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SOUNDS OF THE SUNSET COAST

Short and long range acoustic cues available to marine fauna

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ABSTRACT
Marine fauna operate in visually restricted waters with great efficiency, locating prey over distances of metres to seemingly hundreds of km, while navigating tens to thousands of km routinely. While they use a host of sensory cues to achieve this, acoustics offers biological or physical clues at all spatial scales. At the small, ~ 1 km scale, calls produced by individual invertebrates and fish can be localised by other fauna while in the deep ocean coherent whale signals can transmit to at least 180 km. Invertebrates, fish and whales commonly produce sound en masse, resulting in choruses which are routinely detected at km to tens of km, or at 1000's of km for deep sound channel ducted whale choruses. An example from sonabuoys is presented of a diffuse chorus like source in the 1.8 to 10 kHz band which appeared to emanate from Antarctic krill swarms and was detectable at the tens km scale. If produced by krill this noise would answer a question of how baleen whales locate krill and have implications for extended high frequency hearing in krill eating fauna.

1 INTRODUCTION
There are many references to the advantages long range acoustic signals offer marine fauna, for example: reef based fish choruses as an attractant to larval fish over the many km scale (Radford et al. 2011); offshore fish choruses detected at the 10+ km scale (McCauley and Cato, 2016); long range Antarctic blue whale choruses used over a decade to follow population growth (McCauley et al., 2018); or potential navigation cues offered by localising Antarctic ice cracking signals from glacier heads over several thousand km scales (Li and Gavrilov 2011). While a plethora of authors have highlighted the importance of underwater acoustics to marine fauna, there are comparatively few published examples of measured long range signals which may be routinely used by marine fauna, especially sources which increase the probability of locating prey. Here we present an example recorded by sonabuoys of a biological source measured at distance from Antarctic krill swarms.

2 METHODS
All recordings were made using sonabuoys (SSQ-53, several model versions, some GPS enabled) transmitting to a software defined radio receiver and displayed and logged with versions of PASOR software (L3Harris, https://www.l3harris.com/all-capabilities/pasor-mobile-tracking-range) available on the Australian Defence supported research vessel *RV Whale Song*. The SSQ-53 sonabuoys when operated in DIFAR mode provide bearings to target over 5-2010 Hz at ± 3^{o} resolution by using a sensor package of: magnetic compass; north-south and east-west particle motion sensors; and an omni-directional hydrophone; with all data transmitted in a multiplexed 96 kHz bandwidth VHF radio signal. The buoys were deployed in Omni or DIFAR mode, where Omni mode does not transmit the bearing or compass information but allocates the majority of the radio transmission bandwidth to the hydrophone pressure sensor. Omni mode cannot give bearings but has a higher frequency range than the buoy operating in DIFAR mode. Archived sonabuoy records were loaded into the Matlab (Mathworks) software environment where all analysis was carried out.
Antarctic krill swarms were encountered during the WAVES voyage of *RV Whale Song* (https://www.cwr.org.au/research/whale-song-antarctic-voyage-for-ecosystem-studies.html or described in Owen et al., 2018) which started Hobart, Tasmania on 30-Dec-2013. *RV Whale Song* headed approximately due south, encountering the ice edge 9 days after leaving Hobart on 08-Jan-2014, ran west along the ice edge for 9.1 days to 17-Jan-2014 then headed north for 12 days to return via Fremantle, Western Australia on 29-Jan-2014 (Figure 1). During the cruise along the ice edge many Antarctic krill swarms were encountered, all of which had attendant humpback whales feeding in them. The humpbacks were often shallow feeding and at times Antarctic krill were seen spilling out of their mouths. Sonabuoys of Barra or DIFAR SSQ 53 F types were deployed every three hours through the entire cruise while conditions were suitable or more frequently during

