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Occurrence of Omura's whale, *Balaenoptera omurai* (Cetacea: Balaenopteridae), in the Equatorial Atlantic Ocean based on Passive Acoustic Monitoring

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The current known distribution of Omura's whale includes the tropical and warm temperate waters of the western Pacific, Indian, and Atlantic Oceans. Evidence of their presence in the Atlantic Ocean is based on beach cast specimens found on the coasts of Mauritania (North Atlantic) and Northeastern Brazil (South Atlantic). The present study characterizes the occurrence of this species in the São Pedro and São Paulo Archipelago (SPSPA), on the mid-Atlantic ridge between South America and Africa, based on autonomous recording systems. Acoustic signals were similar, but not identical, to *B. omurai* vocalizations recorded off the coast of Madagascar. Although these signals were recorded for only 11 months, there are peaks in vocal activity between May and June in the vicinities of SPSPA, suggesting either a shift in distribution within the Atlantic equatorial waters or seasonality in the species' vocal behavior in this region. The first acoustic records of Omura's whales in the Equatorial Atlantic suggest that these animals may also use deep-water habitats, in addition to the shallow-water habitat use observed in other regions.

Key words: acoustic detection, Atlantic Ocean, *Balaenoptera omurai*, Balaenopteridae, seasonality, song, vocalization

A atual distribuição conhecida da baleia-de-Omura (*Balaenoptera omurai*) inclui as águas tropicais e temperadas quentes dos oceanos Pacífico ocidental, Índico e Atlântico. A evidência de sua presença no oceano Atlântico baseia-se em espécimes encalhados encontrados em praias da Mauritânia (Atlântico Norte) e do Nordeste do Brasil (Atlântico Sul). O presente estudo caracteriza a ocorrência dessa espécie no Arquipélago de São Pedro e São Paulo (ASPSP), localizado sobre a Dorsal Mesoatlântica entre a América do Sul e a África, com base em sistemas de monitoramento acústico passivo. Os sinais acústicos detectados foram similares, mas não idênticos, às vocalizações de *B. omurai* gravadas na costa de Madagascar. Embora esses sinais tenham sido registrados por apenas 11 meses, há picos na atividade vocal entre maio e junho nas proximidades do ASPSP, sugerindo uma mudança na distribuição da espécie nas águas equatoriais do Atlântico ou uma sazonalidade no comportamento vocal nessa região. Os primeiros registros acústicos das baleias-de-Omura no Atlântico Equatorial sugerem que esses animais também podem utilizar habitats de águas profundas, além de habitats de águas rasas como observado em outras regiões.

Palavras-chave: *Balaenoptera omurai*, Balaenopteridae, canções, detecção acústica, Oceano Atlântico, sazonalidade, vocalização

Balaenoptera omurai, Omura's whale, is one of the least known species of baleen whales. One of the few cetacean taxa discovered in the 21st century, the species was described by Wada et al. (2003), who recognized that a 1998 stranded specimen from Japan, and whaling specimens from Cocos and Solomon Islands, previously referred as small or small-form Bryde's whale (Ohsumi 1980; Yoshida and Kato 1999) actually constituted a distinct species, *B. omurai*. Taxonomic differentiation was based on skeletal morphology and molecular evidence and subsequently, Sasaki et al. (2006) presented a more detailed molecular phylogenetic analysis corroborating the taxonomic status of *B. omurai* as an independent and ancient lineage, sister to a clade comprising Bryde's (*B. edeni* and *B. brydei*) and Sei (*B. borealis*) whales.

The current distribution of Omura's whale includes the tropical and warm temperate Indo-Pacific, Indian, and North and South Atlantic Oceans (Wada et al. 2003; Cerchio et al. 2015; Jung et al. 2016; Ottewell et al. 2016; Ranjbar et al. 2016; Cypriano-Souza et al. 2017; Cerchio and Yamada 2018, Cerchio et al. 2019). In the Atlantic Ocean, the only evidence of the presence of *B. omurai* is based on two beach cast specimens: 1) a specimen stranded in September 2010 on the beach of Pecém, Ceará, Northeast Brazil (3.53378°S, 38.79772°W) in the western South Atlantic (Cypriano-Souza et al. 2017); and 2) a specimen stranded in 3 November 2013 near Chott Boul on the coast of Mauritania (16.54146°N, 16.45055°W) in the eastern North Atlantic (Jung et al. 2016).

Description of a coastal population of Omura's whales was reported in the Southwest Indian Ocean off the northwestern coast of Madagascar (Cerchio et al. 2015). In addition to a detailed study on the ecology and behavior of this whale population, Cerchio et al. (2015) provided the first description of the species' vocal behavior and songs. Vocalizations were recorded in the presence of Omura's whales off Madagascar using a boat-based single hydrophone, and throughout their habitat using archival SoundTrap202 recorders (oceaninstruments.co.nz) sampling at 96 kHz. Documented vocalizations were identified as songs presenting a stereotyped unit structure and characteristic repetition rate; units were on average 9.2 s (*SD*, 0.92 s) duration, amplitude modulated (AM) in a 15- to 50-Hz frequency bandwidth, and were considered distinct from all other known baleen whale vocalizations (Cerchio et al. 2015).

