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Acoustic Parameters of Guiana Dolphin (*Sotalia guianensis*) Whistles in the Southern Gulf of Venezuela

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Abstract

The Guiana dolphin (*Sotalia guianensis*) is widely distributed along the coasts of Central and South America. Similar to other delphinids, this species emits echolocation clicks, burst pulses, and whistles. Although whistling seems to play a major role in the social organisation of dolphins, there is a lack of knowledge about Guiana dolphin whistles outside of its populations in Brazil and Costa Rica. In this study, we describe the acoustic structure of Guiana dolphin whistles from the southern Gulf of Venezuela for the first time. We recorded the whistles using an omnidirectional hydrophone (CR1). For each whistle, we measured maximum frequency (kHz), minimum frequency (kHz), starting frequency (kHz), ending frequency (kHz), duration (s), and number of inflection points, using spectrograms created in *SpectraLAB 4.32*, Version 17. Whistles presented an average starting frequency of 10.58 kHz (SD = 2.49 kHz), a mean ending frequency of 13.96 kHz (SD = 2.60 kHz), an average minimum frequency of 10.31 kHz (SD = 2.33 kHz), a mean maximum frequency of 13.96 kHz (SD = 2.51 kHz), an average duration of 0.27 s (SD = 0.14 s), and a maximum of four inflection points (mode 0). This research provides new insights into the acoustic behaviour of the Guiana dolphin in the Gulf of Venezuela.

Key Words: Guiana dolphin, *Sotalia guianensis*, acoustic structure, acoustic parameters, Gulf of Venezuela, cetacean

Introduction

The Guiana dolphin (*Sotalia guianensis*) is a small cetacean (Delphinidae: Odontoceti) that inhabits shallow brackish water systems (Cunha et al., 2005; Caballero et al., 2007, 2010; Flores et al., 2010). This species is patchily distributed along the coast of Central and South America from Honduras to Florianópolis in southern Brazil (Flores et al., 2010; Santos et al., 2010; Cremer et al., 2011). Its distribution in Venezuela is focused in two main population centres: (1) in the Orinoco and Casiquiare Rivers (Borobia et al., 1991; Gómez-Salazar et al., 2010) and (2) in the Maracaibo Estuarine System (Casinos et al., 1981; Bolaños-Jiménez et al., 2008).

In the Maracaibo Estuarine System, the Guiana dolphin, known locally as *Tonina del Lago*, is the most frequently sighted cetacean species inhabiting this region (Bolaños-Jiménez et al., 2008; Flores et al., 2010). This gregarious species has been observed forming small groups ranging from two to 13 individuals in the western portion of the Maracaibo Lake (Barranquitas locality) (De Turris-Morales et al., 2010; Delgado, 2013) to one to 30 individuals in the southern portion of the Gulf of Venezuela (Carrasquero, 2010). However, groups up to 100 individuals have also been rarely recorded in this region (Barrios-Garrido & Montiel-Villalobos, 2005).

The Guiana dolphin has faced several anthropogenic threats in the Maracaibo Estuarine System, mainly from interactions with the artisanal fisheries (e.g., bycatch and intentional take) (Bolaños-Jiménez et al., 2008) and with the oil industry (Barrios-Garrido et al., 2010; De Turris-Morales et al., 2010; De Turris-Morales, 2012; Delgado, 2013). In particular, low-frequency ambient noise produced by boat traffic, such as oil tankers, may be affecting the acoustic behaviour of local dolphin groups. Several authors have reported significant differences among the whistles' frequencies between dolphins in localities with and without the effects of boat traffic (Morisaka et al., 2005a, 2005b; May-Collado & Wartzok, 2009; Papale et al., 2015).

Similar to other delphinids, Guiana dolphins emit frequency-modulated sounds called whistles. Whistles are considered *social signals* used to coordinate the organisation and functionality of the group, and they appear to serve no other function except in communication (Bazúa-Durán, 2004a; Erber & Simão, 2004; Azevedo & Van Sluys, 2005). These whistles range from 0.9 to 48.4 kHz, and they can last between 0.009 and 2.33 s. Although a few researchers have recorded whistles with up to nine inflection points, most dolphin whistles contain no inflection points (Azevedo & Simão, 2002; Azevedo & Van Sluys, 2005; Pivari & Rosso, 2005; May-Collado & Wartzok, 2009; Guimarães de Andrade et al., 2015).

