Non-song vocalizations of pygmy blue whales in Geographe Bay, Western Australia

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Abstract: Non-song vocalizations of migrating pygmy blue whales (*Balaenoptera musculus brevicauda*) in Western Australia are described. Simultaneous land-based visual observations and underwater acoustic recordings detected 27 groups in Geographe Bay, WA over 2011 to 2012. Six different vocalizations were recorded that were not repeated in a pattern or in association with song, and thus were identified as non-song vocalizations. Five of these were not previously described for this population. Their acoustic characteristics and context are presented. Given that 56% of groups vocalized, 86% of which produced non-song vocalizations and 14% song units, the inclusion of non-song vocalizations in passive-acoustic monitoring is proposed.

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1. Introduction

The identification, description, and quantification of a species' acoustical repertoire are prerequisites to understanding their acoustic behavior, function, and geographic variation. This information is also important to begin to assess the effects of anthropogenic underwater noise on the species ability to communicate, and for effectively implementing passive acoustic detection techniques.

Baleen whales are known for the intense and often complex vocalizations they produce. Many of these vocalizations appear to be associated with specific contexts such as feeding, socializing, and breeding.[1–7] The most well-studied of these vocalizations is the "song," defined as a regular, patterned sequence of notes unique to each population of a species. There is evidence that song in great whales is predominantly produced by males.[7] Single, non-patterned vocalizations not associated with song have also been documented and described as non-song vocalizations.[7,8] Non-song vocalizations have been associated with feeding, foraging or social interactions by both sexes.[7,8]

While much research has been conducted to quantify and understand song and non-song vocalizations produced by humpback whales (*Megaptera novaeangliae*), relatively little is known about blue whale (*Balaenoptera musculus*) vocalizations. Blue whale song has been described,[1,2,4,5] however, there is limited information about the full acoustic repertoire of this species, and even less on non-song vocalizations. For blue whales from the North Pacific and Atlantic, downsweeps ("D" vocalizations) and frequency and amplitude modulated (FM and AM, respectively) vocalizations described as "growls" have been attributed to non-song vocalizations[3,4] and associated to certain behaviors such as feeding.[9] The pygmy blue whale (*Balaenoptera musculus brevicauda*) population, present in Western Australian waters (the East Indian Ocean population) is one of nine blue whale populations globally.[5] For this population the only non-song sound described is a downsweep, similar to the "D-call" reported for the North Pacific and Atlantic populations.[2] This study aims to characterize "non-song" vocalizations for the East Indian Ocean population of pygmy blue whales, during two seasons (2011 and

2012), as they migrated through a coastal embayment in southwestern Australia. The proportion of groups producing sound as they passed through this area is described, and the dominant acoustic behavior of groups of whales (song or non-song vocalizations) is also determined.

2. Methods

Simultaneous land-based visual observations and underwater acoustic recordings were conducted during November of 2011 and 2012 in Geographe Bay, Western Australia. In Geographe Bay, East Indian Ocean pygmy blue whales migrate as close as 500 m from shore over an approximate six week window in November and December each year towards high-latitude foraging areas. Land-based visual observations were conducted using a surveyor's theodolite to position surfacing whales for an average for 6–7 h per day from a 50 m hill, approximately 500 m from the water's edge. The maximum visual detection range for blue whales was ~5 km. The theodolite was a TopCon GTS-603AF Electronic Total Station, and real-time positioning was obtained via a direct link to a laptop running the software CYCLOPS (v.2.8.04). Surfacing location, group composition, and behaviors were documented during visual observations. Acoustic recordings were made using a Curtin University acoustic logger[10] deployed on the seabed, approximately 3 km offshore from the land-based station at 30 m depth (Fig. 1) and scheduled to record 800 s of every 900 s at a sample rate of 12 kHz.

Concurrent real-time visual tracking and acoustic recordings with a single logger were made. Sounds transmission modeling and expected received levels of blue whales producing sound within 2 km of the acoustic logger were previously estimated.[11] These received levels were used to match groups visually tracked within a 3 km radius of the acoustic logger with the recorded vocalizations. Thus, four criteria had to be fulfilled to accept a match between the group of whales being visually tracked and the vocalizations recorded.

