Sound production by the West Australian dhufish (*Glaucosoma hebraicum*)

Miles J. G. Parsons[a]
Centre for Marine Science and Technology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

Simon Longbottom
Curtin Aquaculture Research Laboratory, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

Paul Lewis
Department of Fisheries, Government of Western Australia, PO Box 20, North Beach, WA 6020, Australia

Robert D. McCauley
Centre for Marine Science and Technology, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

David V. Fairclough
Department of Fisheries, Government of Western Australia, PO Box 20, North Beach, WA 6020, Australia

Biological examinations of Glaucosomatid fish species have suggested that they could produce sound via swimbladder vibration, using "sonic" muscles. However, there have been few reported instances of it in the family. West Australian dhufish (*Glaucosoma hebraicum*) is an iconic teleost, endemic to Western Australia. Dissection of *G. hebraicum* in this study identified the presence of "sonic" muscle pairs in immature and sexually mature individuals. The muscle tissue originates in the otic region of the skull with its insertion at the anterior of the swimbladder. Recordings of sounds were acquired from two male *G. hebraicum*, at a range of 1 m, during capture. Calls comprised 1 to 14 swimbladder pulses with spectral peak frequency of 154 ± 45 Hz ($n = 67$ calls) and 3 dB bandwidth of 110 ± 50 Hz. The mean of all call maximum source levels was 126 dB re 1 μPa at 1 m with the highest level at 137 dB re 1 μPa at 1 m. The confirmation of sound production by *G. hebraicum* and the acoustic characteristics of those sounds could be used to gain a better understanding of its ecology and, particularly, whether the production of sound is associated with specific behaviors, such as reproduction.
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I. INTRODUCTION

Over 800 species of fish are known to produce sound via a number of different evolved mechanisms (Kaatz, 2002). Their sounds are often associated with a particular behavior, such as spawning, feeding, or disturbance (Winn, 1964; Myrberg and Spires, 1972; Fine *et al.*, 1977; Slabbekoorn *et al.*, 2010). As sound propagates efficiently underwater (Urick, 1983), recordings of fish calls can offer an effective means of determining natural fish behavior and provide valuable information on the location and timing of associated behavior (Gannon, 2008;, Rountree *et al.*, 2006). Of particular note is the formation of spawning aggregations. Such information could be relevant to management when making decisions about the respective locations and timing of spatial or temporal closures to fishing for vulnerable species. The use of sound as a research tool for determining such behavior is particularly advantageous under certain circumstances, e.g., in conditions of low visibility (turbid waters and/or low light levels) or for shy species (Mackie *et al.*, 2009), when other sampling techniques are less successful. However, it is first necessary to have an understanding of the acoustic features of a species' calls and how they are produced (e.g., swimbladder vibration or stridulation), to determine how best to characterize them.

The West Australian dhufish (*Glaucosoma hebraicum*; Glaucosomatidae) is an iconic and heavily targeted species that is endemic to coastal waters of Western Australia (Fig. 1; McKay, 1997; St John and Syers; 2005; Wise *et al.*, 2007). It is a slow growing, sedentary, demersal species inhabiting reefs and caves to depths of 200 m (Hutchins and Swainston, 1986; St John and Syers, 2005; Hesp *et al.*, 2002). *G. hebraicum* is a large species which reaches 1.22 m total length and 26 kg, and matures at approximately 25% of maximum length (Hutchins and Swainston, 1986; Hesp *et al.*, 2002; Mackie *et al.*, 2009). *G. hebraicum* display little variation in reproductive seasonality along the west coast between Augusta and Kalbarri, with ovarian development commencing as water temperatures begin to increase from their annual low, rather than in relation to a latitudinal gradient, and spawning occurring predominantly in austral summer/autumn (Hesp *et al.*, 2002; St John and Syers, 2005; Lenanton *et al.*, 2009; Mackie *et al.*, 2009). Males have been recorded as co-inhabiting small areas during spawning periods, often with a dominant male displaying a larger dorsal filament than other males, indicating they may exhibit lekking behavior (Mackie *et al.*, 2009; Hauser, 1996). At spawning

