THE SOUNDS OF FISH OFF CAPE NATURALISTE, WESTERN AUSTRALIA

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Fish calls and choruses contribute considerable energy to the underwater soundscapes of Western Australia's waters. There are many fish species of social and economic importance which could be the source of these sounds. For example, the Western Australian dhufish (*Glaucosoma hebraicum*), which is endemic to the coast, has been shown to produce sound when captured. To investigate how much this species contributes to ambient noise levels, loggers were deployed between December, 2011 and February, 2012 at numerous locations around Cape Naturaliste in Western Australia, where some of the largest numbers of *G. hebraicum* are reported. Recordings taken near the site of the HMAS Swan wreck between 2009 and 2010 were also examined. Five fish choruses have been described centred at approximately 0.5, 1, 2 and >2 kHz (two choruses at >2 kHz). Many individual fish calls were detected at various locations around the Cape, particularly in the frequency ranges between 100 and 900 Hz. The acoustic characteristics of these calls are described, as well as the contribution of fish calls and choruses to the local soundscapes. The calls most similar to the previously reported *G. hebraicum* calls have been identified.

INTRODUCTION

Around Australia numerous species of fish produce sound, individually, in small groups or as part of a chorus [1-5]. A chorus is formed when sounds from individual callers overlap, with a significant increase above background levels (>3 dB re 1 μPa) for prolonged periods, using an equipment averaging time of one second [2]. A discontinuous chorus accounts for calls which do not overlap, but are frequent enough to raise time averaged noise levels over one minute, rather than one second [3]. Acoustic characteristics of fish calls can be species-specific, or even individually characteristic, such as call spectral peak frequency (typically defined by a combination of the resonant frequency of a fish's swimbladder, the tension of muscles that vibrate the swimbladder to produce sound and/or the damping of the swimbladder wall), modulation frequency (defined by the rate at which a swimbladder is "pulsed" by the associated muscles) and the rate at which calls are produced [4, 5]. These vocalizations often have associated behavioural functions and can provide insights into the ecology of the fish [6-13]. Indeed, once a species' characteristic calling rates and source levels have been identified it is possible to monitor the relative and theoretically absolute abundance of the fish contributing to a chorus [4, 14, 15].

An increasing number of socially and economically important fish have been studied to confirm if they are soniferous [16, 17]. The use of passive acoustic recording of calls as a complementary data source to monitor vocal aggregations is becoming of increasing benefit to biologists and managers [15, 17-19]. For example, the endemic Western Australian dhufish (*Glaucosoma hebraicum*), an iconic and highly prized species, is notoriously shy, inhabiting reefs and caves to depths of 200 m and, in general, is observed as single fish or sometimes groups of small numbers, often involving a harem of several females to one or two males [20, 21]. While comparatively little is known about the spawning behaviour of the species, catch reports and biological sampling have shown that significant numbers of *G. hebraicum* aggregate each year to spawn in waters around Cape Naturaliste, in the state"s southwest, between December and February [22]. A recent study has been investigating the use of passive acoustics as a means of detecting *G. hebraicum* and confirmed the species as soniferous [16]. Trains of swim bladder pulse driven calls were recorded from captured individuals in 14 m of water, with spectral peak frequencies of 150-160 Hz and pulse repetition frequency of approximately 10 Hz [16]. Whether *G. hebraicum* produce sound during natural behaviour is unknown, though the complex social structure of schools and nocturnal activity suggest that acoustic communication may be a viable alternative to visual cues for this species [21].

The aim of this study was to record and identify sounds in waters where *G. hebraicum* reportedly spawn and investigate whether sounds with similar characteristics to those of *G. hebraicum* were detected. This paper describes some of the fish choruses and calls detected in waters off Cape Naturaliste between December, 2011 and February, 2012.

