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Running headed: Omura's whale songs in the Atlantic

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

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

15

16 Key words: Acoustic detection, song, vocalization, seasonality, Balaenopteridae,
17 *Balaenoptera omurai*, Atlantic Ocean.

18

19 A atual distribuição conhecida da baleia-de-Omura inclui as águas tropicais e
20 temperadas quentes dos oceanos Pacífico ocidental, Índico e Atlântico. A evidência de
21 sua presença no oceano Atlântico baseia-se em espécimes encalhados encontrados em
22 praias da Maurîtânia (Atlântico Norte) e do Nordeste do Brasil (Atlântico Sul). O
23 presente estudo caracteriza a ocorrência dessa espécie no Arquipélago de São Pedro e
24 São Paulo (ASPSA), localizado sobre a Dorsal Mesoatlântica entre a América do Sul e a
25 África, com base em sistemas de monitoramento acústico passivo. Os sinais acústicos

26 detectados foram similares, mas não idênticos, às vocalizações de *B. omurai* gravadas
27 na costa de Madagascar. Embora esses sinais tenham sido registrados por apenas 11
28 meses, há picos na atividade vocal entre maio e junho nas proximidades do ASPSP,
29 sugerindo uma mudança na distribuição da espécie nas águas equatoriais do Atlântico
30 ou uma estacionalidade no comportamento vocal nessa região. Os primeiros registros
31 acústicos das baleias-de-Omura no Atlântico Equatorial sugerem que esses animais
32 também podem utilizar habitats de águas profundas, além de habitats de águas rasas
33 como observado em outras regiões.

34

35 Detecção acústica, canção, vocalização, sazonalidade, *Balaenopteridae*, *Balaenoptera*
36 *omurai*, Oceano Atlântico

37

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

48 The current distribution of Omura's whale includes the tropical and warm temperate
49 Indo-Pacific, Indian, and North and South Atlantic Oceans (Wada et al. 2003; Cerchio et
50 al. 2015; Jung et al. 2016; Cypriano-Souza et al. 2017; Ottewell et al. 2016; Ranjbar et

51 al. 2016; Cerchio and Yamada 2018, Cerchio et al. 2019). In the Atlantic Ocean, the
52 only evidence of the presence of *B. omurai* is based on two beach cast specimens: 1) a
53 specimen stranded in September 2010 on the beach of Pecém, Ceará, Northeast Brazil
54 (3.53378° S, 38.79772° W) in the western South Atlantic (Cypriano-Souza et al. 2017);
55 and 2) a specimen stranded in November 3 2013 near Chott Boul on the coast of
56 Mauritania (16.54146° N, 16.45055° W) in the eastern North Atlantic (Jung et al. 2016).

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

68 Acoustic recordings validated as vocalizations of the species, *i.e.* concomitant visual
69 and acoustic detections, are limited to the Madagascar region (Cerchio et al., 2015: AM
70 15-50 Hz, duration of 9.2 s). However, baleen whale vocalizations recorded off the
71 Northwest Shelf of Australia (Erbe et al. 2017: AM 20-60 Hz, duration 9.2 s) and the
72 Chagos Archipelago (Sousa and Harris 2015: AM 16.9-49.6 Hz, duration 13.1 s) have
73 been attributed to Omura's whales based on similarities to the Madagascar signals by
74 examination of spectrograms (Cerchio et al. 2019). Prior to the description of Omura's
75 whale song or identification of Omura's whales in Australian waters, the vocalizations

76 recorded off northwest Australia were reported on in several unpublished reports; they
77 were tentatively attributed to Bryde's whale vocalizations because this was the only
78 potential candidate species in the region. After the publication of Cerchio et al. (2015),
79 two different research groups independently identified these vocalizations as Omura's
80 whale based on spectrographic similarity (Erbe et al. 2017; Cerchio et al. 2019). Sousa
81 and Harris (2015) reported on two types of baleen whale vocalizations recorded off the
82 Chagos Archipelago from the Diego Garcia (north and south) Comprehensive Nuclear-
83 Test-Ban Treaty Organization (CTBTO) hydrophone arrays, and considered them of
84 unknown species attribution but potentially blue whales; again this was before the
85 publication of confirmed Omura's whale song, and Cerchio et al. (2019) recognized one
86 of the described vocalizations, the "Diego Garcia Croak," as the diagnostic song of this
87 species.

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

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97

MATERIALS AND METHODS

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100

Two hydrophones were moored between February – December 2013 in the
Equatorial Atlantic Ocean during the COLMEIA acoustic experiment in the vicinities of
the Brazilian São Pedro and São Paulo Archipelago (Maia 2013; Maia et al. 2014; Fig.

101 1). Each instrument consisted of a hydrophone connected to an acquisition and storage
102 system developed by the Laboratoire Geosciences Océan (Brest, France; D'Eu et al.
103 2012). To survive long-term immersion, the instrument is contained in a 90cm-long
104 solid titanium tube housed inside a syntactic foam buoy capable of resisting pressure up
105 to 2000m water depth. The hydrophone sensor is fixed to and protected by the buoy
106 metallic frame (Supplementary Data SD1). The instruments are moored in the SOFAR
107 channel axis by adjusting the length of the mooring line according to the depth of the
108 seafloor and the depth of the SOFAR axis in the area. The whole line is held by a 400kg
109 disposable anchor and an acoustic release system is placed just above the anchor for
110 remote retrieval.