Despite the Guiana dolphin's vast distribution, most of what we know about its acoustic parameters is derived from studies on Brazilian populations (Erber & Simão, 2004; Azevedo & Van Sluys, 2005), and more recently from a Costa Rican population (May-Collado & Wartzok, 2009; May-Collado, 2013). The acoustic behaviour of Guiana dolphins from the Gulf of Venezuela is unknown. Guiana dolphins from the Maracaibo Estuarine System have been described as genetically "unique" compared to other populations along their distribution (Caballero et al., 2007, 2010; Bolaños-Jiménez et al., 2008; Barrios-Garrido et al., 2010). Herein, we provide the first description of the whistle acoustic structure of Guiana dolphins from the Gulf of Venezuela.

Methods

Study Area

The Maracaibo Estuarine System includes an extensive coast depression, between 9º and 12º N, and 70º and 72º W. It covers four interconnected aquatic ecosystems: (1) the Gulf of Venezuela, (2) the "El Tablazo" Bay, (3) the Maracaibo Strait, and (4) Maracaibo Lake (Rodríguez, 2001) (Figure 1). This system contains Venezuela's largest active oil deposits, and all of the associated activities surrounding the oil industry have had a large impact on this region (Rodríguez, 2001; Medina & Barboza, 2006; De Turris-Morales, 2012; Delgado, 2013).

The southern area of the Gulf of Venezuela presents specific physicochemical conditions related to the input of salt water supplied by the Caribbean Sea and the output of freshwater from the Maracaibo Lake (Rodríguez, 2001). This area also supports one of the largest Venezuelan populations of *S. guianensis* (Bolaños-Jiménez et al., 2008; Barrios-Garrido et al., 2010). Carrasquero (2010) estimated that the population density of the Guiana dolphin in this area is 5.62 individuals/km^2.

Data Collection

Six data collection surveys were conducted by boat monthly in the southern region of the Gulf of Venezuela between March and August 2011 (Figure 1). All data were collected between 1300 and 1800 h, based upon Carrasquero (2010) who determined that sightings are more frequent during afternoon hours. All data collection surveys started at 10º 58' 53.25" N, 071º 35' 35.66" W; and then we followed the navigation channel north. When a dolphin group was observed, we confirmed that the species was *Sotalia guianensis* based on distinctive morphological characteristics such as body shape and size, coloration, and dorsal fin shape and position (Flores et al., 2010).

Once the species was confirmed, we turned off the boat's engine in order to accurately record the following data from a distance of 20 to 30 m: group size, group composition, audio recordings of whistles, and GPS data of each sighting (Shirihai & Jarrett, 2006; Díaz López & Bernal Shirai, 2007; Perrin et al., 2009; May-Collado, 2013).

Collection of the Guiana dolphin vocalisations was conducted using an omnidirectional hydrophone (Cetacean Research CR1 Hydrophone) (Aubauer et al., 2000), with a frequency response from 0.0002 to 48 kHz (+3/-12 dB, -198.51 dB re 1 V/µPa). This was connected to a dual interface preamplifier (USB Dual Pre ART), which was also connected to a M-Audio Micro Track II recorder (Cetacean Research Technology [CRT], 2011). Recordings were made continuously during the sighting of each dolphin group with the hydrophone at a depth of 2 m. All recordings were monitored through headphones to ensure good quality and high signal-to-noise ratios (Díaz López & Bernal Shirai, 2007).

We obtained acoustic recordings from single groups and multiple groups simultaneously. Single group sizes ranged from one to eight individuals, and the groups often had a mixed composition of adults, juveniles, and calves determined by observed morphological characteristics (e.g., size and colour patterns) (Flores et al., 2010).

