Passive acoustic detection of Shark Bay dugongs (*Dugong dugon*)

Miles J.G. Parsons (1), Dave Holley (2) and Robert D. McCauley (1)

(1) Centre for Marine Science and Technology, Curtin University, Perth, WA, Australia
(2) Department of Environment and Conservation, Government of Western Australia, Shark Bay, WA, Australia

ABSTRACT

Shark Bay, Western Australia is home to the one of the largest populations of dugongs (*Dugong dugon*) in the world. During winter months the dugongs predominantly reside in warmer western and northern waters of the gulfs, moving south between September and October as the shallower, more southern waters warm. Two underwater noise loggers, sampling at 12 kHz were deployed off Guichenault Point and Skipjack Point in Shark Bay's eastern gulf between the 16th September and 21st October, 2011 to record sounds produced in waters between 4 and 15 m depth. Speculated dugong calls were recorded sporadically throughout the deployment. However, on the 4th and 5th October several hours of biological 'short chirps' were recorded by the Guichenault Point logger. These calls displayed similar acoustic characteristics to chirps in previous reports, though of much shorter duration. Maximum received levels of 134 dB re 1µPa (±5.2 s.d., max = 143.3, min = 123.8) and maximum received sound exposure levels 114 dB re 1µPa^2.s (±5.3 s.d., max = 121.9, min = 103.4) were observed from 40 calls. Mean spectral peak frequency of 333 Hz (±316, max = 3610, min = 1957) with a 6 dB down bandwidth of 2746 Hz (±1685, max = 5250, min = 731) over a duration of 0.2 s (±0.17, max = 0.7, min = 0.004) were observed over the group of calls. The calls were also split into 3 smaller types and the acoustic characteristics of these speculated dugong calls are discussed.

INTRODUCTION

Dugongs, (*Dugong dugon*), are a marine, herbivorous species, mainly inhabiting coastal areas of tropical regions and are listed as a vulnerable species in the Red List of the IUCN (IUCN, 2008, Marsh et al., 1978, 2002). The species thrives on seagrass, which has a depth range limited mainly by attenuation of light (Abal, and Dennison, 1996, Duarte, 1991). Indeed, dugongs spend 72% of their day in waters of less than 3 m depth, where density of seagrass is often at its greatest (Chilvers et al., 2004).

The Shark Bay Marine Park plays host to one of the worlds largest populations of dugongs which are significant contributors to the marine park's world heritage status (Holley, 2006, Riley and Riley, 2005). The estimated population of approximately 16, 000 dugongs can be spread over roughly 10, 000 km^2 (DEC, 2012). Monitoring such a large population of megafauna across such a broad area is a logistically difficult task. During summer months the dugongs can be found in the southern, warmer waters of the gulf, typically between 1 and 3 m deep. In the winter months the population moves north into the safer, deeper waters and in the Spring months of September and October they can often be found at the bottom of banks in 5-15 m of water (Holley, 2006). Periodically, at high tide, the dugongs move up the bank to feed on seagrass. Again, here they are vulnerable to predators, which is possibly why they often move back into the deeper waters (Wirsing et al., 2006). Thus while the overall required survey area can be significantly reduced by considering movement patterns it is still a considerable undertaking to monitor the entire population within the Marine Park.

Current methods of surveying dugongs include aerial-, boat- or land-based surveys (Anderson, 1986, Anderson and Barclay, 1995, Marsh and Sinclair, 1989, Marsh et al., 1999). However, visual census can be logistically labour intensive, expensive, suffer from availability bias which is dependent on weather conditions, water clarity, dugong depth and light levels (night time surveys, for example, are nearly impossible), and are hindered by the predominantly sub-surface activity (Marsh and Sinclair, 1989, Akamatsu et al. 2005). There is the additional issue of perception bias associated with the use of multiple observers. There are methods for accounting for these biases and estimating confidence limits (Marsh et al., 1994, Pollock et al., 2004, 2006, Salgado Kent et al., 2012), however, a complementary, cost-effective monitoring technique which provides an alternative robust source of data to help minimise bias is needed.

