

Dhu they or don't they? A study of sound production by three fish species of commercial and recreational importance in Western Australia

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ABSTRACT

Over 800 species of fish produce sound, for a variety of reasons including distress, spawning and agonistic behaviour. An increasing number of sparids have been shown to be soniferous, but while studies of glaucosomatids (pearl perch- es) have shown the presence of likely 'sonic' muscles confirmed reports of sound production in the wild has been elusive. In Western Australia, a project examined whether West Australian dhufish (*Glaucosoma hebraicum*), snapper (*Pagrus auratus*) and black bream (*Acanthopagrus butcheri*) produce sound. Recordings of dhufish, an iconic fish in Western Australia, have provided proof of sound production and some acoustic characteristics of dhufish sounds are presented. For black bream, while sounds were recorded at a known spawning location at a time of spawning, black bream could not be confirmed as the source. No confirmed evidence of sound production was found for snapper, either during spawning or upon capture. It is possible that in data-limited situations for fisheries, monitoring of sound-producing fishes using passive acoustic techniques could elucidate additional information about ecology, reproductive behaviour and relative abundance.

INTRODUCTION

Sound propagates efficiently through water and is relatively unaffected by variations in conditions such as light, current and turbidity, thus underwater acoustic methods can sample a broad area limited only by ambient noise levels and propagation (Urick, 1983, Simmonds and MacLennan, 2005). Over 800 species of fish have been reported to produce sound (Slabbekorn et al., 2010), many of which do so with associated spawning behaviours (Fine et al., 1977). These vocalisations have been realised for hundreds of years as Chinese fishermen used fish calls to track spawning aggregations (Moulton, 1964). Passive acoustic recording of fish sounds has developed over recent decades (Rountree et al., 2006) and, as a result, fish sounds are being used to spatially and temporally delineate spawning areas and for certain species the sound pressure levels (SPLs) produced has correlated with numbers of sampled eggs (Barrios, 2004, Parsons, 2010, Luczkovich et al., 1999). Modelling the numbers of calling fish from SPLs is advancing (Parsons, 2010, Sprague and Luczkovich, 2011), though proving this concept still requires effort. In niche areas, passive acoustic recording has begun to provide data on aggregations, where other sources have been inconsistent or not provided data. For example, this method has been able to consistently acquire data on spawning mullet (*Argyrosomus japonicus*) in dark, turbid estuarine waters over entire spawning seasons (Mackie et al., 2009, Parsons et al., 2009).

Many fish species often exhibit biological and/or behavioural characteristics which can bias or restrict data acquisition using traditional sampling techniques. For example, fish which are susceptible to barotrauma or handling stress and exhibit high release-mortality, such as mullet and West Australian dhufish (*Glaucosoma hebraicum*) (Mackie et al.,

2009), may not be appropriate species for sampling methods which require catch and release techniques, e.g. tagging studies. Also, fish which aggregate at night or in turbid waters can be difficult to detect with underwater visual techniques (Halford and Thompson, 1994, Nagelkerken et al., 2001), while eggs produced by fish in waters of high current flow may not be easily sampled. Additionally, fishes which are highly mobile during spawning require survey techniques capable of sampling broad areas. Species that form aggregations for short periods of time may be missed by short-term or one-off surveys (Robichaud and Rose, 2001, Luczkovich et al., 1999, Lo and Macewicz, 2004). An additional, complementary data source, such as acoustic recordings, could significantly enhance knowledge of data deficient species or particular aggregations.

The recent advances in technology have allowed almost continuous recording of sound for periods of several months, up to years, ensuring that vocalisations from events such as spawning are not missed, even if over a relatively short time period (Parsons, 2010). Additionally, as target fish are unaware their sounds are being recorded their behaviour remains unaffected (Parsons et al., 2009, Mackie et al., 2009). The technique does, however, have the limitation that a species has to be vocal to be recorded. Characterising call functions and call rates, identifying ratios of callers to non-callers and correlating SPLs with egg or fish relative abundance still needs extensive investigation before these methods could provide any relevant fisheries-independent data. However, once completed such a method, being non-extractive would be of particular benefit to species which exhibit high release-mortality rates (Mackie et al., 2009). The first step towards gaining a better understanding of an aggregation and its behaviour via passive acoustic recording is to identify whether a species is vocal and if any sound is produced during periods of spawning.

WA dhufish, snapper (*Pagrus auratus*) and black bream (*Anthopagrus butcheri*) are commercially and recreationally important species in Western Australia (Brown et al., 2011, Fairclough et al., 2011). WA dhufish and snapper are employed as indicator species for monitoring demersal fish resources along the west coast of Australia (DoFWA, 2011), while black bream has become one of the pioneering species for studies of restocking estuaries (Gardner et al., 2010). Accurate monitoring of stocks of these three species is of ecological, social and economic importance to Western Australia.

