Mapping cetacean sounds using a passive acoustic monitoring system towed by a Wave Glider on the Southwestern Atlantic Ocean

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Abstract

Passive acoustic monitoring techniques have been shown to be useful to monitor marine fauna efficiently since they do not depend on good visibility and weather conditions. An unmanned surface vehicle, type Wave Glider, equipped with an autonomous recording system collected acoustic data on the Brazilian offshore waters of the Southwestern Atlantic Ocean between 6–25 February 2016. Nearly continuous data was provided during this period (light and dark hours) for the 377 km traveled. There were 165184 high-frequency detections in 31 events, being 1839 whistles, 389 burst-pulse sounds and 162956 echolocation clicks. Low-frequency detections summed up to 705, all tonal signals, in 5 events. Although high-frequency detections occurred at all hours of the day, the majority was at dark hours. Low-frequency detections

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did not occur at all hours of the day, but the majority also occurred during dark hours. High-frequency and low-frequency detections represented 26% and 3% of the recording hours, respectively. Duration, the number of emissions, and ocean depth varied among acoustic events. Events composed by high-frequency sounds were separated into seven different groups, probably different species. One of the events presented whistles that were previously recorded in the Rio de Janeiro Coast for *Steno bredanensis* (Rough-toothed dolphins). All of the low-frequency events were composed of a type of *Balaenoptera brydei* (Bryde’s whales) call. This type of data collection is unprecedented for the Southwestern Atlantic Ocean and highlighted the use of the sampled area by delphinids on different days and different times of the day, including the dark hours.

**Keywords:** Passive Acoustic Monitoring, Cetaceans, Unmanned Surface Vehicle, Wave Glider, South Atlantic Ocean, Brazil, Upwelling

1. Introduction

The continental shelf edge is a productive ocean environment, and the occurrence of large marine vertebrates is often associated with oceanographic features (Baumann-Pickering et al., 2016). Most studies focused on assessing diversity are performed with ship surveys, relying mostly on visual observation data and thus restricted to animals that can be seen from the surface. Passive acoustic monitoring (PAM) can bring reliable information on marine vertebrates movements because many aquatic animals have species-specific sound emissions and can be acoustically identified (Klinck et al., 2012; Luczkovich et al., 2008; Oswald et al., 2007). Therefore, PAM tech-
Techniques have been shown efficient to find and monitor marine fauna, allowing scientists to identify patterns of seasonal variation and habitat use in distinct environments (Baumgartner and Fratantoni, 2008; Bittencourt et al., 2016; Lammers et al., 2008; Locascio, 2010; Luczkovich et al., 2008; Moore et al., 2006; Wall et al., 2013; Wiggins et al., 2013; Wilson et al., 2013).

Autonomous data samplers are capable of performing monitorings for long periods at a low cost and are non-invasive to the environment, allowing data collection even during rough weather conditions at remote locations worldwide. These recorders can either be fixed, moored to the marine floor or ocean buoys (Sousa-Lima et al., 2013; Van Parijs et al., 2009), or mobile, coupled to autonomous vehicles, like ocean gliders (Baumgartner and Fratantoni, 2008; Wall et al., 2012). While submarine buoyancy-driven gliders can trace vertical and horizontal paths on the water column collecting data, Wave Gliders harness energy from waves to endure long cruises transporting sensors close to the surface (Rudnick et al., 2004; Hine et al., 2009). Traditionally, gliders have been deployed to collect a variety of chemical, biological and physical oceanographic variables (Villareal and Wilson, 2014; Martin et al., 2009). More recently, studies with gliders started collecting acoustical data (Baumgartner and Fratantoni, 2008; Wall et al., 2017, 2013; Bingham et al., 2012), opening a window to the soundscape of vast oceanic areas.

Data regarding marine vertebrates’ occurrence in the South Atlantic Ocean is still scarce. Previous studies have identified several species of whales and dolphins in the waters covering the continental shelf and the continental slope of South America (Di Tullio et al., 2016a; Zerbini, 2004), but efforts are con-
centrated on visual surveys or stranding data. In the present study, we used an unmanned surface vehicle coupled to a passive acoustic monitoring system to sample offshore waters in a region of the Brazilian coast well known for upwelling occurrence, searching for possible patterns of acoustical presence of cetaceans.