Acoustic recordings validated as vocalizations of the species, i.e., concomitant visual and acoustic detections, are limited to the Madagascar region (Cerchio et al. 2015: AM 15–50 Hz, duration of 9.2 s). However, baleen whale vocalizations recorded off the Northwest Shelf of Australia (Erbe et al. 2017: AM 20–60 Hz, duration 9.2 s) and the Chagos Archipelago (Sousa and Harris 2015: AM 16.9–49.6 Hz, duration 13.1 s) have been attributed to Omura's whales based on similarities to the Madagascar signals by examination of spectrograms (Cerchio et al. 2019). Prior to the description of Omura's whale song or identification of Omura's whales in Australian waters, the vocalizations recorded off northwest Australia were reported in several unpublished reports; they were tentatively attributed to Bryde's whale vocalizations because this was the only potential candidate species in the region. After the publication of Cerchio et al. (2015), two different research groups independently identified these vocalizations as Omura's whale based on spectrographic similarity (Erbe et al. 2017; Cerchio et al. 2019). Sousa and Harris (2015) reported on two types of baleen whale vocalizations recorded off the Chagos Archipelago from the Diego Garcia (north and south) Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) hydrophone arrays, and considered them of unknown species attribution but potentially blue whales; again this was before the publication of confirmed Omura's whale song, and Cerchio et al. (2019) recognized one of the described vocalizations, the "Diego Garcia Croak," as the diagnostic song of this species.

This study reports the first detection of *B. omurai* in the open waters of Atlantic Ocean, based on passive acoustic monitoring of vocalizations from the vicinities of the São Pedro and São Paulo Archipelago (SPSPA). The use of the passive acoustic monitoring method, especially long-term monitoring, in the SPSPA region addresses several questions, namely: distribution, geographical variation, seasonality, migration, movements, and habitat use. In addition, unlike visual monitoring methods, this methodology does not present any limitation in terms of time of day and climate conditions.

Materials and Methods

Two hydrophones were moored between February and December 2013 in the Equatorial Atlantic Ocean during the COLMEIA acoustic experiment in the vicinities of the Brazilian SPSPA (Maia 2013; Maia et al. 2014; Fig. 1). Each instrument consisted of a hydrophone connected to an acquisition and storage system developed by the Laboratoire Geosciences Océan (Brest, France—D'Eu et al. 2012). To survive long-term immersion, the instrument is contained in a 90-cm-long solid titanium tube housed inside a syntactic foam buoy capable of resisting pressure up to 2,000 m water depth. The hydrophone sensor is fixed to and protected by the buoy metallic frame (Supplementary Data SD1). The instruments are moored in the SOFAR channel axis by adjusting the length of the mooring line according to the depth of the seafloor and the depth of the SOFAR axis in the area. The whole line is held by a 400-kg disposable anchor and an acoustic release system is placed just above the anchor for remote retrieval.

Each hydrophone was moored on the axis of the Sound Fixing and Ranging (SOFAR) channel at a depth of ca. 770–780 m, at sites of bottom depth greater than 2,900 m (Table 1). The hydrophone had a sampling frequency from ~1 to 120 Hz (± 3 dB) and sensitivity of −163.5 dB re 1 V/Pa, including preamplifier gain of 22 dB; acoustic data were collected at a sampling rate of 240 Hz using a 24-bit analog-to-digital conversion. Upon recovery of the COLMEIA hydrophones, data were downloaded and analyzed for the presence of whale calls.

Song phrases of Omura's whales from the Southwest Indian Ocean (Nosy Be, Madagascar) were compared to the sounds recorded near the SPSPA in the Atlantic Ocean (Fig. 2). The Madagascar recordings were collected with a SoundTrap