METHODS

Autonomous underwater sea-noise loggers, developed by the Centre for Marine Science and Technology and the Defence Science and Technology Organisation, were deployed to the seabed in waters around Cape Naturaliste at various times between 2008 and 2012 (Figure 1). Recordings were taken using a calibrated, omni-directional, HTI 90-U or 96-min hydrophone (HighTech Inc., MS, USA). Sampling schedules, deployment periods and approximate locations for these deployments can be found in Table 1. Each system was calibrated with a white noise generator at -90 dB re 1 V^2/Hz and data analysed using the CHaracterisation Of Recorded Underwater Sound (CHORUS) Matlab toolbox, written at the Centre for Marine Science and Technology (CMST). Spectrograms were produced with a 1024 point Hanning window at a frequency resolution of either 1 or 10 Hz.

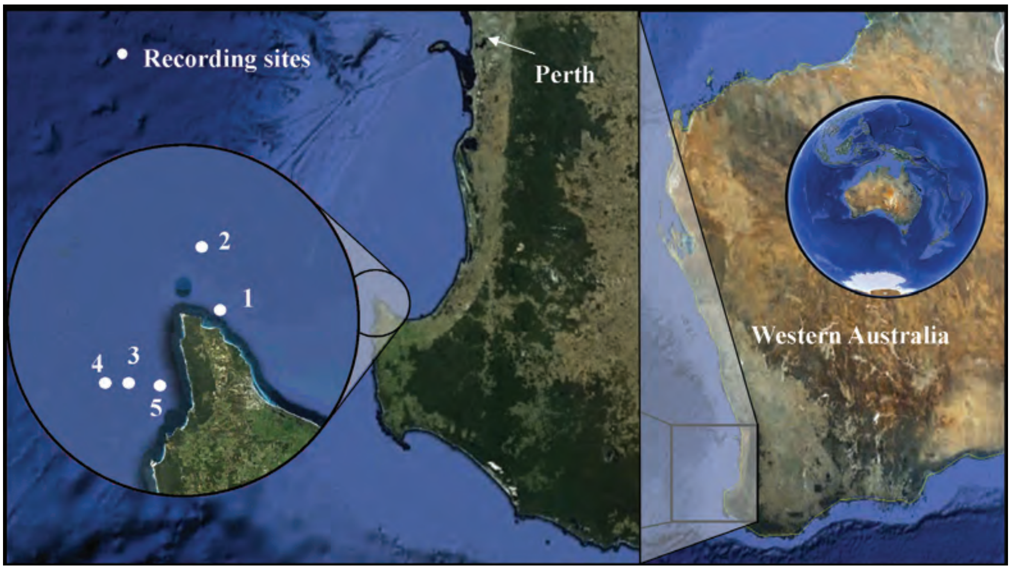

Figure 1. Map of southwest Australia with expanded inset of Cape Naturaliste and local waters. Approximate locations of deployed loggers shown by white circles (1: near the wreck of the HMAS Swan, 2: Geographe Bay logger, 3: Offshore logger A, 4: Offshore logger B, 5: Inshore Logger). Image source: Google earth 14/7/12

Table 1. Deployment periods and schedules of underwater noise loggers between 2008 and 2012

Deployment location	Depth (m)	Start date	End date	Sample rate	Low frequency roll-off	Anti-aliasing filter	Sampling schedule
1:HMAS Swan	26	21/12/08	15/03/09	6 kHz	8 kHz	2.8 kHz	780 s every 900 s
	26	23/11/09	26/07/10	6 kHz	8 kHz	2.8 kHz	780 s every 900 s
2: Geographe Bay logger	29	13/12/10	26/01/11	8 kHz	8 kHz	2.8 kHz	700 s every 900 s
3: Offshore logger A	41	21/12/11	26/02/12	11 kHz	8 kHz	5 kHz	540 s every 660 s
4: Offshore logger B	57	21/12/11	26/02/12	11 kHz	8 kHz	2.8 kHz	540 s every 660 s
5: Inshore logger	37	08/02/11	12/02/11	6 kHz	8 kHz	2.8 kHz	700 s every 900 s

RESULTS

Numerous fish calls and choruses were recorded at the various logger sites around Cape Naturaliste. Sounds from individual callers or small groups of fish were typically in the frequency band of 100 to 900 Hz, while five predominant choruses that were detected were centred at approximately 0.5, 1, 2 and >2 kHz (two types of chorus were detected >2 kHz).

