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Detection of humpback whale (*Megaptera novaeangliae*) non-song vocalizations around the Vema Seamount, southeast Atlantic Ocean

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Abstract: Humpback whales are a cosmopolitan, highly vocal species. Investigated here are their vocalizations recorded at the Vema Seamount (31°38′S, 08°20′E) from moored hydrophones in the austral spring of 2019. During the 11-d recording period over 600 non-song calls were detected. Calls were predominantly detected at night over three consecutive days. The most common calls were low, frequency-modulated sounds (whups). An impulsive sound (gunshot) previously unknown in humpback whales was also detected. The location and timing of the calls suggests that humpback whales may be using the Vema Seamount as a temporary stop on their migration to their polar feeding grounds.

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1. Introduction

Humpback whales (*Megaptera novaeangliae*) undertake long annual migrations between their breeding and feeding grounds, sometimes covering over 8000 km each way (Stone *et al.*, 1990). During migration, individuals may use shallow areas, such as seamounts, as regular stopping places to feed or rest (Best *et al.*, 1998), or as navigation beacons (Derville *et al.*, 2020; Garrigue *et al.*, 2015; Rogers, 2018). Seamounts are isolated elevations in the open ocean with summits of over 1000 m above the sea floor (Rogers, 2018) that can provide important habitats for cetaceans [sperm whales: Hann *et al.* (2016), beaked whales: Johnston *et al.* (2008), and dolphins: Morato *et al.* (2008)] as they are often points of high primary productivity surrounded by deep waters, providing potential food sources for predators (Clark *et al.*, 2010; Yesson *et al.*, 2011). Data on humpback whale behavior (e.g., feeding calls) at seamounts will help to determine how important these features are during migration and potentially reveal important foraging locations, that will help improve international marine management objectives.

Two separate humpback whale sub-stocks are found in the eastern South Atlantic Ocean, breeding stock B1 (BSB1)—which breed off Angola and equatorial west Africa—and BSB2—which feed in the Benguela Ecosystem off western South Africa but whose breeding area is unknown (Fig. 1) (Best and Allison, 2010; Findlay and Best, 1995). The southwards migration of both sub-stocks from their breeding grounds towards their Antarctic feeding grounds takes place between September and November (Rosenbaum *et al.*, 2009). Evidence from photographic identification, genetic recaptures (Barendse *et al.*, 2011), and satellite tracking (Rosenbaum *et al.*, 2014), shows that humpback whales move south from the Gulf of Guinea using two main routes: (1) along the continental shelf or (2) following the Walvis Ridge (Fig. 1). This second route may possibly bring them close to the Vema Seamount ("Vema" from here on).

Vema (31°38′S, 08°20′E) is in the eastern South Atlantic Ocean, roughly 1000 km west of Cape Town, South Africa. It boasts a high level of biodiversity of both shallow and deep-water species (Bergstad *et al.*, 2019) making it the target of intensive fishing, which began five years after its discovery in 1959 (Simpson and Heydorn, 1965). After heavy exploitation, Vema was closed to fisheries in 2007 and is now classified as a vulnerable marine ecosystem according to the United Nations Food and Agriculture Organization criteria (FAO, 2019).