Endemic to marine waters of Western Australia, WA dhufish is a slow growing, sedentary, demersal species inhabiting reefs and caves to depths of 200 m (McKay, 1997, Hesp et al., 2002; St John and Syers, 2005, Mackie et al., 2009). Lack of variation in seasonal reproductive timing along the west coast of Australia suggests that factors such as social cues, in addition to environmental variables, influence spawning (Mackie et al., 2009). Male co-habitation of an area, indicative of lekking behaviour, has been observed in WA dhufish. Males are also large, relative to females, with a dorsal filament indicative of sexual display behaviour. Combining these traits with a negative relationship between female size and their length of spawning period, corroborates a social structure whereby the largest males sire the greater number of juveniles with the largest female (Mackie et al., 2009). Additionally, WA dhufish have relatively small testes, like many protogynous hermaphrodites, such as labrids, indicative of pair spawning – i.e. the male spawns with one female at a time and only releases a small amount of sperm. Vocalisation in the Glaucosomatidae (pearl perches) has not yet been reported, however, WA dhufish possess bi-lateral intrinsic muscles connecting the skull and swimbladder (Chiu, 2006, Vu, 2007, Parsons, 2010). In other species similar muscles are used to vibrate the swimbladder and produce sound (McCauley, 2001).

Snapper are typically found from shallow coastal lagoons and embayments to depths greater than 200 m on the continental slope of southern Australia and northern New Zealand. This species is known to form dense spawning aggregations in only two embayments on the west coast of Australia, which are both characterised by their shallow depth and hydrodynamics which retain eggs and larvae in nearby nursery habitats (Moran et al., 1998, Wakefield, 2010; Wakefield et al., 2011). In one of those embayments, Cockburn Sound, spawning peaks have been observed at new, and to a lesser extent, full moons when tidal ranges are at their greatest (Wakefield, 2010). Within Cockburn Sound, egg concentrations have shown that an aggregation forms firstly in the northeast area of the sound, moving to the middle and ending in the north-west across the spawning season (Wakefield, 2010), suggesting that the aggregations respond to changing flow dynamics. During spawning, the fish are mobile and form aggregations in shallow waters (Mackie et al., 2009). Egg release is thought to occur predominantly at dusk and therefore at times of low light levels when visual cues at long range are ineffective. Although sound production is unreported in snapper, some members of the Sparidae family are soniferous (Tavolga, 1974, Cruz and Lombarte, 2004). Paxton (2000) hypothesised that members of the Sparidae family with relatively large sagittal otoliths, such as snapper, are likely to be soniferous, similar to other species of the family. Overall the relative size of sparid sagittae is greater than the labrids (few vocal species) and smaller than the sciaenids (a family that contains soniferous species and is recognised as 'drummers' or 'croakers').

Black bream are a true estuarine species found in most estuaries of south-western Australia (Lenanton, 1977). Although the types of preferred habitat may vary (Norris et al., 2002), during spawning the species often congregate in deep holes, possibly due to advantageous salinity and high dissolved oxygen conditions (Newton, 1992, Sarre, 1999, Sherwood and Blackhouse, 1982, Sarre and Potter, 1999, Norris et al., 2002). Together with aggregations forming in low visibility conditions, a lack of species sexual dimorphism suggests that communication other than using visual cues may play a part in spawning.

This study has used passive acoustic techniques to investigate sound production in the wild at locations where these species are known to spawn (in a glaucosomatid and two sparids) – in conjunction with physical examination of individuals for existence of sound producing muscles.

METHODS

Passive acoustic recordings of underwater noise were acquired using several configurations of HTI 90-U or HTI-min hydrophones attached to either a HR-5 Jammin Pro recorder or a CMST-DSTO developed underwater sound recorder (Parsons 2010; Figure 1). These deployments occurred across Western Australia for each species at locations where spawning aggregations have been reported (Figure 2, Table 1). Deployments targeting WA dhufish were over varying marine habitat, usually including seagrass beds while recordings of snapper were obtained predominantly over sand and black bream recordings were taken at a known fishing location in the Frankland River in a 7 or 11 m deep hole.

Each recording system was calibrated with a white noise generator at -90 dB re 1 V²/Hz and data analysed using the CHARACTERISATION OF RECORDED UNDERWATER SOUND (CHORUS) Matlab toolbox written at the Centre for Marine Science and Technology (CMST). Sampling rate at each logger deployment was 8 kHz with cut-off frequencies of 8 Hz and 2.8 kHz, recording at different schedules, throughout the deployment (Table 1 and 2). Drift based recordings were taken with the HR-5 recorder sampling at 48 kHz. Spectrograms were produced with a 1024 Hanning window at a frequency resolution of 10 Hz. Recordings taken in conjunction with DoF sampling were often conducted during the capture of individual fish by DoF researchers using handlines.