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[a]Author to whom correspondence should be addressed. Electronic mail: m.parsons@cmst.curtin.edu.au
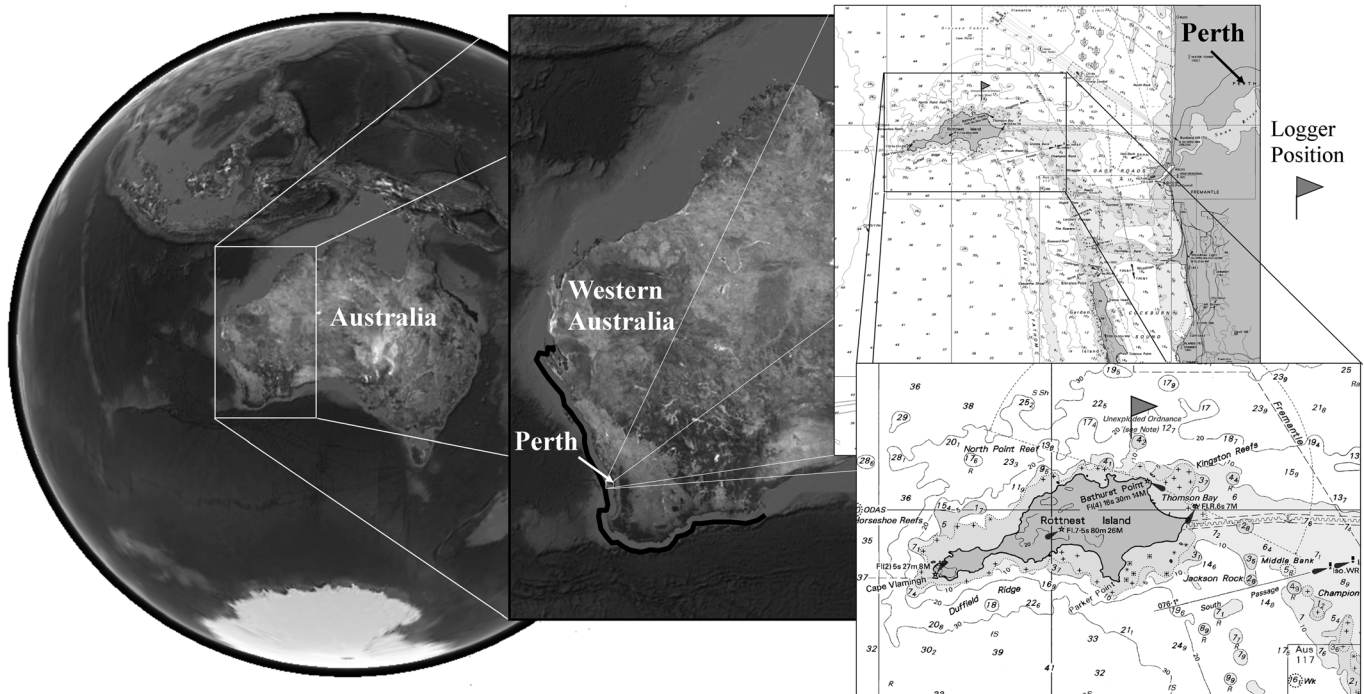
FIG. 1. Map of Western Australia with a magnification of Rottnest Island. Distribution of *G. hebraicum* in WA shown by black line.

times, groups of up to three fish are typical, up to ten fish to a lesser extent, and occasionally tens or hundreds of fish, have been reported (Mackie *et al.*, 2009). Males have small testes relative to other gonochoristic species, which implies they are likely to exhibit pair spawning behavior. Furthermore, spawning frequency has a positive relationship with size and the larger males are thought to spawn most frequently with the largest females (St John and Syers, 2005). Together, these facts indicate that social cues, such as visual or acoustic cues, may be important during spawning. Mackie *et al.* (2009) also suggested that vocalization may be a form of communication in this species.

Chiu *et al.* (2006) reported that biochemical assessment of elevated levels of citrate synthase and L-lactate dehydrogenase (enzymes associated with energy supply for muscle contraction) in swimbladder muscles of the pearl perch (*Glaucosoma buergeri*) suggested the ability of the muscle to act as a "super-fast" twitch muscle (Rome, 2005). This muscle may be involved in sound production. Mok *et al.* (2011) detailed the mechanism for sound production in *G. buergeri* demonstrating that the "sonic" muscles could vibrate two different chambers within the swimbladder.

This study tested the hypothesis that, like its congener *G. buergeri*, *G. hebraicum* contains the physical mechanisms to produce sound. Once confirmed, direct field recordings were acquired of *G. hebraicum* calls to describe the acoustic characteristics of the calls, including source levels (SLs) and the behaviors with which those calls may be associated.

II. METHODS

Six adults (purchased or donated to Curtin University) and two juvenile *G. hebraicum* were dissected (the latter as part of a Department of Fisheries research project). The total length and sex of each fish were recorded. Examinations were conducted to identify the presence and location of potential sonic muscles used in sound production similar to those in *G. buergeri* (Chiu *et al.*, 2006) and determine whether such muscles were present in sexually immature and mature individuals (Fig. 2).

On 13 December 2011, sound recordings of two *G. hebraicum,* captured using rod and line in 14 m of water near Rottnest Island (Fig. 1; approximately E115°30′, S32° 0′), were made using calibrated, omni-directional, HTI 90-U and 96-min hydrophones (HighTech Inc., Long Beach, MS). The 90-U hydrophone was attached to an autonomous sea-noise logger developed at Curtin University, Western Australia and the Defense Science and Technology Organisation, sampling for five of every seven minutes at a rate of 11 kHz. The HTI-min hydrophone was attached to an HR-5 "Jammin-pro" recorder sampling continuously at 16 kHz. The fish were raised to the surface over a period of 10 min to limit swimbladder expansion, during which time a hydrophone (HTI 96-min) was located approximately 1 m from the fish. In each case, a snorkeler at the water's surface capable of free-diving to the seafloor ensured the range between fish and hydrophone was kept as close to 1 m as possible.

The fish was briefly removed from the water so the sex could be determined from the presence/absence of a dorsal fin filament, which is only present in males (Mackie *et al.*, 2009), and the total length was measured to the nearest 1 mm. Each fish was then rapidly returned to the seabed using a release weight, attached to the fishing line, which reduces the effects of barotrauma (Bartholomew and Bohnsack, 2005). The release weight comprises a weighted, barbless hook which is passed through the upper jaw, from above, so that the hook points downward. The weight and fish are lowered to the desired depth, whereby a sharp tug on