2. Materials and Methods

Acoustic data collection occurred through the deployment of an unmanned surface vehicle type Wave Glider model SV2 on the Brazilian offshore waters of the southwestern Atlantic during the austral summer of 2016. The Wave Glider used for this study consists of a submerged glider with wings connected by a 7-m umbilical to a float element that remains at the surface. The Wave Glider converts wave motion into forwarding thrust, while solar panels charge onboard batteries that power the vehicle’s command and control system, communications and sensors (Hine et al., 2009; Carragher et al., 2013).

The recording system was composed of a Reson/Teledyne TC4014-5 hydrophone (-180 dB re 1V/μPa, 15 Hz–480 kHz) and a SAIL Decimus@digital acquisition and processing system (sampling rate of 50 kHz in 16 bits, with 26 dB gain) housed in a tow-fish attached to the glider by a 15-m cable assembly with floats and weights fitted to its length (Figure 1).

The Wave Glider traveled a distance of 377 km between 6–25 February, performing constant and uninterrupted recordings, generating 24 one-hour files per day. The only two occasions in which a whole 24-hour period was not sampled were on 6 February, on which nine hours were sampled because
the equipment deployment occurred in the middle of the day; and on 12 February, on which there was an equipment failure, and recordings were restricted to nine non-consecutive hours.

The local depths were obtained from GEBCO-2014 Grid, available at http://www.gebco.net (Weatherall et al., 2015).

Sound analyses were performed in Raven 1.5 (Program, 2011). Five detectors were employed to look for signals of biological origin in two different frequency scales (Table 1). Frequency and duration parameters used in each detector configuration were chosen based on literature available on marine fauna sound signals. Detectors with spectrograms of 512-point Hanning windows and 50% overlap were used to find tonal and pulsed sounds above 2 kHz, which presented characteristic frequencies and durations of signals produced by delphinids. Recordings were decimated from 50 kHz to 6 kHz sampling rate with tuneR package (Krey et al., 2011) from R software so that low frequency sounds produced by whales and fishes could be found. For these sounds, we used detectors in Raven 1.5 with spectrograms of 512-point Hanning window and 75% overlap. Although each detector had different frequency and duration parameters, signal-to-noise ratio above 5 dB was maintained for all five detectors.

All the detections were inspected by two experienced observers (LB and IMSL) and classified as positive or negative. Detection was considered negative when it was identified as being a signal of non-biological origin (e.g., glider generated noise, shipping generated noise) and positive when it could be identified as a signal of biological origin. The positive detections were then classified according to the signals characteristics: tonal signals, burst-pulsed
sounds, echolocation click as shown in Figure 2. High-frequency tonal signals were referred to as whistles. A single detection event may sometimes include more than one type of sound, and in these cases, all sounds were counted. Consecutive detections with a time interval shorter than one hour were considered as belonging to the same detection event, meaning an encounter with a group of animals or an encounter with single vocalizing animals. In case only one vocalization was detected and separated by more than one hour from others, this detection was accounted for in the number of total detections but not considered as an individual detection event. It is unlikely that a group of delphinids would produce only a single sound emission of any kind, indicating that it belonged to another event in which the group of delphinid was too far from the glider.

Detection events were quantified and mapped to obtain the spatial distribution of encounters with animals in the sampling area. Temporal distribution of detection events was also observed by quantifying the number of detections per hour and per day. To investigate if the number of detections differed through different hours of the day, a Mann-Whitney U Test was used to compare the number of whistles, burst-pulses and echolocation clicks between light hours and dark hours, after verifying data distribution was not normal.