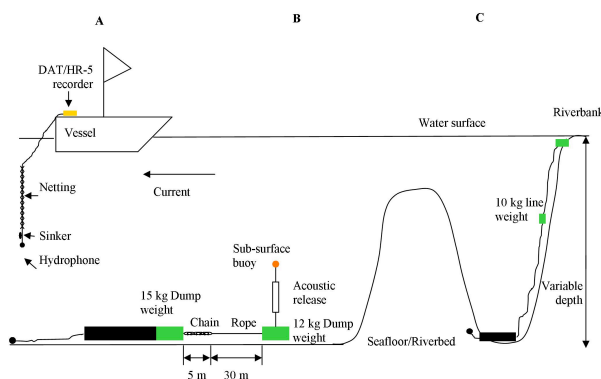


Figure 1. Hydrophone and recorder configurations for drift-net (A), seabed (B) and riverbed (C) deployments. Black rectangles and circles represent loggers and hydrophones.

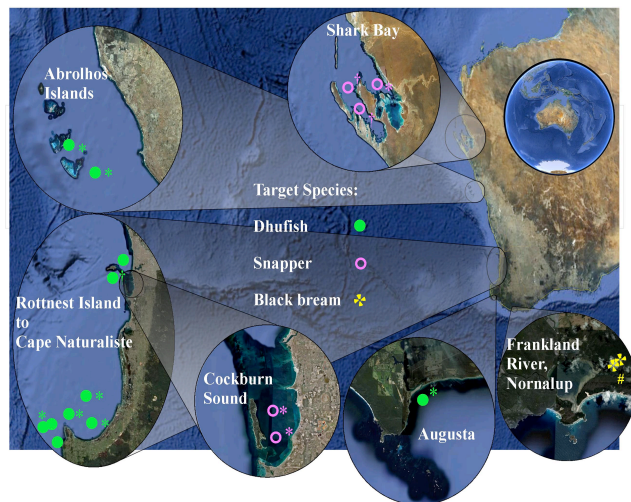


Figure 2. Deployment locations for WA dhufish (filled circle), snapper (empty circle) and black bream (crosses), together with deployment configuration of seabed (*), riverbed-bank (#) or drifting (†) positioned hydrophone. Image source: Google Earth accessed 5/5/12.

Table 1. Deployment locations, dates and sound-sampling schedule

Location	GPS	Target species	Start Date	End Date	Schedule number
Shark Bay	25°43'S 113°49'E	Snapper	11/07/10	14/07/10	1
Shark Bay Western Gulf	Numerous	Snapper	13/07/10	13/07/10	3
Cockburn Sound †	32° 12 'S 115° 44 'E	Snapper	8/10/10	16/10/10	1+3
Cockburn Sound †	32° 10 'S 115° 44 'E	Snapper	8/10/10	16/10/10	1+3
Frankland River	34° 59 'S 116° 49 'E	Black bream	20/10/10	26/10/10	1
Cockburn Sound	32° 12'S 115° 44 'E	Snapper	9/11/10	17/11/10	1
Geographe Bay	33°27'S 115° 7'E	WA dhufish	13/12/10	17/01/11	2
Geographe Bay	33° 30'S 115° 20'E	WA dhufish	13/12/10	26/01/11	1
Horseshoe Reef, Cowaramup	33° 40'S 114° 51'E	WA dhufish	08/02/11	11/02/11	1
Rat Island, Abrolhos	28° 46 'S 113° 48'E	WA dhufish	21/2/11	26/2/11	1
CARL	Curtin University	WA dhufish	Various	Various	3
Frankland River	34° 59'S 116° 49'E	Black bream	30/11/11	16/12/11	1
Rottneest Island	31°59'S 115°33'E	WA dhufish	Various	Various	3

† Mid-water vessel based recordings were also taken at this site during the deployment of the long-term logger

*All locations given to the nearest minute to maintain privacy of fishing locations

Table 2. Deployment sampling settings and schedules used

Schedule number	Sample rate	Low frequency roll-off	Anti-aliasing filter	Sampling schedule
1	8 kHz	8 Hz	2.8 kHz	600 s each 900 s
2	8 kHz	8 Hz	2.8 kHz	360 s each 900 s
3	32 kHz	--	--	Periodic recordings

Deceased samples of WA dhufish ($n = 6$) and snapper ($n = 10$) were donated to the CMST either by the Department of Fisheries (DoF) or recreational fisherman or purchased. These fish were dissected either at the survey site or the CARL. Individuals were examined for possible mechanisms of sound production, such as intrinsic or extrinsic sonic muscles (to vibrate the swimbladder) or pharyngeal teeth (to produce grinding sounds) and likely acoustic characteristics of calls related to size and material of swimbladder.