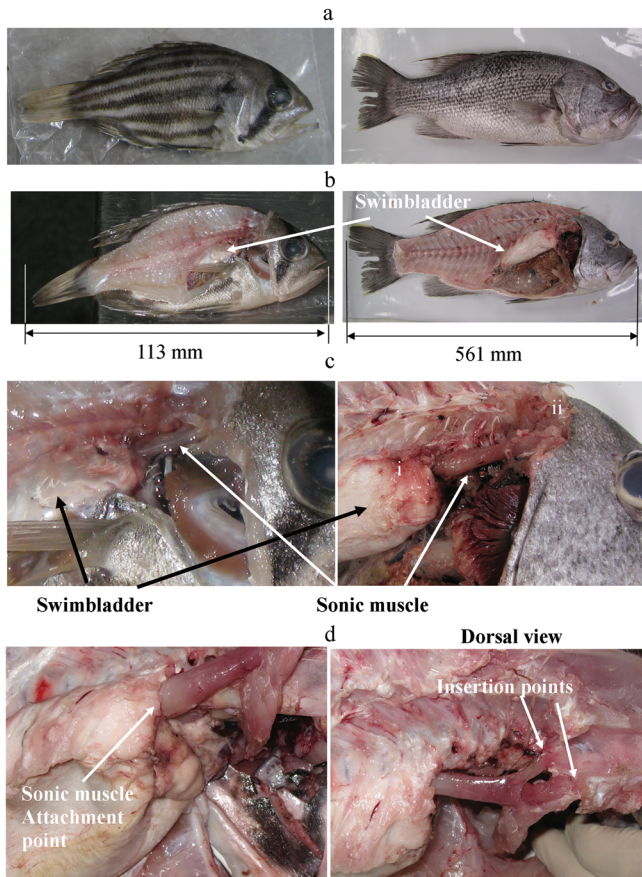Parsons *et al.*: Sound production by dhufish

FIG. 2. (a) Whole and (b) dissected 113 mm (left images) and 425 mm (right images) male *G. hebraicum*. Magnification of likely sonic muscles connected at the anterior of the swimbladder (i) and posterior of either side of the brain case (ii) are shown (c). Structure of adult sonic muscle and vascularized muscle are highlighted. (d) Lateral view of sonic muscle attachment to swimbladder (left) and dorsal view of sonic muscle separating to two insertion points around the otic region of the brain casing (right) in the adult *G. hebraicum*.

the line releases the fish. The release weight is then retrieved. During the release, the Centre for Marine Science and Technology (CMST) logger (HTI 90-U) was simultaneously deployed to the seabed, as close as possible to 1 m from the fish. Once again, a free-diving snorkeler maintained the range between hydrophone and fish.

Removal of background noise and call energy level analyses were conducted using methods outlined in McCauley (2001) and Parsons *et al.* (2012) with a suite of MATLAB programs developed at the CMST, including the characterisation of recorded underwater sounds (CHORUS) toolbox. Spectrograms were produced using either a 1024 - or 256-sample Hanning window. Spectral peak frequency of each call and pulse was determined from power spectral density plots. For comparison, the durations of the first and second cycles of each pulse and the pulse duration were determined from the waveforms of numerous calls, as per Connaughton *et al.* (2000). The frequencies of each cycle and the total duration were then compared to that of the spectral peak frequency of the equivalent pulse.

Where recordings were taken at a range of 1 m, the transmission loss was 0 dB and therefore received levels (RL) and SL were effectively the same. However, maintaining a range

of 1 m between a fish on a line and a hydrophone was non-trivial. Three standard deviations in the distribution of ranges at which recordings were taken have been estimated at 0.5 m to provide maximum and minimum limits in the possible SL of each recorded call. For each maximum and minimum, the transmission loss between fish and hydrophone was assumed to be equal to spherical spreading (Cato, 1998). The RLs were measured for all calls from time-averaged power spectrum densities over the 50 Hz to 750 Hz bandwidth. Mean levels and confidence limits were calculated in the linear domain.

Similar to Parsons *et al.* (2012), the call SLs are presented in three formats to aid comparison of the results reported here with other past and future results. SLs have been quoted in sound pressure level (SPL; dB re 1 μPa at 1 m), sound exposure level (SEL; dB re 1 μPa2 s at 1 m), and peak–peak pressure (Pa) as defined in Southall *et al.* (2007).

III. RESULTS

Dissections revealed that in each adult and juvenile *G. hebraicum*, the swimbladder was located at the posterior end of the abdominal cavity, approximately halfway along the body [Figs. 2(a) and 2(b)]. Bi-lateral sonic muscles (Chiu *et al.*, 2006; Mok *et al.*, 2011), were observed in all examined individuals (Fig. 2). These muscles had the same characteristics as Baudelot's ligament, originating in the otic region of the skull, either side of the posterior part of the brain casing, near the otoliths [Fig. 2(c), mark ii]. Two insertion points were observed [Fig. 2(d), right image] before the muscle joined, forming one striated muscle which extended posteriorly to insert at the anterior of the swimbladder [Figs. 2(c), mark i and 2(d), left image]. The sonic muscles were the only muscles observed to be attached to the swimbladder. In the adult *G. hebraicum* (range of 32.5–56.1 cm total length), these muscles were striated, highly vascularized, and deep red in color, while in the 11 and 13 cm juveniles, the muscles were striated, but white.

The two *G. hebraicum* captured in the field were male and were 45 and 32 cm total length and considered likely to be sexually mature, based on comparison with the length at sexual maturity (L_{50}) of males of this species (Hesp *et al.*, 2002). Both captured individuals produced sounds while being raised to the surface and when lowered back to the seafloor (see Table I for acoustic characteristics). When the fish was close to the surface or handled, vibrations of the body were visibly detectable at the same time as these sounds were being produced, confirming the *G. hebraicum* as the sound source.