periods of targeted whale follows. Data from Barra sonabuoys was logged using the Sonix software system but are not considered here. The Antarctic krill work involved a Biosonics DTX 1000 sonar deployed with 38 and 120 kHz transducers at three m depth on a towed sled. The sonar data was downloaded into Matlab files as calibrated backscatter (*Sv*) using Biosonics software then processed using purpose built software. Humpback whales were tagged with a 'Lander' or 'Limpet' tag fired by a Dan-inject pneumatic line throwing gun fired from the bow of *RV Whale Song* (see details in Owen et al., 2018). The Lander tag contained a Fast-Loc GPS unit (surface activated, transmitted GPS ephemeral data only), 3-axis accelerometers, 3 axis magnetic field declination sensors, depth and temperature sensors and a VHF transmitter outputting GPS ephemeral information which we could access from an antenna on *RV Whale Song* and decode the whales position in real time. The Lander tag needed to be recovered to obtain logged data. The Limpet tag had the same Fast-Loc GPS plus depth and temperature sensors with data accessed via satellite links (Argos) or from the ship if it was in range. Either tag types transmitted whale ephemeral GPS location so enabling us to follow whales through krill swarms. The time between whale surfacing's and so radioed position, combined with the whales meandering track, meant we could not follow exact whale tracks.

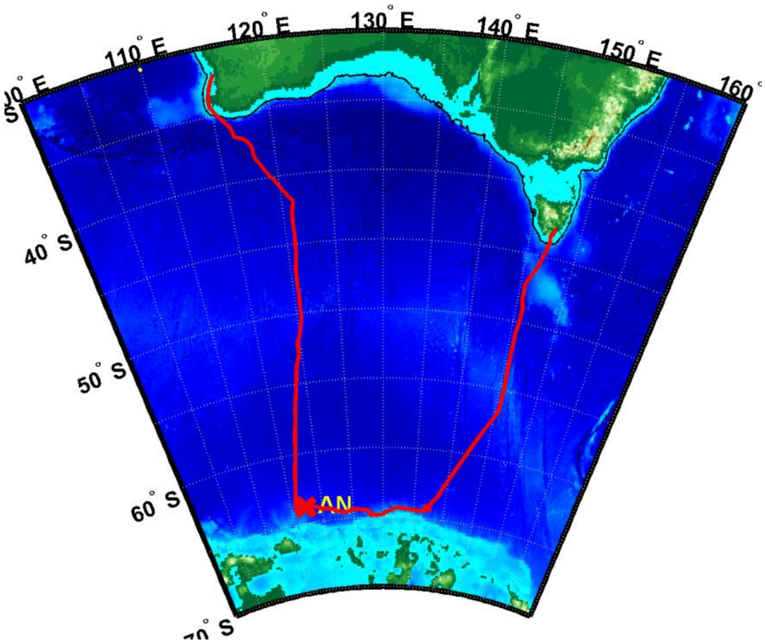

Figure 1: Location of site with major Antarctica krill swarm measured (AN). The cruise track of RV Whale Song is shown by the red line.

The sonabuoy numbering system used refers to a recording session number then a channel number to identify a unique buoy. Omni sonabuoy data was calibrated using a gain with frequency curve saved by the PASOR software which included radio transmission and signal conditioning gains. This curve was combined with the hydrophone sensitivity (-125.5 re 1µPa^2/V, Miranda 2001) and A-D gain (18.27 dB) to calibrate power spectra. Spectrograms or power spectra shown were made using the 96 kHz sample rate signal, 8192 point FFT's (11.72 Hz frequency resolution), no overlap and hanning windows, although given the multiplexed 96 kHz radio channel the upper Omni frequency limit was 24 kHz. Spectrograms used 117 FFT averages (9.98 s) while averaged power spectra used a specified time period (usually an hour). DIFAR sonabuoy data was analysed for bearing only using 1024 point FFT's (0.21 s length) to give a 4.69 Hz frequency resolution. Bearings were averaged in selected time and frequency bands to generate time-averaged distributions using a 1^o resolution.