RESULTS

West Australian dhufish

Upon dissection, each WA dhufish revealed evidence of sonic muscles. In one individual of standard length 333 mm, the swimbladder and total sonic muscle lengths were 180 and 46 mm, respectively. The swimbladder is located approximately halfway along the body at the posterior end of the abdominal cavity (Fig. 3B). Intrinsic, bi-lateral sonic muscles are attached to the anterior of the swimbladder and extend forward, attached at points either side of the rear of the brain case and otoliths (Figure 3C). The sonic muscles are formed in sections of short, highly vascularised muscle (Figure 3 C) which twist around each other, similar to those suggested by Parmentier *et al.* (2003). An area of thick-walled tissue protrudes forwards at the anterior of the swimbladder, just below the attached sonic muscles. With the exception of the thick-walled tissue on the anterior of the swimbladder, its remainder appeared to be of one material. No evidence of pharyngeal teeth which could produce sound were observed in any of the dissected WA dhufish.

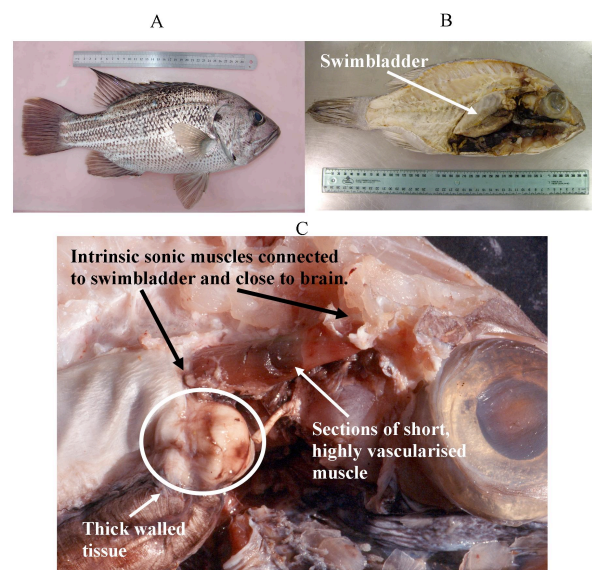


Figure 3. West Australian dhufish (A, photograph taken by Mike Mackie) and skeleton after filleting (B). Swimbladder location is highlighted with the points of interest of the swimbladder (B and C) and bi-lateral, highly vascularised muscle in short sections attaching the anterior of the swimbladder to the side of the brain case (C) are shown.

Recordings taken near Rottneest Island in 8 m of water, during the capture of two WA dhufish on handlines, have provided definitive evidence of sound production by the species. The calls ranged between 1 and 14 pulses at a repetition rate of 0.11 pulses per second (± 0.033 s.d., max 0.19, min 0.06, $n = 24$) for calls of more than 1 pulse. The pulse repetition, combined with damping of the swimbladder vibration (Figure 4,

pulse waveform) meant that for calls of multiple pulses, each swimbladder pulse could be audibly discriminated. Mean spectral peak frequency for calls from one fish was 156.75 Hz (± 44.6 s.d., max 251, min 82, $n = 40$) with an average frequency bandwidth of 122 Hz (using a 6 dB drop from the peak frequency). Power spectral density levels of the calls with highest received levels were at least 35 dB re $1\mu\text{Pa}/\text{Hz}^2$ higher than background noise (Figure 4, right hand call)

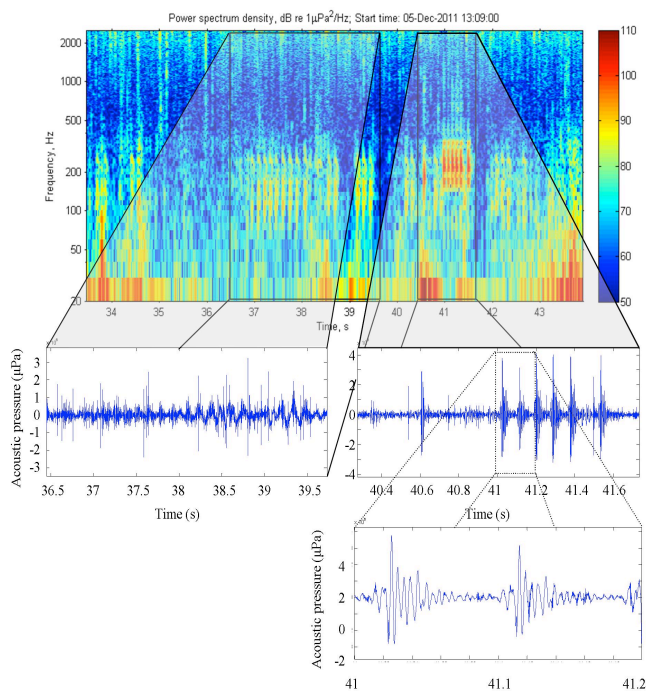


Figure 4. An example spectrogram (top) and waveforms (bottom two rows of panels) of two sets of WA dhufish calls acquired off Rottnest Island in 8 m of water (frequency resolution of 10 Hz).