The mean of call maximum root-mean-square (rms) SLs of the two fish was 126 dB re 1 μPa ($n = 67$, max = 137, min = 113) with upper and lower confidence limits of 130 and 116 dB re 1 μPa, respectively. Separately, the mean of the maximum SLs of calls from the first (45 cm, $n = 13$) and second (32 cm, $n = 54$) fish were 128 and 125 dB re 1 μPa, respectively (Table I). The mean of the call maximum SELs for both fish together, the 45 cm fish, and the 32 cm fish were 117, 110, and 118 dB re 1 μPa^2 s, respectively. The difference between upper and lower confidence limits for the rms SL was 8 and 17 dB re 1 μPa for the first and second fish,

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TABLE I. Characteristics of calls of differing numbers of pulses, produced by two male WA dhufish (*G. hebraicum*), including SLs in peak-to-peak pressure (Pa), SPL (dB re 1 μPa at 1 m), maximum SEL (dB re 1 μPa^2 s at 1 m), duration (s), and spectral peak frequency (Hz). Numbers in parentheses in the fish column are the sample number. Elsewhere, numbers in parentheses represent the standard deviation, maximum and minimum values.

| Call type	Fish (*n*)	Peak–peak pressure (Pa)	Maximum SL (dB re 1 μPa)	Maximum SEL (dB re 1 μPa^2 s)	Call duration (s)	Spectral peak frequency (Hz)
All calls	All (67)	10.8 ($\pm$7.4, 35.2, 2.3)	126 (130, 116, 137, 113)	117 (122, 109, 126, 97)	0.38 ($\pm$0.37, 2.6, 0.01)	154 ($\pm$43.5, 251, 82)
	1 (13)	0.39 ($\pm$0.29, 0.85, 0.05)	128 (131, 123, 133,122)	110 (113, 104, 117, 97)	0.39 ($\pm$0.29, 0.85, 0.05)	144 ($\pm$38, 199, 95)
	2 (54)	0.38 ($\pm$0.39, 2.6, 0.02)	125 (130, 113, 137, 113)	118 (122, 112, 126, 108)	0.38 ($\pm$0.39, 2.6, 0.02)	157 ($\pm$45, 250, 82)
1 Pulse	1 (0)	n/a	n/a	n/a	n/a	n/a
	2 (9)	15 ($\pm$9.3, 28.3, 5.4)	128 (133, 119, 133, 115)	120 (124, 113, 124, 112)	0.11 ($\pm$0.12, 0.39, 0.08)	148 ($\pm$45, 220, 98)
2 Pulse	1 (3)	6.13 ($\pm$3.5, 9.2, 2.3)	130 (134, 123, 134, 122)	108 (113, 97, 113, 98)	0.11 ($\pm$0.06, 0.15, 0.05)	113 ($\pm$15.6, 122, 95)
	2 (16)	11.4 ($\pm$9.2, 35.2, 4.9)	125 (130, 121, 137, 115)	118 (122, 112, 126, 113)	0.21 ($\pm$0.07, 0.38, 0.13)	161 ($\pm$42, 221, 97)
3 Pulse	1 (5)	5.3 ($\pm$2.4, 9.0, 3.6)	129 (132, 125, 132, 125)	112 (115, 106, 117, 108)	0.38 ($\pm$0.26, 0.75, 0.17)	170 ($\pm$32, 193, 121)
	2 (9)	12.2 ($\pm$5.3, 20.1, 6.8)	125 (129, 117, 131, 117)	119 (122, 114, 123115)	0.26 ($\pm$0.05, 0.35, 0.20)	157 ($\pm$37, 217, 103)
4 Pulse	1 (0)	n/a	n/a	n/a	n/a	n/a
	2 (6)	14.7 ($\pm$6.8, 21.2, 4.5)	128 (131, 121, 132, 119)	120 (123, 113, 123, 110)	0.43 ($\pm$0.08, 0.55, 0.35)	198 (52, 251, 117)
5 Pulse	1 (3)	4.5 ($\pm$0.9, 5.4, 3.6)	127 (127, 126, 127, 126)	109 (111, 106, 111, 107)	0.54 ($\pm$0.35, 0.79, 0.14)	148 ($\pm$48, 199, 103)
	2 (6)	7.8 ($\pm$2.7, 12.6, 4.7)	120 (123, 113, 125, 113)	114 (116, 110, 116, 110)	0.57 ($\pm$0.17, 0.93, 0.46)	134 ($\pm$22, 166, 107)
6 Pulse	1 (0)	3.1	123	115	0.79	156
	2 (6)	10.4 ($\pm$4.8, 14.6, 4.8)	124 (128, 116, 130, 116)	118 (122, 112, 123, 111)	0.65 ($\pm$0.13, 0.81, 0.51)	159 ($\pm$41, 205, 127)
7 Pulse	1 (1)	2.5	122	108	0.85	141
	2 (0)	n/a	n/a	n/a	n/a	n/a
8 Pulse	1 (0)	n/a	n/a	n/a	n/a	n/a
	2 (0)	20.6	126	123	0.75	237
9 Pulse	1 (0)	n/a	n/a	n/a	n/a	n/a
	2 (0)	10	120	118	1.3	82
14 Pulse	1 (0)	n/a	n/a	n/a	n/a	n/a
	2 (0)	11.2	117	111	2.6	102
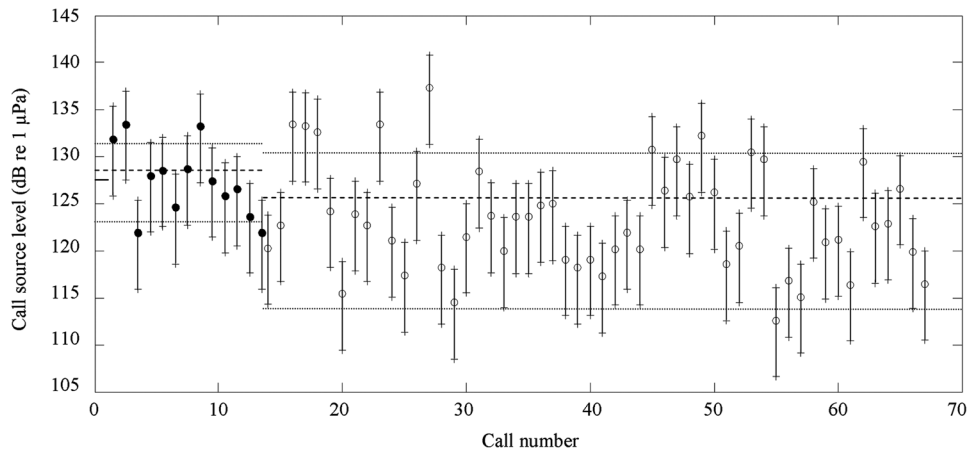
FIG. 3. Residual SPLs around the relationship between SL and pulse number plotted against the number of pulses in each call for the 45 (filled circles) and 32 (empty circles) cm *G. hebraicum*. Error bars show the maximum and minimum possible SLs assuming 0. m as three standard deviations in the range between fish and hydrophone for each call. The mean SL for each fish is shown by the dashed line and the 95% confidence limits shown by the dotted lines (calculated in the linear domain).