111 Each hydrophone was moored on the axis of the Sound Fixing and Ranging
112 (SOFAR) channel at a depth of ca. 770 – 780 m, at sites of bottom depth greater than
113 2900 m (Table 1). The hydrophone has as sampling frequency from ~1 Hz – 120 Hz (\pm
114 3 dB) and the sensitivity was of -163.5 dB re 1 V/Pa, including preamplifier gain of
115 22dB; acoustic data were collected at a sampling rate of 240 Hz using a 24 - bit analog-
116 to-digital conversion. Upon recovery of the COLMEIA hydrophones, data were
117 downloaded and analyzed for the presence of whale calls.

118 Song phrases of Omura's whales from the Southwest Indian Ocean (Nosy Be,
119 Madagascar) were compared to the sounds recorded near the SPSPA in the Atlantic
120 Ocean (Fig. 2). The Madagascar recordings were collected with a SoundTrap 300STD
121 (<http://www.oceaninstruments.co.nz>) during December 2015 on a static bottom mount
122 in shallow water (37.2 m) near Banc du Goliath, located at the north of Nosy Be,
123 Madagascar (13.112° S, 48.237° E). The SoundTrap hydrophone has a flat response
124 from 20 Hz - 60 kHz (\pm 3dB) with a 34 dB re 1 μ Pa noise floor and a full-scale response
125 of 174.1 dB re 1 μ Pa including system gain. Recordings were undertaken at a 24 kHz

126 sampling rate at 16 - bit, and down-sampled to 2 kHz for analysis. Sounds were
127 manually detected and analyzed using Raven Pro 1.5 (Cornell Laboratory of
128 Ornithology, New York, USA). Table 1 indicates the exact location of the hydrophones
129 and the number of selected sounds from each sensor from all locations.

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

136 The main AM unit of the song was characterized by two temporally consecutive sec-
137 tions, each with two peak-energy frequency bands (see Fig. 2, and detailed description
138 in Results). To assess variation between song units from Equatorial Atlantic and Mada-
139 gascar recordings, quantitative measurements were carried out using Raven Pro 1.5 on
140 the song unit (full signal), and Sections 1 and 2 separately (FFT size of 512 samples
141 (Atlantic data) or 4096 samples (Madagascar data) yielding a frequency resolution of
142 ca. 0.5 Hz for each data set, 50% overlap, Hann window). Measurements included dura-
143 tion and minimum and maximum frequencies as defined by a manually drawn Raven
144 selection box. Peak frequency for the lower and upper bands were measured separately,
145 as determined by Raven's Peak Frequency measurement extracted from two separate
146 Raven selection boxes for each band, bounded by the minimum frequency of the song
147 unit and 32 Hz for the lower band, and 32 Hz and the maximum frequency of the unit
148 for the upper band (see Fig. 3). Each measurement variable was first tested for normal-
149 ity with the Kolmogorov-Smirnov test. A Tukey test (parametric) or the Mann-Whitney
150 U test (nonparametric) was applied to test for significant variation between the regions,

151 determined at the $P < 0.05$ level. The tests were carried out using Statistica software
152 (StatSoft, Tulsa, Oklahoma, USA).

153 A custom automated template detector was used in software XBAT (eXtensible Bio-
154 Acoustics Tool package, version 6.1.0.1; Bioacoustics Research Program, Cornell La-
155 boratory of Ornithology, New York, U.S.A.; www.birds.cornell.edu/brp/; Figueroa and
156 Robbins 2008), and an acoustic analysis program written in MATLAB version 7.0.4
157 (The Mathworks, Natick, Massachusetts, USA). The detector labeled all signals that met
158 the similarity criteria to a set of known target signals (templates) so as to identify any
159 potential Omura's whale song units in the SPSPA data.

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

169

170 **RESULTS**

171 A total of 13,050 sounds were labelled as Omura's whale song units by the XBAT
172 template automated detector in the Equatorial Atlantic recordings. From this total,
173 4,620 detections were found in recordings from Hydrophone C2 and 8,430 in
174 Hydrophone C5. After exhaustive manual validation, 6,794 auto-detections were
175 confirmed to be Omura's whale song units by visual examination (52% true positives

176 found in Hydrophones C2 and C5 combined). Manual identification of false negatives
177 accounted for an additional 5,991 sound units from Hydrophones C2 and C5, resulting
178 in a total of 12,785 validated Omura's whale song units (and consequent 47% false
179 negative rate).

180 Vocalizations from the Equatorial Atlantic samples were composed of two distinct
181 sections. The first (Section 1) consisted of an amplitude modulated signal with a
182 bimodal energy distribution and gradually transitioned into the second tonal section
183 (Section 2) with two bands at an apparent harmonic interval (Figs. 2, 3). Two similar
184 sections also were apparent in vocalizations from Madagascar. However, Section 2 was
185 significantly shorter in this region (Table 2) and displayed a more complex frequency
186 banding structure with an additional tonal frequency at 30 Hz not so clearly attributable
187 to a harmonic interval (Table 2; Fig. 2b, 2c). In addition, off Madagascar, the described
188 vocalizations sometimes were followed by a second single-banded tonal vocalization at
189 16 Hz (Fig. 2c). Neither the 30 Hz band in Section 2 nor the second 16 Hz vocalization
190 were observed in any Atlantic sample. For all selected Atlantic vocalizations with SNR
191 > 10 dB ($N = 36$) in which both frequency bands were visible, the full signal frequency
192 bandwidth ranged from approximately 13.5 to 51.5 Hz. This frequency band is similar
193 to that described for Madagascar Omura's whales, where the frequency bandwidth was
194 reported between 15 Hz and 50 Hz (Cerchio et al. 2015), as well as the sounds
195 attributed to Omura's whales from the northwestern Australian platform with a
196 bandwidth between 20Hz and 60Hz (Erbe et al. 2017).