Snapper

The dissected snapper from Shark Bay and Cockburn Sound were all mature and ready to spawn. The vast majority of the body cavity of a spawning 758 mm male snapper from Cockburn Sound comprised its testes and a comparatively large swimbladder with a volume of 741 cm^3 (individual was raised slowly from <10 m depth; Fig. 5A, B). Only white muscle fibres were observed surrounding the swimbladder (Figure 5C), although two red muscles were attached close to the anterior of the swimbladder (Figure 5D). No evidence of pharyngeal teeth capable of noise production was observed (Figure 5E). The interior of the swimbladder displayed a complex structure whereby ribs and tendons were woven through the top section of the swimbladder (Figure 5F and G). The effect this structure might have on the vibration of the swimbladder and therefore any produced sound is unknown. Similar physical characteristics were found in male and female samples taken from the Western Gulf of Shark Bay in July 2010.

The seafloor recordings in Shark Bay and Cockburn Sound, taken during known snapper spawning periods, displayed an increase in sound pressure levels (SPL) below 300 Hz, beginning around sunset each evening (Figure 6 shows an example of the Shark Bay recordings). This time period, however, also often occurred approximately 3-5 hours after an increase in wind levels, recorded at nearby wind stations. Whether the increase in SPLs at frequencies below 300 Hz is attributable to snapper or wind-driven waves has yet to be determined. During this period, no individual calls could be reliably identified as originating from fish.

Additionally, mid-water recordings were taken in Shark Bay's western gulf and Cockburn Sound during biological sampling of aggregating snapper by the DoF. At the same time as the recordings, 22 mature snapper in Shark Bay (16 male, 6 female) and 5 mature snapper in Cockburn Sound (4 male, 1 female) were captured. No sounds were emitted by the fish during capture.

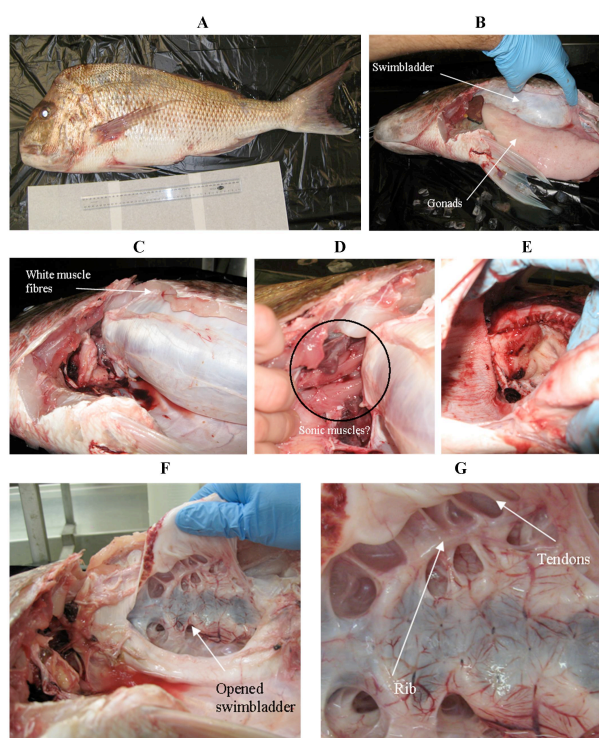


Figure 5. Spawning male snapper (758 mm)(A), captured in Cockburn Sound. Dissection highlighting the relative size of swimbladder, gonads and internal organs within the body cavity (B). White muscle fibres found surrounding the swimbladder (C). Bi-lateral, highly vascularised muscles loosely attached to the anterior of the swimbladder (D). Forward-view from the swimbladder towards the rear of the mouth, no grinding pharyngeal plates were found (E). Swimbladder opened (F) to reveal that the ribs run through the swimbladder and are connected together by white tendons (G).