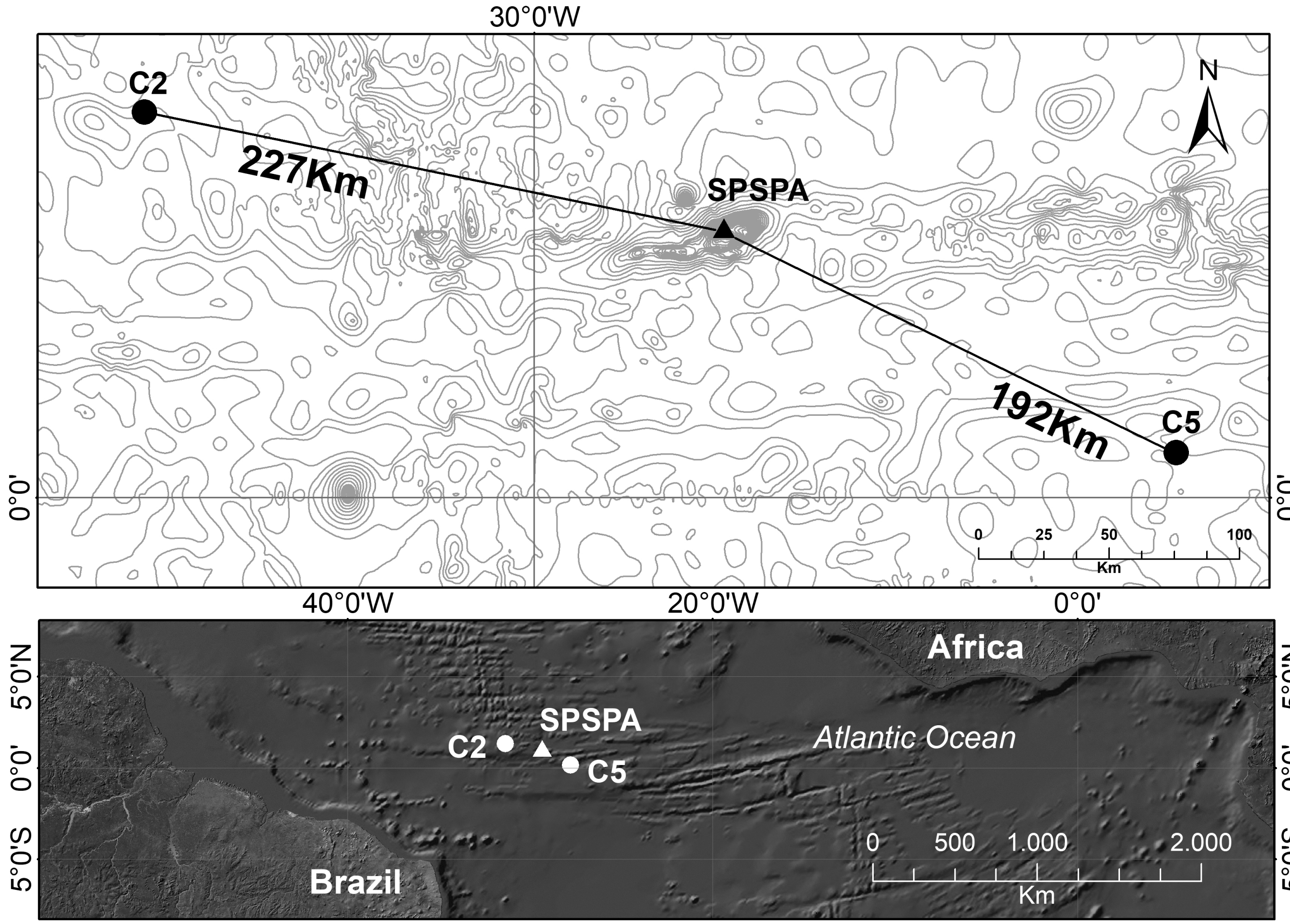

Fig. 1.—Location of the COLMEIA hydrophones (C2 and C5) in the Equatorial Atlantic Ocean, relative to the São Pedro and São Paulo Archipelago (SPSPA). Hydrophone deployments: C2: 1.32900°N, 31.34400°W, from 2 February to 22 August 2013; C5: 0.1500°N, 27.78600°W, from 25 February to 26 December 2013.

Table 1.—Summary of the data used to characterize signals recorded during the COLMEIA acoustic experiment in the Equatorial Atlantic Ocean, off the of São Pedro e São Paulo Archipelago, and off Nosy Be, Madagascar. SNR = signal-to-noise ratio.

Hydrophone	Local depth (m)	Hydrophone depth (m)	Latitude	Longitude	Number of selected sounds with SNR > 10 dB
COLMEIA 2	2,980	780[a]	1.329°N	31.344°W	29
COLMEIA 5	3,770	770[a]	0.155°N	27.786°W	7
Madagascar	37.2	36	13.112°S	48.237°E	22

[a]Exact values may vary due to deep current conditions.

300STD (http://www.oceaninstruments.co.nz) during December 2015 on a static bottom mount in shallow water (37.2 m) near Banc du Goliath, located at the north of Nosy Be, Madagascar (13.112°S, 48.237°E). The SoundTrap hydrophone has a flat response from 20 to 60 kHz (± 3 dB) with a 34 dB re 1 µPa noise floor and a full-scale response of 174.1 dB re 1 µPa including system gain. Recordings were undertaken at a 24-kHz sampling rate at 16-bit, and downsampled to 2 kHz for analysis. Sounds were manually detected and analyzed using Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, New York). Table 1 indicates the exact location of the hydrophones and the number of selected sounds from each sensor from all locations.

Baleen whale vocalizations resembling those reported by Omura's whales off Madagascar (Cerchio et al. 2015, 2018) were identified by browsing the COLMEIA data from February to December 2013 (326 days, 29.4 GB of total record of acoustic passage). Thirty-six (N = 36) vocalizations with high signal-to-noise ratio (SNR > 10 dB) attributed to Omura's whales were selected for further analyses and for comparison with high-quality vocalizations recorded off Madagascar (N = 22).

The main AM unit of the song was characterized by two temporally consecutive sections, each with two peak-energy frequency bands (see Fig. 2, and detailed description in "Results"). To assess variation between song units from