197 Vocalizations occurred in rhythmic sequences in all Equatorial Atlantic detections
198 (Fig. 2d), as were the vocalizations described from Madagascar (Fig. 2e), and thus
199 considered a typical balaenopterid song (Cerchio et al. 2015, 2018). The repetition rate
200 of the song phrase was similar in both regions, with a rate of 172.18 sec \pm SD 32.52

201 sec in the Equatorial Atlantic (measured from 216 individual series ranging from 14 to
202 230 repeated phrases), whereas off Madagascar this was reported as $189.7 \text{ sec} \pm SD$
203 19.04 sec (Cerchio et al. 2018; from 118 individual series ranging from 20 to 250
204 repeated phrases).

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

221 The 12,785 confirmed Omura's whale vocal units were heterogeneously distributed
222 throughout the sampled period (February to December), suggesting marked seasonality
223 in vocal activity (Fig. 4). The highest number of detections occurred in June (40%),
224 followed by May (34%) and April (15%). Detection rates decreased dramatically in

225 August (0.19%), November (0.19%) and December (0.69%). No detections were
226 obtained for September or October.

227

228

DISCUSSION

229 Since the species was described in 2003, there have remained gaps in our knowledge
230 of Omura's whale distribution, behavior, and vocal behavior, due to the paucity of
231 records and targeted studies on the species. The importance of a new record, particularly
232 in a new region, substantially increases our knowledge of the species in its distribution,
233 behavior, and descriptions of vocalizations. Acoustic recordings made near the São
234 Pedro and São Paulo Archipelago (Brazil) in the Equatorial Atlantic have demonstrated
235 the presence of baleen whale vocalizations that we attribute to Omura's whales. The
236 vocalizations are similar to Omura's whale song described off Madagascar (Cerchio et
237 al. 2015), as well as to other Omura's whale song descriptions from the northwest coast
238 of Australia and the Chagos Archipelago (Erbe et al. 2017; Cerchio et al. 2019). Our
239 confidence of the attribution of the signals recorded in the Mid-Atlantic Ocean to
240 Omura's whales is high, given the similarity in the duration of the signals and frequency
241 distribution of the spectral energy in the vocalizations, the overall structure of the song
242 phrase, and the rhythmic repetition of the phrases. In addition, the presence of a beach
243 cast specimen on the coast of Brazil in the South Atlantic on September 10, 2010
244 (Cypriano-Souza et al. 2017) and on the coast of Mauritania in the African North
245 Atlantic on November 3, 2013, during the same period of this work (Jung et al. 2016)
246 confirms that Omura's whales range includes the Equatorial Atlantic Ocean.

247 The main differences between the Madagascar and SPSPA detections are: 1) the lack
248 of the second tonal unit at 16 Hz found in some of the Madagascar phrases (Cerchio et
249 al. 2018); 2) central tendency values of frequencies (except in the peak frequency of the

250 lower band of Section 1 and maximum frequency of the Full Signal, where values were
251 not significantly different); 3) duration of each of the two Sections: Section 1 is shorter
252 in Equatorial Atlantic vocalizations while Section 2 is shorter in Madagascar
253 vocalizations (note that full signal durations are similar); and 4) the habitat in which the
254 detections occurred, with the Atlantic detections occurring in open ocean deep water
255 habitat, as opposed to the Madagascar samples that were recorded in shallow water shelf
256 habitat. These spectral differences might result from multiple non-exclusive factors,
257 most notably geographic variation in the vocalization, which is typical for baleen whale
258 songs, but also from differences in propagation, transmission loss and masking due to
259 background noise, and individual variation and behavioral context. As it is a new
260 species with few records of its vocalizations, only with further study in the Atlantic and
261 Indian Oceans, as well as globally, will we be able to understand geographic variation in
262 the vocalizations of Omura's whale throughout its range.

263 Omura's whale song units were detected most prominently from February to June
264 and to a much lesser extent between July and December. No detections were made in
265 September or October. In January the hydrophones were not in the water, thus we
266 cannot determine if Omura's whales can be detected during the first month of the year.
267 The observed temporal variation gives the impression of seasonality, although the song
268 occurrence never completely disappears during any season, as might be expected for a
269 migratory species, and we do not have multiple years of data to assess the consistency
270 of temporal variation across years. This apparent seasonal singing pattern is in contrast
271 to other parts of the species' range (Madagascar, Chagos Archipelago, and northwest
272 Australia), where long-term acoustic monitoring has documented Omura's whale
273 singing throughout the year with no clear seasonality (Sousa and Harris 2015; Erbe et
274 al. 2017; Cerchio et al. 2018, 2019). It is worth noting that in Madagascar, there appears

275 to be strong spatial heterogeneity in singing activity, with two sites only 50 km apart
276 having very different temporal variation: one with consistent occurrence throughout the
277 year, the other during only a few months of the year, thereby giving the false impression
278 of seasonality (Cerchio et al. 2018). We can therefore postulate two hypotheses: the
279 species might be present year round, but presents a seasonal pattern in its acoustic
280 activity; or, the steep decline in vocalizations observed between June and July is due to
281 the displacement of individuals from the area, suggesting a shift in the distribution
282 pattern possibly associated with changes in prey abundance. These hypotheses should
283 be assessed with additional acoustic and visual data from the Atlantic Ocean.