Choruses

Five types of recorded choruses are described here. The first four were recorded at the site near the HMAS Swan wreck between January and March, 2009. Over a two week period the four choruses were present on the same days (Figure 2), illustrating that there was often overlap in frequency and temporal bands of each chorus.

The first chorus (Figure 2a, black ellipse and 2b) was centred at approximately 500 Hz and lasted approximately 1 hour each day, beginning approximately an hour before sunset at 18:30 and comprising few callers (estimated at between 5 and 10 calling fish).

The second chorus (Figure 2a, orange ellipse and 2c) began before the first finished, around the time of sunset, and lasted 1 to 1.5 hours. This chorus comprised series of short “pops”, likely generated by either a click or a single pulse of a swim bladder, centred around 1 kHz (Figure 2c, waveform).

The third and fourth choruses (Figure 2a, green and yellow ellipses, respectively) were both centred above 2 kHz (the sampling frequency of 6 kHz restricted the identification of the upper frequency limit of the chorus). The first of these two choruses began in the evening, after sunset, prior to the end of the 1 kHz centred chorus (Figure 2a, green ellipse) and lasted approximately 2 hours. The second occurred in the morning, lasting up to 2 hours either side of sunrise (Figure 2a, yellow ellipse). Both of these choruses comprised sounds centred above 2 kHz, with all energy above 1 kHz, similar to those of the planktivorous fish described by McCauley [5].

An example of the fifth type of chorus (Figure 3) was recorded at the Inshore logger (5), in 40 m of water. The chorus began quickly, with many fish calling shortly after sunset, but ended as the calls slowly diffused, with odd callers sometimes continuing for several hours into the night. This chorus comprised calls of pulse trains centred between 2 and 2.2 kHz in frequency. While pulse repetition rate was high, so was the damping of the swim bladder, thus the calls were audibly detected as a series of knocks. These pulse trains ranged considerably in pulse number (48 ±12, n = 50, min = 12, max =71) and duration (1.971 ±0.493 s, min = 1.112, max = 2.9523), often containing upwards of 50 pulses (Figure 3c). This type of chorus was also detected on recordings from the two loggers located further west of Cape Naturaliste (Figure 1) in January and February.