respectively, and 9 and 10 dB re 1 μPa^2 s for the SEL confidence limits, respectively (Fig. 3). The ranges between maximum and minimum rms SL estimates were 11 and 24 dB re 1 μPa for the first and second fish, respectively, and the same values for SELs were 20 and 18 dB re 1 μPa^2 s, respectively (Table I, Fig. 4). If these extreme ranges in SLs were due to maximum differences in distance between fish and hydrophone (i.e., recordings of highest estimated SL were actually taken at 0.5 m and those of the lowest taken at 1.5 m), the range in rms SL for each fish could have been as low as 2 and 15 dB re 1 μPa and in SELs, 11 and 9 dB re 1 μPa^2 s (Table I, Fig. 3).

Similar to the estimated SLs, the distribution of spectral peak frequencies were also broad (Fig. 4) and while the call SLs of the larger, first fish, were higher than that of the second fish overall, the spectral peak frequencies were lower. The mean spectral peak frequency over all calls was 154 Hz (± 43.5, max $= 251$, min $= 82$) with a mean 3 dB bandwidth of 110 Hz (see Fig. 5 for spectrograms and waveforms of example calls). For the 45 and 32 cm fish, this frequency was 144 and 157 Hz, respectively. In each call, bands of energy were also observed at frequencies above the spectral peak, similar to those in Figs. 5 and 6, at approximately 350 and 450 Hz.

The duration of cycles in the waveforms of 44 pulses from 15 calls of the second fish were compared to the spectral peak frequency of the respective pulse. In each case, the frequency of the first cycle was similar to that of the second cycle with an average difference of 13 Hz (approximately 6% of the cycle frequency). The frequency of both first and

second cycles related closely to the spectral peak frequency of the respective pulse (Fig. 7).

Although calls contained between 1 and 14 pulses, 2 pulses were most common (Table I). For calls from both fish, the mean of maximum rms SLs and SELs decreased with calls of an increasing number of pulses (Fig. 8). This decrease was similar for both fish and appeared to be more prominent in the rms SL than the SEL (compare Fig. 8, left with Fig. 8, right).

IV. DISCUSSION

This study has investigated the capability of *G. hebraicum* to produce sound, by determining the biological mechanisms and the recording of sounds produced by individuals during capture. Dissections identified the presence of sonic muscles in adults of both sexes and in juveniles. The majority of soniferous fish species produce sound associated with spawning behavior, which may also be the case for *G. hebriacum*. However, the fact that adults produced sound during capture also indicates that individuals may make sound when distressed. Furthermore, similar sounds to those reported here have been heard by the authors while observing juveniles underwater, which may also indicate their use as a warning signal.

The reported SLs of 126 dB re 1 μPa at 1 m for *G. hebraicum* are lower than that of silver perch (*Bairdiella chrysoura*; 135 dB re 1 μPa at 1 m; Sprague and Luczkovich, 2004) and Oyster toadfish (*Opsanus tau*; 132 dB re 1 μPa at 1 m; Barimo and Fine, 1998). Therefore, despite the large
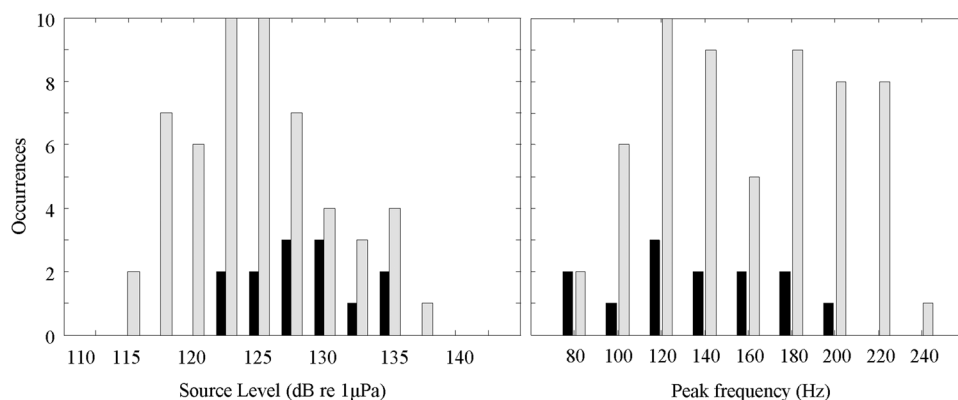