Whistle Contours

High-quality whistles with good signal-to-noise ratios were manually analysed using spectrograms created by *SpectraLAB 4.32*, Version 17 (Zhoglikov et al., 2010; May-Collado, 2013) and categorised according to definitions used by Azevedo & Van Sluys (2005), May-Collado & Wartzok (2009), and Guimarães de Andrade et al. (2015). These categories are defined as follows:

ascending (A) – whistles mainly rising in frequency with a descending frequency span (if any) less than 1 kHz; *descending* (D) – whistles in which the frequency mainly falls with an increasing frequency span (if any) less than 1 kHz; *ascending-descending* (A-D) – whistles which initially rise in frequency in a span over 1 kHz then fall in frequency over 1 kHz with one inflection point in between the ascending and descending frequencies; *descending-ascending* (D-A)

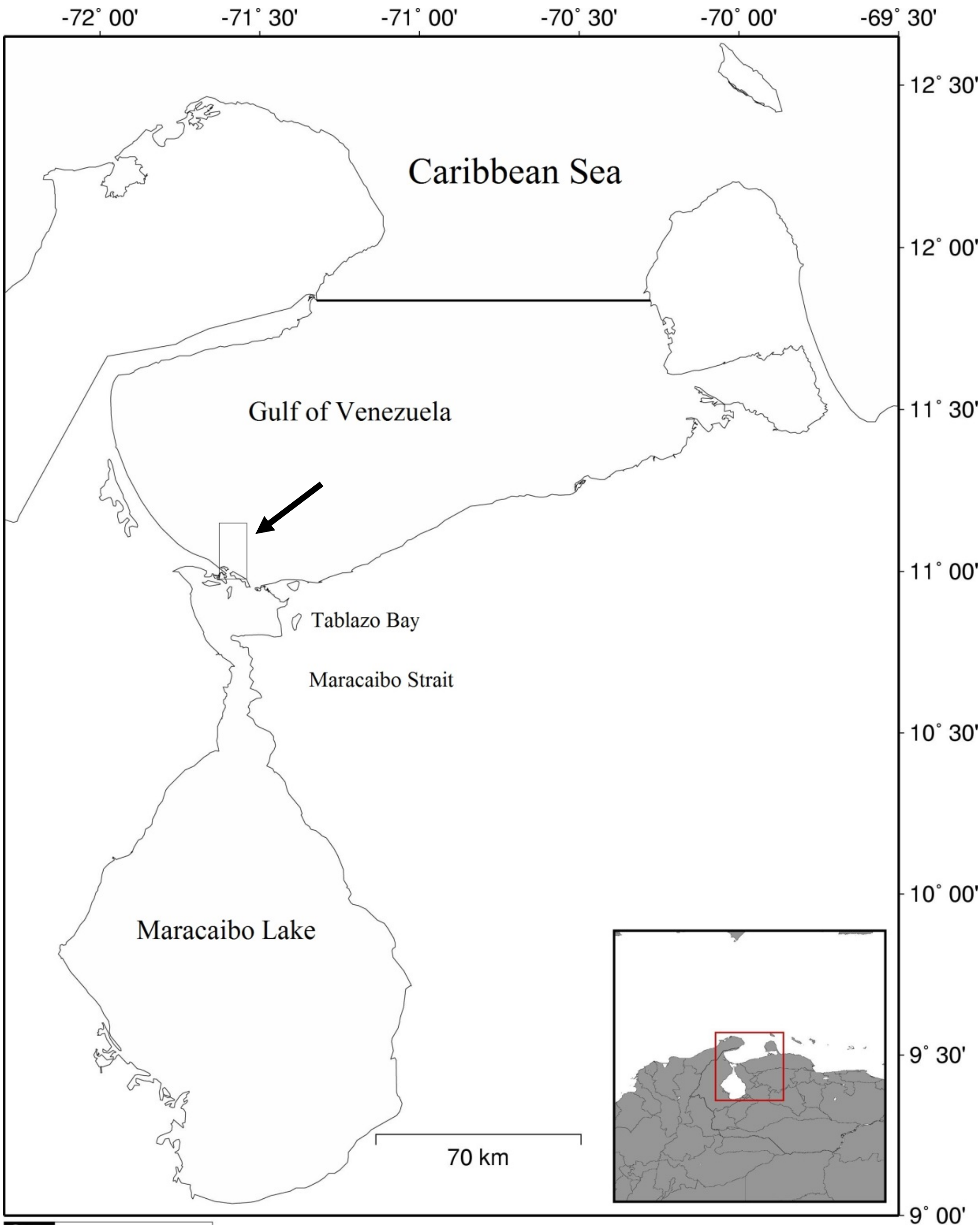

Figure 1. Map of the study area. Hydrographic divisions of the Maracaibo Lake System (Maracaibo, Venezuela) indicating where surveys were conducted (black arrow) (*Source: MapTool*, Version 3.4, SeaTurtle.org, 2015)

– whistles which initially fall in frequency in a span over 1 kHz then rise in frequency over 1 kHz with one inflection point in between the descending and ascending frequencies; *constant* (C) – whistles in which the frequency remained fairly constant during more than 90% of duration of the whistles with any frequency changes spanning less than 1 kHz; and *multi* (M) – whistle contour with a repeating pattern of either an initial rise in frequency then falling, or vice versa, with two or more ascending/descending frequency spans over 1 kHz and at least two inflection points (Figure 2).