Dugong eyesight is poor (Dexler and Freund, 1906), possibly because of the low visibility habitats in which they live. Together with their tendency to be active at night (Anderson, 1986, Ichikawa, 2006), this promotes the need for alternatives to visual cues, such as sound. Several studies have been conducted to detail characteristics of dugong calls (Niezrecki et al., 2003, Shiraki et al., 2003, Tsutsumi et al., 2006, Miksis-Olds and Wagner, 2011, Sousa-Lima et al., 2002, 2008). Anderson and Barclay (1995) categorised Shark Bay dugong calls into chirps, trills and barks with the chirps and trills emitting energy over bandwidths of 1-18 kHz. However, little work has been reported to relate calls to an associated behavioural function (Ichikawa et al., 2006) and confirm call rates (Akamatsu et al. 2008). This in itself is logistically complex as many previous studies have induced behavioural bias by the very platform from which the recording took place (Ichikawa et al., 2011, Anderson, 1986). While passive recording of marine fauna also suffers from availability bias (if they are not vocalising, they are not available) and perception bias (what one perceives as a vocalisation may be perceived by another as some other source noise) acoustics can offer a much larger sample size because the surveying is not as limited by weather, night-time, remoteness, cost, turbidity, therefore offering a different opportunity to reduce uncertainty (if the animals vocalise sufficiently and the detection range is large enough to get a good sample size).

Automated detection of marine mammal calls has increased steadily over the past decades from studies of the great whales (Heupel et al., 2006, Cato et al., 2011, Gavrilov et al., 2011, Parnum et al., 2011), through to dolphins and porpoises (Wang et al., 2005, Akamatsu et al., 2001, Akamatsu et al., 2009), seals (Pahl et al., 1996) and more recently, Sirenia (Niezrecki et al., 2003, Ichikawa et al., 2006).

The aim of this study was to acquire behaviourally unbiased recordings of dugongs in Shark Bay. As the acoustic loggers used were unlikely to be noticed, any confirmed dugong calls would originate from behaviourally unbiased individuals and would therefore be a step to identifying characteristics of Shark Bay dugong calls exhibiting normal behaviour.

METHODS

Autonomous acoustic sea-noise loggers developed at Curtin University of Technology, Western Australia and Defence Science and Technology Organisation (DSTO), were deployed from the Department of Enviroment and Conservation (DEC) vessel *RV Sirenia III* in the eastern gulf of the Shark Bay Marine Park (Figure 1). Each logger was located in patchy coverage of *Halophila australis* and *Amphibolis antarctica* in waters between 4 and 6 m depth off Guichenault Point and Point Peron (Figure 1 and 2). The loggers recorded between 16th September and 21st October for 12 of every 15 minutes at a sample frequency of 12 kHz with cut-off frequencies of 8 Hz and 6 kHz to capture all likely noises produced by du-gongs within the surrounding area. 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 Un-derwater 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 10 Hz.

Call energy levels have been shown in sound pressure levels (SPLs) and sound exposure levels (SELs), calculated by removing noise from a signal containing both call and background noise. Statistics on the received levels have been conducted in the dB scale to reflect our perception of sound energy. For each call a 1 s recording of ambient noise was analysed to compare the call receive levels with that of ambient noise.

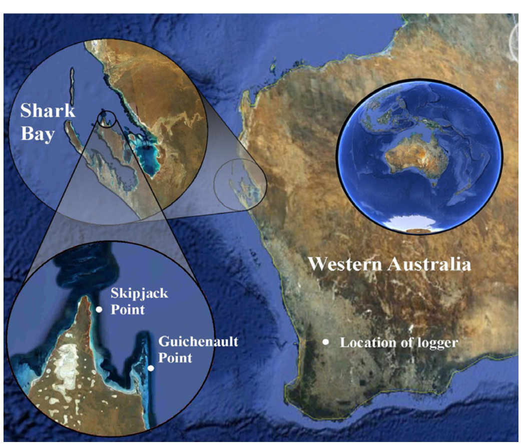

Figure 1. Map of Western Australia with expanded insert of Shark Bay and Point Peron. Locations of deployed loggers shown by white circles. Image source: Google earth 24/5/12.

