Vocalizations produced by southern right whale (Eubalaena australis) mother-calf pairs in a calving ground off Brazil

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Aiming to gather information on southern right whale (Eubalaena australis) mother-calf pairs’ vocal behavior, archival acoustic recorders were deployed at a calving area off Brazil. Manual inspection of spectrograms revealed seven call classes: upcall, downcall, down-upcall, tonal variable, tonal constant, hybrid, and pulsive calls, which are consistent with those previously described for this species in Argentina. Gunshots and warbles, vocalizations described from other right whale species, were not detected. Mean values of start, end, maximum, minimum and peak frequencies, frequency bandwidth and duration were calculated for each call class. Start and end frequencies, frequency bandwidth and duration of upcalls recorded off Brazil were compared to those from other right whale populations and species. Only mean duration of upcalls from Brazil were significantly different from upcalls from all other populations. Differences in call duration may be driven by differences in demographic factors or background noise features among study areas. The repertoire characterization presented in this study will contribute to increase the utility of passive acoustic monitoring as a tool for conservation and research of southern right whales off Brazil as it provides important baseline information on the vocal behavior of this species.

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I. INTRODUCTION

Owing to the major role that acoustic communication plays in cetacean ecology (Au, 1993; Tyack, 2000), descriptions of acoustic repertoires are an important step to better understand the life history of cetacean species and to design effective research and management tools (Bradbury and Vehrencamp, 1998; Van Parijs et al., 2009). Passive acoustic monitoring (PAM) is a collection of methods aimed to monitor sounds in the environment and has been frequently used to investigate acoustic signals of dolphins and whales (Van Parijs et al., 2009). The development of PAM has increased the capacity of data acquisition over different temporal and spatial scales and therefore has improved the applicability of bioacoustic scientific assessment into management and mitigation measures (Clark et al., 2009; Van Parijs et al., 2009). However, the efficiency of PAM methods depends on the ability of researchers to detect and interpret acoustic signals and consequently, it relies on baseline information about natural features of the target species’ vocal behavior and vocalizations (Mellinger et al., 2007; Van Parijs et al., 2009). Therefore, baseline bioacoustic data are especially useful when combined with other monitoring methodologies, such as visual observations to confirm the source of the signals (Mellinger et al., 2007).

Right whales (Eubalaena sp.) are known to produce mostly low frequency calls (<1000 Hz) for communication (Clark, 1983; Parks and Tyack, 2005). The species vocal repertoire may be described as a collection of sounds that encompasses stereotyped and variable calls, from tonal sweeps to broadband pulsive sounds (Clark, 1982, 1983; Parks and Tyack, 2005). Over the past decade, extensive effort has been made to understand the vocal behavior of the highly endangered North Atlantic right whale Eubalaena glacialis – NARW
Brazilian Threatened Fauna (O. australis) are affected by coastal anthropogenic activities and habitat degradation that created the Right Whale Environment Protected Area. Little attention has been given to this species’ acoustic ecology in the Southwest Atlantic. In order to characterize its repertoire. Such information will support the use of PAM for further scientific and management purposes at an important wintering ground for SRW.

**II. MATERIAL AND METHODS**

**A. Acoustic recordings**

Archival acoustic loggers DSG-Ocean (Loggerhead Instruments) were deployed in two locations off the state of Santa Catarina within the Right Whale EPA: Gamboa (27°57’S, 48°37’W) for 14 days and Ribanceira (28°11’S, 48°37’W) for 16 days. Recordings were done between October 14 and November 19, 2011. Water depth at deployment sites ranged from 8 to 11 m including tide variation. The devices were moored 1.5 m above the sea floor and set to continuously record at a sampling rate of 8 kHz and 16-bit resolution. Hydrophones sensitivity was −240 dB re 1 V μPa−1 between 2 Hz and 30 kHz and the frequency response of the recording system was ±1 dB 20 Hz−3.3 kHz. A low-pass filter was applied to recordings yielding an effective analysis bandwidth of 20 Hz to 3.3 kHz.