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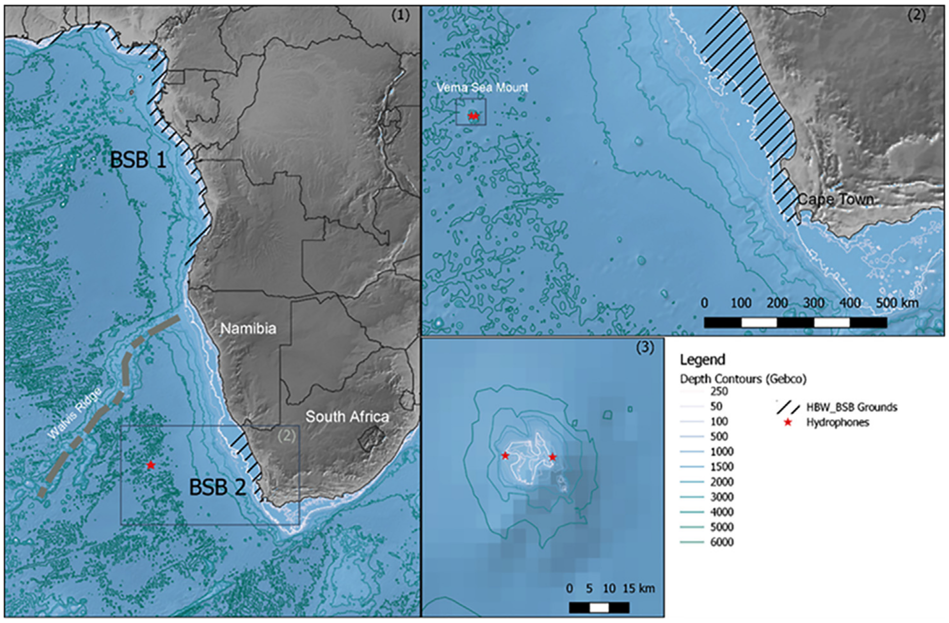

Fig. 1. The location of the Vema Seamount (red star, panel 1) in relation to South Africa and the BSB1 breeding grounds and BSB2 feeding grounds (see panel 2). Also shown: the approximate migration route of the BSB humpback whale population along the Walvis Ridge (gray line) (Rosenbaum *et al.*, 2014). The eastern and western locations of the hydrophones are indicated with red stars (panels 2 and 3).

The importance of Vema for cetaceans is unknown due to its remoteness and lack of survey effort. Passive acoustic monitoring (PAM), however, is a useful tool to monitor remote areas such as this and is a well-established method to detect stereotypical sounds of marine megafauna (Kowarski and Moors-Murphy, 2021; Warren *et al.*, 2021; Stanistreet*et al.*, 2016; Varga *et al.*, 2017), and humpback whale vocalizations specifically (Helble *et al.*, 2013; Ross-Marsh *et al.*, 2020; Stimpert *et al.*, 2011; van Opzeeland *et al.*, 2013).

Humpback whale vocalizations are divided into song and non-song calls (Dunlop *et al.*, 2008; Payne and McVay, 1971). In general, they are highly characteristic and easily distinguishable from background noise in the marine environment. PAM is, therefore, useful to determine humpback whale presence (Dunlop *et al.*, 2008; Rekdahl *et al.*, 2015) on their breeding (Kobayashi *et al.*, 2021) and feeding (Cerchio and Dahlheim, 2001) grounds as well as migration routes (Clapham and Mattila, 1990). Here, we investigate the humpback whale vocalizations detected at Vema and the potential significance of this area for the species.

2. Methods

2.1 Data collection

Acoustic data were collected as part of a multi-objective, ship-based cruise from Cape Town, South Africa to Vema (Fig. 1) conducted by Greenpeace on board the RV *Arctic Sunrise* (23 October 2019 to 7 November 2019). Vema is roughly conical in shape, rising approximately 3000 m above the sea floor. The summit measures 11 km by 8 km, averaging 90–100 m in depth, with its most shallow point at 20 m deep (Bergstad *et al.* 2019). Two moored autonomous hydrophones (SoundTrap 300HF, Ocean Instruments Inc., NZ) were deployed on both the eastern (31.6371°S, 8.40481°E; deployed: October 25th, 2019) and western slopes (31.6338°S, 8.27811°E; deployed: October 27th, 2019) at water depths of 70 m and 55 m, respectively, roughly 12 km apart. The hydrophones were mounted approximately mid-water column (east: 35 m; west: 25 m) to limit the amount of background noise from the surface of the reef. The devices were deployed mid-afternoon, and recordings were timed to start at 18:00 h. Both moorings were fitted with acoustic release mechanisms and surface buoys to minimize the risk of instrument loss and successfully retrieved on November 4th, 2019.