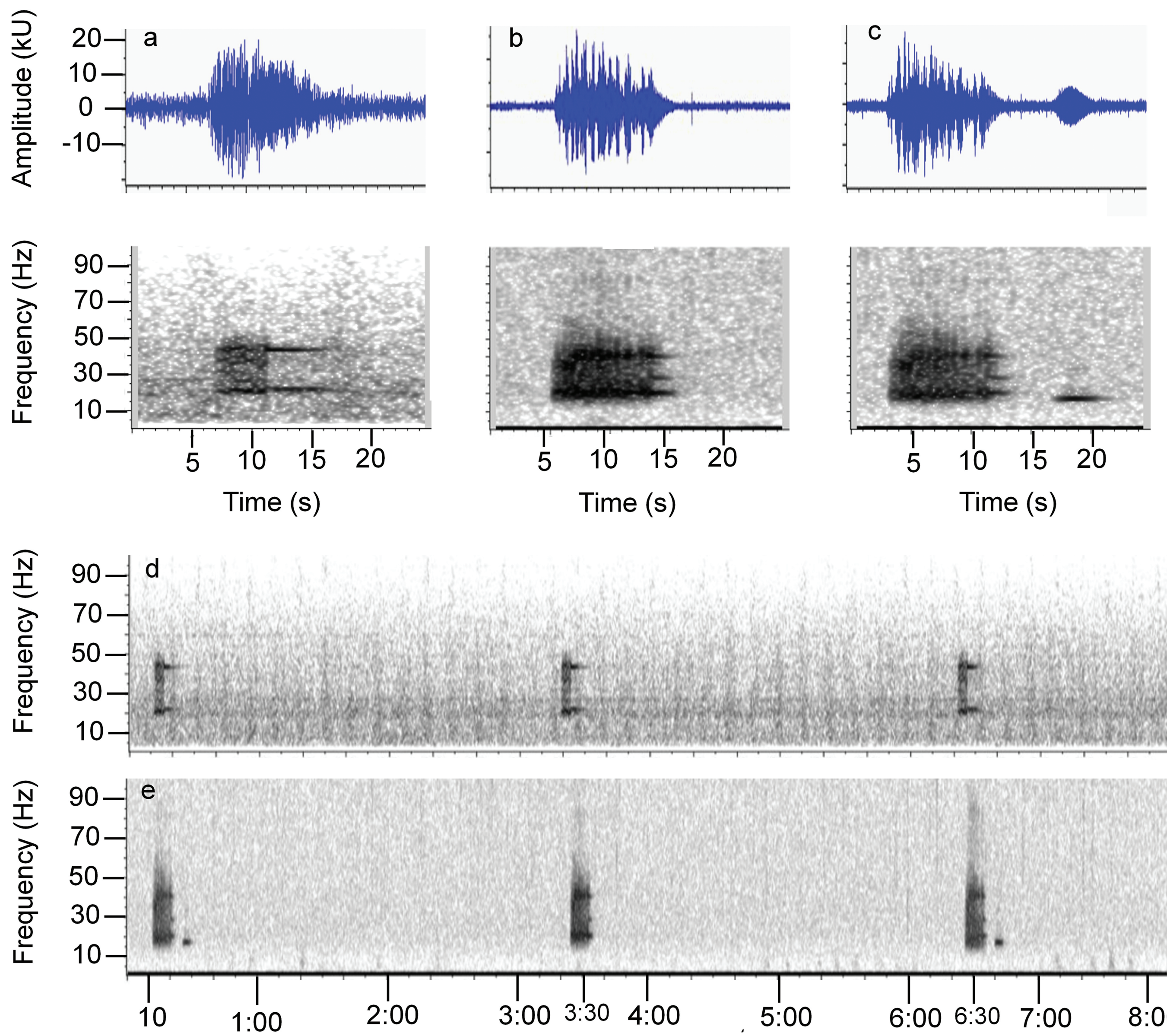

Fig. 2.—Sound spectrograms and waveforms illustrating similarities between song vocalizations attributed to Omura's whales from Equatorial Atlantic and Madagascar. Shown are 25-s spectrogram and waveform (in blue) examples of (a) the vocalization recorded off SPSPA, Brazil, attributed to Omura's whale, (b) a single song phrase from northwest Madagascar, as described in Cerchio et al. (2015) with confirmed attribution to Omura's whales, and (c) a second phrase type from Madagascar that includes a tonal 16 Hz unit after the amplitude modulated unit (Cerchio et al. 2018). Typical sequences of the vocalizations from an 8-min sample from (d) Equatorial Atlantic, and (e) off Madagascar are also shown, illustrating similar repetition rates of vocalizations in each region. For both regions, spectrograms were generated with frequency and time resolution of 1.0 Hz and 100 ms, respectively, using the Hann window.

Equatorial Atlantic and Madagascar recordings, quantitative measurements were carried out using Raven Pro 1.5 on the song unit (full signal), and Sections 1 and 2 separately (FFT size of 512 samples [Atlantic data] or 4,096 samples [Madagascar data] yielding a frequency resolution of ca. 0.5 Hz for each data set, 50% overlap, Hann window). Measurements included duration and minimum and maximum frequencies as defined by a manually drawn Raven selection box. Peak frequency for the lower and upper bands were measured separately, as determined by Raven's Peak Frequency measurement extracted from two separate Raven selection boxes for each band, bounded by the minimum frequency of the song unit and 32 Hz for the lower band, and 32 Hz and the maximum frequency of the unit for the upper band (see Fig. 3). Each measurement variable was first tested for normality with the Kolmogorov–Smirnov test. A Tukey test (parametric) or the Mann–Whitney U-test (nonparametric) was applied to test for significant variation between the regions, determined at the $P < 0.05$ level. The tests were carried out using Statistica software (StatSoft, Tulsa, Oklahoma).