On the 16th, 17th and 21st October the *RV Sirenia III* patrolled waters between Guichenault Point and Skipjack Point taking opportunistic recordings whenever a dugong was sighted. The vessel approached the dugongs slowly setting an anchor line up-wind from the sight dugong. The anchor line was laid out, allowing the vessel to drift back towards the dugong without disturbing it. Once within 20 m of the dugong (or the last sighting of the dugong) a hydrophone, attached to an HR-5 Jammin pro recorder, was suspended at a depth of 2 m from the vessel. Recordings were then taken until the dugong moved on or 20 minutes has passed, at which time the vessel departed and searched for another dugong.

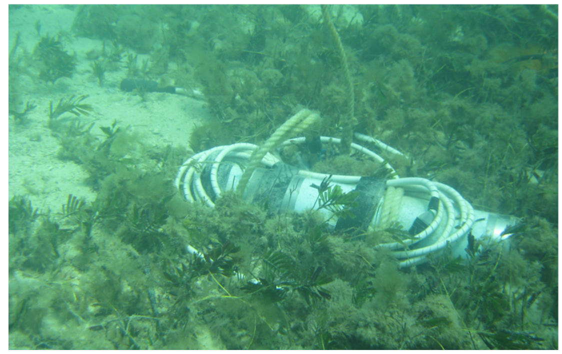

Figure 2. Photo of acoustic logger, located in predominantly *Amphibolis antarctica* off Guichenault Point, Shark Bay

RESULTS

At the time of deployment 8 dugongs were sighted within 150 m of the Guichenault Point logger. It was not known how long they remained after the logger was deployed. There were no dugongs sighted at the Skipjack Point site at the time of deployment. During the 3 days of opportunistic recording, a total of eight dugongs were sighted with a maximum of 4 dugongs within 50 m of the boat on one occasion. No sounds were recorded during these observations.

During the deployment, a number of biological sounds were recorded. Frequent fish calls and fish choruses (200-700 Hz), humpback whales (200-500 Hz) and dolphins (>1000 Hz) were identified on both loggers (Figure 3). Daily patterns of invertebrate clicks, predominantly between 2 and 6 kHz were also observed on both loggers (Figure 3). The logger at Guichenault point recorded significantly greater wave and mooring noise than the one at Skipjack Point.

Between 11:45 and 14:30 on the 4th October and between 12:00 and 13:15 on the 5th October many narrow bandwidth sounds were recorded at frequencies above 1000 Hz (Figure 3). Maximum received SPLs of 134 dB re 1μPa (±5.2 s.d., max = 143, min = 124) and SELs of 114 dB re 1μPa^2.s (±5.3 s.d., max = 122, min = 103) were observed from 40 of these calls, over the 500-6000 Hz bandwidth. The mean spectral peak frequency from these 40 calls was 3335 Hz (±316 s.d., max = 3610, min = 1957) with a 6 dB down bandwidth of 2746 Hz (±1685 s.d., max = 5250, min = 731) over a duration of 0.2 s (±0.17 s.d., max = 0.7, min = 0.004). The calls differed somewhat in that they were made up of 1, 2 or 3 sections which, when put together, formed a short 'chirp' (Figure 4). Acoustic characteristics of these 3 types of call also differed in terms of their received levels, spectral peak frequency, frequency bandwidth and duration (Table 1). The calls with multiple parts included one sound with a narrower bandwidth and lower spectral peak frequency followed by a sound with a wider bandwidth. As a result the Type 3 sounds, which included that third section, were of higher, wider bandwidth frequency (Figure 4, Table 1).