3 RESULTS

3.1 Antarctic krill noise.

A large Antarctic krill swarm with at least 10 attendant feeding humpback whales was encountered on the 15 Jan-2014 centred at ~ 63^o 50' S, 117^o 22' E, with water depth ~ 2.4 km (Figure 2). Two omni buoys were deployed at the northern end of the krill patch (B29-2, 47 minutes later a second buoy B29-3) and 17.3 hours after deployment of B29-2, an omni buoy was deployed at the southern patch side (B32-2) as shown on Figure 2. Buoy B29-3 was GPS enabled. Vessel sightings of the surface float of B29-2 confirmed its position followed the same drift with time as B29-3. The krill patch was dense. We tagged a feeding humpback whale near the northern patch end then followed this animal with the whale leading us through what appeared to be a 'wriggling' narrow (several hundred m wide) band of krill which formed an arc enclosed in an ~ 4 km east-west x 4 km north-south area, moving slowly south. The sonabuoys B29-2 and B29-3 drifted north indicating the krill swarm was heading into the surface current.

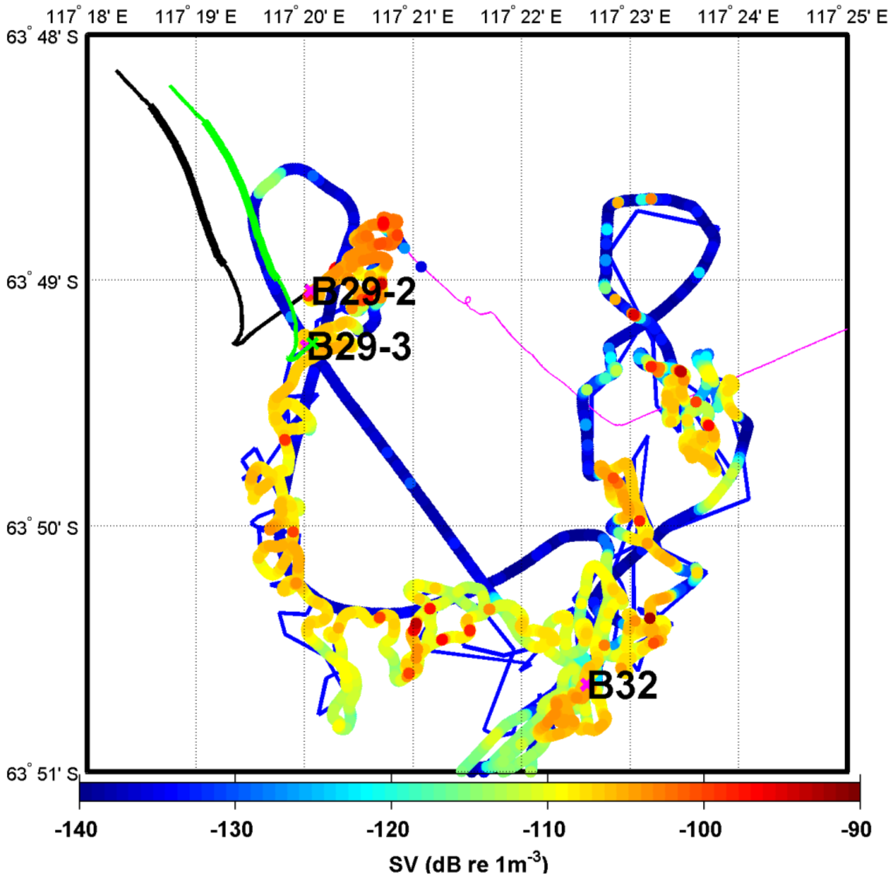

Figure 2: Krill patch showing: sonar volume backscatter (120 kHz) averaged with depth (to 100 m) and along track (5 m) as the heavy coloured line with *SV* scale below; *RV Whale Song* track prior sonar deployment (magenta line); locations of sonabuoys B29-2, B29-3 and B32 (heavy black text and magenta crosses) and for B29-2 and B29-3 their drift (black and green respectively, the heavy sections corresponding to the spectrogram time frame shown on Figure 4); and the tagged humpback whale track (thin blue line, the tagged whale led WS through krill patch).