FIG. 4. Distribution of maximum SLs (left) and spectral peak frequencies (right) of all calls from the 45 (black bars) and 32 (gray bars) cm *G. hebraicum*.
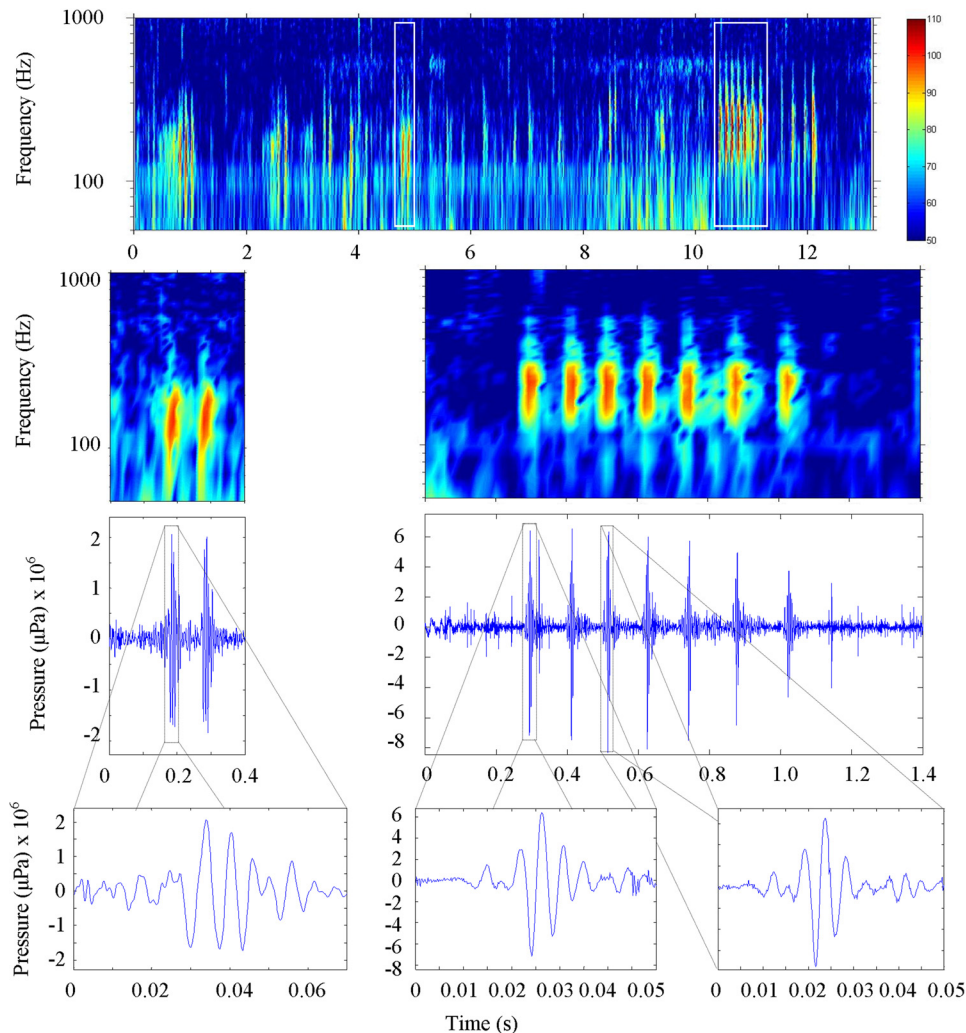
FIG. 5. (Color online) Spectrogram of a recording taken off Rottnest Island, including two example *G. hebraicum* calls, comprising two (left magnified call) and seven (right magnified call) swimbladder pulses. Frequency resolution in each spectrogram is 15 Hz. Waveforms of each call are shown with the waveform from individual pulses from each call shown.

body size of *G. hebraicum*, their calls are of comparatively low level and are of similar intensity to those of the above smaller species. This is most likely due to the different method of sound production which appears to be specific to the Glaucosomatid family (Mok *et al.*, 2011). Large sciaenids, such as mulloway (*Argyrosomus japonicus*) or black jewfish (*Protonibea diacanthus*), whose reported maximum lengths are 1.81 and 1.50 m, respectively (Sasaki, 2001; Silberschneider *et al.*, 2009), can produce calls of mean SL over 150 and up to 172 dB re 1 μPa at 1 m (Cato, 1980; McCauley, 2001; Parsons, 2010; Locascio and Mann, 2011; Parsons *et al.*, 2012) which can propagate several hundred meters (Parsons *et al.*, 2009, 2012). Individual *G. hebraicum* calls are more likely to be effective at ranges of up to around 100 m (assuming typical ambient noise levels of 80–90 dB re 1 μPa over the same bandwidth and spherical spreading as the maximum transmission loss). Given the likely number of calling fish, it is less probable that the calls are used as a long-range advertisement and more likely that they are involved in close-range mating behavior.