A custom automated template detector was used in software XBAT (eXtensible BioAcoustics Tool package, version 6.1.0.1; Bioacoustics Research Program, Cornell Lab of Ornithology, Ithaca, New York; www.birds.cornell.edu/brp/; Figueroa and

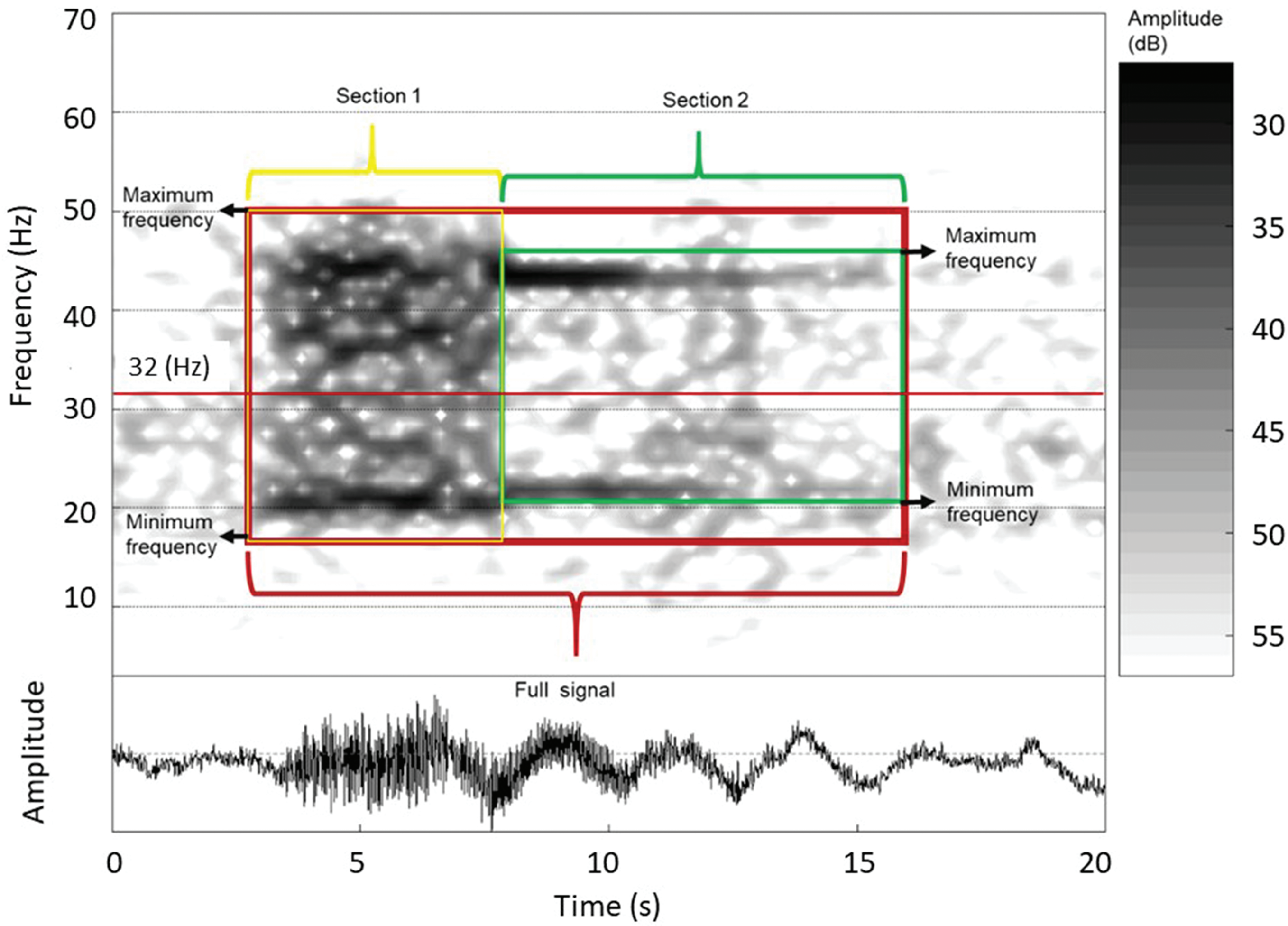

Fig. 3.—Detailed sound spectrogram of an Equatorial Atlantic song unit illustrating some of the measurements used in the quantitative analyses. Note that the upper and lower band selections are not shown but were limited by 32 Hz and by the minimum and maximum frequencies of each section.

Robbins 2008), and an acoustic analysis program written in MATLAB version 7.0.4 (The Mathworks, Natick, Massachusetts). The detector labeled all signals that met the similarity criteria to a set of known target signals (templates) so as to identify any potential Omura's whale song units in the SPSPA data.

In all acoustic monitoring data, interference from sonar, airguns, other whale vocalizations, seismic events, and other acoustic sources can result in false-positive detections. These interfering signals also can mask the whale's vocalization, thus creating false negatives. The performance of the XBAT detector was assessed in terms of the correct detection rate and the number of false detections through verification of spectrograms by an experienced human operator. Raven Pro 1.5 was used to manually browse the recordings to review and validate all sounds identified by the automatic XBAT detector, removing all false positives and labeling all false negatives. The data thus were exhaustively validated and to the best of our ability, errors eliminated.

Results

A total of 13,050 sounds were labeled as Omura's whale song units by the XBAT template automated detector in the Equatorial Atlantic recordings. From this total, 4,620 detections were found in recordings from Hydrophone C2 and 8,430 in Hydrophone C5. After exhaustive manual validation, 6,794 auto-detections were confirmed to be Omura's whale song units by visual examination (52% true positives found in Hydrophones C2 and C5 combined). Manual identification of false negatives accounted for an additional 5,991 sound units from Hydrophones C2 and C5, resulting in a total of 12,785 validated Omura's whale song units (and consequent 47% false-negative rate).