On all three omni sonabuoys deployed in or near the krill patch shown on Figure 2, a 'crackling noise' was heard across the 1.8 to 10 kHz frequency band which was especially notable at the B32 buoy located in the southern krill patch end. In addition sperm whale clicking (3-15 kHz) and seal calling were present intermittently through all recordings, with the sperm whale clicking dominating late in the day (UTC time) at the northern buoys. Sperm whale clicking was audibly different from the background crackling noise and mostly intermittent. The 'crackling' noise can be seen on spectrograms at a consistent level over many hours from the two northern buoys (B29-2 and B29-3) as shown on Figure 3. On Figure 4 power spectra averaged cross one hour periods for the three omni buoys displayed on Figure 3 plus spectra from: 1) a buoy deployed several days prior (B26) in a different krill patch at 14-Jan-2014 07:05:21 (UTC), location 64^{o} 0.55' S, 119^{o} 33.55' E; 2) a windy location with no biological input (B8); and 3) a calm location with no biological input (B23). Table 1 lists details of the averaged spectra shown on Figure 4. The spectral peaks over ~ 1.8 to 10 kHz with a peak in the 3-6 kHz range were consistently recorded from in or near Antarctic krill patches only. Using DIFAR buoys we could obtain bearings in this frequency band over 1800-2400 Hz with 2400 Hz the maximum DIFAR bandwidth, from > 20 km range to the krill patch assumed position on the 14-Jan-2025 (north of the position on 15-Jan when we encountered it) and to positions of whale feeding areas as given by tagged whales and their movement behaviour. This data is not presented here. This assumed 'krill' source was easily differentiated from sperm whale clicking, was not recorded at the location with no biological noise input and was swamped by wind noise of 15-20 kn or more.