(1) Groups being matched had to be visually confirmed to be within 3 km of the acoustic logger, and no other whales (humpback or blue) could be within 3 km of the logger at the time.
(2) Only a single group of blue whales could be in the study area so that no confusion could occur in discerning which group produced sounds when multiple groups were present (in all but one case was there one group in the study area at a time).
(3) The time the sounds were recorded had to coincide with the time a group was being visually tracked through the study area.
(4) The sounds recorded had to have received levels corresponding to the distances of the groups from the position of the acoustic logger at the time the sounds were recorded. The distances of the groups from the acoustic logger were measured using the theodolite track. The expected received levels at range from the noise logger were based on transmission loss estimates estimated previously.[11]

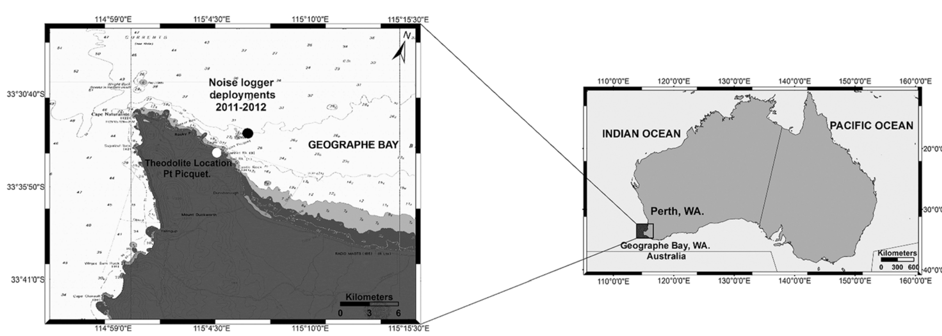

Fig. 1. Location of acoustic logger (black circle) and land-based theodolite platform (white circle), in Geographe Bay, Western Australia. The inset shows the location of the study area (highlighted in black) within Australia.

While there is a possibility that there were visually undetected groups of whales in the study area, the likelihood is assumed to be small given that the average time for a group of whales to traverse the area (within visual detection range of 5 km) was approximately an hour, giving multiple opportunities for sighting when surfacing.

Acoustic data were analyzed using Curtin University's, custom designed Characterization of Recorded Underwater Sound (CHORUS) MATLAB graphic user's interface toolbox. Once features of interest were identified, spectrograms were produced for inspection using a 1024-point Hanning window with 95% overlap over a frequency range of 5 Hz to 4 kHz. Pygmy blue whale vocalizations were identified by visual scrutiny of spectrograms, based on their similarity in frequency and duration to previous reports.[1–5] While humpback whales were present during the study period, pygmy blue whale vocalizations were easily distinguished by their patterns, frequencies, and descriptions for the 2011 and 2012 seasons.[11] As stated above, comparison of signal received level with that expected for a whale at a given range corroborated matching a sighted whale to a recorded sound.

3. Results

A total of 27 groups of blue whales passed within acoustic detection range during the 107 h of visual tracking in this study. Blue whales were present in the study area for 11h and 6.5 h within 3 km of the noise logger. During this period, six types of vocalizations that were not repeated in a pattern or a particular sequence, nor produced in association with song, were attributed to blue whale groups. These vocalizations were identified as non-song vocalizations. Five of these comprised new non-song vocalizations for the East Indian Ocean population of blue whales (Fig. 2), plus a previously reported downsweep.[2] All call types comprised acoustic energy under 200 Hz, with the exception of an EIO2 which extended to 750 Hz [Fig. 2(b)]. In each call type the peak of the spectral content was below 100 Hz, the exception was EIO3 producing the lowest peak frequency at approximately 20 Hz [Fig. 2(c)]. EIO1 [Fig. 2(a)], EIO4 [Fig. 2(d)], and EIO5 [Fig. 2(e)], call types all contained at least two spectral peaks of which the highest were at approximately 50 and 100 Hz (Table 1). All vocalizations included one or more harmonics or overtones, varying in frequency throughout the individual call. Durations ranged between approximately 0.9 and 4.4 s, and EIO2 was the longest call type [EIO2, Table 1; Fig. 2(b)]. Three vocalizations were observed with different groups [EIO1, EIO4, and EIO5, Table 2; Figs. 2(a), 2(d), and 2(e)], while the remaining two were produced by only one group each [EIO2 and EIO3, Table 2 and Figs. 2(b) and 2(c)].