Vocalizations from the Equatorial Atlantic samples were composed of two distinct sections. The first (Section 1) consisted of an AM signal with a bimodal energy distribution and gradually transitioned into the second tonal section (Section 2) with two bands at an apparent harmonic interval (Figs. 2 and 3). Two similar sections also were apparent in vocalizations from Madagascar. However, Section 2 was significantly shorter in this region (Table 2) and displayed a more complex frequency banding structure with an additional tonal frequency at 30 Hz not so clearly attributable to a harmonic interval (Table 2; Figs. 2b and 2c). In addition, off Madagascar, the described vocalizations sometimes were followed by a second

Table 2.—Descriptive statistics and test results of the comparison of the central acoustic parameter tendency values of Omura's whale vocalizations from the Equatorial Atlantic (SPSPA) and Indian (off Madagascar) Oceans. Note that the upper and lower band selections made in Raven Pro 1.5 were limited by 32 Hz in both samples, as displayed in Fig. 3. These values therefore result from the selection method by sections (1 and 2). Values in bold are similar ($P > 0.05$). Median/IQR values are indicated by #, while mean/*SD* are indicated by *. Atlantic Ocean ($N = 36$), Indian Ocean ($N = 22$). AM = amplitude modulated; IQR = interquartile range.

Measurements	Section 1 (AM) lower band			Section 1 (AM) upper band			Section 2 (harmonic) lower band			Section 2 (harmonic) upper band			Full signal (entire duration and bandwidth)		
Central tendency/ dispersion	Atlantic Ocean	Indian Ocean	*P*-value	Atlantic Ocean	Indian Ocean	*P*-value	Atlantic Ocean	Indian Ocean	*P*-value	Atlantic Ocean	Indian Ocean	*P*-value	Atlantic Ocean	Indian Ocean	*P*-value
Duration (s)	4.88/0.50#	8.22/0.27#	<0.001	4.85/0.37#	8.22/0.27#	<0.001	4.9/1.0#	1.92/0.37#	<0.001	4.96/1.01#	1.92/0.37#	<0.001	**10.42/1.16***	**10.16/0.31***	**0.276**
Peak frequency (Hz)	**20.6/0.0#**	**20.75/4.8#**	**0.809**	43.6/0.9#	40.0/1.6#	<0.001	21.6/0#	20.0/7.8#	0.013	43.10/0#	41.0/2.0#	<0.001	43.1/0#	40.9/9.47#	<0.001
Minimum frequency (Hz)	16.96/1.28*	16.11/1.15*	0.014	NA	NA	NA	17.3/2.1#	18.35/0.3#	<0.001	NA	NA	NA	20.19/4.24*	15.99/0.98*	<0.001
Maximum frequency (Hz)	NA	NA	NA	46.9/1.1#	47.85/4.7#	0.045	NA	NA	NA	46.6/1.4#	41.4/0.5	<0.001	**47.57/0.6***	**48.65/2.89***	**0.122**
Delta frequency (Hz)	15.04/1.28*	15.89/1.15*	0.014	**14.95/0.93#**	**16.18/3.28#**	**0.980**	14.7/2.1#	13.65/0.3#	<0.001	14.7/0.25#	9.4/0.5#	<0.001	27.38/4.8	32.66/3.05	<0.001

single-banded tonal vocalization at 16 Hz (Fig. 2c). Neither the 30 Hz band in Section 2 nor the second 16 Hz vocalization were observed in any Atlantic sample. For all selected Atlantic vocalizations with SNR > 10 dB ($N = 36$) in which both frequency bands were visible, the full signal frequency bandwidth ranged from approximately 13.5 to 51.5 Hz. This frequency band is similar to that described for Madagascar Omura's whales, where the frequency bandwidth was reported between 15 and 50 Hz (Cerchio et al. 2015), as well as the sounds attributed to Omura's whales from the northwestern Australian platform with a bandwidth between 20 and 60 Hz (Erbe et al. 2017).

Vocalizations occurred in rhythmic sequences in all Equatorial Atlantic detections (Fig. 2d), as were the vocalizations described from Madagascar (Fig. 2e), and thus considered a typical balaenopterid song (Cerchio et al. 2015, 2018). The repetition rate of the song phrase was similar in both regions, with a rate of 172.18 s ± *SD* 32.52 s in the Equatorial Atlantic (measured from 216 individual series ranging from 14 to 230 repeated phrases), whereas off Madagascar this was reported as 189.7 s ± *SD* 19.04 s (Cerchio et al. 2018; from 118 individual series ranging from 20 to 250 repeated phrases).

Despite the qualitative similarities in frequency and temporal characteristics of the song units from the Equatorial Atlantic and Madagascar, variations were evident in the detailed structure of the units and distribution of energy across the frequency band. Most measurements were significantly different between the Equatorial Atlantic and Madagascar samples, with a few key exceptions that describe some of the most basic unit characteristics: peak frequency of the lower band in Section 1, and duration and maximum frequency of the full signal (Table 2). Section 1 (AM) is shorter and displays a narrower frequency range in the Equatorial Atlantic sample. Section 1 from Madagascar has a significantly lower minimum frequency and a higher maximum frequency (Table 2), which may be due to different SNRs and propagation loss characteristics. The upper band of Section 1 presents higher peak frequencies in the Equatorial Atlantic sample, but the maximum frequency is higher in the Madagascar sample, therefore yielding a wider frequency bandwidth in that region. Section 2 (harmonic) is longer in Equatorial Atlantic vocalizations and peak and maximum frequencies are higher, while the minimum frequency is lower. These vocalizations therefore occupy a wider frequency range than the sample from Madagascar.