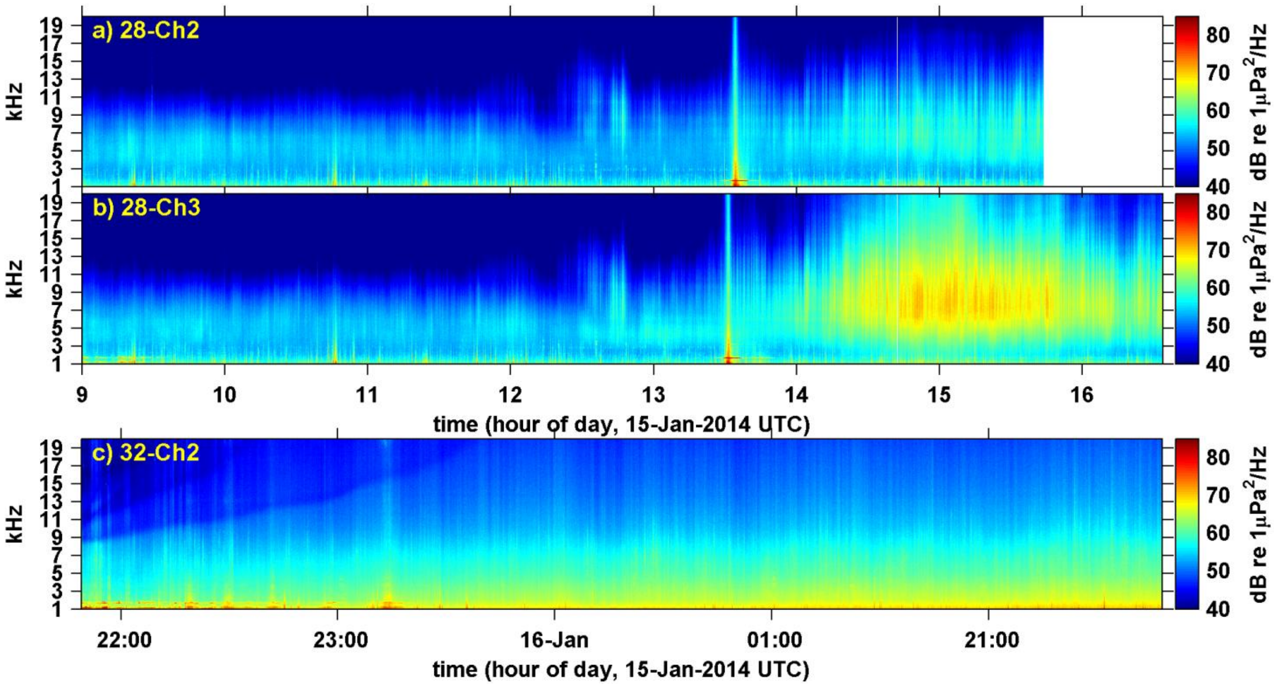

Figure 3: Spectrograms of omni buoy noise from 1 to 20 kHz over 7.5 hours from buoys B28-2 and B28-3 and almost five hours after these buoys ended, from buoy B32-2. Post 12:30 (UTC) on 15-Jan sperm whale clicks become increasingly frequent at the northern buoys, causing the chorus like appearance over 14:00 to 16:00 hours on buoys B28-2 and B28-3.

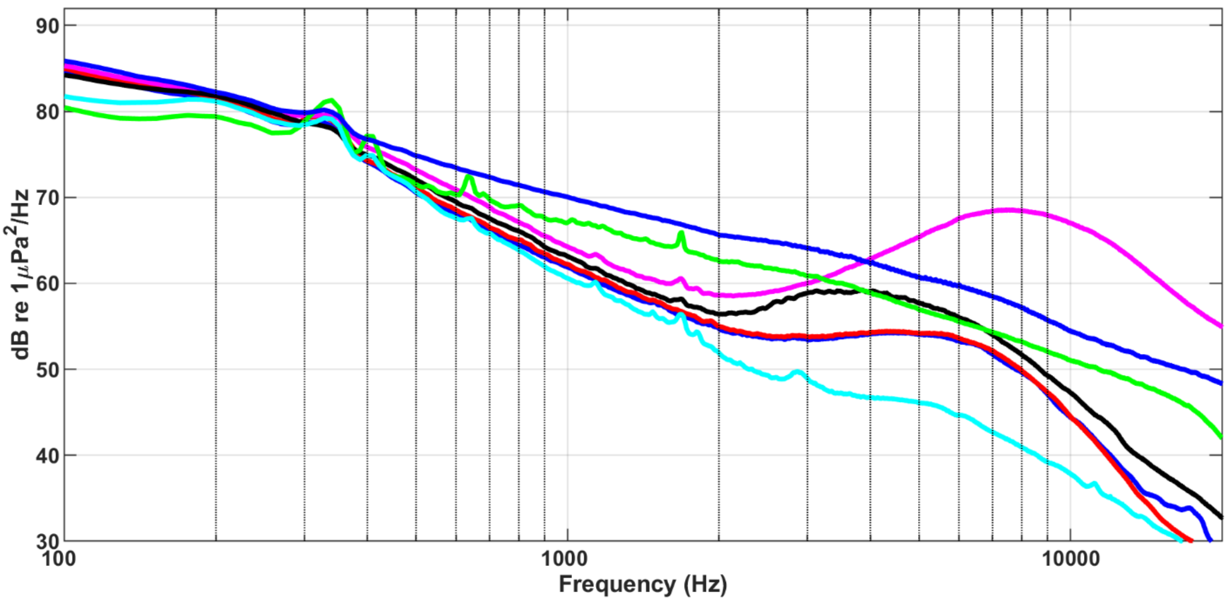

Figure 4: One hour averaged power spectra taken from omni buoys in Antarctica. See Table 1 for details of each recording.

Table 1: Details of one hour power spectra shown on Figure 5.