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

298 Alternatively, the detection of Omura's whale song by the COLMEIA hydrophones
299 could be an acoustic phenomenon within the SOFAR channel. Because the hydrophones

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

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

325 unlikely that these animals can dive to and vocalize at the depths of the SOFAR
326 channel, so it is uncertain whether information exchange occurs among individuals in
327 the Atlantic Ocean at these large inferred distances.

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

334

335

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349 provided by a grant from the U.S. Marine Mammal Commission.

350

351

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

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356

357

LITERATURE CITED

358

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- 428

FIGURE LEGENDS

429

430

431 **Fig. 1.**—Location of the COLMEIA hydrophones (C2 and C5) in the Equatorial
432 Atlantic Ocean, relative to the São Pedro and São Paulo Archipelago (SPSPA).
433 Hydrophone deployments: C2: 1.32900° N, 31.34400 W, from 02 Feb to 22 Aug 2013;
434 C5: 0.1500° N, 27.78600° W, from 25 Feb to 26 Dec 2013.

435

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

448

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

453

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

457

458 **Table 1.**—Summary of the data used to characterize signals recorded during the
 459 COLMEIA acoustic experiment in the Equatorial Atlantic Ocean, off the of São Pedro e
 460 São Paulo Archipelago, and off Nosy Be, Madagascar.

Hydrophone	Local depth (m)	Hydrophone depth (m)	Latitude	Longitude	Number of selected sounds with SNR >10dB
COLMEIA 2	2980	780*	N 1.329°	W 31.344°	29
COLMEIA 5	3770	770*	N 0.155°	W 27.786°	7
Madagascar	37.2	36	S 13.112°	E 48.237°	22

461 * Exact values may vary due to deep current conditions.

