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Baseline

Underwater noise in an impacted environment can affect Guiana dolphin communication

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ABSTRACT

This study focused on whistles produced by Guiana dolphin under different noise conditions in Guanabara Bay, southeastern Brazil. Recording sessions were performed with a fully calibrated recording system. Whistles and underwater noise levels registered during two behavioral states were compared separately between two areas. Noise levels differed between the two areas across all frequencies. Whistle duration differed between areas and was negatively correlated with noise levels. Whistling rate was positively correlated with noise levels, showing that whistling rate was higher in noisier conditions. Results demonstrated that underwater noise influenced Guiana dolphin acoustic behavior.

Studies have observed an increase in underwater sound levels (McDonald et al., 2006) related to the enlargement of the global fleet of ships and large vessels (Andrew et al., 2011). Noise pollution and its effects on aquatic organisms, therefore, has become a growing concern in the marine environment (Clark et al., 2009; Nowacek et al., 2007; Slabbekoorn et al., 2010). Because sound propagates very well underwater, many marine vertebrates have adapted to use it as a primary sense (Myrberg, 1997; Tyack and Miller, 2002). Currently, marine organisms are at risk of noise masking and several studies have shown animal responses to noise pollution in the marine environment (Castellote et al., 2012; Foote et al., 2004; Holt et al., 2011; Lesage et al., 1999; McQuinn et al., 2011; Rolland et al., 2012; Tyack, 2008; Vasconcelos et al., 2007; Wysocki et al., 2007, 2006).

Delphinids are known to produce a wide range of sounds, of which whistles are the most studied. These sounds can be species specific (Oswald et al., 2003) and aspects such as behavior (Díaz López, 2011) and physiology (May-Collado et al., 2007) can influence whistle variation. Recently, the rise in underwater noise has been considered an important factor in the observed changes in sounds produced by odontocetes (May-Collado and Wartzok, 2008). Effects reported in the acoustic behavior include: increasing vocalization amplitude, shifting fundamental frequency band, changing signal duration and altering vocalization rate (Tyack, 2008). These responses have been observed in several species (Foote et al., 2004; Lesage et al., 1999; Morisaka et al., 2005).

The acoustic structure of Guiana dolphin *Sotalia guianensis* (Cetartiodactyla: Delphinidae, Van Benédén, 1864), whistles has been studied extensively in recent years (e.g. (Andrade et al., 2015b; Azevedo and Van Sluys, 2005; Deconto and Monteiro-Filho, 2013; May-Collado and Wartzok, 2009)). However, the influence of underwater noise pollution on whistles produced by Guiana dolphin is poorly known. This study aims to investigate how noise levels may promote whistle variation in *Sotalia guianensis*.

Guanabara Bay, southeastern Brazil, is an important economic area in Brazil and is severely impacted by environmental degradation (Kjerfve et al., 1997). A recent study has shown that the bay has different underwater noise profiles, and that vessel traffic is the major acoustic influence in some areas (Bittencourt et al., 2014). In the bay there is a resident population of Guiana dolphins that is daily exposed to several anthropogenic threats such as pollution, spatial loss due to construction and fisheries (Azevedo et al., 2004, 2007, 2008).

Acoustic recordings of underwater sound produced by Guiana dolphins were conducted in Guanabara Bay (22°50′S 43°0′W), southeastern Brazil (Fig. 1), between April of 2012 and January of 2013. A 5.5 m long boat with a 90 hp. engine was used for covering the study area. The boat's engine remained off during all recordings. The hydrophone was deployed at 2 m below the surface. The recording system consisted of an omnidirectional HTI-96MIN hydrophone with a flat frequency response of 5 Hz to 30 kHz (±3 dB mean sensitivity of −170.5 dB re: 1 V/μPa) combined with a digital recorder Marantz PMD 671 with a 96 kHz sample rate and a 24-bit resolution. We calibrated the recording system