Of the 27 groups visually tracked, 56% (15) emitted sound and of these 14% (2) produced song or song units while 86% (13) produced non-song vocalizations. On

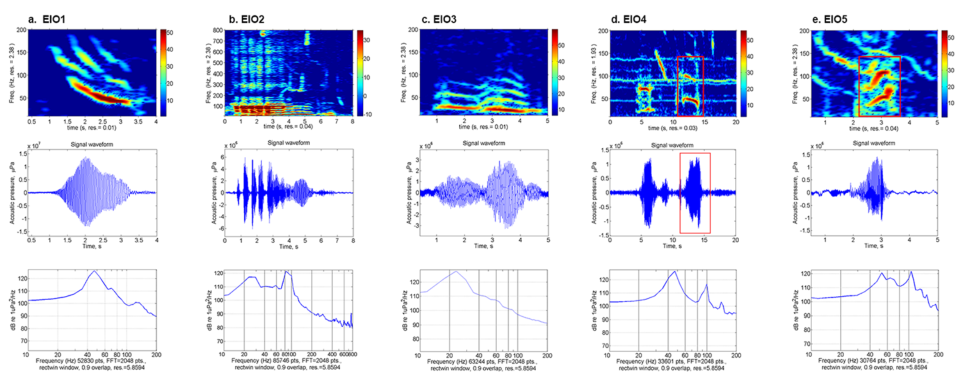

Fig. 2. (Color online) Spectrogram (top panels) of (a) EIO1, downsweep with non-harmonic overtones; (b) EIO2, broadband, pulsed AM growl with harmonics; (c) EIO3, grunt with harmonics; (d) EIO4, short FM tone with harmonics (highlighted in the square); and (e) EIO5, upsweep with harmonics (highlighted in the square). Medium and bottom panels present the waveforms and power spectrum density plot (PSD) for each signal, respectively.

Table 1. Characteristics of new non-song vocalizations recorded in Geographe Bay, Western Australia. Frequency characteristics were extracted from the power spectrum density plot.

	Feature measure					
Call	Approximate frequency range of all energy (Hz)	Peak frequency (Hz)	Frequency band 10 dB of peak (Hz)	Duration (s)	# of analyzed vocalizations[a]	# times recorded
EIO1	20–200	Peak 1:∼52 Peak 2:∼102	30–105	1.62 ± 0.29	6	6
EIO2	10–750	86	13–105	4.42	1	1
EIO3	10–120	∼21	11–31	3.42	1	1
EIO4	20–150	Peak 1: ∼43 Peak 2: ∼99	Peak 1: 33–51 Peak 2: 82–107	2.96 ± 0.83	2	4
EIO5	20–120	Peak 1:∼51 Peak 2:∼102	40–120	0.92	1	3

[a]Vocalizations analyzed were selected based on high signal to noise ratio and low levels of background noise (i.e., no humpback whales or vessels in the area).

average, 10.25 non-song vocalizations per group were detected (max = 38, min = 1). Of the non-song vocalizations, 10 groups produced the previously described downsweep, and five produced the new non-song vocalizations described here. The total number of new non-song vocalizations detected was 15. Given that group transit times across the study area are ∼1 h, approximately three new non-song vocalizations an hour were detected, per group the average estimated was 2.6 (min = 1, max = 6). A summary of the group composition associated with the vocalizations is presented in Table 2. All groups were observed traveling in the same general direction.

4. Discussion

Five vocalizations not previously described for the East Indian Ocean pygmy blue whale population have been attributed to blue whales in Geographe Bay. Their characteristics were different from those of song for this species,[2] and because of their non-patterned and variable nature, these are described here as non-song vocalizations. A sixth non-song sound was also detected and identified as a previously reported downsweep.[2] While the new non-song vocalizations are unique in their modulation and duration, some have minor similarities with vocalizations reported from other populations. First, EIO2, is similar to an AM sound in the North Pacific reported for blue whales[3] in that it is pulsed and has comparable frequency range and bandwidth;

Table 2. Association between composition of groups tracked in Geographe Bay and vocalization type (including song units and downsweeps). The identifications for groups producing the sound types (three groups produced multiple sound types) are given in parentheses.