Of the detected signals, we analyzed the whistles with clear and strong contours (Oswald et al., 2004) that did not surpass the superior frequency limit of the recording system and that did not overlap with other signals. Seven acoustic parameters were extracted from tonal signals, as follow: initial frequency (IF), ending frequency (EF), minimum frequency (MinF), maxi-
We used the principal component analysis (PCA) to estimate the possible number of species recorded in the area. This analysis finds the combination of acoustic variables that is responsible for as much variation as possible (Quinn and Keough, 2002). The factors with the highest eigenvalues were considered to be the ones responsible for most of the variations. The correlations between each variable and the main factors of the PCA were used to define which of these variables were the most important. The main components were then used in place of the original acoustic variables in a posterior discriminant function analysis (DFA) so that the assumption of homoscedasticity of the DFA could be met (Quinn and Keough, 2002). The means of the canonical variables of the centroids of each event in relation to the two main roots of the DFA was plotted. The position of each centroid relative to each other and the roots were used to define the estimated number of species recorded.

Also, an effort to identify the species, or at least the taxa, through visual inspection of detected signals was performed. Good quality signals were selected and had their contour visually compared to the bibliography and to the available delphinid signals in the MAQUA sound database.

3. Results

3.1. Temporal Distribution and Mapping

In total, there were 165184 high-frequency detections, of which 165164 were in detection events, and 20 were in isolated occurrences. Echolocation
clicks were the most common high-frequency sound, with 162956 detections, followed by 1839 whistles and 389 burst-pulsed sounds. Low-frequency detections summed up to 705, being all tonal signals. High-frequency detections occurred on all days of the sampling period, representing 26% of all recording hours (Fig. 3). In contrast, low-frequency detections occurred on five days of the sampling period, representing 3% of all recording hours (Fig. 3). High-frequency detections occurred in all hours of the day at least once, but the majority of detections occurred during dark hours with peak detection time being 04:00 am (Fig. 4). Low-frequency detections did not occur in all hours of the day, but the majority of detections also occurred during dark hours, possibly biased by a large detection peak at 02:00 am (Fig. 4).

There were 31 high-frequency detection events (HF1 to HF31), which lasted from one up to eleven hours (Table 2). The composition of sound types varied among detection events. There were events composed solely of echolocation clicks and events composed solely of whistles, but both were of rare occurrence. Events composed of multiple sound types were the most common. The number of echolocation clicks did not differ between light hours and dark hours events (Mann-Whitney U, \( p > 0.05 \)), but there was a difference for whistles (Mann-Whitney U, \( z = -2.09, p = 0.03 \)) and burst-pulses (Mann-Whitney U, \( z = -2.49, p = 0.01 \)), which were more numerous during dark hours.

Mapping of detection events showed that delphinid encounters occurred across the entire sampling area (Fig. 5). Because the Wave Glider moved constantly, longer encounters covered larger distances.

There were 5 low-frequency detection events (LF1 to LF5), which lasted
from one up to three hours (Table 3), with only tonal signals of the same type occurring. Less frequent than high-frequency events, low-frequency events covered smaller areas as shown on the map in Figure 6.

3.2. Species Identification

The first three components of the PCA presented the highest eigenvalues and were responsible for 80.4% of the variation found in the data. The first component presented 41.7% of the total variance and the second, 19.9% of the variance. The frequency variables, especially maximum frequency, ending frequency and minimum frequency presented high correlations (> 0.7) with the first component. The number of inflection points presented high correlation, while delta frequency, minimum frequency, and duration had a moderate correlation (between 0.4 and 0.6) with the second component.

The PCA plot of the events shows that there is overlap among several events while some do not mix. That is the case of HF5 and HF11 that are apart between themselves and from most of the other events (Figure 7). The plot of DFA centroids shows that events were separated into seven different groups, probably seven different species (Figure 8). Although the centroids of HF5, HF11 and HF12 were separated by both roots, the remaining events were grouped, which means that they share similar whistle characteristics and could be recordings from the same delphinid species. Examples of this are the group formed by HF7 and HF26, and the one formed by HF31, HF4, HF1, and HF21.

The whistles from one of the detection events could be identified as part of the acoustic repertoire from rough-toothed dolphins, *Steno bredanensis* (Fig. 9). The whistle contour types registered in this study had positive
matches with whistles found both in the literature and in the MAQUA sound
database.

All low-frequency sounds were identified as being a type of Brydes whale
(Balaenoptera brydei) call (Fig. 10). The calls were all descendent in fre-
quency, with: mean minimum frequency of 71.2 ± 8.7 Hz; mean maximum
frequency of 182.0 ± 11.8 Hz; mean delta frequency of 110.8 ± 14.2 Hz; and
mean duration of 442.8 ± 115.5 ms. The calls occurred in bouts of two or
three, with bouts usually separated by two seconds on average, repeated
during approximately one hour.