The 12,785 confirmed Omura's whale vocal units were heterogeneously distributed throughout the sampled period (February to December), suggesting marked seasonality in vocal activity (Fig. 4). The highest number of detections occurred in June (40%), followed by May (34%) and April (15%). Detection rates decreased dramatically in August (0.19%), November (0.19%), and December (0.69%). No detections were obtained for September or October.

Discussion

Since the species was described in 2003, there have remained gaps in our knowledge of Omura's whale distribution, behavior,

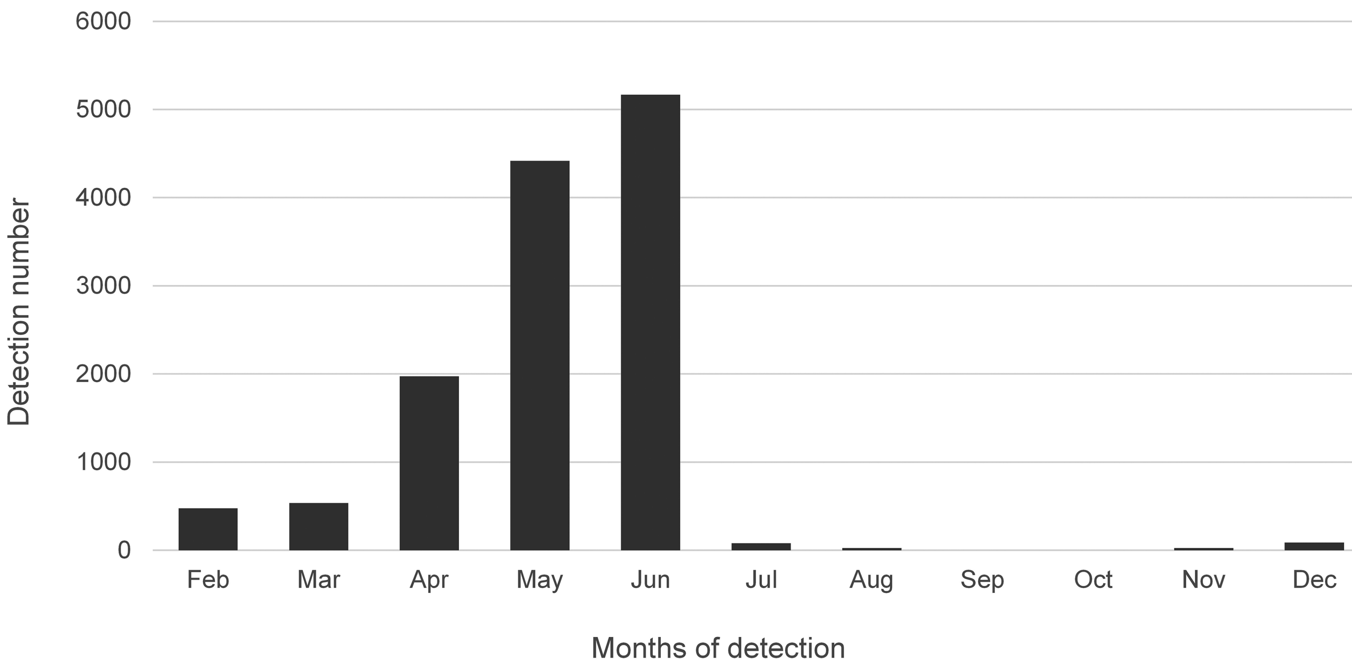

Fig. 4.—Seasonal occurrence of Omura's whale vocalizations. Vocal activity detection in Equatorial Atlantic is highest in May and June, although recording efforts were not conducted in January.

and vocal behavior, due to the paucity of records and targeted studies on the species. The importance of a new record, particularly in a new region, substantially increases our knowledge of the species in its distribution, behavior, and descriptions of vocalizations. Acoustic recordings made near the SPSPA (Brazil) in the Equatorial Atlantic have demonstrated the presence of baleen whale vocalizations that we attribute to Omura's whales. The vocalizations are similar to Omura's whale song described off Madagascar (Cerchio et al. 2015), as well as to other Omura's whale song descriptions from the northwest coast of Australia and the Chagos Archipelago (Erbe et al. 2017; Cerchio et al. 2019). Our confidence of the attribution of the signals recorded in the Mid-Atlantic Ocean to Omura's whales is high, given the similarity in the duration of the signals and frequency distribution of the spectral energy in the vocalizations, the overall structure of the song phrase, and the rhythmic repetition of the phrases. In addition, the presence of a beach cast specimen on the coast of Brazil in the South Atlantic on 10 September 2010 (Cypriano-Souza et al. 2017) and on the coast of Mauritania in the African North Atlantic on 3 November 2013, during the same period of this work (Jung et al. 2016) confirms that Omura's whales range includes the Equatorial Atlantic Ocean.

The main differences between the Madagascar and SPSPA detections are: 1) the lack of the second tonal unit at 16 Hz found in some of the Madagascar phrases (Cerchio et al. 2018); 2) central tendency values of frequencies (except in the peak frequency of the lower band of Section 1 and maximum frequency of the full signal, where values were not significantly different); 3) duration of each of the two sections: Section 1 is shorter in Equatorial Atlantic vocalizations while Section 2 is shorter in Madagascar vocalizations (note that full signal durations are similar); and 4) the habitat in which the detections occurred, with the Atlantic detections occurring in open ocean deep-water habitat, as opposed to the Madagascar samples that were recorded in shallow-water shelf habitat. These spectral differences might result from multiple nonexclusive factors, most notably geographic variation in the vocalization, which is typical for baleen whale songs, but also from differences in propagation, transmission loss and masking due to background noise, and individual variation and behavioral context. As it is a new species with few records of its vocalizations, only with further study in the Atlantic and Indian Oceans, as well as globally, be able to understand geographic variation in the vocalizations of Omura's whale throughout its range.