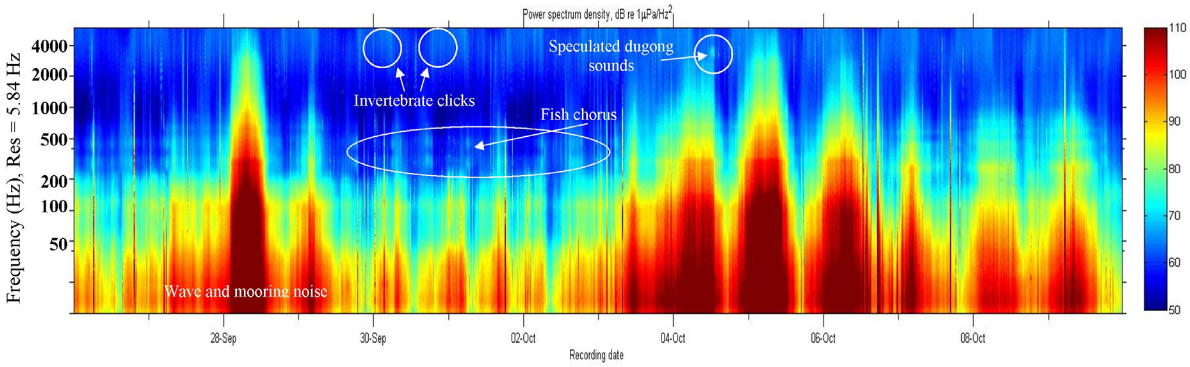

Figure 3. Spectrogram of 14 days of recordings from waters of Guichenault Point, Shark Bay. Invertebrate clicks, fish chorus, wave noise, mooring noise and speculated dugong calls are highlighted.