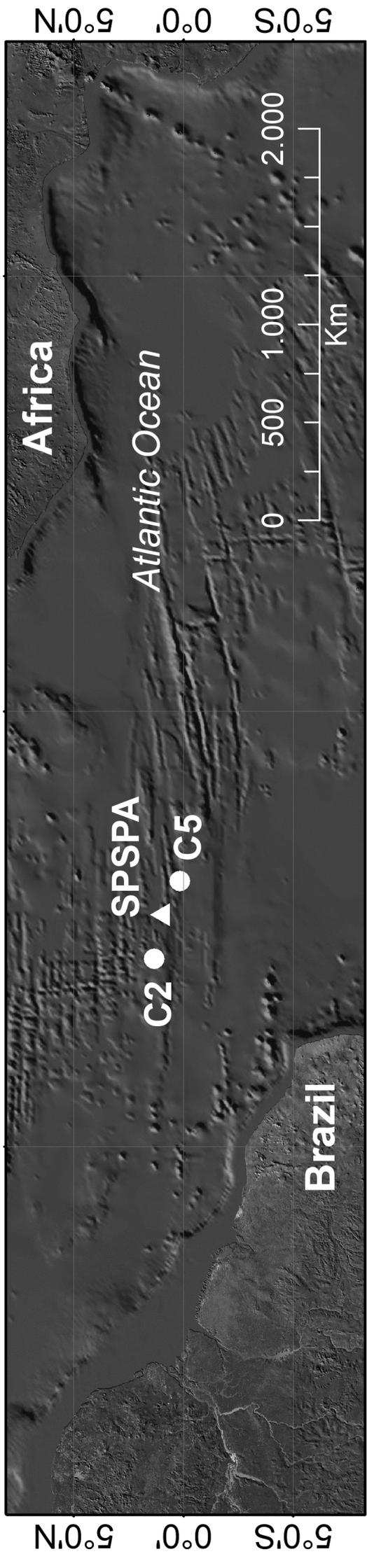
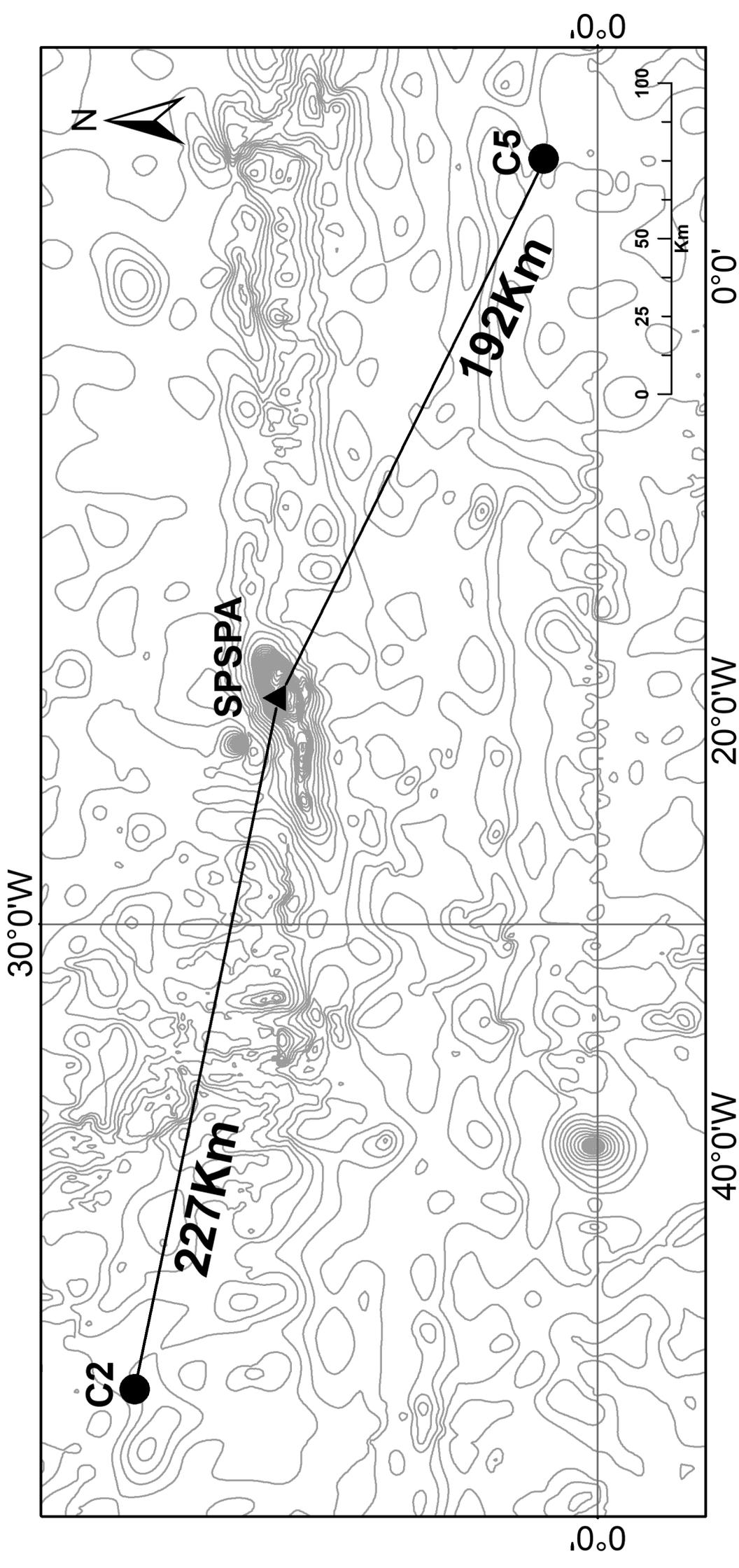
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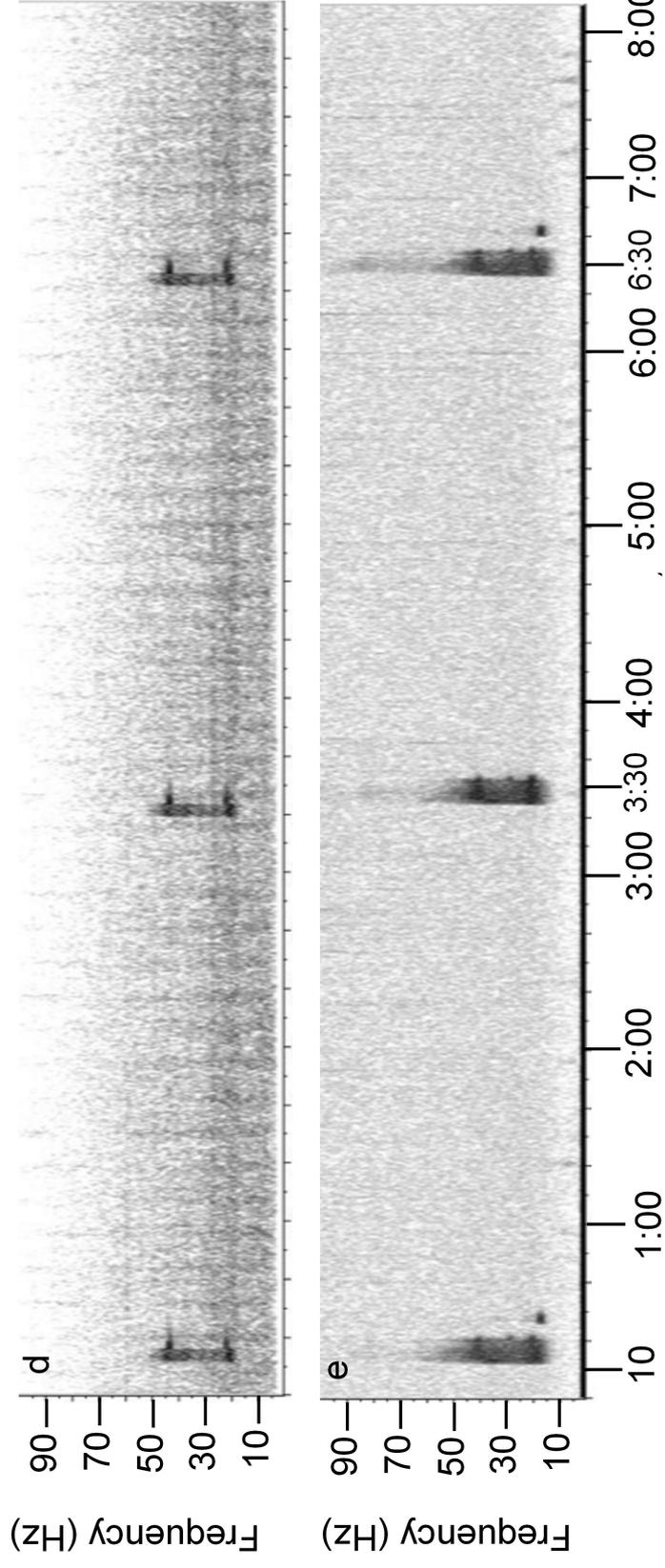
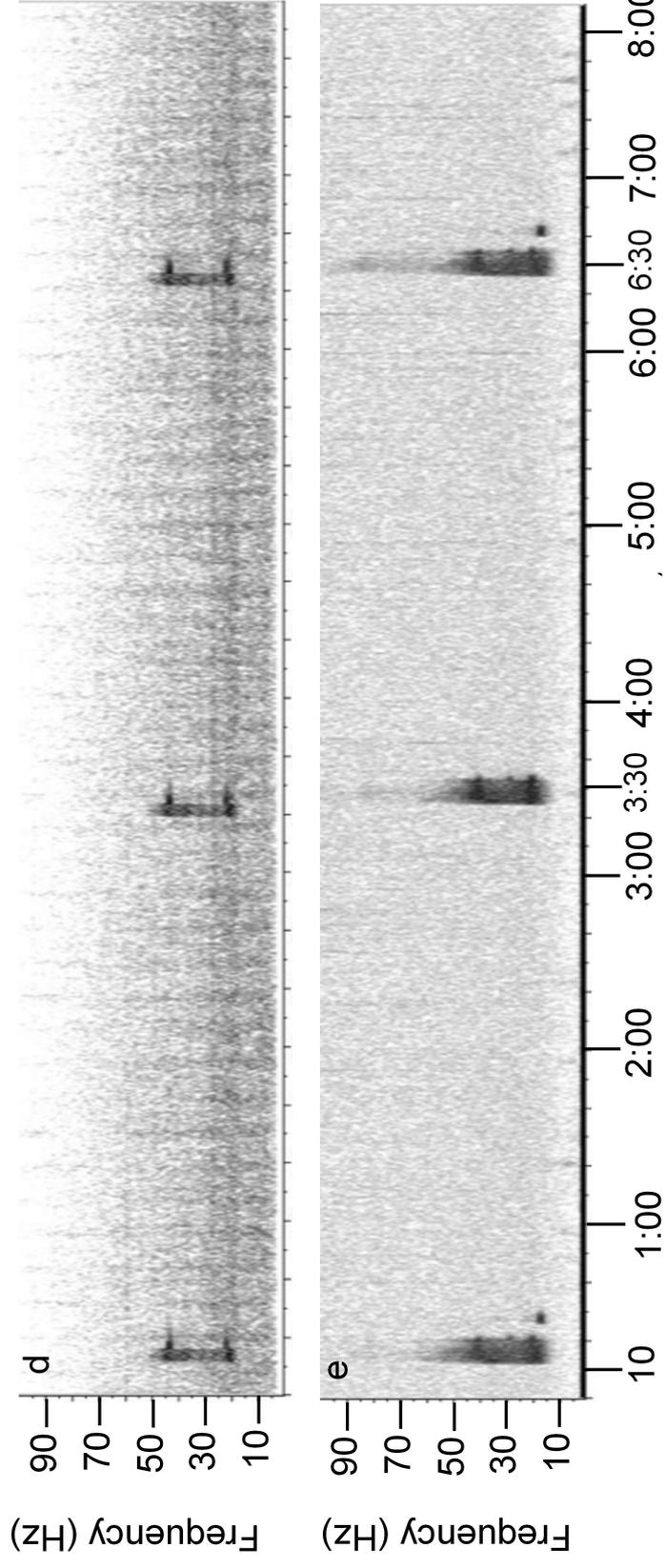
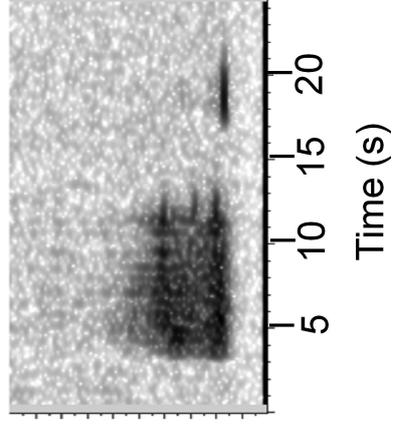
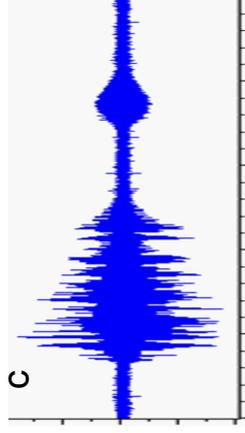
