 0.78, respectively.

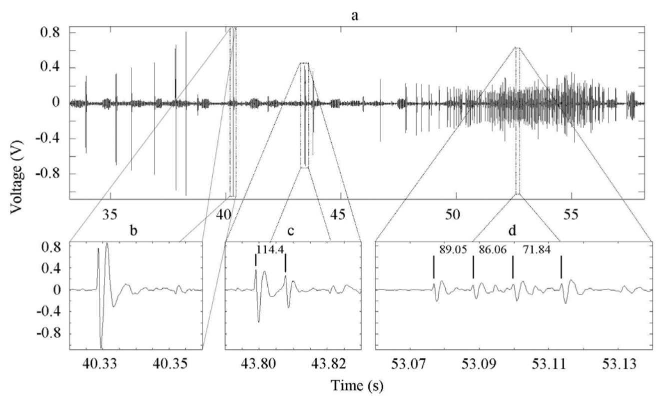

Figure 5. Waveforms of a series of Category 3 calls (a) recorded on the 8th March, 2008 at 19:57 post sunset. Expansions of single (b), double (c) and quadruple (d) pulse calls within this category are also shown with pulse repetition rates highlighted above (Hz). As with all Category 3 calls the PRR of the multiple pulses in (d) decreased through the call (i.e. the spacing between pulses increased)

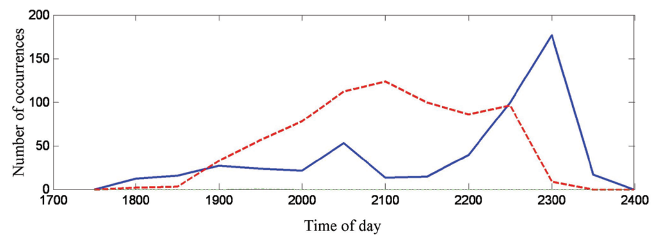

Figure 6. Number of occurrences for each call in the first minute of every half hour of an example evening spawning cycle from 17:00 to 24:00. Category 1 (continuous line) and Category 2 (dashed line) are shown, however, an unknown number of calls could not be counted between 19:30 and 23:31 due to call overlap

Calls B, D and E, and Figure 3c and c). Cat. 2c calls contained a break later in the call ('Baa-aarp'; Figure 3c). Finally, Cat. 2d calls contained a number of different parts characterised by two of more points of cessation within the call ('Bup-baa-aaarp'; Figure 3c).

In general, recorded mean peak-to-peak amplitudes of the first cycle in the pressure waveforms of Cat. 2 calls were 30-50% greater than those of Cat. 1 calls. This observation did not account for caller position and therefore signal propagation to the hydrophone, although a random distribution of Cat. 1 and Cat. 2 caller ranges was assumed. Additionally, it was observed that in many cases the first one and often two initial pulses of the long calls were of lower detected amplitude than the successive pulses (Figure 3c). The distribution of calls as a function of the number of pulses within a call illustrates separation between short Cat. 1 and long Cat. 2 calls (Figure 4a). There was a distinct relationship between the number of pulses in a call and the call duration (Figure 4b and c) in both categories.

During the hour prior and post sunset, series of calls were often recorded which could not be classed as Cat. 1 or 2 calls, and so were deemed of a third category (Figure 5). This call category was less frequent than the others, observed only once or twice in an evening, throughout the spawning season. These Cat. 3 calls each comprised 1-5 pulses at PRRs of 91.3 ±10.3 Hz (max = 114.2, min = 74.3, n =22), significantly higher than those of Cat. 1 and 2 calls (Table 1 and Figure 5c and d). The calls began with seconds between each call and increased in rate to a maximum with several multiple pulse calls per s (Figure 5a, at approximately 55 s).

Evening calling cycles (within the hydrophone detection range) typically began approximately 2 hrs before sunset with few Cat. 1 calls from a small number of distant individuals (Figure 6), although on occasion these were recorded up to 4 hrs before sunset. As calls became recorded at increasingly closer range from the hydrophone they became of sufficient signal-to-noise ratio to analyse acoustic characteristics (Table 1). With time the number of Cat. 1 calls increased, along with the number of callers (Figure 6). By comparing waveform amplitude, shape and spectral peak frequency and localisation data [11] it was possible to discriminate between some callers and note individual repetitive calling (Figure 2, marks * and †). At times of low calling density this discrimination allowed a mean estimate of repetitive calling rates of 3.6 ± 0.85 s (n = 17) for Cat. 1 calls.

The number of Cat. 2 calls increased as sunset approached, with types 2a, 2b, 2c and 2d in order of occurrence (Table 1, Figure 6) and repetitive calling was determined at 3.72 ± 0.65 s between Cat. 2 calls. The peak in call numbers occurred approximately an hour after sunset and during this period predominantly Cat. 2 calls were observed (Figure 6). Whether Cat. 1 calls were not emitted at this time or were masked by Cat. 2 calls could not be confirmed. Cat. 2 calls then became less frequent and Cat. 1 calls were heard again, in greater numbers than before (Table 1, Figure 6). Cat. 1 calling intervals at this time ranged between approximately 1.8 and 3.1 s (calling rates of each individual reduced in rate as the evening progressed). Several hours after sunset the Cat. 2 calls had all but disappeared leaving a few callers emitting Cat. 1 calls of comparatively low received SPLs, typically between the hours of 22:00 and 00:00, until all calls ceased.

DISCUSSION

The *in situ* recordings demonstrated that Mosman Bay *A. japonicus* have a greater variety of vocalisation linked to times of spawning than previously thought [25,26]. In addition, a greater variety of calls were recorded here than similar studies in Taiwan [19,20], possibility illustrating the behavioural changes in geographically separated populations. This is a large repertoire, similar to the Atlantic croaker *Micropogonius undulates* [27], compared with that of other species [8,16,28,29]. *A. japonicus* produce sounds via multiple contractions of sonic muscles, exciting the swimbladder in a train of pulses [19]. In contrast to many soniferous Sciaenidae, such as the weakfish *Cynoscion nebulosus* [8], *A. japonicus* PRRs are greater, such that the produced sound can be a singular tone, rather than a series of knocks, similar to *Argyrosomus regius* [30].

Assuming call source levels of different, but similar sized fish are comparable [27], the difference in detected waveform amplitudes show that individual fish are separated by a minimum distance. Consistency in this separation highlights the low density of calling fish in the recording area and corroborates the suggestion of individual calling territories for *A. japonicus* in the wild [26]. This separation also supports a proposal of pair spawning in Mosman Bay, rather than group spawning where an indistinguishable (dense) chorus would be more prominent, similar to that of other species [16,30,31]. Thus while callers are exhibiting repetitive calling behaviour from stationary, or near stationary, locations it is possible to observe the different fish within the detection range of the hydrophone. A continuous chorus does form in Mosman Bay, during peak calling, however, the high source levels of *A. japonicus* calls [26], compared with those of other fish [26,32] means that fish from greater ranges contribute significantly to the overall sound pressure levels in the chorus. They would therefore still be able to call from separate locations and still form a chorus from an aggregation that is spread over a considerable area.

Lagadere and Mariani [30] observed that *A. regius* short calls are of lower intensity than the long calls, similar to the Cat. 1 calls here, compared with Cat. 2 calls. However, in many Cat. 2 calls the initial pulses were also of lower amplitude, raising the question of whether the sonic muscles take time to attain the tension required to generate amplitudes exhibited by later pulses of the long calls. Further study, including analysis of muscle tension during contraction is planned to elucidate this.

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