Buoy	Ch.	Colour	Start (UTC)	End	Wind	Notes 1-20 kHz band
8	2	Green	08-Jan 03:30	04:30	NE 18-20 kn	Wind noise dominates
23	4	Cyan	13-Jan 10:00	11:00	NW 5-6 kn	Low wind noise, little biological input
26	2	black	14-Jan 07:48	08:48	Calm 1-3 kn	Noise associated with krill swarms present
29	2	Blue	15-Jan 11:00	12:00	Calm 0-3 kn	Noise associated with krill swarms present
29	3	Red	15-Jan 11:00	12:00	Calm 0-3 kn	Noise associated with krill swarms present
29	3	Magenta	15-Jan 14:30	15:30	Calm 0-5 kn	Sperm whale clicks dominate, plus noise associated with krill swarms present
32	2	blue	16-Jan 00:00	01:00	E 18-20	Wind noise dominates

4 DISCUSSION

The persistent presence of the 1.8 to 10 kHz 'crackling sound' with Antarctic krill swarm locations and as found using DIFAR sonabuoy bearings pointing towards krill swarms (authors data), suggested the noise was produced by krill. To the authors knowledge there are no records of krill of any species producing sound, which is possibly more a reflection of a lack of studies attempting to detect noise produced by the swarms than reality. Krill do not have any known deliberate sound producing morphological structures. They do have a highly crystalline and so rigid, outer chitin body structure (Izadi et al., 2025), made up of many thin, overlapping plates. Krill do not remain stationary, they constantly swim, migrating vertically and as here, swimming slowly horizontally southwards into a northward setting current. In addition their chitinous feeding appendages are constantly moving, filtering water and passing phytoplankton to the mouth. It is possible the rigid chitinous plates rub against each other during swimming or feeding motions producing noise. Any noise produced this way by one krill would be inconsequential and probably not measurable. But given krill swarms are made of large numbers of individuals, many millions in the swarm measured here, any cumulative noise produced may be detectable and capable of producing the chorus like signal reported here. There were no obvious alternative noise sources other than krill which could have produced this noise. Snapping shrimp do not inhabit Antarctic waters nor water 2.4 km deep. The noise had little structure to it, primarily appearing as an increase in noise level so ruling out fish as they generally have pulsed sounds which are recognisable. The sperm whale and seal noise detected was easily distinguishable from the 'krill' noise source discussed and had different frequency bandwidths.

The comparatively low level of this 'krill' noise, at a maximum ~ 10 dB above low sea state ambient at a spectral peak of 3-5 kHz (Figure 5), meant it was easily masked by wind noise as occurred for the higher wind state spectra shown on Figure 4. If the noise was produced by krill this would imply the detection of krill swarms by marine fauna would be weather dependent and only accessible in low sea state conditions.

If this noise was produced by krill it has major implications for marine fauna which feed on krill, such as: 1) a sensory cue for locating krill swarms; 2) an evolutionary driver for krill eating fauna to develop modestly high frequency hearing (up to 10 kHz here); and 3) a potential answer to a puzzle asked by almost everyone whom works on baleen whales, which is how do they locate their prey? The bandwidth of the signal reported here was 1.8-10 kHz. Antarctic krill are ~ 6 cm in length and weigh ~ 1 g (https://www.antarctica.gov.au/about-antarctica/animals/krill/). Many baleen whales feed on krill in temperate and tropical areas where the krill species consumed are much smaller, down to 1-1.5 cm length. If these krill also produce noise its probable the frequency bandwidth of any noise produced will be shifted upwards due to the smaller animal body size. We do measure high frequency (up to 20 kHz) choruses of unknown origin in sea noise in open water around the Australian coast (authors data). Is this also krill? It should be noted acoustic detection of krill swarms will be only one of many sensory clues available to krill eating fauna for locating swarms, but it has the potential for modest range detection (tens km given the size of some swarms) in low sea state conditions.

5 CONCLUSIONS

Acoustic measurements made near Antarctic krill swarms recorded a persistent noise increase in the frequency band 1.8-10 kHz only found in or near swarms and which gave bearings to swarms using DIFAR sonabuoys. We speculate that this noise may be produced by krill as a by product of their swimming motion and the movement of rigid, chitinous body plates together. If this is correct and krill swarms do produce a chorus like sound it offers a cue for baleen whales to locate krill swarms in low seat state conditions and presents as an evolutionary driver for enhanced hearing in the higher frequencies for krill eating marine fauna.

ACKNOWLEDGEMENTS

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