4. Discussion

Our results demonstrated that delphinid species used the studied area
daily during the sampling period. Since recordings were continuous, except
for two system failure occasions, the observed temporal distribution is free of
recording cycle effect (Riera et al., 2013). Despite the fact that previous stud-
ies had already identified the presence of delphinid species in the study area
using visual observer methods (Di Tullio et al., 2016a), the higher number of
delphinid acoustic detections during dark hours in this study highlights the
importance of using PAM to assess cetacean occurrence. This methodology
can be used independent of good light and weather conditions, which are
necessary for visual surveys.

The number of hours and sound emissions found in each detection event
varied and this could be either due to delphinid group size, to the distance
in which the animals were to the Wave Glider, or even to different acoustic
behavior from different species. Events that lasted longer and presented a
higher number of sound emissions could be composed by larger groups of delphinids and could also be involved in higher activity rates (dos Santos et al., 2005). Some of the detection events grouped together in statistical analysis not only have similar whistle characteristics but also occurred during similar times of the day, such as events HF8 and HF19. Temporal patterns of vocalization behavior can differ among odontocetes, with certain species producing more sound emissions during the night while others produce more during the day (Baumann-Pickering et al., 2016). Although the number of detected echolocation clicks did not differ between light and dark hour events, the number of detected whistles and burst-pulses did, corroborating that events from different hours of the day could be of different species.

Habitat partitioning among different species is known to occur in these waters (Di Tullio et al., 2016b; Moreno et al., 2005), and now nocturnal data of cetacean presence can be added to this knowledge. It is noteworthy that the Wave Glider covered a broad range of depths while navigating through areas possibly occupied by distinct species which can show a preference for different depths and slope variations (Ballance et al., 2006; Dalla Rosa et al., 2012; De Stephanis et al., 2008). The delphinid encounters occurred across all depths, but no detection event covered an area in which local depth varied more than 400 m, suggesting that each registered group could have preferred depth association.

Previous studies have shown that oceanographic features can influence the cetacean distribution (Ballance et al., 2006; Tynan et al., 2005), and that feeding habits and prey distribution are major components of habitat partitioning (Cañadas et al., 2002; Friedlaender et al., 2006; Hastie et al.,
It is known that oceanographic features can influence cetacean distribution (Ballance et al., 2006; Tynan et al., 2005). Feeding habits and prey distribution are major components of habitat partitioning of cetacean species in a given area (Cañadas et al., 2002; Friedlaender et al., 2006; Hastie et al., 2004). The occurrence of upwelling characterizes the region in the vicinities of the Cape Frio (23°S, 42°W) where relatively cold waters, rich in nutrients, surface creating a high biological productivity region (Valentin, 1984; Costa and Fernandes, 1993; Matsuura, 1996). The change of coastline orientation from north-south to east-west and the proximity of the 100-m isobath are favorable topographic conditions for the coastal upwelling next to the Cape Frio (Rodrigues and Lorenzzetti, 2001), but the primary process is the wind-driven Ekman transport due to persistent E-NE winds that prevail in spring and summer in the region (Emílsson, 1961; Ikeda et al., 1974; Castro and Miranda, 1998). Other mechanisms work to rise cold waters offshore the Cape Frio, like the passage of cyclonic eddies and meanders of the Brazil Current (Campos et al., 2000; Castelao et al., 2004) and vertical transport driven by the wind stress curl (Castelao and Barth, 2006).

Upwelling regions are highly productive and aggregate diverse marine fauna, attracting top marine predators (Croll et al., 2005; Tynan et al., 2005). Since the Wave Glider passed through an area closely related to an upwelling system in the Southwestern Atlantic Ocean, it is possible that the great abundance of delphinid detections is due to prey concentration associated with nutrient-rich waters.