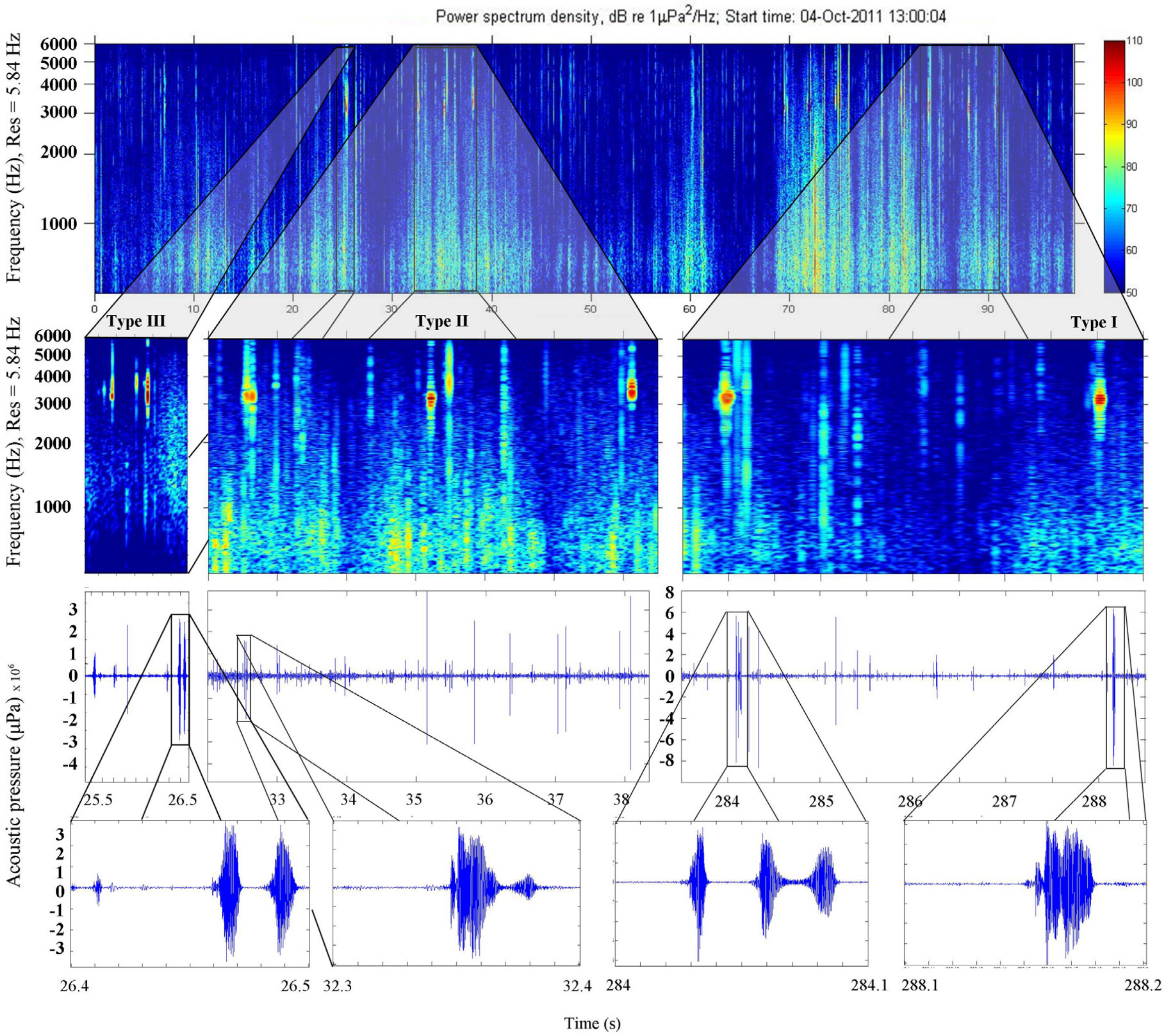

Figure 4. Spectrogram of 90 seconds of recording (top image) from a sea-noise logger located at Guichenault Point at 13:00 on the 4th October. Magnified spectrograms and waveforms illustrate 3 types of call speculated to originate from a dugong (bottom panels).

Table 1. Characteristics of speculated dugong 'short-chirp' calls broken down into 3 types. Mean (± s.d., max, min) values are shown.

Call type (n)	Peak to peak pressure (μPa)	Maximum Received Level (dB re 1μPa)	Maximum Sound Exposure Level (dB re $1\mu Pa^2$.s)	Spectral Peak Frequency (Hz)	Frequency band (Hz)	Duration (s)
All calls (40)	21.7 (16.5, 75.2, 5.4)	134 (5.2, 143, 124)	114 (5.3, 122, 103)	3335 (316, 3610, 1957)	2746 (1685, 5250, 731)	0.20 (0.17, 0.70, 0.004)
1 (15)	14.8 (7.7, 27.3, 5.4)	132 (5.6, 139, 124)	112 (5.4, 122, 104)	3395 (142, 3550, 3155)	1841 (1311, 4500, 731)	0.09 (0.07, 0.34, 0.0043)
2 (14)	17.7 (6.6, 28.1, 6.1)	134 (3.8, 140, 126)	114 (5.6, 122, 104)	3410 (184, 3610, 3157)	2415 (1749, 5250, 750)	0.18 (0.173, 0.53, 0.017)
3 (11)	31.9 (25.9, 75.2, 6.0)	136 (5.7, 143, 125)	114 (5.4, 121, 103)	3228 (500, 3562, 1957)	3428 (1766, 5000, 800)	0.31 (0.18, 0.70, 0.16)

Mean ambient noise levels (SPLs and SELs) at the receiver, at the times of the recorded sounds, were 102 dB re 1μPa (±6.2 s.d.) and 92 dB re $1\mu Pa^2$.s (±4.7 s.d.) respectively. This meant there was a maximum difference of 45 and 29 dB (SPLs and SELs respectively) between the ambient noise and the calls.

During the 12:45 and 13:00 recordings on the 4^{th} October, signals of longer duration than the speculated dugong calls were also recorded. The received levels of these signals were only just greater than ambient noise and so not always discernible, likely due to a source at greater range or of lower source level than the calls described above. The ones which could be discriminated were signals of frequency greater than 2 kHz. Some of these calls have been attributed to dolphin 'whistles', however, others were more characteristic of the 'trill's or 'squeaks' of dugongs recorded in other studies (Anderson and Barclay, 1995, Ichikawa et al., 2003).

DISCUSSION

The recordings taken at Skipjack Point and Guichenault Point have displayed a number of biological sounds attributed to various fauna. One set of calls displayed some spectral characteristics similar to the 'chirps' of dugongs reported elsewhere (Anderson and Barclay, 1995, Ichikawa et al., 2011), but of significantly shorter duration. They were also similar to signals in unpublished data which also contained dugong sounds. However, there was no visual confirmation that these sounds were produced by dugongs. It is also uncommon for dugongs to emit only one type of sound.