2.2 Acoustics analysis

Acoustic data were recorded continuously during deployment, with a 96 kHz sample rate. Recordings were viewed in RAVEN PRO v1.6 (Center for Conservation Bioacoustics, 2019) with spectrograms created using a Hann window (overlap of 75%) with a fast Fourier transform (FFT) of 8096, viewed in 60 s windows with a frequency range of 0 to 8000 Hz. East and west recordings were investigated separately, both visually and aurally (E.C.R-M) in their entirety for song and non-song calls. Hydrophone recordings were treated independently, as we could not confidently determine whether calls were detected simultaneously on both devices. Detections from both hydrophones were pooled during analysis. Song was found only once, lasting <30 s and was therefore excluded from analysis. Non-song calls ("calls" from here on) were classified as "whups," "grumbles," "grumble-whups," "tonals," and "impulsive sounds" (Table 1) by authors E.C.R-M and T.G. as per previous studies for South Africa (authors' unpublished data) and other locations (Dunlop *et al.*, 2008; Fournet *et al.*, 2015; Rekdahl *et al.*, 2017). For further validation, representative call type examples from Vema were compared with those recorded near (<100 m) feeding whales encountered in coastal South Africa (authors' unpublished data).

Once calls were identified and grouped into recognized call types, call classification accuracy was quantitatively assessed using a supervised random forest analysis conducted in R 4.0.2 (R Core Team, 2020) and RSTUDIO (RStudio Team, 2020) ["*randomForest*" package—Liaw and Wiener (2002)]. The random forest analysis was conducted on 11 robust signal measurements derived from RAVEN PRO, namely, Center Frequency, Bandwidth 50%, Bandwidth 90%, Frequency 5%, 25%, 75%, and 95%, Maximum Frequency, Duration 90%, Peak Frequency, and Delta Time. These measurements are based on signal power distributions and, therefore, do not rely heavily on the exact bounds of the selection created in RAVEN (Charif *et al.*, 2010). Calls were randomly assigned to a 75% training (n = 414 calls) and a 25% test dataset (n = 138 calls) with the maximum number of trials set to 1000. Classification of calls to four types was assessed through out of bag (OOB) error rates and the Cohens Kappa test was used to assess classification against chance in the unbalanced dataset. Parameter importance was assessed through mean decrease in accuracy and the Gini index.

Diel trends in call production were investigated. Data from SunCalc (2022) for Vema over the recording period were used to divide a 24 h day into five sections: Dawn (nautical dawn to sunrise), Morning (sunrise to solar noon), Afternoon (solar noon to sunset), Dusk (sunset to nautical dusk), and Night (nautical dusk to nautical dawn, when sun altitude is between 0° and 12°). The times chosen for these periods shifted each day, therefore, time intervals were averaged to determine a generalized start and end time for an average day at Vema resulting in Dawn = ∼1.5 h, Morning ≃ 6.5 h, Afternoon ≃ 6.5 h, Dusk ≃ 1.5 h and Night ≃ 8 h. Presence-absence of non-song calls were determined for each period in each day and plotted in RSTUDIO [using the "*mgcv*" package—Wood (2017) and "*nlme*" pacakge—Pinheiro *et al.* (2019)] to create a binomial generalized additive model (GAM) to determine potential diel patterns.

3. Results

Hydrophones deployed at Vema were active for 11 days, totaling 423 h 8 min of recordings when pooled between both devices. Of the 652 calls identified, 558 were classified as either whups (n = 38, 68%), grumbles (n = 76, 14%), grumble-whups (n = 6, 1%), tonals (n = 19, 3%), or impulsive sounds (n = 77, 14%). These visually matched sound types previously documented during focal group recordings of humpback whales in coastal South Africa (Fig. 2). Ninety-four calls remained "unclassified," and were excluded from analysis, as they were mostly recorded with low signal-to-noise ratio. Unclassified calls did not conform to any known or described call type, nor did they show any clear groupings amongst themselves to justify a new call type.