Calls from both fish displayed a broad range in SLs (11 and 24 dB re 1 μPa range for rms SL for the two fish, respectively) and peak frequencies (104 and 169 Hz range, respectively). A possible source of variation in the SLs is the variation in range between fish and hydrophone. An estimate of ±0.5 m was made for three standard deviations in the distribution of distances at which measurements were taken. This difference in source range would have a greatest impact, contributing approximately 9.5 dB to variation in SL, assuming spherical spreading as the only transmission loss. The remaining SL variation is not unusual in the wild. Parsons *et al.* (2012) determined 17 dB re 1 μPa confidence
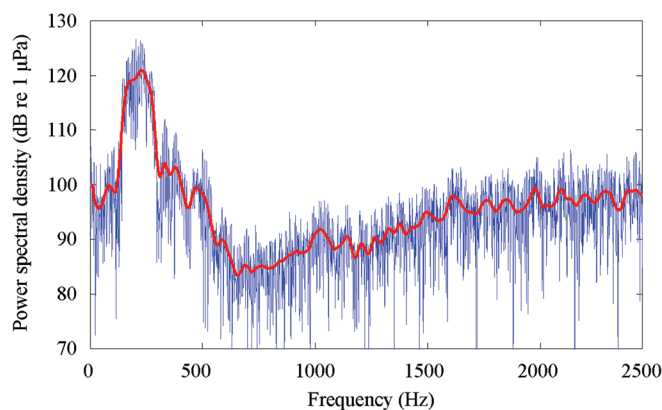

FIG. 6. Power spectral density for the seven pulse *G. hebraicum* call shown in Fig. 5. Frequency resolution of 2 Hz (blue line) and 20 Hz (red line) are shown, highlighting the main band of energy between approximately 125 and 300 Hz, with energy bands at around 350 and 450 Hz.
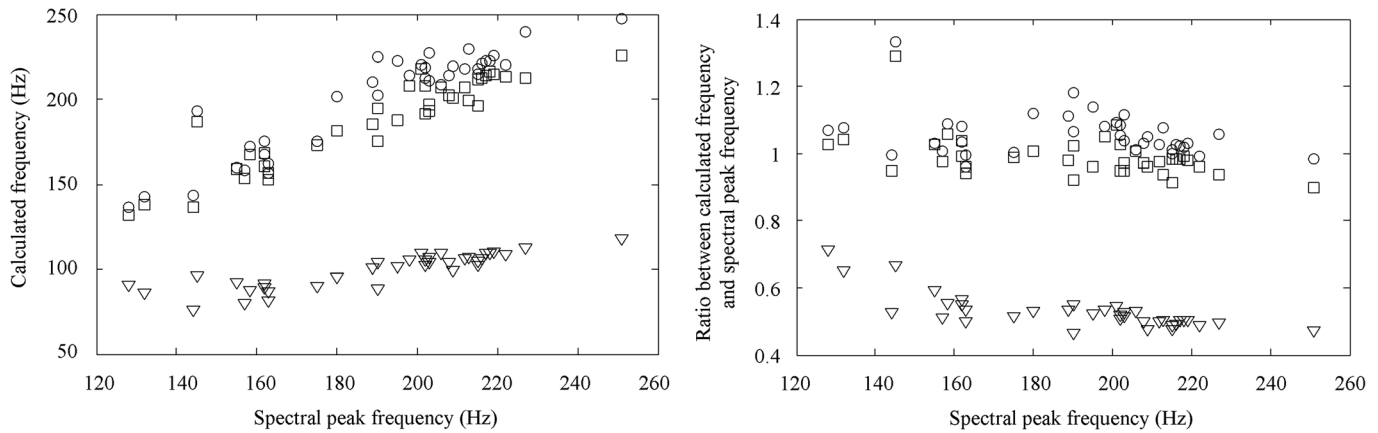
FIG. 7. Relationship between calculated frequency (left) and ratio between calculated and spectral peak frequency (right) and the spectral peak frequency of the first cycle (circles), second cycle (squares), and total duration (triangles) of individual pulses of calls where the peaks of cycles were free of surface reflections.

limits in SLs of a single *A. japonicus* at various ranges, while Lagardere and Mariani (2006) noted considerable differences in pressure amplitudes of consecutive pulses within single calls of *Argyrosomus regius*. Such variation has been noted in calls of other species as well (Nilsson, 2004). As call SLs are related not only to fish size, but also muscle tension among other factors (Sprague, 2000), it is conceivable that the fish is responsible for some of this variation in SL. As muscle tension also relates to peak frequency (Sprague, 2000; Rome, 2005), it follows that some of the variation in call frequency may also be attributed to differences in sonic muscle tension applied by the fish. Other factors likely to contribute to variations in estimated SL were the environment, changing fish depth, and surface reflections, not to mention the changes in fish behavior during capture, retrieval, and release. Connaughton *et al.* (2000) noted the relationship between the frequency of the second cycle in the pulse pressure wave and the peak frequency of the call.

A similar relationship was observed in this study; however, both the first and second cycle in the *G. hebraicum* calls here were similar to the spectral peak frequency of the pulse indicating a lack of damping compared with that of the weakfish.

While this study only had a sample of two fish, there were points of note with the difference in size between the fish. Here, the rms SLs of calls from the larger fish were greater than those of the smaller fish, while the spectral peak frequencies were lower. In other species, it has been shown that SL increases with size while peak frequency decreases (Connaughton *et al.*, 2000), thus the observed differences were expected. In contrast, the maximum SELs in the larger fish were lower than the smaller fish suggesting that the pulse duration was longer (Parsons *et al.*, 2012). This is in line with the lower peak frequencies in calls of the larger fish.