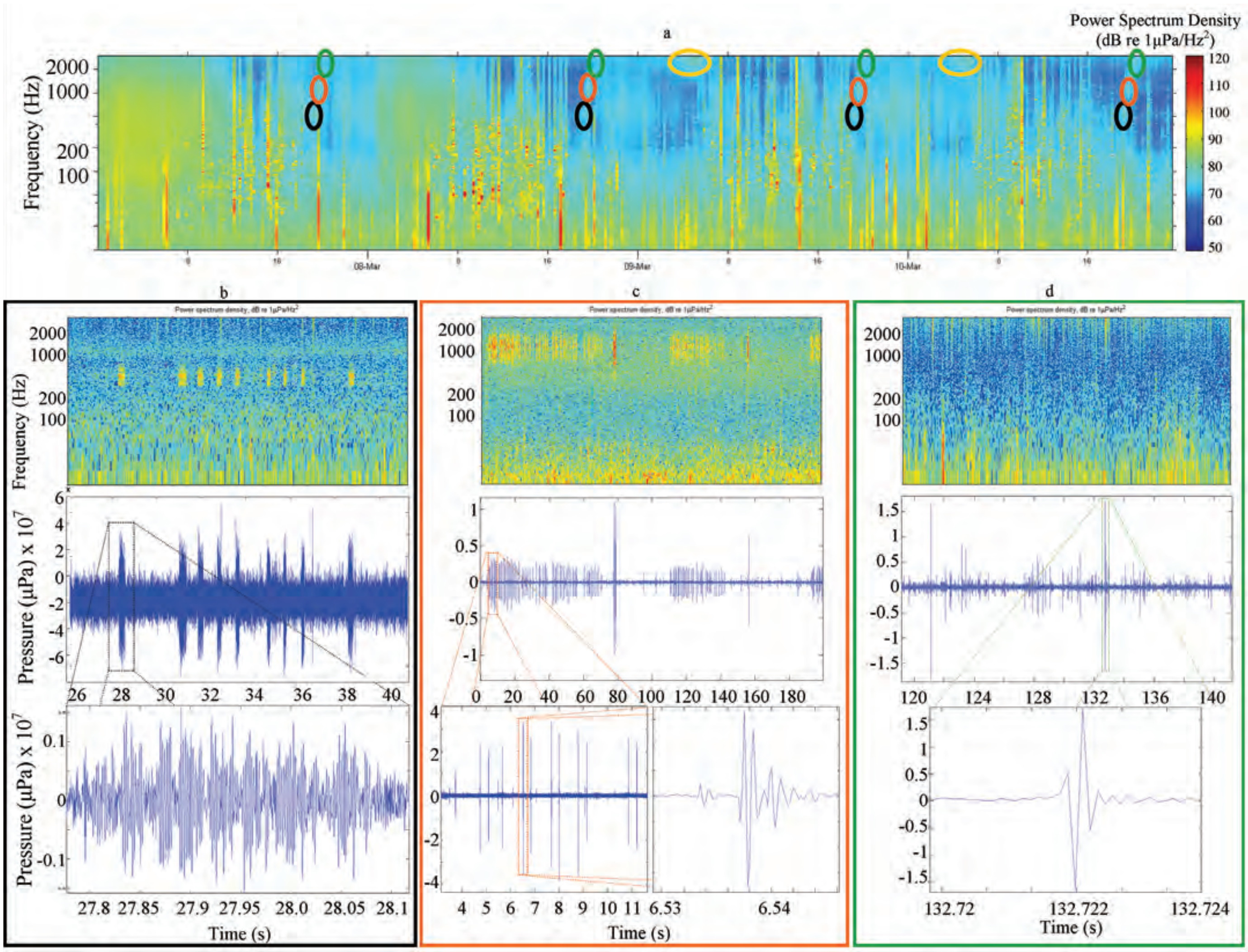

Figure 2. Spectrogram of four days of acoustic recording in Geographe Bay (a). Magnified examples spectrograms and waveforms for four types of recorded calls contributing to each chorus centred around 500 Hz (2a black ellipse and 2b), 1000 Hz (2a orange ellipse and 2c) and greater than 2000 Hz (2a green and yellow ellipses and 2d). Points of interest are explained in the text