Results from the random forest analysis (Table 1) showed strong support for the visual and aural categorization of call types. Low sample sizes prevented reliable inclusion of the call category "grumble-whup," but random forest classification of the remaining call types had an overall classification success rate of 86%. Call classification success ranged from 67% to 100% depending on call type (see supplementary material for a table detailing the call classification success[1]). A Cohen's kappa statistic of 0.7 indicates moderate classification above chance in this unbalanced data set. The greatest error in classification was for the grumble category, as one third of cases (n = 6 of 18) were misclassified into the whup category. In contrast, confidence of whup classification, the dominant call recorded, was high with 90% correct classification for this call type. Classification was based mostly on the bandwidth 90% and 95% frequency parameters.

Most of the calls included in the analysis (n = 485, 87%) were detected on only three days of the deployment period, the 27th to the 29th of October (Fig. 3), with minimal to no detections on the other 8 days. No visual observation effort was made during the time of peak call detection. Grumble-whups were only detected on one day (29th October). Although rare, these calls were detected very clearly both visually and aurally (SNR of ∼17.2 dB), and easily matched to representative calls recorded off the coast of South Africa supporting identification of this novel combination call type.

The stereotyped impulsive sound recorded were broadband (50 to 16 000 Hz). Peak frequency was 122 ± 170 Hz (duration = ∼1.2 s), (see supplementary material for a recording example of the impulsive sound[1]). Half of the impulsive sounds (n = 39) detected were recorded mid-morning, between 06:00 and 08:30. The impulsive sounds were structurally

Table 1. Outcome of the random forest call classification test for humpback whale call types grumble, impulsive sound, tonal, and whup recorded at the Vema Seamount. True call types are shown in the rows and the predicted classification from the random forest model are shown in the columns. Number represented show the classification percentage (%) of each call type.

	Grumble	Impulsive sound	Tonal	Whup
Grumble	67	0	0	33
Impulsive sound	0	84	0	16
Tonal	0	0	100	0
Whup	8	2	0	90

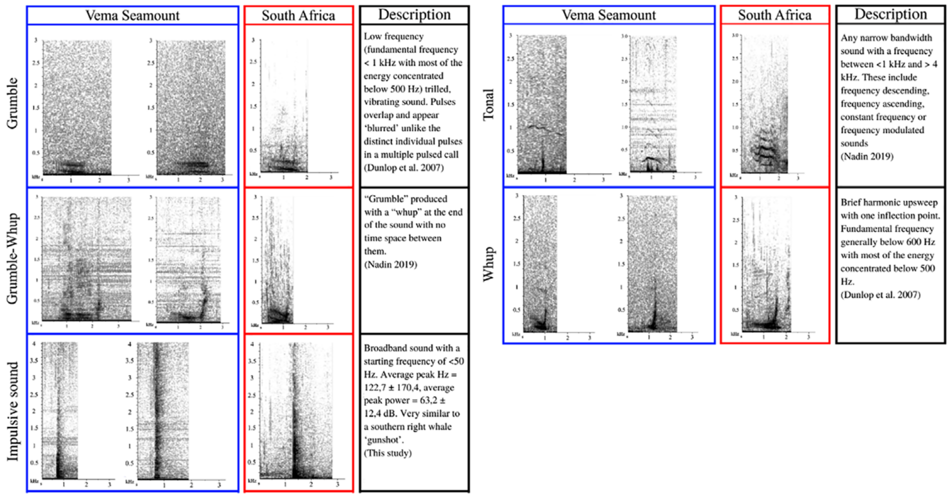

Fig. 2. A comparison of call types recorded at the Vema Seamount (two examples; blue block) to those recorded off the west coast of South Africa (one example; red block). Call types represented are whup, grumble, grumble-whup, tonal, and impulsive sound, with a brief description of each (black block).

similar to the right whale "gunshot" (Parks *et al.*, 2005; Shabangu *et al.*, 2021) but were detected simultaneously (within ± 10 s) with other known humpback whale calls (whups and grumbles) strongly indicating that they are produced by humpback whales.