Group type	Vocalization type
Singleton	Song units$^{(Bw0311)}$
Two adults	EIO1$^{(Bw0112, Bw0212, Bw0512)}$, EIO2$^{(Bw0112)}$, EIO3$^{(Bw0112)}$, EIO4$^{(Bw0112)}$, EIO5$^{(Bw0112)}$, Downsweep$^{(Bw0411, Bw0112, Bw0212, Bw0512, Bw0612, Bw1212)}$, song units$^{(Bw0211)}$
Cow-calf	EIO4$^{(Bw0812)}$, downsweep$^{(Bw0912)}$
Cow-calf-additional adult	Downsweep$^{(Bw1512)}$
More than two adults	EIO5$^{(Bw1312)}$, Downsweep$^{(Bw0412, Bw1312)}$

however, it is approximately half the duration. Consistent with the AM sound recorded here (EIO2), the growl in the North Pacific was not identified as part of song. Second, EIO4 [see Fig. 2(d)] recorded here has a weak resemblance to unit three of the East Indian Ocean blue whale song.[5] However, the new signal described here is significantly shorter in duration and does not have the exact frequency range as song unit three. Also, no song or song units were evident in the recordings here, prior to, or after, these vocalizations were produced. Third, EIO5, is very similar to the one reported as the second unit of the blue whale song of the Sri Lankan population.[1] However, both are very different in duration (almost 2 s for the non-song unit reported in this study vs 1 s for the Sri Lanka song unit) and frequency (fundamental ranging from ~30–40 Hz vs 30–80 Hz, respectively). Fourthly, the vocalization EIO1 reported here comprises simultaneous tones at different frequencies that are not harmonics [see EIO1, Table 1 and Fig. 2(a)]. This is of particular interest and is a characteristic also identified in the last unit of song from the East Indian Ocean population of pygmy blue whales.[2] The structure of the non-song sound here may be the result of multiple sources of sound production in the whale's vocal apparatus as has been suggested for production of the last unit of their song.[2] The prevalence or lack of this type of sound production across baleen whale species also remains un-quantified. Last, the most prevalent non-song sound, the variable downsweep with harmonics recorded here and described previously for this population,[2] has a striking similarity to "call type D" from North Pacific and Atlantic blue whale (*Balaenoptera musculus*) populations.[3,4,9] However, unlike the findings from the North Pacific, where vocalizations were produced by groups exhibiting feeding dive behavior in a foraging area,[3] in Geographe Bay the surface behavior was that of traveling in one general direction, indicative of migratory behavior. Geographe Bay is not considered a feeding ground, but it is worth noting that there is a known foraging area 150 km to the north in the Perth Canyon and perhaps in the region of the Mentelle Basin westward. It is unclear whether the downsweep recorded in this study has a different function, or whether it is associated with the presence of foraging grounds nearby.

During this study, there was one instance of multiple groups in the area. This period was the occasion when the broadband, pulsed EIO2 was recorded, and there was a significant increase in repetition of downsweeps (7.0/800 s ± 4.24 vs 4.18/800 s ± 2.64). Increased signal complexity, repetition and variability has been speculated to correlate with activity type in southern right whales (*Eubalaena australis*)[12] and bowhead whales (*Balaena mysticetus*),[13] and agonistic interactions among fin whales (*Balaenoptera physalus*).[14] Further research is required to disentangle the social and behavioral context of increased repetition and complexity of non-song vocalizations. In this study, EIO4 and EIO2 were produced mostly by groups containing two animals and no calves (although the EIO4 was also observed in cow-calf pairs). This paper presents evidence of the production of non-song vocalizations by pairs of adults as well as cow-calf groups, thus provides support for the possibility of fulfilling a similar role to social vocalizations described for other species of mysticetes, such as humpback whales.[8]

The high proportion of groups traveling through Geographe Bay producing sound (>50%), and the majority of which produced non-song vocalizations (almost 90%) as compared to song or song units (just over 10%) suggests that non-song communication serves an important function at this location. Given that non-song vocalizations dominated in the numbers of groups producing them in Geographe Bay, we suggest that at locations with the same level of non-song sound proliferation, the inclusion of non-song vocalizations in passive acoustic detection censuses will significantly increase counts (rather than basing methods solely on song). Furthermore if social context for the different vocalizations is verified, an even more powerful tool for population studies will be available.

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