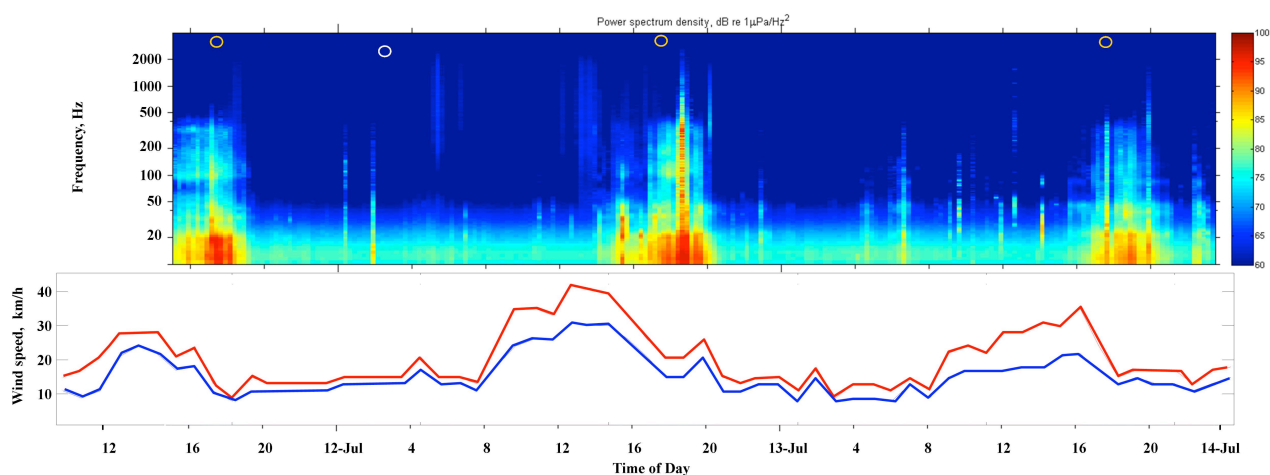


Figure 6. Stacked spectrograms of acoustic recordings taken at 'The Patch' in the Eastern Gulf of Shark Bay, together with the hourly mean and maximum wind speeds (blue and red lines of bottom plot) measured at Shark Bay airport provided by the Bureau of Meteorology. Orange and white circles in the top plot represent time of sunset each day and of the new moon, respectively.