The following acoustic parameters were measured: starting frequency (kHz), ending frequency (kHz), maximum frequency (kHz), minimum frequency (kHz), duration (s), and number of inflection points (Figure 2) (Azevedo & Simão, 2002; Azevedo & Van Sluys, 2005). The minimum, maximum, average, and standard deviation (SD) were calculated for each whistle parameter using *Statistica*, Version 8.0 (Weiß, 2007). The mode was calculated for inflection points only.

Results

A total of 289 Guiana dolphin whistles were recorded from analysis of 1,062.6 recorded min (17.71 h). We excluded 38 whistles due to a poor signal-to-noise ratio, leaving 251 high-quality whistles (Table 1).

The number of recorded whistles by Guiana dolphins in the southern Gulf of Venezuela differed among the surveys. In fieldtrip III (Table 1), we recorded the highest number of whistles (n = 98; 39% of total) produced by *S. guianensis*. This is in contrast with fieldtrips II and IV in which no whistles were recorded even though sightings a short distance (~30 m) from the boat were documented. Interestingly, the number of whistles recorded was not associated with number of individuals present at the time of a recording session.

All 251 high-quality whistles could be placed into the six types of whistle categories previously reported for *S. guianensis*. The ascending whistle contour type was the most frequently produced by *S. guianensis* in the Gulf of Venezuela comprising 64.94% of all whistles (n = 163), followed by descending with 12.35% (n = 31), ascending-descending with 8.76% (n = 22), descending-ascending with 7.17% (n = 18), multi contour type with 5.98% (n = 15), and constant contour type representing 0.80% of the total recorded whistles (n = 2).

Guiana dolphins in the Gulf of Venezuela emitted whistles ranging in frequency from 5.31 to 20.88 kHz, zero to four inflection points, and a duration that ranged from 0.05 to 1.19 s. All descriptive statistics of acoustic variables of whistles are shown in Table 2. The most common type of whistle contour was ascending with a frequency that ranged from 9.89 to 14.27 kHz and a mean