As the number of pulses in *G. hebraicum* calls increased, the maximum recorded SL decreased for calls of
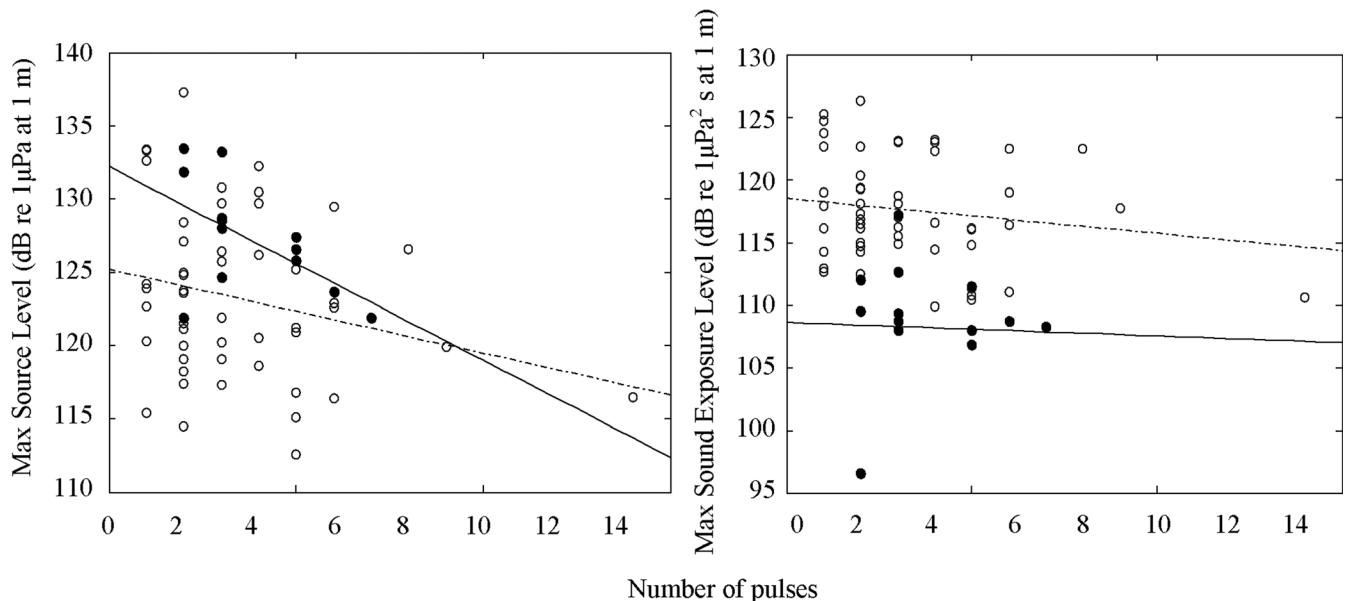

FIG. 8. Distribution of maximum SLs (left) and SELs (right) against the number of pulses within the calls recorded from the 45 (filled circles) and 32 (empty circles) cm *G. hebraicum*. Continuous and dashed lines illustrate the trend in SL with increasing numbers of pulses within a call for fish 1 and fish 2, respectively.

both fish. Therefore, calls became quieter as more swimbladder pulses were used. This suggests that an increase in call duration causes muscle fatigue, therefore limiting the production of sounds of multiple pulses, as suggested for other species (Nilsson, 2004; Parsons, 2010; Mitchell *et al.*, 2008). Amorim *et al.* (2002) reported that sound production does not appear to be a costly activity for *O. tau* at the whole body level, thus it is likely that in the two *G. hebraicum* recorded, their muscles did not possess the fitness to produce calls of many pulses. Whether this is similar for other *G. hebraicum* and if not, whether the differences provide information to the call recipient about the caller requires testing.

Many fish species, despite low call SLs, increase their call catchment area by calling *en masse*, numbering in the thousands of fish (McCauley, 2001). However, the small numbers of *G. hebraicum* groups observed by Mackie *et al.* (2009) suggest that today a chorus of *G. hebraicum* involving groups of hundreds to thousands of fish, similar to those of lekking species, where males group together first to attract females (Höglund and Alatalo, 1995), is unlikely. However, between December and March each year, *G. hebraicum* spawn along the Western Australian coast, most notably in waters off Cape Naturaliste, southwestern Australia (Mackie *et al.*, 2009). Although exact locations of spawning may not be known, commercial fishers report significant catches in this area of spawning *G. hebraicum* (Mackie *et al.*, 2009). It is possible that the numbers of *G. hebraicum* aggregating in this area are sufficient to produce a detectable chorus and studies are underway to locate and record such an event.

V. CONCLUSIONS AND FUTURE WORK

The ability of *G. hebraicum* to produce sound has been confirmed through an examination of physical characteristics and recording of sound directly from individual fish. It is necessary to determine the associated functions of calls to gain an understanding of whether they are made in relation to spawning or other behavior. There is the potential to use these identified calls to locate vocalizing *G. hebraicum* in the future, possibly to delimit sites where the fish aggregate and/or spawn. To investigate sound-related behavior further, an array of sea-noise loggers have been deployed at sites around southwestern Australia, where commercial fishers reportedly catch significant numbers of *G. hebraicum*, and also at sites near Augusta where juvenile *G. hebraicum* have been observed and sounds heard by researchers.

ACKNOWLEDGMENTS

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