Confirmation of species identification through whistles contour was pos-
sible only for one event. Few studies characterized whistles of the species found in the Southwestern Atlantic Ocean and most of these used recordings from coastal areas (de Andrade et al., 2015; Azevedo et al., 2010, 2007; Lima et al., 2012). Another difficulty is the possibility that more than one species has been recorded in the same detection event. Thus the presence of many whistle types with varying characteristics made the exclusion of some species of varied whistle repertoire impossible. Mixed-species associations among delphinids are common in several areas and present a challenge to species classification and identification through acoustic methods (Oswald et al., 2003). More bioacoustics studies focusing on acoustic repertoire characterization are necessary to fill the data gap on oceanic waters from the South Atlantic.

The HF5 was the only event in which species identification was possible. The whistles from Rough-toothed dolphins, *Steno bredanensis*, were compared to a previous characterization of the species’ whistle repertoire in the coastal region of the Rio de Janeiro State Coast, adjacent to the Guanabara Bay (Lima et al., 2012). We found contour similarities between whistles from the database and the present study. The whistles were in most part differentiated from other delphinid species both in frequency and duration (Lima et al., 2016). Furthermore, in the Southwestern Atlantic Ocean rough-toothed dolphins are known to occur both in coastal waters (Lima et al., 2016, 2012) and offshore waters (Wedekin et al., 2014), and the record from the present study adds information about the area of occurrence of this species.

Despite species identification having been restricted, the acoustic parameters extracted from whistles presented significant variations and no over-
lapping among some events, which means that the sampled area was used by at least seven delphinid species. Previous studies have shown that whistle repertoires have species-specific characteristics that result in interspecific differences (Lima et al., 2016; Oswald et al., 2007; Steiner, 1981). Therefore, highest differences among whistle variables of different events in the present study may be related to the recordings of different species. The lowest differences registered among whistles of some events may reflect intraspecific variation, which can be influenced by the social context and environmental factors at the time in which each group was recorded (Azevedo et al., 2010; Bonato et al., 2015; López, 2011; May-Collado, 2013). However, it is likely that one species has been recorded on more than one event, so this could account for some of the overlap observed among events. Also, some degree of overlap among whistles of different species is to be expected, as shown in previous studies of interspecific comparisons (Oswald et al., 2007, 2003).

Considering that the PAM system was towed close to the surface, it is possible that this has restricted the system’s capacity of registering deep-diving animals such as beaked whales and sperm whales (Physeter microcephalus). Although the sample rate employed in this study is not adequate to record beaked whale signals since their fundamental frequency is usually higher than 100 kHz (Baumann-Pickering et al., 2014; Zimmer et al., 2008), sperm whale clicks, otherwise, fall within the recording system frequency range (Antunes et al., 2011; Rendell and Whitehead, 2005), and the species has been sighted in the area in previous studies (Di Tullio et al., 2016a; Zerbini, 2004). It is possible that either the sound detectors were not adequate to find sperm whale clicks, or that ecological factors influenced their absence.
All calls produced by Brydes whales in the present study were of the same type and identified as a call first described in the eastern tropical Pacific ocean (Oleson et al., 2003), also registered in the Gulf of Mexico (Širović et al., 2014), indicating that this call type might be shared across different Brydes whale populations. During the austral summer, Brydes whales occur close to the southeastern coast of Brazil (Zerbini et al., 1997), thus, considering the sampling season, no baleen whale except for Brydes whale was expected to be recorded. Although it is possible that some unidentified signals were produced by minke whales, known for their mechanic sounding vocalizations (Gedamke et al., 2001; Rankin and Barlow, 2005), it is also possible that these signals are undescribed vocalizations produced by Brydes whales.

Furthermore, data from PAM coupled with unmanned vehicle technology is unprecedented for the Southwestern Atlantic Ocean. This study was conducted through 20 days, and it produced large volumes of data, generating evidence that several species of delphinids use the area. The high number of detected sound emissions on some events also hints at the presence of large groups of delphinids engaging on high activity rates, indicating an abundant and diverse community of dolphins on the outer continental shelf and slope of the Southwestern Atlantic Ocean during the summer. Further research covering acoustic characterization and behavior of cetacean species, seasonality of habitat use and relationship with oceanographic features should be conducted to increase knowledge regarding this habitat.
5. Acknowledgements