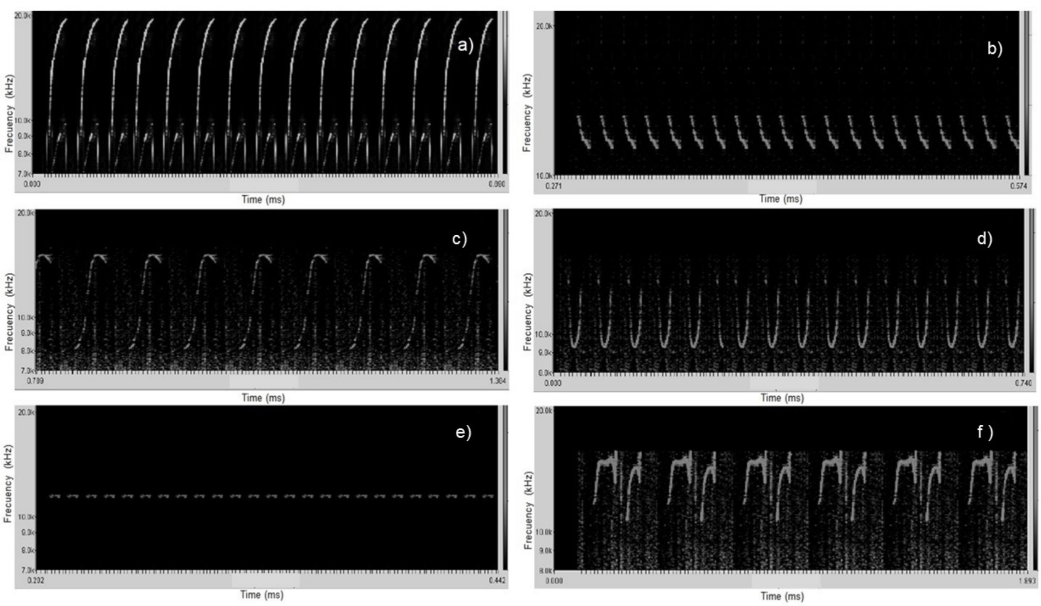

Figure 2. Spectrogram of whistle contour types for *Sotalia guianensis* in the southern Gulf of Venezuela: (a) ascending, (b) descending, (c) ascending-descending, (d) descending-ascending, (e) constant, and (f) multi

Table 1. Survey data (date, sighting duration, number of individuals, recording time, and total number of high-quality whistles) and descriptive statistics (mean, SD, range, and median) for six acoustic parameters (SF = Starting Frequency, EF = Ending Frequency, MaxF = Maximum Frequency, MinF = Minimum Frequency, D = Duration, and IP = Inflection Points) of Guiana dolphin (*Sotalia guianensis*) whistles in the southern Gulf of Venezuela. The duration was measured in s and the frequency parameters in kHz.

						Acoustic parameters					
Fieldtrip	Date (day/ month/ year)	Sighting duration (min)	Number of individuals (n)	Recording time (min)	Total whistles (n) (%)	SF (mean kHz ± SD) (range) (median)	EF (mean kHz ± SD) (range) (median)	MaxF (mean kHz ± SD) (range) (median)	MinF (mean kHz ± SD) (range) (median)	D (mean s ± SD) (range) (median)	IP (mean value ± SD) (range) (mode)
I	3/3/2011	240.0	213	20.89	68 (27.09%)	11.18 ± 2.22 5.31-13.84 12.06	13.67 ± 3.01 10.99-21.63 12.05	14.21 ± 2.68 10.99-21.64 13.18	10.51 ± 1.90 5.31-13.58 11.26	0.27 ± 0.17 0.05-0.32 0.26	0.24 ± 0.46 0-2 0
II	30/4/2011	300.0	5	0.00	0	0	0	0	0	0	0
III	11/5/2011	120.0	155	20.94	98 (39.05%)	10.64 ± 2.25 6.82-9.67 10.69	14.20 ± 2.07 14.37-15.84 14.87	14.49 ± 2.02 14.37-15.84 15.15	10.47 ± 2.12 6.82-9.67 10.67	0.29 ± 0.16 0.24-0.33 0.27	0.44 ± 0.83 0-4 0
IV	3/6/2011	139.8	79	0.00	0	0	0	0	0	0	0
V	14/7/2011	109.8	458	40.39	48 (19.12%)	10.59 ± 3.13 5.42-15.97 10.82	13.99 ± 2.32 7.81-18.14 14.99	14.03 ± 2.33 7.81-16.14 15.49	10.51 ± 3.08 5.42-15.54 10.82	0.26 ± 0.11 0.09-0.63 0.24	0.04 ± 0.20 0-1 0
VI	1/8/2011	153.0	339	9.53	37 (14.74%)	9.34 ± 2.33 5.47-14.81 9.39	12.05 ± 2.83 7.84-15.97 11.90	12.09 ± 2.79 8.10-15.97 11.91	9.30 ± 2.30 5.47-14.81 9.40	0.23 ± 0.11 0.09-0.50 0.20	0.42 ± 0.89 0-4 0
	Total	**1,062.6**	**1,249**	**91.75**	**251**	**10.48 ± 2.65** **2.22-15.7** **10.83**	**13.56 ± 2.88** **2.07-21.64** **13.86**	**13.86 ± 2.82** **2.03-21.64** **14.52**	**10.21 ± 0.15** **1.89-15.54** **10.76**	**0.27 ± 0.15** **0.05-1.19** **0.24**	**0.32 ± 0.71** **0-4** **0**