**B. Sound analyses**

Sound analyses were done using Raven Pro Software 1.4 (Charif et al., 2010). Manual inspection of spectrograms followed a call-accumulation curve: 1-h files were randomly examined until no new call type or call type variation (e.g., upswells with sharp or gradual ascending contours where considered variations of upcalls) was identified in the recordings. Background noise samples were taken (1 s duration, frequency range from 50 to 600 Hz) allowing comparisons between background noise and right whale calls. Calls with signal-to-noise ratio (SNR) <10 dB or overlapping with noise and/or other sounds were withdrawn from the dataset.

Values of the following acoustic parameters were extracted from the fundamental frequency of SRW calls: maximum frequency, minimum frequency, start frequency, end frequency, frequency bandwidth, peak frequency and total duration (Fig. 2). All feature extractions were performed in spectrograms with FFT 1024, hop size 32 and 15.6 Hz of grid spacing whereas the extraction of temporal features were done in spectrograms with FFT 512, hop size 64 and 7.81 Hz of grid spacing. Start and end frequency of calls with unclear harmonic structure were calculated by extracting the peak frequency in the initial and final portions of the call that concentrated the first and last 5% of the signal’s total energy, as described in Trygonis et al. (2013). Listed parameters were chosen to be comparable to other right whale’s call descriptions.

In order to compare values of features obtained from upcalls recorded off Brazil to other SRW populations—from Argentina (Parks et al., 2007) and Uruguay (Tellechea and Norbis, 2013)—and species—NARW in Bay of Fundy (Parks et al., 2007) and in the southeastern United States (Trygonis et al., 2013)—two-sided *t*-tests for independent samples were individually performed. Statistical calculations were done using SPSS 21 (IBM Corp., Armonk, NY).
III. RESULTS

In total, 162 h of combined recordings from both deployment locations were manually analyzed. Overall, 3898 SRW calls were detected from which 1427 were used for repertoire characterization. High quality calls (SNR > 10 dB) were categorized in seven call classes: upcall (A), downcall (B), down-upcall (C), tonal variable call (D), tonal constant call (E), pulsive call (F) and hybrid call (G). Spectrographic representation of call classes are shown in Fig. 3.

Upcalls, stereotyped tonal sweeps with ascending contour [Fig. 3(A)], were the most frequent vocalization type representing 56% of calls. Other 13% of calls were classified as downcalls [Fig. 3(B)], stereotyped tonal sweeps with descending contour. The down-upcall category, tonal v-shaped calls [Fig. 3(C)], represented 12% of all vocalizations. Upcalls, downcalls and down-upcalls were frequently found in bouts that lasted from 25 s to 3 min (Fig. 4).

Tonal calls with very little frequency modulation were categorized as tonal constant calls and represented 10% of calls [Fig. 3(E)]. Hybrid calls [Fig. 3(G)] with both pulsive and tonal components, and tonal variable calls [Fig. 3(D), tonal sounds with variable contour and frequency modulation] were rare. Pulsive vocalizations (noisy, growl-like sounds) were the rarest sound type representing less than 1% of all calls [Fig. 3(F)]. Pulsive and hybrid calls were found among other call types in periods of high vocal activity. Gunshots and warbles—sound types previously described by Parks and Tyack (2005) for NARW—were not detected.

Table I shows the descriptive statistics (± standard deviation [SD], range and median) of measured acoustic features in each call class recorded off Brazil.

Upcalls from Brazil presented the lowest mean start, end frequencies, narrower mean bandwidth and shorter mean duration values next to other Southwest Atlantic SRW populations and northern species (Table II).
FIG. 3. Spectrogram of southern right whale call classes recorded off Brazil: (A) upcall, (B) downcall, (C) down-upcall, (D) tonal variable call, (E) tonal constant call, (F) pulsive call, and (G) hybrid call. Arrows in G show pulsive components in a hybrid call. Spectrograms calculated with 1024 (A to E) and 512 FFT points (F and G) in Hamming window. Note differences in frequency and time scales between spectrograms.