All call types were more prevalent in the early morning and late evening (Fig. 4). Only five calls of any type were detected between 14:00 and 21:00 during the recording period (Fig. 4). This result was supported by the GAM analysis. Hour of the day [approximate significance of smooth terms: s(Hour) edf = 3, $\chi^2 = 10{,}52$, $P < 0.05$] was a significant predictor of call presence, showing a decreased probability of detecting calls during the afternoon and dusk hours. Day period, however, was not a significant predictor of call presence ($P > 0.05$). Whup calls were most prevalent in the late evening and early morning with roughly 48% (n = 269) of all whup calls occurring between 23:00 and 03:00. Grumble-whups only occurred during the 08:00 h on one day during the recording period.

4. Discussion

This is the first description of humpback whale vocalizations near a seamount in the southeast Atlantic. Overall, calling showed a strong diel pattern and when detected, humpback whale calls were found predominantly at night during the recording period and peaked between 27 and 29 October. Nighttime calling is consistent with calling behavior in other areas [Gulf of Maine, USA: Huang *et al.* (2016) and Gully MPA, Canada: Kowarski *et al.* (2018)] and singing behavior off the coast of southern Africa (Ross-Marsh *et al.*, 2020). In contrast to coastal South Africa, song was not clearly detected at Vema during the recording period. This was unexpected as humpback whales are generally common in the South Atlantic Ocean (Wedekin *et al.*, 2017), especially during their southward migration between September and November (Barendse *et al.* 2011) when they are known to sing (Ross Marsh *et al.*, 2020; Gridley *et al.*, 2018; Hawkey *et al.*, 2020).

Five call types were identified and visual classification of four of these was supported by random forest analysis. Visual identification of a combination call type—the grumble-whup—was straightforward and matched regional data from

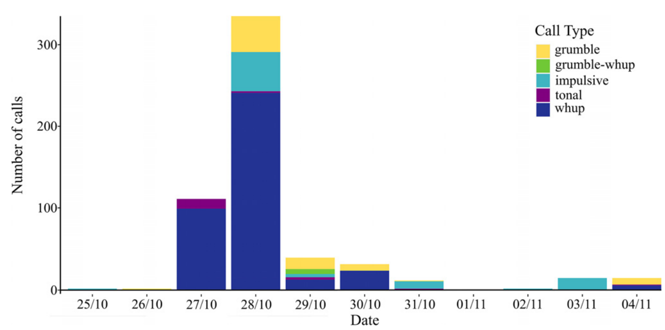

Fig. 3. Count of non-song calls detected over the deployment period from 25 October 2019 to 11 April 2019 at the Vema Seamount. Call detections from both hydrophones were pooled.

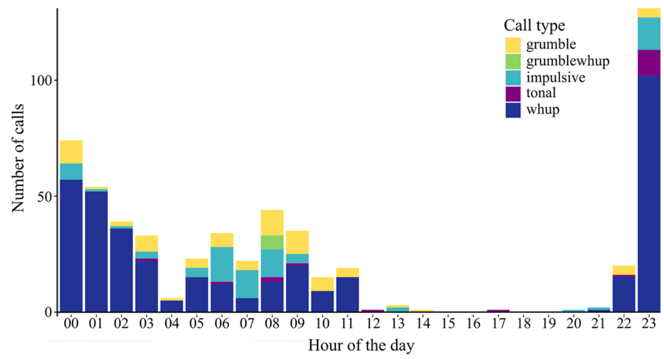

Fig. 4. Number of call types detected at the Vema Seamount per hour of the day from 00:00 (00) to 23:00 (23) during the recording period. Call detections from both hydrophones were pooled.