duration of 0.24 s (ranging from 0.05 to 0.62 s). The type of whistle contour with the longest duration was constant (0.27 s ± 0.14) (Table 2).

The average duration time of all whistles was 0.27 s (± 0.14) (Table 1). However, the contour types with one or more inflection points (multi, ascending-descending, and descending-ascending) all have greater mean duration times than the overall mean (Table 2).

Discussion

This study demonstrates that the Venezuelan Guiana dolphins primarily emit an ascending whistle contour type with a maximum frequency of 20.88 kHz. These results are similar to those reported in Brazil (Azevedo & Van Sluys, 2005; Guimarães de Andrade et al., 2015) and Costa Rica (May-Collado & Wartzok, 2009) in which *ascending* was the most commonly recorded whistle structure.

Overall, the whistles' contour from Guiana dolphins is simple and shows a low number of inflection points. Privari & Rosso (2005) and Azevedo & Van Sluys (2005) reported high rates of whistles without inflection points (85% and 92.5%, respectively), similar to our results (78.09%). In previous studies, Guiana dolphins have been reported to produce whistles with up to nine inflection points; however, the occurrence of these whistles was relatively rare (Erber & Simão, 2004).

Differences between the observed range of frequencies in this study and similar studies of other populations of *S. guianensis* may be due to the limitations in the range of frequency detectable by the equipment used. For instance, May-Collado & Wartzok (2009), using a broadband recording system with a sample rate ranging from 1 to 384 kHz, found whistles with maximum frequencies up to 48.40 kHz. Rossi-Santos & Podos (2006) proposed the possibility of a latitudinal variation (South-North) among initial and minimal frequencies reported for the Brazilian populations. However, Deconto & Monteiro-Filho (2013), using a recording system with a higher frequency bandwidth, found that Guiana dolphins in Brazil emit whistles with frequencies similar to those described in Costa Rica by May-Collado & Wartzok (2009). These results indicate that such latitudinal variation in frequency is likely an artefact of differences between recordings systems.

Based on the work by May-Collado & Wartzok (2009), we predict that Guiana dolphins in the southern area of the Gulf of Venezuela are likely to produce high-frequency whistles. Therefore, the variation between the whistle frequencies among several populations of Guiana dolphins is likely related to environmental characteristics (Deconto & Monteiro-Filho, 2013) and behavioural state (May-Collado, 2013). As we did not record this information during our study, we are limited in the extent to which we can draw comparisons with

Table 2. Whistle contours and acoustic parameters analysed for the Guiana dolphin in the southern Gulf of Venezuela. Types of contours are labelled as follows: A = ascending, D = descending, A-D = ascending-descending, D-A = descending-ascending, C = constant, and M = multi. Acoustic parameters are labelled as follows: SF = Starting Frequency, EF = Ending Frequency, MaxF = Maximum Frequency, MinF = Minimum Frequency, D = Duration, and IP = Inflection Points.