This work was supported by PETROBRAS and the Brazilian Oil Regulatory Agency (ANP), within the project PT-128.01.12041 - “New Technologies and Innovations in Sensors and Metocean Sampling”. The acoustic survey was executed in a partnership of PETROBRAS/CENPES, WesternGeco/LROG, and Brazilian Navy/IPqM. Liquid Robotics Oil and Gas (LROG), previously a joint venture between Liquid Robotics and Schlumberger, became wholly owned by Schlumberger on August 29, 2016, and has been renamed Schlumberger Robotics Services. We would like to acknowledge Fabian Van Der Werth and Levent Alkan, former employees of LROG, for the system setup and field operations. The authors would like to thank IPqM and Faculdade de Oceanografia (UERJ) for data analysis support. LB received a scholarship from CAPES. IMSL received a scholarship from FAPERJ. AFA and JL-B have research grant from CNPq (PQ-1D), FAPERJ (JCNE) and UERJ (Prociência).

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Figure 1: The Wave Glider model SV2 connected to the PAM system through a 15-m tow cable on deck after recovery.
Table 1: Detectors parameters used in Raven 1.5 to look for biological signals from the offshore waters of the Southwestern Atlantic Ocean.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Parameters</th>
<th>Spectogram Frequency Limit</th>
<th>Focal Sound Types</th>
</tr>
</thead>
</table>
| Det1     | Minimum frequency: 8 kHz  
          Maximum frequency: 22 kHz  
          Minimum duration: 60 ms  
          Maximum duration: 900 ms  
          Minimum separation: 50 ms | 25 kHz | Whistles and burst-pulsed sounds |
| Det2     | Minimum frequency: 2 kHz  
          Maximum frequency: 7 kHz  
          Minimum duration: 60 ms  
          Maximum duration: 900 ms  
          Minimum separation: 50 ms | 25 kHz | Whistles and burst-pulsed sounds |
| Det3     | Minimum frequency: 15 kHz  
          Maximum frequency: 24 kHz  
          Minimum duration: 5 ms  
          Maximum duration: 10 ms  
          Minimum separation: 10 ms | 25 kHz | Echolocation clicks |
| Det4     | Minimum frequency: 50 Hz  
          Maximum frequency: 300 Hz  
          Minimum duration: 200 ms  
          Maximum duration: 600 ms  
          Minimum separation: 300 ms | 3 kHz | Tonal and burst-pulsed sounds |
| Det5     | Minimum frequency: 300 Hz  
          Maximum frequency: 800 Hz  
          Minimum duration: 100 ms  
          Maximum duration: 600 ms  
          Minimum separation: 100 ms | 3 kHz | Tonal and burst-pulsed sounds |
Table 2: High-frequency acoustic detection events obtained through passive acoustic monitoring in Brazilian offshore waters in the Southwestern Atlantic Ocean during the austral summer.