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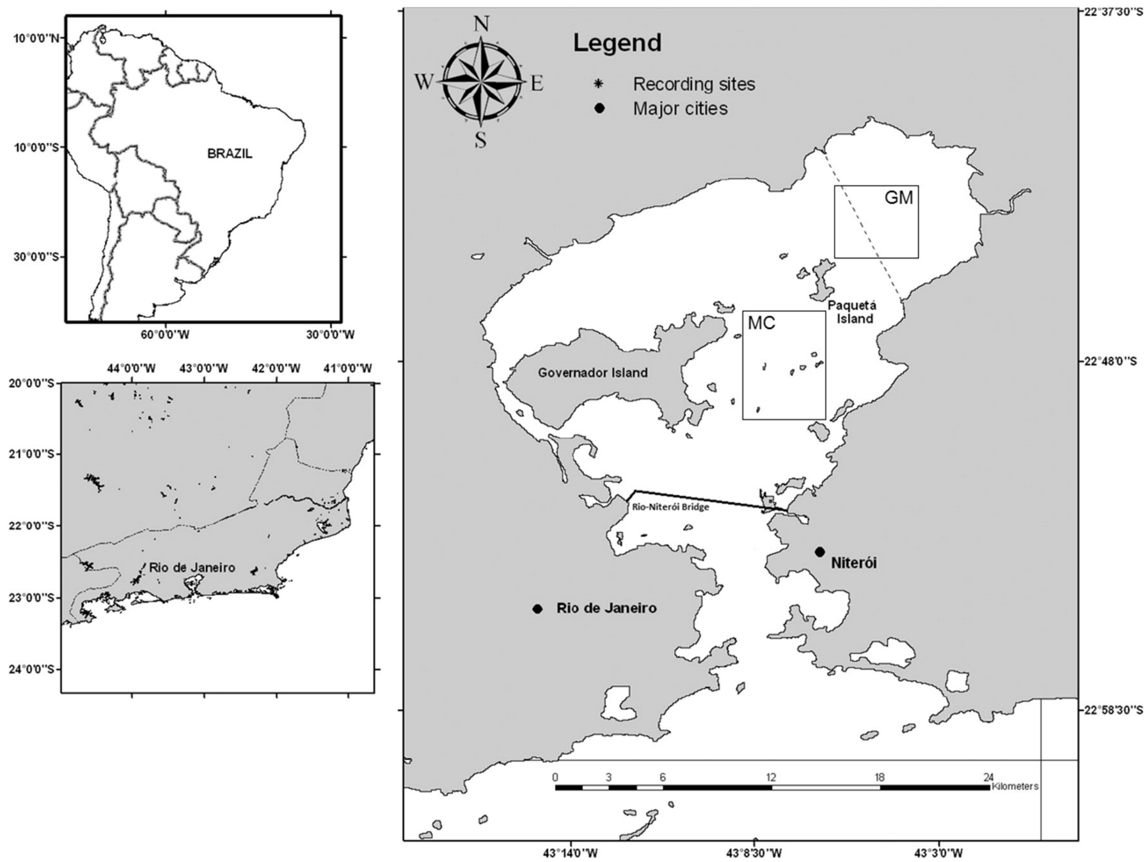

Fig. 1. Guanabara Bay, southeastern Brazil (22°50′S 43°0′W). Recording areas are indicated by squares: GM (Guapi-mirim Environmental Protection Area and adjacent areas) and MC (main channel and adjacent areas).

with a 1 kHz tone. The calibration provided equipment noise gain for all possible input levels in the digital recorder. In addition, we plotted the hydrophone calibration curve and obtained the mean sensitivity to use in noise levels calculation.

All our recordings were conducted under similar sea state conditions (Beaufort < 2), thus avoiding great natural noise variation, such as waves hitting the researcher boat and turbulence interference with the equipment. Recordings were made continuously in files of 5 min. During recordings we took notes of all artificial sound sources operation within 1 km radius of our location. Guanabara Bay has distinct noise profiles, with the highest sound pressure levels being found in the bay's main channel and the lowest in the Guapi-mirim Environmental Protection Area (Bittencourt et al., 2014). Seeking to record Guiana dolphin whistles under different conditions regarding vessel traffic (e.g. no boats present, distant boats passage, fishing vessels present, during ferry line passage, amongst operating ships), we performed the acoustic recordings in the main channel (MC) and in Guapi-mirim EPA (GM) and adjacent waters.

In order to avoid other ecological factors influence on whistle variation, some procedures were established. Only groups of five or more individuals and with the presence of at least one calf were recorded, therefore, all recorded groups had similar composition. This procedure was established because this is the most frequent group size and composition observed for Guiana dolphins in Guanabara Bay (Azevedo et al., 2007), and reduced the influence of different group compositions on sound production. At least two experienced observers sampled group behavior, size and composition for 20 min after a group was sighted. We used this period to assure that the boat's presence did not alter group behavior. Predominant surface behavior of the group was sampled during recordings, every 5 min, through scan sampling (Altmann, 1974). Two behavioral states were used in the analysis: feeding and socializing, following the definition of Azevedo and Van Sluys (2005). Since other behavioral states such as resting or traveling were rarely observed during this study, recordings from these behavioral states were not included. Whistles registered during different behavioral state were then analyzed separately. All recording sessions included in the analysis were in the presence of a single group. When another group's presence was detected in the area, the recording was not included in the analysis.

Whistle analysis was performed using Raven 1.4 sound analysis software (BRP, 2011). Spectrograms were computed with a Hanning window with 512 points and 50% overlap. All whistles in the recording were quantified, but only high quality whistles with strong and clear contour were selected for acoustic parameter analysis (Andrade et al., 2015a; Papale et al., 2013). If the start or end of the whistle could not be clearly defined due to noise masking or weak whistle amplitude, the whistle was considered as poor quality and was not included in the acoustic parameter analysis. In order to avoid pseudo-replication we did not include more than two whistles from the same recording that had similar contours. Whistles that overlapped with other signals also were not included in the acoustic parameter analysis. All quantified whistles were then used for whistling rate calculation. The number of whistles in each recording file (5 min) was divided by the recording duration, then divided by the number of individuals present during the recording (Buckstaff, 2006). This calculation provided information about the number of whistles per minute per dolphin.

Ten acoustic parameters were extracted from each whistle: duration (DUR), starting frequency (ST), ending frequency (EF), minimum frequency (MinF), maximum frequency (MaxF), delta frequency (DF, DF = MaxF − MinF), first quartile frequency (1QF), third quartile frequency (3QF), central frequency (CF) and peak frequency (PF). All frequency parameters are here given in kilohertz and duration is given in