coastal South Africa. The most common call detected was the whup, which is widely considered as a contact call (Wild and Gabriele, 2014). This could indicate interactions taking place between individuals in the area (Dunlop, 2017), such as between mother-calf pairs moving southward after the breeding season (Dunlop, 2017; Dunlop *et al.*, 2008; Indeck *et al.*, 2021). Whup and grumble calls are also produced by foraging whales and commonly heard on feeding grounds (Cerchio and Dahlheim, 2001; Fournet *et al.*, 2018; Rekdahl *et al.*, 2013; Wild and Gabriele, 2014). Feeding is consistent with behavioral observations (JF) of two humpback whales at Vema from the RV *Arctic Sunrise* on 4 November 2019, which overlapped with call detections. The individuals engaged in repeated long dives (estimated 10 min in duration) in the same location, interspersed with surface activity (including pectoral slapping).

Impulsive sounds (gunshot-like calls) were also detected regularly at Vema. Until now, impulsive gunshots had only been associated with other baleen whale species—notably bowhead whales, who do not inhabit the region (Best, 2007), and right whales (Shabangu *et al.*, 2021; Stafford *et al.*, 2008). Right whale calls are readily detected in South African waters (Hofmeyr-Juritz and Best, 2011), and gunshot sounds in offshore waters between Vema and South Africa have been attributed to southern right whales (Shabangu *et al.*, 2021). However, no right whales were seen during the survey (JF), nor were any southern right whale calls detected on the moored hydrophones (this study), therefore, it seems unlikely that the sounds reported here were made by right whales. The regular detection of these impulsive sounds at Vema, which were temporally associated with well-defined humpback whale calls, along with the support of several detections of impulsive sounds by author S.H.E. in coastal South Africa near feeding super-groups of humpback whales, indicates that these impulsive call types might be generated by humpback whales. Additionally, a similar sound type, the "bop," was recorded near Peregain Beach, Brisbane during the southward migration and reported by Rekdahl *et al.* (2015). This may further indicate the ability of humpback whales to produce impulsive sounds such as those reported here.

The detection of non-song calls from humpback whales at Vema indicates that the area is used as more than just a migration "marker" by humpback whales, although conclusions are limited by the short duration of the recording period. The presence of non-song calling in conjunction with observed feeding behavior may indicate that Vema could provide humpback whales with the opportunity to feed. Globally, whale populations are beginning to struggle as food resources shift and decline (Schleimer *et al.*, 2019; Simmonds and Isaac, 2007; van den Berg *et al.*, 2021). It is possible, therefore, that areas like Vema and the Benguela feeding ground may provide important supplementary feeding opportunities along migration routes. Although we were not able to determine the population origin of the humpback whales recorded using the current data, telemetry data reported by Rosenbaum *et al.* (2014) and the South African Department of Environmental Affairs (Department of Environmental Affairs, 2016) shows that individuals from both breeding stock B and breeding stock C migrate past this area. In conjunction with acoustic monitoring and repertoire matching between recordings at the seamount and known populations, satellite telemetry could help to determine the residence time for humpback whales in the region as well as their origin. Further, fine scale telemetry devices (for example, acoustic tags) could potentially elucidate behavior and habitat use for this area (Bejder *et al.*, 2019; Derville *et al.*, 2020). Integrating these complementary streams of data, as well as extending the duration of acoustic monitoring at the seamount, would enable us to better understand the function of the calls made during their time at Vema, and potentially other seamounts in the area. This could be an important first step in providing a clearer picture on routes and timings of migrations for whales that transit the South Atlantic Ocean. Knowledge of migration routes, timings, and the associated behaviours of pelagic cetaceans is an important step towards the understanding of the health and drivers of deep ocean ecosystems.

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[1]See the supplementary material at https://www.scitation.org/doi/suppl/10.1121/10.0010072 for a table detailing the call classification success and a recording example of the impulsive sound.

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