<table>
<thead>
<tr>
<th>Detection event</th>
<th>Duration (h)</th>
<th>Time of day interval</th>
<th>Detection composition</th>
<th>Local depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF1</td>
<td>8</td>
<td>15 pm to 23 pm</td>
<td>8815 EC, 62 W, 32 BP</td>
<td>$339 \pm 78$ (243–427)</td>
</tr>
<tr>
<td>HF2</td>
<td>7</td>
<td>00 am to 07 pm</td>
<td>37452 EC, 30 W, 54 BP</td>
<td>$711 \pm 74$ (626–841)</td>
</tr>
<tr>
<td>HF3</td>
<td>1</td>
<td>14 pm to 15 pm</td>
<td>55 EC</td>
<td>1612</td>
</tr>
<tr>
<td>HF4</td>
<td>1</td>
<td>10 am to 11 am</td>
<td>16 EC, 8 W</td>
<td>1643</td>
</tr>
<tr>
<td>HF5</td>
<td>2</td>
<td>06 am to 08 am</td>
<td>9349 EC, 18 W, 12 BP</td>
<td>$1629 \pm 1$ (1628–1629)</td>
</tr>
<tr>
<td>HF6</td>
<td>1</td>
<td>09 am to 10 am</td>
<td>31 clicks EC</td>
<td>1627</td>
</tr>
<tr>
<td>HF7</td>
<td>5</td>
<td>20 pm to 01 am of the following day</td>
<td>4564 EC, 159 W, 23 BP</td>
<td>$1629 \pm 5$ (1621–1633)</td>
</tr>
<tr>
<td>HF8</td>
<td>3</td>
<td>04 am to 07 am</td>
<td>2722 EC, 18 W, 6 BP</td>
<td>$1504 \pm 6$ (1497–1508)</td>
</tr>
<tr>
<td>HF9</td>
<td>4</td>
<td>21 pm to 01 am of the following day</td>
<td>18714 EC, 448 W, 47 BP</td>
<td>$1569 \pm 11$ (1555–1579)</td>
</tr>
<tr>
<td>HF10</td>
<td>2</td>
<td>02 am to 04 am</td>
<td>10651 EC, 20 W, 11 BP</td>
<td>$1218 \pm 11$ (1213–1255)</td>
</tr>
<tr>
<td>HF11</td>
<td>6</td>
<td>21 pm to 03 am of the following day</td>
<td>1757 EC, 122 W, 6 BP</td>
<td>$697 \pm 35$ (667–756)</td>
</tr>
<tr>
<td>HF12</td>
<td>5</td>
<td>11 am to 15 pm</td>
<td>2995 EC, 59 W, 3 BP</td>
<td>(352–468)</td>
</tr>
<tr>
<td>HF13</td>
<td>2</td>
<td>03 am to 05 am</td>
<td>1594 EC, 3 W, 2 BP</td>
<td>$144 \pm 1$ (144–145)</td>
</tr>
<tr>
<td>HF14</td>
<td>2</td>
<td>19 pm to 21 pm</td>
<td>3 EC, 39 W, 6 BP</td>
<td>$174 \pm 5$ (170–177)</td>
</tr>
<tr>
<td>HF15</td>
<td>3</td>
<td>04 am to 07 am</td>
<td>7 W, 4 BP</td>
<td>$417 \pm 91$ (334–515)</td>
</tr>
<tr>
<td>HF16</td>
<td>1</td>
<td>10 am</td>
<td>28 EC</td>
<td>805</td>
</tr>
<tr>
<td>HF17</td>
<td>2</td>
<td>03 am to 05 am</td>
<td>763 EC</td>
<td>$1364 \pm 33$ (1341–1387)</td>
</tr>
<tr>
<td>HF18</td>
<td>2</td>
<td>18 pm to 20 pm</td>
<td>4180 EC, 4 W, 48 BP</td>
<td>$1566 \pm 6$ (1562–1570)</td>
</tr>
<tr>
<td>HF19</td>
<td>2</td>
<td>04 am to 06 am</td>
<td>11118 EC, 91 W, 53 BP</td>
<td>$1791 \pm 21$ (1776–1806)</td>
</tr>
<tr>
<td>HF20</td>
<td>1</td>
<td>11 am</td>
<td>389 EC</td>
<td>1906</td>
</tr>
<tr>
<td>HF21</td>
<td>7</td>
<td>23 pm to 06 am</td>
<td>2575 EC, 26 W, 9 BP</td>
<td>$2058 \pm 23$ (2031–2084)</td>
</tr>
<tr>
<td>HF22</td>
<td>2</td>
<td>03 am to 05 am</td>
<td>3 BP</td>
<td>$1638 \pm 19$ (1624–1651)</td>
</tr>
<tr>
<td>HF23</td>
<td>2</td>
<td>03 am to 05 am</td>
<td>1188 EC, 2 BP</td>
<td>$1177 \pm 21$ (1162–1191)</td>
</tr>
<tr>
<td>HF24</td>
<td>1</td>
<td>06 am</td>
<td>9017 EC, 9 W, 4 BP</td>
<td>1120</td>
</tr>
<tr>
<td>HF25</td>
<td>1</td>
<td>09 am</td>
<td>18 W</td>
<td>1026</td>
</tr>
<tr>
<td>HF26</td>
<td>11</td>
<td>22 pm to 09 am</td>
<td>18682 EC, 249 W, 52 BP</td>
<td>$378 \pm 160$ (177–573)</td>
</tr>
<tr>
<td>HF27</td>
<td>1</td>
<td>11 am</td>
<td>36 EC</td>
<td>145</td>
</tr>
<tr>
<td>HF28</td>
<td>3</td>
<td>13 pm to 16 pm</td>
<td>85 EC</td>
<td>$131 \pm 1$ (130–132)</td>
</tr>
<tr>
<td>HF29</td>
<td>5</td>
<td>19 pm to 00 am</td>
<td>654 EC, 74 W</td>
<td>$379 \pm 1$ (224–513)</td>
</tr>
<tr>
<td>HF30</td>
<td>8</td>
<td>00 am to 08 am</td>
<td>15519 EC, 177 W, 12 BP</td>
<td>$515 \pm 27$ (488–555)</td>
</tr>
<tr>
<td>HF31</td>
<td>2</td>
<td>09 am to 11 am</td>
<td>148 W</td>
<td>470</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>111</td>
<td>-</td>
<td><strong>162952 EC, 1823 W, 389 BP</strong></td>
<td><strong>935 ± 619 (130–2084)</strong></td>
</tr>
</tbody>
</table>
Table 3: Low-frequency acoustic detection events obtained through passive acoustic monitoring in Brazilian offshore waters in the Southwestern Atlantic Ocean during the austral summer.