FIG. 4. Sequence of down-upcalls (Hamming window, 1024 FFT, 50% overlap) of southern right whales recorded off Brazil.
Nevertheless, duration was the only parameter from which mean values were significantly different (Brazil: 0.6 s ± 0.2; Argentina: 0.82 s ± 0.23, \( p = 0.027 \); Uruguay: 1.4 s ± 0.27, \( p = 0.028 \); Bay of Fundy: 0.87 s ± 0.27, \( p = 0.027 \); Southeastern United States: 1.49 s ± 0.42, \( p = 0.029 \); Fig. 5). Mean start frequency of upcalls from Brazil (65 Hz ± 22) was also statistically different from North Atlantic right whales upcalls recorded in Southeastern United States (120 Hz ± 22, \( p = 0.014 \) by Trygonis et al. (2013).

**IV. DISCUSSION**

**A. The mother-calf pair repertoire**

The diversity of calls produced by the right whales can be associated to behavior and group composition (Clark et al. 1983, Parks and Tyack, 2005). Consequently, one may expect differences in repertoire size when comparing recordings from feeding to wintering grounds, areas where distinct evolutionary factors are acting on the whales’ behavior leading to behavior variance among those areas; or when paralleling a collection of sounds recorded off areas where main group composition are distinct, such as the wintering area off Santa Catarina (primarily used by mother-calf pairs) and other reproductive grounds where SAGs and lone individuals are frequently spotted. In this paper, the sounds described were produced by southern right whale mother-calf pairs off a calving area during a period when only mother-calf pairs were present. The size of repertoires recorded in different areas and contexts may vary in relation to this repertoire description and therefore other call types may be found.

**TABLE II. Mean ± SD extracted from upcalls of SRW from Brazil (our study) and mean ± SD from SRW upcalls recorded off Argentina and Uruguay and from NARW from Bay of Fundy and Southeastern United States. Reported \( p \) values correspond to \( t \) test performed to compare acoustic variables values from Brazil to other populations: italic, bold numbers means that averages are statistically different (Brazil × other population).**

<table>
<thead>
<tr>
<th>Location/species</th>
<th>Reference</th>
<th>Start Frequency (Hz)</th>
<th>End frequency (Hz)</th>
<th>Frequency Bandwidth (Hz)</th>
<th>Duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil (n = 796)</td>
<td>Present study</td>
<td>65 ± 22</td>
<td>144 ± 38</td>
<td>78 ± 35</td>
<td>0.60 ± 0.20</td>
</tr>
<tr>
<td>Argentina/SRW (n = 78)</td>
<td>Parks et al. (2007)</td>
<td>78 ± 15</td>
<td>156 ± 29</td>
<td>86 ± 23</td>
<td>0.82 ± 0.23</td>
</tr>
<tr>
<td></td>
<td>( p = 0.565 )</td>
<td></td>
<td>( p = 0.756 )</td>
<td>( p = 0.842 )</td>
<td>( p = 0.027 )</td>
</tr>
<tr>
<td>Uruguay/SRW (n = 11)</td>
<td>Tellechea and Norbis (2012)</td>
<td>70 ± 9(^b)</td>
<td>173 ± 8(^b)</td>
<td>not reported</td>
<td>1.40 ± 0.27(^b)</td>
</tr>
<tr>
<td></td>
<td>( p = 0.863 )</td>
<td></td>
<td>( p = 0.450 )</td>
<td></td>
<td>( p = 0.028 )</td>
</tr>
<tr>
<td>Bay of Fundy/NARW (n = 929)</td>
<td>Parks et al. (2007)</td>
<td>101 ± 22</td>
<td>195 ± 38</td>
<td>100 ± 37</td>
<td>0.87 ± 0.27</td>
</tr>
<tr>
<td></td>
<td>( p = 0.109 )</td>
<td></td>
<td>( p = 0.184 )</td>
<td>( p = 0.551 )</td>
<td>( p = 0.027 )</td>
</tr>
<tr>
<td>Southeastern USA/NARW (n = 49)</td>
<td>Trygonis et al. (2013)</td>
<td>120 ± 22</td>
<td>214 ± 44</td>
<td>not reported</td>
<td>1.49 ± 0.42</td>
</tr>
<tr>
<td></td>
<td>( p = 0.014 )</td>
<td></td>
<td>( p = 0.068 )</td>
<td></td>
<td>( p = 0.029 )</td>
</tr>
</tbody>
</table>