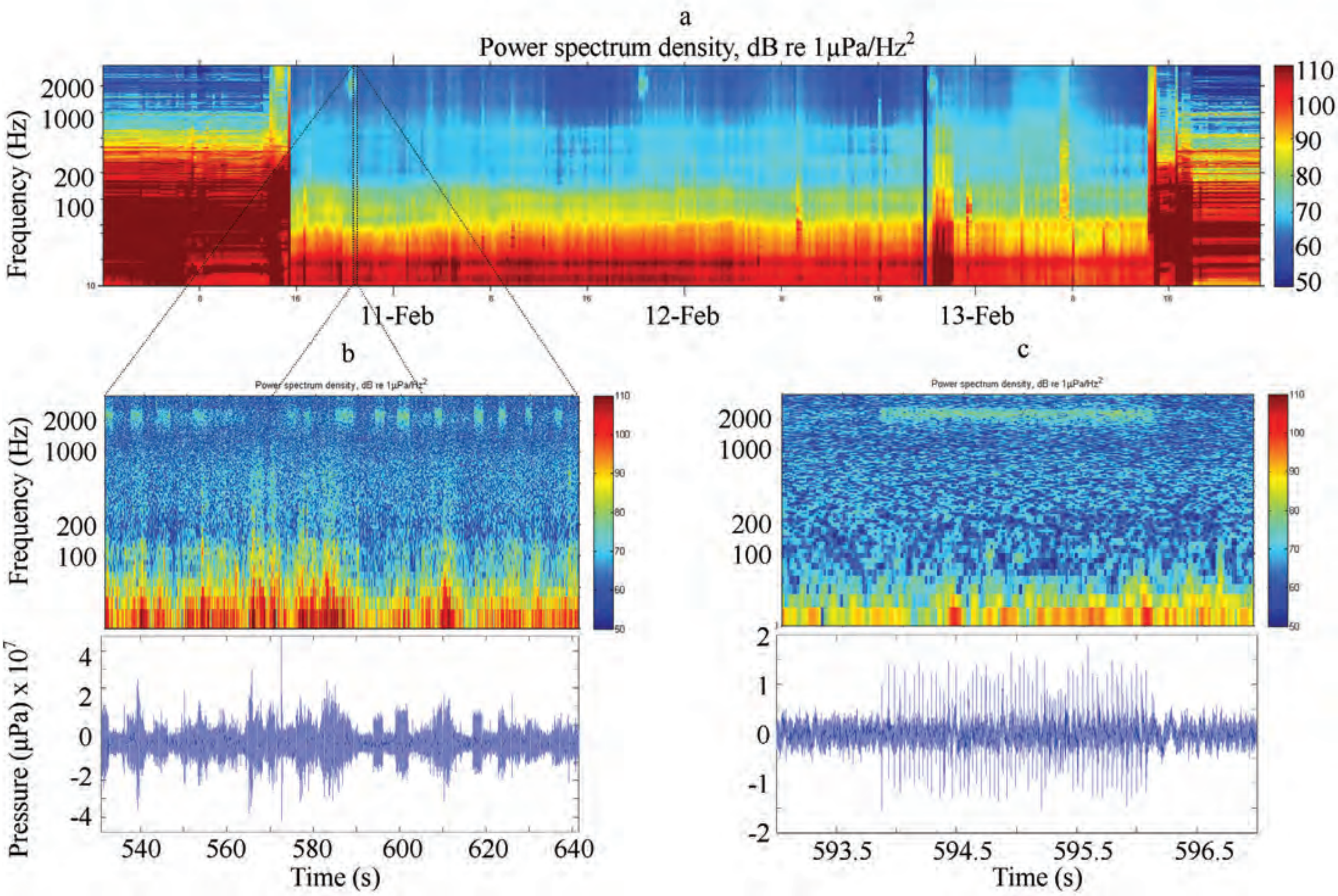

Figure 3. Spectrograms and waveforms of a chorus recorded in waters around the Inshore Logger (Figure 1 Point 5), Western Australia, in 40 m of water. Innumerate calls over the 2-2.2 kHz band (b) where each call comprised a pulse train of often >50 pulses (c) audibly detected as a series of knocks

Individual fish calls

Several types of individual fish calls were recorded. These calls were few in number and did not build to constitute a chorus. In each case the calls were most likely emitted by a single fish or few individuals. In general, the majority of energy within these calls was between 100 and 900 Hz (Figure 4). Four common examples of those calls are described here.

The first call type (Figure 4a, n = 11 calls) comprised 7.55 ± 2.70 pulses (min = 3, max = 12) at spectral peak frequency of 521 ±53 Hz and pulse repetition frequency of 42 ±11 Hz.

The second type (Figure 4b, n = 2) comprised a train of 19 ±2 pulses. The spectral peak frequency over the call was 198 ±27 Hz, however, throughout the call the spectral peaks rose and then fell (Figure 4b, spectrogram) due, in part, to the decrease (129 Hz to 87 Hz) and then increase in pulse repetition frequency (87 to 105 Hz) during the call (Figure 4b).

The third type of call (Figure 4c, n = 53) was a series of pulse sets (up to 4 pulses within a set) of spectral peak frequency of 857 ±46 Hz (min = 741, max = 979), at a pulse repetition frequency of 9.1 ±1.8 Hz.