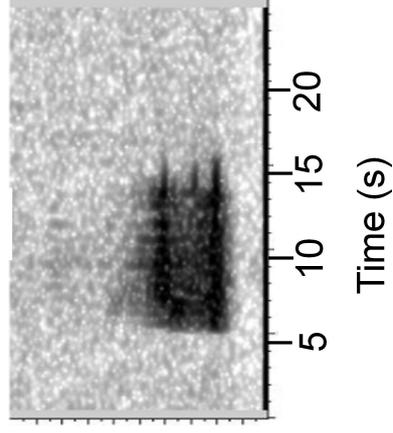
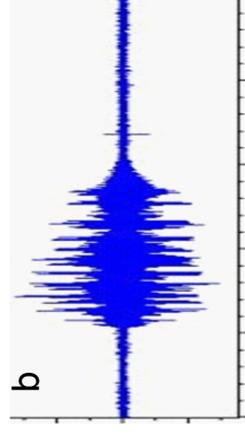
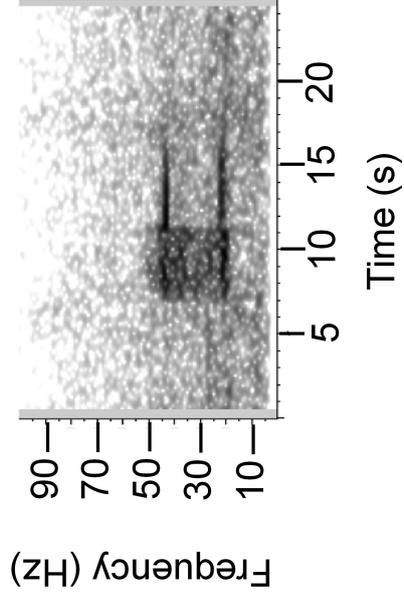
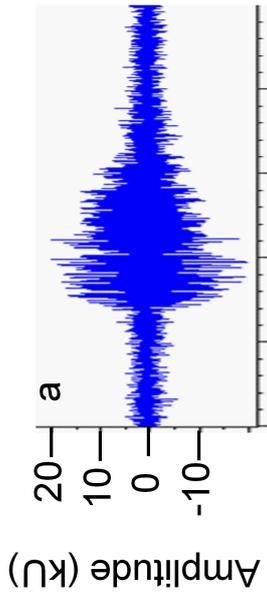
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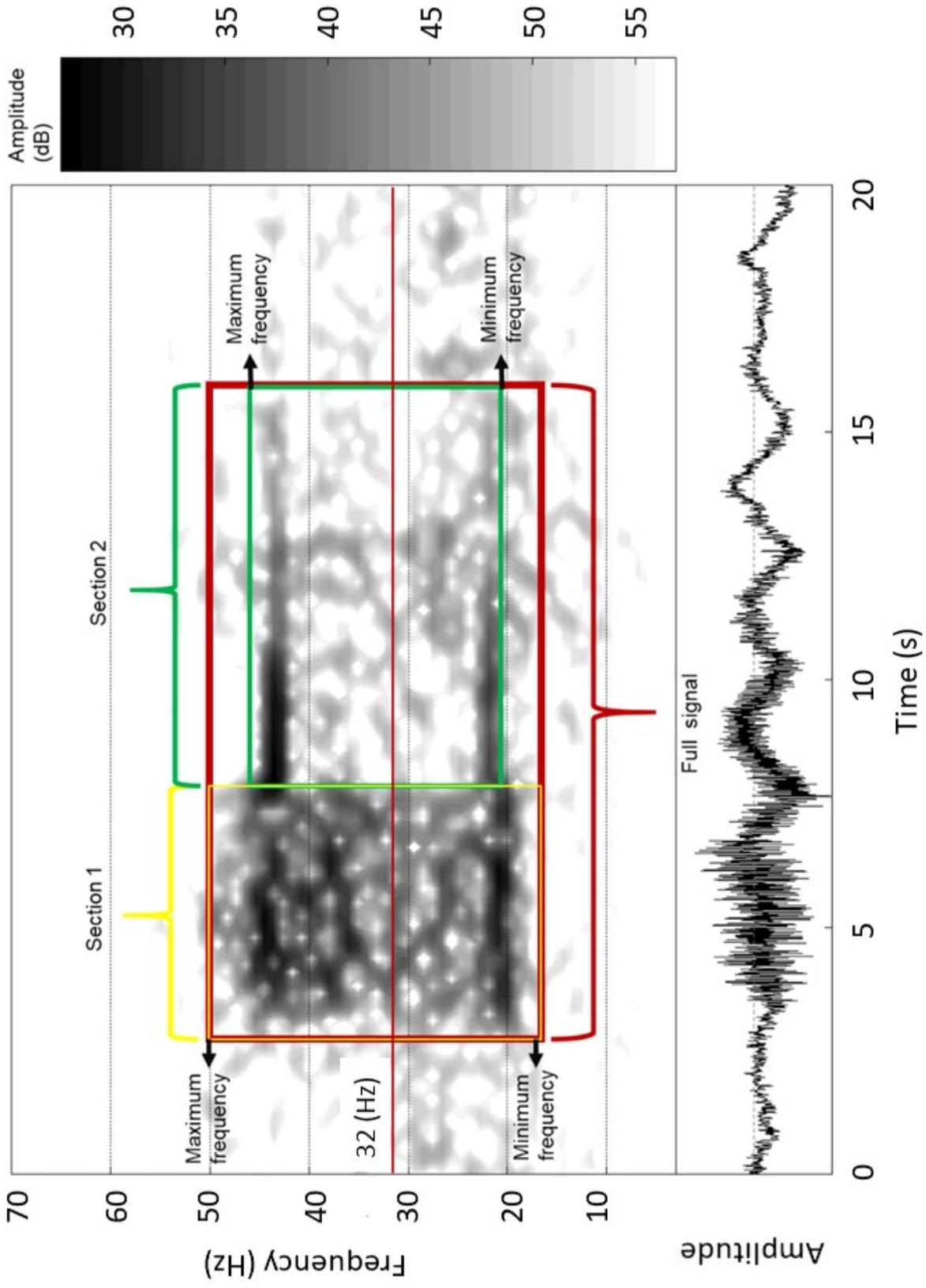
Table 2.— Descriptive statistics and test results of the comparison of the central acoustic parameter tendency values of Omura’s whale vocalizations from the upper and lower band selections made in Raven Pro 1.5 were limited by 32 Hz in both samples, as displayed in Figure 3. These values therefore result from the median/IQR values are indicated by #, while mean/SD are indicated by *.