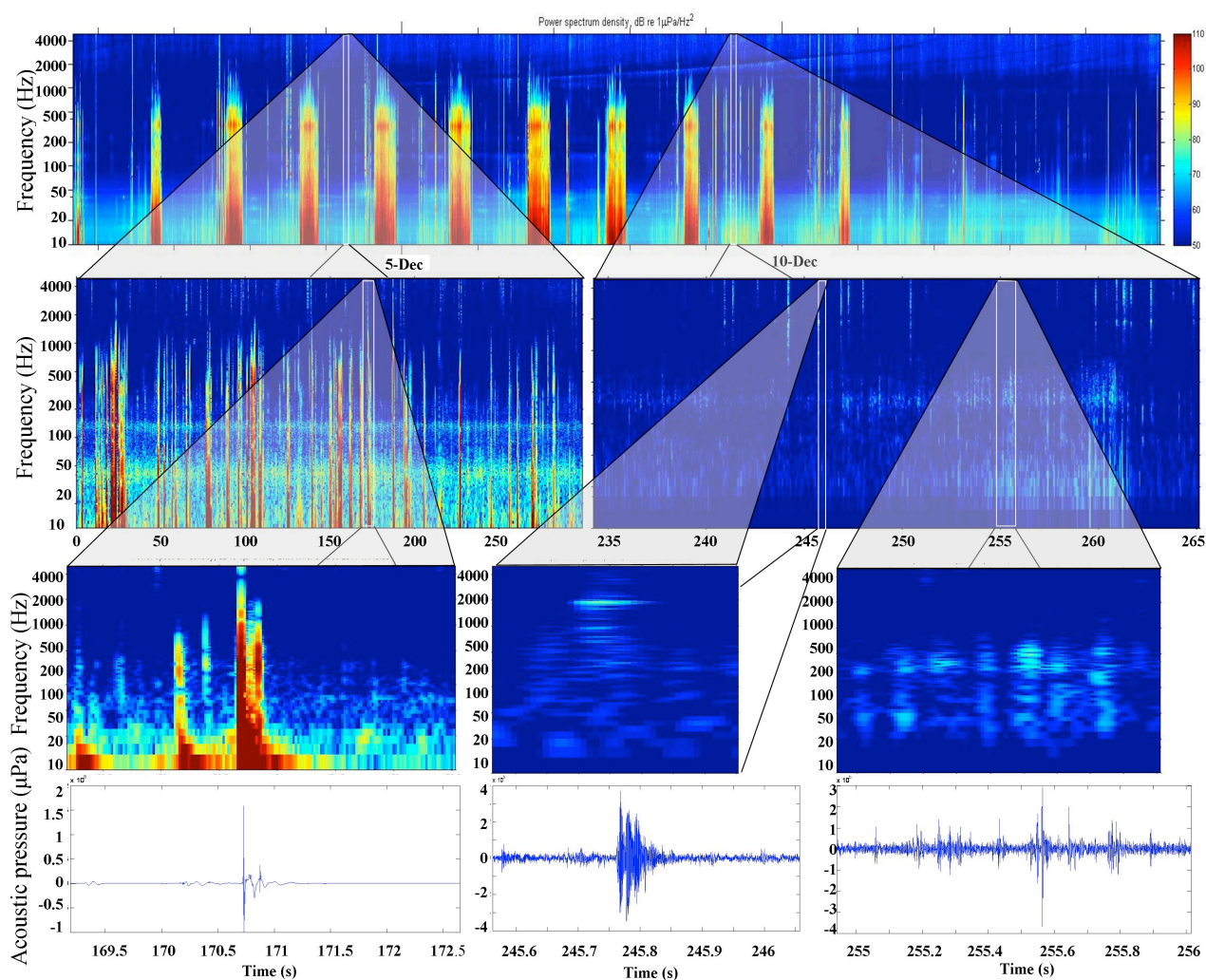


Figure 7. Stacked spectrograms of 6 days acoustic recordings taken in the Frankland River (top), together with expanded sections of the spectrograms (middle) and waveforms of signals of interest (bottom).

Black bream

Specific fish sounds were not detected in the Frankland River in 2010. Broadband, high frequency clicks (centred at frequencies greater than 2 kHz) of short duration, thought to originate from crustaceans or possibly jaw snaps of fish, were the only biological sounds observed in recordings. Water-movement induced sound, speculated to be caused by swimming fish were also observed. However, anecdotal evidence from fishers suggest that spawning occurred early in the 2010 season and the black bream may have departed the sampled area of the river prior to the recordings.

Anecdotal evidence from fishers suggest that the late rain in the 2011 season delayed the arrival of the black bream into this area of the Frankland River and that spawning may have been occurring during the acoustic recordings. During these recordings significant mooring noise up to 1000 Hz was observed for a period of 10 days (1/12-11/12, Figure 7, top image) from the early afternoon until several hours after dark (Figure 7, left hand images). These noises were due to tapping on the hydrophone (rather than wind generated wave movement of the hydrophone), likely to be caused by an animal. As the mooring noises began, so did sounds between 100 and 500 Hz (predominantly around 200 Hz, Figure 7, right hand images). At their peak these sounds were produced throughout the day (sunrise to several hours after sunset). While the mooring noises became infrequent after the 11th December the calls persisted for several days, at a considerably reduced rate, during hours of darkness (Figure 7, 11th to 14th December).

Aural inspection of the sounds between 100 and 500 Hz showed they were most likely generated by a vibrating swimbladder, though the mechanism of vibration and numbers of pulses within each call is unknown. As range could not be determined for these sounds the number of sources is unknown. Infrequent sounds most likely originating from fish and containing energy around 2000 Hz were observed (Figure 7, lower middle images).

DISCUSSION

The analysis of passive acoustic recordings in the environment and dissection of individuals of West Australian dhufish, snapper and black bream has provided strong evidence that individuals of the former species can produce sound. Snapper do not produce sounds which could be used to investigate spawning behaviour, while further effort is required to confirm whether black bream may produce swimbladder driven calls.

The recordings taken off Rottnest Island have confirmed that WA dhufish can produce sound (Figure 4), most likely from individual twitches of the sonic muscles attached to the anterior of the swimbladder (Figure 3). These have been shown to be centred between 100 and 200 Hz. The power spectral density levels of at least 35 dB re 1 μ Pa/Hz² higher than background noise (Figure 4) indicate that the sound could be heard from at least 50 m from the hydrophone (based purely on a simple estimate of transmission losses from spherical spreading of 20log r). While these levels are lower than those typically received from other vocal species, such as mullet (Parsons et al., 2009, 2012), they may be detected over greater ranges if the ambient noise levels are low, which frequently occurs in the waters of Geographe Bay, southwestern Australia (Salgado Kent et al., 2012), a typical spawning ground for WA dhufish (Berry et al., 2012). If

these sounds could be detected at its spawning sites, they could be used to provide considerable information on their behaviour. In particular, as WA dhufish have been shown to exhibit limited onshore-offshore movements (Mackie et al., 2009) at what time of the year, WA dhufish arrive at known spawning sites each year, such as Geographe Bay, and whether fish return to those sites each year. At low densities of callers within the hydrophone detection range it may be possible to discriminate between calls and estimate the number of callers present. Once these calls overlap significantly, in the form of a chorus, it may be possible to model the number of callers present from the overall chorus sound pressure levels (Parsons, 2010, Sprague and Luczkovich, 2011). However, significant effort would be required to characterise call source level, call rate and function before this could be estimated.