A fourth type of call was categorised from recordings taken between December, 2011 and February, 2012. Offshore logger B, deployed approximately 6 n.m. west of Cape Naturaliste (Figure 1) recorded many fish calls (Figure 5b). Of 75 analysed calls the mean spectral peak frequency was 239 ± 37 Hz (min = 86, max = 297) with pulse repetition frequency of 8.3 ± 3.2 Hz (min = 4.2, max = 14.7). The logger also recorded an increase in sound pressure levels (SPLs) between 50 and 200 Hz for prolonged periods. The most notable of these periods was between the 29th December and the 4th January, a period when anecdotal evidence from recreational fishers suggested significant numbers of *G. hebraicum* were caught in the surrounding area.

Individual fish calls of characteristics similar to those of mulloway [4, 23, 24] were also detected during recordings, as well as numerous other biological sounds. For brevity these have not been described here.

DISCUSSION

This study has highlighted numerous different types of fish choruses and calls around the Cape Naturaliste region of Western Australia. The choruses displayed distinct differences in frequency content, likely due to the size of fish and/or mechanism of sound production, providing a means of discrimination between species for the intended recipients of the calls [3-5].

The species producing the choruses presented here are currently unknown. However, the first chorus, centred around

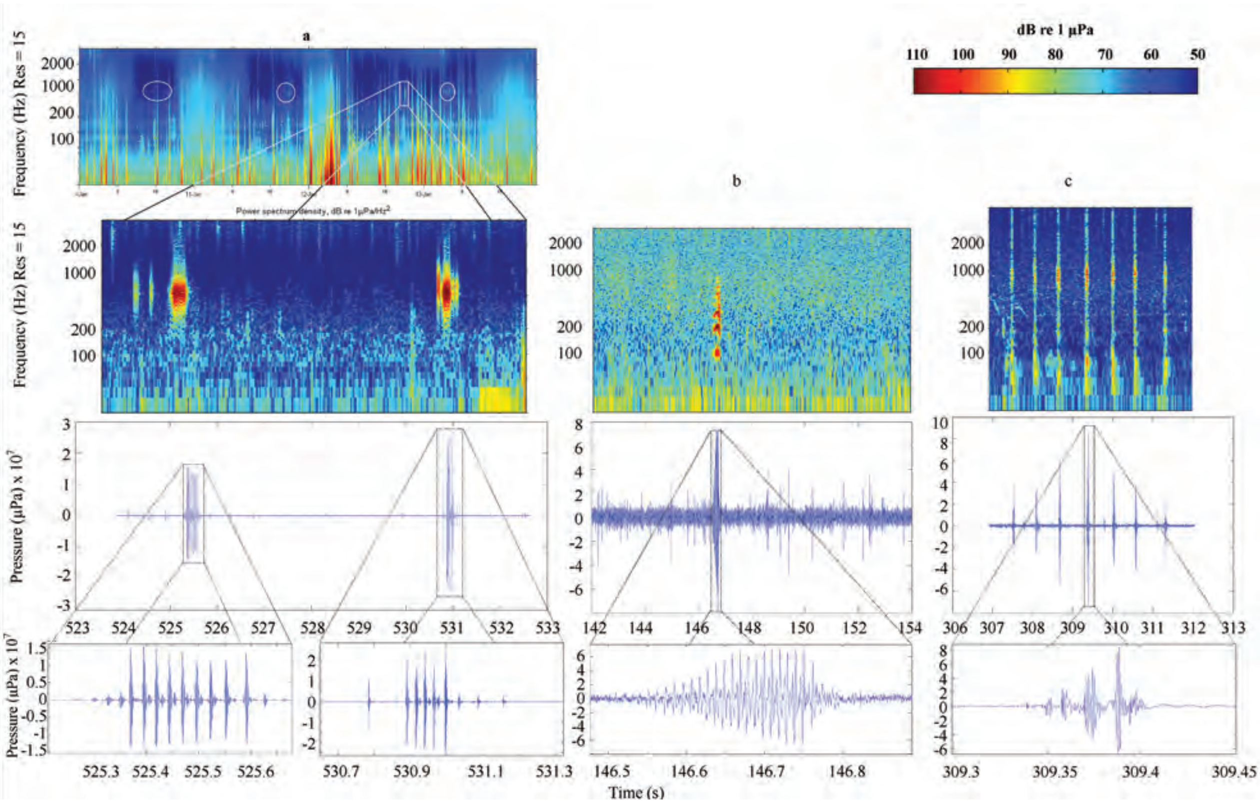

Figure 4. (a) Spectrogram of 4 days recording in Geographe Bay with a magnified spectrogram of 10 s at approximately 20:00 hrs on the 12th January, 2011. Waveforms of two recorded calls are shown with swimbladder pulses magnified. Circles in the top spectrogram highlight periods at dawn and dusk when similar calls were observed. (b and (c) Spectrogram and waveform of unidentified calls recorded on 10th December 2010 at approximately 10:15 and 11:15 in Geographe Bay.

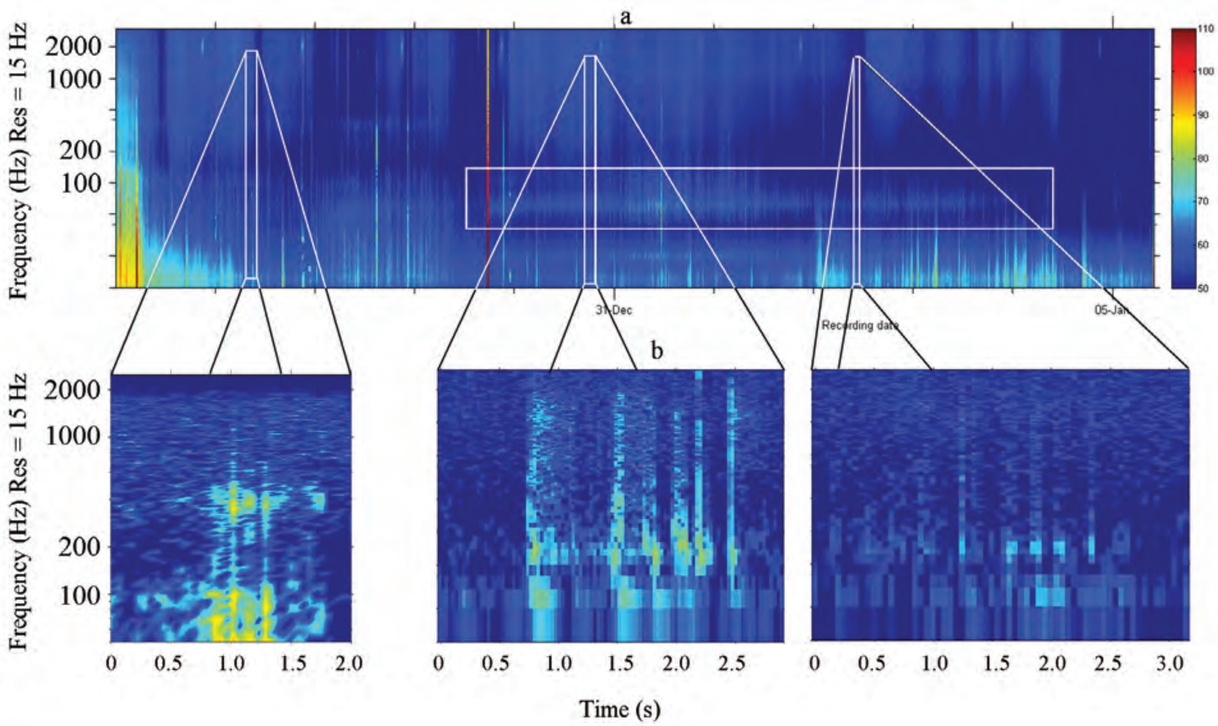

Figure 5. Spectrogram from 10 days recording in waters west of Cape Naturaliste (a). Spectrograms of a example sound with similar characteristics to *G. hebraicum* calls (b) and increase SPLs during a period when significant numbers of *G. hebraicum* were capture in the area and this period is within the known spawning season of *G. hebraicum* (highlighted by horizontal rectangular white box)