<table>
<thead>
<tr>
<th>Detection event</th>
<th>Duration (h)</th>
<th>Time of the day interval</th>
<th>Detection composition</th>
<th>Local depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF1</td>
<td>2</td>
<td>08 am to 10 am</td>
<td>139 tonal signals</td>
<td>1041 ± 59 (999–1083)</td>
</tr>
<tr>
<td>LF2</td>
<td>2</td>
<td>20 pm to 22 pm</td>
<td>48 tonal signals</td>
<td>1576 ± 2 (1576–1579)</td>
</tr>
<tr>
<td>LF3</td>
<td>3</td>
<td>19 pm to 22 pm</td>
<td>122 tonal signals</td>
<td>841 ± 82 (756–920)</td>
</tr>
<tr>
<td>LF4</td>
<td>3</td>
<td>00 am to 03 am</td>
<td>393 tonal signals</td>
<td>677 ± 13 (667–692)</td>
</tr>
<tr>
<td>LF5</td>
<td>1</td>
<td>14 pm</td>
<td>3 tonal signals</td>
<td>392</td>
</tr>
<tr>
<td>Sum</td>
<td>11</td>
<td>-</td>
<td>705 tonal signals</td>
<td>926 ± 372 (392–1579)</td>
</tr>
</tbody>
</table>

Figure 2: Examples of biological signals categories as classified by two observers during detection validation. (A) echolocations clicks (overlapped with a whistle), (B) burst-pulsed sound, and (C) tonal signal, referred to as whistles in the case of delphinid.
Figure 3: Number of hours with high-frequency and low-frequency detections in all days of the sampling period.
Figure 4: Sum of high-frequency (A) and low-frequency (B) detections per hour of the day of the total sampling period.
Figure 5: Mapping of high-frequency detection events through unmanned vehicle passive acoustic monitoring on Brazilian offshore waters in the Southwestern Atlantic Ocean between 6-25 February 2016.
Figure 6: Mapping of low-frequency detection events through unmanned vehicle passive acoustic monitoring on Brazilian offshore waters in the Southwestern Atlantic Ocean between 6-25 February 2016.
Figure 7: Principal components analysis of 13 high-frequency events of delphinid detections registered during passive acoustic monitoring in Brazilian offshore waters in the Southwestern Atlantic Ocean.
Figure 8: DFA centroids separating high-frequency events into seven groups, indicating probable seven delphinid species registered during passive acoustic monitoring in Brazilian offshore waters in the Southwestern Atlantic Ocean.
Figure 9: Examples of whistles of the same contour type in two situations: (A) whistle recorded in the present study; and (B) whistle recorded during visual surveys of rough-toothed dolphins and found in the MAQUA sound database.
Figure 10: Brydes whale calls recorded through unmanned vehicle passive acoustic monitoring on Brazilian offshore waters in the Southwestern Atlantic Ocean.