The recordings of WA dhufish were taken in 8 m of water. However, in Geographe Bay, WA dhufish form small groups on the seafloor in around 40 m of water to spawn. Thus, the effect of the additional depth on the characteristics of WA dhufish calls is unknown. Theoretically, the additional pressure at that depth would reduce the volume of the swimbladder and therefore the resonant frequency for each pulse (Simmonds & MacLennan, 2005). However, many species of fish maintain swimbladder pressure while at depth by secretion of gas via a specialised organ, the *rete mirabile*, with a vascular countercurrent system for enhanced gas secretion or absorption in order to maintain neutral buoyancy (Steen, 1970, Pelster, 2004). Therefore, further work is also required on the influence of depth on the characteristics of WA dhufish calls.

The Cockburn Sound and Shark Bay datasets derived from snapper spawning aggregations have shown that snapper do not appear to vocalise, but possess physical characteristics which may produce sound as a product of vigorous swimming. If they do vocalise, their sounds are not easily distinguishable from wave noise, as signals were not powerful enough to be individually detected and would be of a similar frequency to wave noise. Given the large volume of a mature snapper's swimbladder it is possible that the resonant frequency occurs at low levels (e.g. 50-100 Hz). It would then be feasible that vigorous swimming motions could cause the swimbladder to vibrate and increase SPLs at those frequencies, without discernible calls being emitted. Sound production around these frequencies would make using passive acoustics to observe snapper behaviour a very complex task. Sexual dimorphism that has been recorded in snapper, e.g. difference in head morphology, may be enough for individuals to use visual cues to distinguish between sexes (Moran et al., 1998), however, spawning in Cockburn Sound occurs at night and despite the species adaptation to low/no light may require other cues to increase spawning success (Wakefield, 2010).

The Frankland River datasets from 2011 indicated that black bream may produce sound. However, more work is needed to confirm the source of sounds recorded and, if they were bream calls, characterise the calls. The anecdotal evidence suggesting that spawning had finished prior to the 2010 recordings (where no calls were observed) combined with the times of spawning and recording in the 2011 season implies black bream is a likely candidate for the calls recorded. Given the lack of other fish species caught at this time and location in the river adds credence to black bream as the source.

Fish calls recorded around 2000 Hz were too infrequent to be used as a future indicator of whether the source is present in

the Frankland River. In contrast, the sounds between 100 and 200 Hz and the mooring noises only occurred for 10 days of the deployment. Both the mooring noises and the fish sounds reduced in spectral levels at the same time, implying a single source is responsible for both types of sound. Although the catch evidence prior, during and post sound production was too small a sample to be conclusive, this period of increased noise matched the times when black bream were caught in the river by local fishers. Video evidence to confirm the source was restricted by heavy tannin concentration in the Frankland River and therefore visibility at the bottom of the 7 and 11 m holes in which the surveys were conducted. Without identifying the source level of each call, or characterising call rates it is difficult to monitor the number of callers. If the black bream were the source of these sounds, passive acoustics could provide a good method to monitor when they are present in the river, given that the sounds were recorded in the holes for a one week period, at a time when local fishers expected them to be there and indeed caught some. This could provide valuable information on the drivers of spawning, such as salinity, temperature and tide, similar to that of mullet in the Swan River (Parsons, 2010).

The confirmation of vocal behaviour in dhufish means passive acoustics holds great potential for the observation of both individuals and groups, to understand aspects of their behaviour. However, significant effort is still required to investigate whether vocalisations are related to natural functions, such as spawning, rather than distress calls during capture. Further work is required to confirm whether sounds in the Frankland River originated from black bream and thus whether this method could be used to investigate its presence if proven to be the source. However, visual confirmation of aggregations is anticipated to be the most reliable avenue for study of this species. It is not anticipated that passive acoustic methods will offer an efficient means to gather information on spawning snapper.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Australian Government via the Fisheries Research and Development Corporation for funding this project. The Department of Fisheries, Western Australia (particularly Gary Jackson, Jeff Norriss, Ian Keay and Brett Crisafulli), the Department of Environment and Conservation (Dave Holley) and the Shark Bay Ecosystem Research Project (Cindy Bessey) have supplied significant logistical support in the study of snapper and black bream. The recreational fishers of Shark Bay are also thanked for their help in catching snapper during a DoF study. We are grateful to Brett Molony and Lindsay Joll for providing constructive comments on this manuscript.

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