500 Hz is of similar frequency band to those of weakfish (*Cynoscion regalis*), for fish ranging between 25 and 35 cm [25]. Thus a species of similar size and possessing a swimbladder is suggested to be the source of these sounds. The frequency band and duration of "pops" in the second chorus are similar to that of urchin noises, which produce sound between 700 and 1500 Hz [26], which could be a possible source of this chorus. The third "evening" chorus is typical of small planktivorous fish reported by McCauley [3, 5] and are likely to also be the source of the fourth "dawn" chorus. The fifth chorus comprised calls produced via long trains of swimbladder driven pulses. While the source of this chorus has not been determined calls of similar spectral peak and modulation frequencies have been reported at other recordings sites around Australia [3, 5] and observed by the authors at other locations around the world.

The choruses recorded in this study provide significant information on at least four different aggregations of fish. While there was temporal overlap at the start and beginning of the choruses detected here there were discrete differences in the timing of the peak of calling. This implies that the calling fish use not only frequency, but also time to discriminate between choruses, similar to that found on the northwest shelf [5]. Parsons [4] and McCauley [3] described how environmental drivers such as temperature, salinity and lunar phase can affect the timing and caller numbers in a fish chorus. Although assessment of the long-term timing of the southwest choruses has not been documented and would require substantially longer datasets than those presented here, the variable presence of the choruses suggest different external drivers affect each of the aggregations and requires examination. This type of monitoring of long-term variations in fish chorus levels is the subject of a future CMST study.

The individual calls recorded displayed distinct differences in spectral peak and modulation frequencies. The duration of each call type also varied significantly, not only from other individual call types, but also the calls that contributed to the five chorus types. The fourth type of call was centred between 200 and 300 Hz with pulse repetition frequency of 8.3 ± 3.2 Hz and was most similar to the calls of the *G. hebraicum* reported by Parsons et al. [16] at approximately 154 ± 45 Hz and 10 Hz spectral peak and pulse repetition frequencies, respectively. While the difference in peak frequency between the call type here and reported *G. hebraicum* calls is noted, Parsons et al. [16] recorded the *G. hebraicum* calls at depths of less than 14 m. The recordings in this study were taken at depths of between 27 and 57 m. Increased pressure with depth reduces the size of an uncompensated swim bladder and therefore increases the resonant frequency (and therefore spectral peak frequency in individual pulses) of a call [27]. Some fish species secrete a gas into the swim bladder to compensate for the additional pressure and therefore maintain swim bladder size and call frequency [3]. It is currently unknown whether *G. hebraicum* maintain buoyancy via secretion of gas into the swim bladder, although their susceptibility to barotrauma [28] would suggest that the species possess little control over swim bladder volume. At the depths recordings were in this study it is unknown whether a *G. hebraicum* call spectral peak frequency would increase and, if so, by how much. The pulse repetition frequency of the fourth call type was the most similar to the reported *G. hebraicum* calls of those recorded here and, combined with the spectral peak frequencies, it is suggested that this is the most the likely call type to have been emitted by *G. hebraicum*. It should be noted, however, that it is not inconceivable that spawning *G. hebraicum* at 40 m depth emit calls of elevated peak frequency and/or increase the pulse repetition rate. Haddock (*Melanogrammus aeglefinus*), and Atlantic cod (*Gadus morhua*) for example, emit calls at a range of pulse repetition frequencies [29, 30] during different behaviour.

The increase in sound pressure levels between 50 and 200 Hz in the Offshore Logger A recordings between the 29th December and 5th January were due to short pulsed sounds, often of the fourth call type. This period coincided with a time when anecdotal evidence from fishers suggested the largest number of *G. hebraicum* were caught in the area (author, unpublished data). Whether the *G. hebraicum* are responsible for this increase is unknown and is the subject of further study.

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