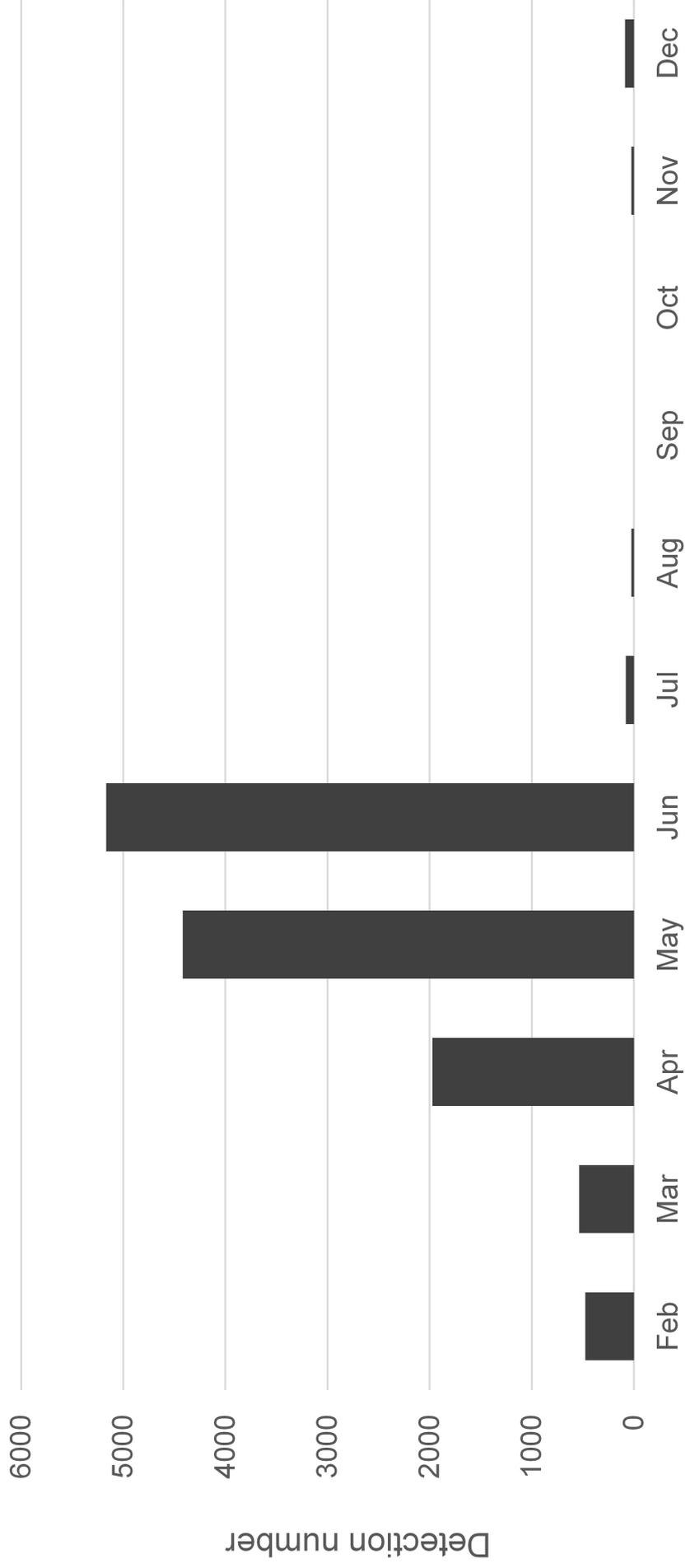
Measurements central tendency / dispersion	Section 1 (AM) lower band			Section 1 (AM) upper band			Section 2 (Harmonic) lower band			Section 2 upper
	Atlantic Ocean	Indian Ocean	p-value	Atlantic Ocean	Indian Ocean	p-value	Atlantic Ocean	Indian Ocean	p-value	Atlantic Ocean
Duration (s)	4.88/.50#	8.22/.27#	<.001	4.85/.37#	8.22/.27#	<.001	4.9/1.0#	1.92/.37#	<.001	4.96/1.01#
Peak frequency (Hz)	20.6/.0#	20.75/4.8#	0.809	43.6/.9#	40.0/1.6#	<.001	21.6/0#	20.0/7.8#	0.013	43.10/0#
Minimum frequency (Hz)	16.96/1.28*	16.11/1.15*	0.014	NA	NA	NA	17.3/2.1#	18.35/.3#	<.001	NA
Maximum frequency (Hz)	NA	NA	NA	46.9/1.1#	47.85/4.7#	0.045	NA	NA	NA	46.6/1.4#
Delta Frequency (Hz)	15.04/1.28*	15.89/1.15*	0.014	14.95/.93#	16.18/3.28#	0.980	14.7/2.1#	13.65/.3#	<.001	14.7/.25#

Atlantic Ocean (N = 36), Indian Ocean (N = 22)









Months of detection