\( ^b \)Data from 2000 to 2004 for NARW and from 2000 for SRW.

\( ^b \)Calculated based on data available on Tellechea and Norbis (2012).
Studies have been investigating the vocal behavior of right whales’ surface-active groups (SAG), but little is known about the repertoire and vocal behavior of mother-calf pairs (Kraus and Hatch, 2001; Parks and Tyack, 2005; Trygonis et al., 2013; Soldevilla et al., 2014). When comparing vocal activity of mother-calf pairs and SAGs, some variance in the relative proportion of recorded calls is expected due to differences in groups’ behavioral context and in the assumed functions of certain call types (Parks and Tyack, 2005; Parks et al., 2005).

Upcalls were the most frequent call type detected in SRW wintering grounds off Brazil where predominant whale group were mother-calf pairs as well as NARW wintering areas (Soldevilla et al., 2014). The upcall hypothesized function is to announce presence of one individual to other(s) and for contact maintenance (Clark, 1983; Parks and Tyack, 2005). During SAG’s activities, males produce upcalls when approaching the group or when the focal female is diving or leaving (Parks and Tyack, 2005). The use of upcalls by mother-calf pairs may be associated with intra-pair signaling (communication between mother and calf) to contact maintenance, and/or inter-pair signaling (communication between pairs). The use of technologies that allow the identification of the caller (sender), as acoustic tags, will be fundamental in revealing further details of mother-calf communicative dynamics.

Gunshots and moans were the most common calls detected in SAG focal studies (Parks and Tyack, 2005; Trygonis et al., 2013). Gunshots are intense, brief, broadband sounds that may function as sexual advertisement and/or agonistic signals. Gunshots were mostly recorded in the presence of males (Parks et al., 2005; Parks and Tyack, 2005) though sex bias in gunshot production is not yet clear. Clark (1983) observed the production of a gunshot when an adult male approached a female with calf and hypothesized that perhaps the female had produced the gunshot (referred as underwater slap). Gunshots were not detected in SC where sightings males are extremely rare (Groch et al., 2005; Seyboth et al., 2015). In other words, there were no males in the area and no gunshots were recorded. Thus, our results favor the hypothesis that gunshots have minor importance in mother-calf pair communication and are mostly produced by males, at least for the southern right whale.

Down-upcalls were previously described as part of North Pacific right whale (Eubalaena glacialis) repertoire (McDonald and Moore, 2002) however, no previous record of such call type was found among described vocalizations of other right whale populations in the Southwest Atlantic (Clark, 1983). That may be because the down-upcall may have been placed along with “upcall” category in previous descriptions, as in NARW studies (McDonald and Moore, 2002; Parks and Tyack, 2005). Non-stereotyped calls previously described for southern right whales such as constant, hybrid and pulsive calls (Clark, 1983) were also detected in recordings from SC. However, a different category was included (tonal variable) and high call class was suppressed.
Differences in call classification criteria between authors are common and general classes (e.g., scream calls in Parks and Tyack, 2005) are frequently used. However, general categories may mask the diversity of sounds produced by the species and may likely impair detailed comparisons of repertoire. In order to allow comparative studies of sound use between populations and call structure evolution (Leuchtenberger et al., 2014), richer descriptions of classification methods and standards, and approaches based on statistical approaches using acoustic physical descriptors of calls may be useful.