Omura's whale song units were detected most prominently from February to June and to a much lesser extent between July and December. No detections were made in September or October. In January the hydrophones were not in the water; thus, we cannot determine if Omura's whales can be detected during the first month of the year. The observed temporal variation gives the impression of seasonality, although the song occurrence never completely disappears during any season, as might be expected for a migratory species, and we do not have multiple years of data to assess the consistency of temporal variation across years. This apparent seasonal singing pattern is in contrast to other parts of the species' range (Madagascar, Chagos Archipelago, and northwest Australia), where long-term acoustic monitoring has documented Omura's whale singing throughout the year with no clear seasonality (Sousa and Harris 2015; Erbe et al. 2017; Cerchio et al. 2018, 2019). It is worth noting that in Madagascar, there appears to be strong spatial heterogeneity in singing activity, with two sites only 50 km apart having very different temporal variation: one with consistent occurrence throughout the year, the other during only a few months of the year, thereby giving the false impression of seasonality (Cerchio et al. 2018). We can therefore postulate two hypotheses: the species might be present year-round, but presents a seasonal pattern in its acoustic activity; or, the steep decline in vocalizations observed between June and July is due to the displacement of individuals from the area, suggesting a shift in the distribution pattern possibly associated with changes in prey abundance. These hypotheses should be assessed with additional acoustic and visual data from the Atlantic Ocean.

If these singers were in fact in deep-water habitat, then this assessment represents a significant addition to our understanding of Omura's whale behavior. Current information from Madagascar indicates residency and a strong preference for shallow shelf waters (Cerchio et al. 2015, 2018). A global survey of all known accounts of Omura's whales also suggests a preference for shallow-water distribution, albeit with several notable exceptions (Cerchio et al. 2019). Several of the original specimens used by Wada et al. (2003) were collected by Japanese whalers in deep abyssal plain waters off the Cocos (Keeling) Islands and in the Solomon Sea (Ohsumi 1980), while Cerchio et al. (2019) also noted that shallow-water accounts of animals from several regions (Solomon Islands, New Caledonia, West Sumatra, East Kalimantan, and the Philippines) displayed heavy scarring from the deep-water cookie-cutter shark, suggesting that these populations may partially use the deep-water habitat. The detection of Omura's whale song over deep water in Equatorial Atlantic presented herein may corroborate the use of deep-water habitat by at least some populations during some periods of the year.

Alternatively, the detection of Omura's whale song by the COLMEIA hydrophones could be an acoustic phenomenon within the SOFAR channel. Because the hydrophones were placed in the axis of the channel, they could as a result receive low frequency signals emitted at very long distances (e.g., estimated detection distances 10 to 200 km—Stafford et al. 2007; Samaran et al. 2010, 2018). This is not to imply that an Omura's whale could dive to and sing at the depth of the SOFAR channel, rather it is feasible that signals from a whale singing at a shallower depth (i.e., < 100 m) over deep water could leak into the SOFAR channel and propagate longer distances than at the surface, notwithstanding the limitations on sound propagation imposed by the thermocline. At this point, we are not sure of the detection range of the hydrophone, it is therefore difficult to interpret these data with confidence due to our uncertainty in the detection range and the current inability to locate them. In the future it would be preferable to use hydrophones arrays with localization capability. Notably, although recordings off Madagascar and Australia suggest that singers use shallow-water habitat, it is conceivable that the Equatorial Atlantic Omura's whales were singing over deep waters and their songs ranged far into the SOFAR channel.

Multiple overlapping song unit sequences also were observed in the COLMEIA recordings in the Equatorial Atlantic Ocean, similar to those reported off Madagascar (Cerchio et al. 2015). It is possible that it represents a chorus of closely associated individuals in the general vicinity of the hydrophone, as was interpreted off Madagascar (due to the presumed small detection radius of shallow-water hydrophones deployed on the shelf). However, given that the SOFAR channel favors long-distance acoustic propagation at these frequencies, these may represent singers at great distances from each other. Such Omura's whale chorusing could be propagation dynamics artifacts at the SOFAR channel or interpreted as an emerging property of male–male interactions (sensu Greenfield and Schul 2008; Cholewiak et al. 2018), namely, an indication of male–male competition or mating system tactics. It is important to note that it is highly unlikely that these animals can dive to and vocalize at the depths of the SOFAR channel, so it is uncertain whether information exchange occurs among individuals in the Atlantic Ocean at these large inferred distances.

The observation of Omura's whales and the recent observation of Antarctic blue whales in the COLMEIA data set (Samaran et al. 2018) confirm that the SPSPA region is a favorable area for monitoring large baleen whales in the Equatorial Atlantic Ocean. Notably, these acoustic records of Omura's whales in the Equatorial Atlantic suggest that these animals also may use deep-water habitat in addition to the shallow-water habitat use observed in other regions.

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Supplementary Data

Supplementary data are available at *Journal of Mammalogy* online.

Supplementary Data SD1.—(a) Design of the hydrophone instrument and (b) titanium cylinder housing the batteries, electronic board, and data storage (hard disk drive). (c) Hydrophone electronic board and sensor.

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