Although the calls reported here have been split into three types of signal, by comparison with other reports there was only one call type, a 'short-chirp' of spectral peak frequency 3335 Hz (±316 s.d.), with a 6 dB down bandwidth of 2746 Hz (±1685 s.d.), over a duration of 0.2 s (±0.17 s.d.). Chirp calls have accounted for approximately 90% of all calls recorded in previous surveys (Ichikawa et al., 2003; Ichikawa et al., 2006; Okumura et al., 2007; Hishimoto et al., 2005). While these short-chirps do not fit into previous descriptions of dugong 'chirps', 'trills' or 'barks' (Anderson and Barclay, 1995) there were significant similarities between the spectral content of dugong 'chirps' recorded elsewhere of spectral peak frequency between 3.5 to 5 kHz and bandwidth of approximately 1000 Hz (Anderson and Barclay, 1995, Ichikawa et al., 2011) and the sounds recorded in Shark Bay. The 'short-chirps' presented here displayed similar peak frequency, bandwidth and harmonics to that of the longer 'chirps'. It is suggested that the short-chirps recorded in this study originated from a single dugong, produced in the same way as the longer chirp, but of shorter duration.

From previous reports it is unusual for dugongs to produce one type of call. There are a number of possible explanations as to why only one type of call was recorded in this study. Previous reports of Shark Bay dugong 'trills' and 'chirps' contain energy over 3 kHz and 18 kHz bandwidths (Barclay and Anderson, 1995). However, these calls, and similar reports were conducted at a time when the dugong was aware of vessel presence. Whether behavioural bias is a factor in the sounds produced by Shark Bay dugongs is unknown. The acoustic logger in this study recorded at a maximum sampling of 12 kHz and thus all energy above 6 kHz has not been considered. Additionally, other faint calls were observed on the recordings, however, due to the low received levels (either because of the source range or source level) it could not be confirmed whether they were dugong calls or unusual dolphin signals. Thus it is conceivable that either other dugong call types were produced during the recordings in this study, but not detected or that the call types reported elsewhere were produced for a specific call function which was not required by the caller during this study.

The loggers were deployed at locations known to be inhabited by dugongs at this time of year. In fact eight were located at the logger site at the time of deployment. However, this does no necessarily mean they were vocal. In the three days of survey, prior to retrieving the loggers, only eight dugongs were sighted, none of which were at the Skipjack Point study site. Given the lack of dugongs at this time it is likely that during the recording period few dugongs were within the hydrophone detection range. The calls reported here occurred near the time of high tide (also illustrated by the increased wave and mooring noise recorded by the logger at Guichenault Point shown in Figure 3) when the dugongs are more inclined to enter the shallower water from the safety of deeper waters (Holley, unpublished data) adding credence to the suggestion that a dugong is responsible for the sounds.

Dugongs are known to remain in the deeper waters between Skipjack Point and Guichenault Point in Spring where they can safely remain in deeper waters at low tide, moving up the bank at low tide to feed on the seagrass. As temperatures warm when Summer approaches the dugongs move further south into the eastern gulf and congregate in the warmer, shallower waters, feeding on the more prevalent seagrass in that area. Anecdotal evidence suggests it is possible that the dugongs moved south early during this season, thus fewer dugongs were present around the loggers than expected, resulting in a lack of calling.

Although caller range was unknown if it is assumed that it was greater than 1 m then the minimum source level of one of these calls would be 143 dB re 1μPa and 121 dB re

1μPa^2.s., 45 dB re 1μPa and 29 dB re 1μPa^2.s above that of ambient noise respectively. Using spherical spreading as a maximum estimate for transmission losses and backstepping from the minimum source level estimate to ambient noise levels this would suggest minimum detection ranges for dugongs under conditions similar to this study of at least 50 m. This range is similar to those esimtaed by Ichikawa et al., (2011). It should be noted that this is a basic calculation and does not consider probability of detection and has taken geometrical spreading as the only transmission loss.

CONCLUSIONS

The calls recorded on the 4th and 5th October displayed similarities to the spectral content of previously report dugong 'chirps' and those of unpublished data. However, the sounds recorded here were of significantly shorter duration. Additionally only really one type of sound was recorded, a short 'chirp'. By comparison, other reports have shown multiple types of call, including long and short 'chirps'. The difference being that many of the other reports induced behavioural bias (knowledge of vessel/diver presence or the emission of an acoustic signal). While there is no visual confirmation of the source of the calls presented here it is the authors' opinion is that a single dugong was the source and that while there may have been other dugongs present, any vocalisations produced by them were out of the detection range of the hydrophone.

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