B. Call parameters and population comparison

The first systematic attempt to characterize calls and relate surface to vocal behavior from southern right whales was conducted by Clark (1982, 1983) off wintering grounds in Argentina. To date, the study by Clark (1983) is still being used as reference for right whale call classification (Parks and Tyack, 2005; Trygonis et al., 2013). Despite differences in categories set to classify calls, vocalizations here described are similar to sounds described by Clark (1983). Nonetheless, Clark did not report precise mean values for acoustic features. Instead, he reported frequency intervals of highest energy (dominant frequency band) and duration intervals of most calls in each category. For instance, for the upcall class, most energy was reported to be concentrated between 50 and 200 Hz and duration from 0.5 to 1.5 s. Mean values of dominant frequency (101 ± 97 Hz) and duration (0.6 ± 0.2 s) measured from upcalls recorded off Brazil are within such intervals as well as downcalls and other non-stereotyped calls as hybrid calls.

Results showed that duration of upcalls recorded off Brazil were significantly different from the northern species and other southern populations. Such inconsistency may be related to demographic characteristics (age of predominant vocally active individuals in each study area), soundscape and background noise features, and/or genetics.

Calves go through a process of vocal maturation during their first years of life and therefore, acoustic features of their vocalizations contrast of those from adults’ signals (Cartwright and Sullivan, 2009; Parks et al., 2014; McCordic et al., 2016). Among structural and modulation dissimilarities, calves’ sounds are shorter in duration than calls from vocally mature individuals (Parks et al., 2014; McCordic et al., 2016). Sightings off SC wintering ground are known to be exclusively of mother-calf pairs between October and November, the period when our survey was conducted (Groch et al., 2005; Seyboth et al., 2015). The greater presence of vocally active calves in SC than in any other study area may explain the significantly shorter mean duration of calls recorded there.

Because of variations in ambient noise, characteristics of acoustic signals produced by right whales may change (Parks et al., 2007; Parks et al., 2015). Whales may shift the spectral features of their calls depending on background noise scenarios (Parks et al., 2007; Parks et al., 2015). If dominant ambient noise is lower in frequency than whales’ calls, spectral features may shift to higher frequencies. In the other hand, if dominant background noise is higher (in frequency), frequency parameters of vocalizations may shift down to lower values (Parks et al., 2015). Signal duration can also vary in accordance with background noise (Parks et al., 2007). Therefore, it is possible that differences in upcall duration among species and populations found in our study are reflective of differences in the soundscape and dominant noise in right whales’ habitats. Modifications of signal duration do not follow as clear a trend as the spectral features do (Parks et al., 2007). Thus, it is not possible to predict the characteristics of background noise in each recording site from the whale’s signal duration differences. Because it may affect acoustic parameters, future studies should take ambient noise in consideration when describing a species acoustic repertoire.

Finally, differences in upcall’s mean duration found between Brazilian and northern right whales might have some relation to genetic drift. During the speciation process, selective pressures would favor signal features to improve specie-specific identification resulting in different duration values for the northern and southern species. Nevertheless, the upcall duration may contain individual recognition features and therefore would be less vulnerable to sexual selective forces (McCordic et al., 2016). Call duration differences between the Brazilian and other southwestern populations are unlikely linked to genetic factors as whales that visit Southwestern Atlantic wintering grounds share important genetic characteristics (IWC, 2012).

V. CONCLUDING REMARKS

Our study describes for the first time the vocalizations produced by mother-calf pairs off Brazil. Baseline knowledge about the southern right whale vocal behavior is vital to maximize the use of passive acoustic monitoring for conservation and research purposes. Future acoustic studies should take in consideration the caller identity and characteristics of background noise in order to provide further details on mother-calf acoustic communication dynamics and vocal plasticity of southern right whales, as well as noise levels in wintering areas.

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