Contour types	SF (kHz) (mean) (range)	EF (kHz) (mean) (range)	MaxF (kHz) (mean) (range)	MinF (kHz) (mean) (range)	D (s) (mean) (range)	IP (mean) (range)
A	9.89 (5.31-15.54)	14.27 (7.81-20.88)	14.27 (7.81-20.88)	9.89 (5.31-15.54)	0.24 (0.05-0.62)	0 (0-0)
D	12.73 (10.87-15.96)	11.62 (10.05-14.10)	12.73 (10.87-15.96)	11.62 (10.05-14.10)	0.18 (0.05-0.46)	0 (0-0)
A-D	10.96 (6.64-15.35)	12.74 (7.83-15.35)	13.76 (8.10-15.91)	10.72 (6.64-15.35)	0.44 (0.24-0.83)	1 (1-1)
D-A	12.61 (9.80-15.77)	13.27 (10.90-16.22)	13.66 (11.38-16.22)	11.24 (8.79-15.35)	0.32 (0.15-1.19)	1 (1-1)
C	13.12 (11.43-14.80)	13.12 (11.43-14.80)	13.12 (11.43-14.80)	13.12 (11.43-14.80)	0.22 (0.13-0.32)	0 (0-0)
M	10.18 (6.11-14.80)	13.35 (8.13-17.15)	13.72 (8.13-17.15)	10.06 (6.11-14.80)	0.45 (0.2-0.63)	2.28 (1-4)

other studies. Future studies should increase the sampling rate in order to capture the entire whistle repertoire for this species in the study area.

It is worth noting that areas where dolphin sightings were made but whistles were not detected by our recording systems might be due to signal masking by the active boat traffic within the southern Gulf of Venezuela. This area is frequently utilised by boats, ships, and tankers for the transportation of tourists, goods, and oil (Rodríguez, 2001), as well as by small-scale artisanal fishing conducted daily by the inhabitants of the nearby islands (Wildermann et al., 2009). These nautical disturbances may cause a significant amount of ambient noise that could affect the whistle structure of Guiana dolphins in the Gulf of Venezuela (May-Collado, 2013; Papale et al., 2015); however, this requires further evaluation.

The average duration of whistles produced by the population of *S. guianensis* in the southern Gulf of Venezuela (0.27 s) is relatively shorter than those reported by Erber & Simão (2004) by Guiana dolphin populations in Brazil (1 s). Several authors (Bazúa-Durán, 2004a; Erber & Simão, 2004; Deconto & Monteiro-Filho, 2013; May-Collado, 2013; Santos et al., 2013) suggested that this difference may be related to various factors such as the behaviour exhibited by dolphins, habitat disturbance (e.g., anthropogenic disturbances, vessel traffic, and fishing), or the characteristics of each population (e.g., dialect). These results might also indicate that the absence of whistles with high numbers of inflection points could be related to the short whistle duration analysed, which may have limited the number of modulation frequencies (Azevedo & Simão, 2002).

The mean ending frequency of the Guiana dolphin whistles in the southern Gulf of Venezuela was higher than the mean starting frequency (Table 1). Previous studies with *S. guianensis* have demonstrated that this species emits different types of whistles and that they have significant variations in their frequencies. The majority of these studies assert that whistles with an increasing frequency (ascending) are most commonly emitted and registered among the repertoire of this species (Norris et al., 1972; Simão et al., 1988; Ding et al., 2001; Monteiro-Filho & Monteiro, 2001; Azevedo & Simão, 2002; Erber & Simão, 2004; Azevedo & Van Sluys, 2005; Privari & Rosso, 2005; Simão & Azevedo, 2006; Ansmann et al., 2007). This characteristic of the whistle repertoire is also shared with other species such as the spinner dolphin (*Stenella longirostris*; Bazúa-Durán, 2004a) and the bottlenose dolphin (*Tursiops truncatus*; Bazúa-Durán, 2004b), among others (Tyack, 1986).

Further studies should record the complete whistle repertoire of the Guiana dolphin in this study area using a broadband recording system. Behavioural observations should also be documented in order to facilitate the formulation of accurate descriptions of their whistle structure under different behavioural patterns. Additionally, further studies about the Guiana dolphin's habitat in the Gulf of Venezuela needs to be acoustically characterised in order to evaluate the potential impacts that ambient noise may have on the acoustic structure of the Guiana dolphin's whistle.

We acknowledge that limitations in the recording system bandwidth and lack of behavioural and environmental context hinder comparisons with studies in other populations; however, we present evidence that the Guiana dolphins in our study area emit primarily ascending whistles, which is consistent with the results of other studied populations in Brazil and Costa Rica. The simplicity of these whistles in terms of modulation is likely limited by the short duration of the whistle. This study comprises the first acoustic description of Guiana dolphin whistles in the Gulf of Venezuela.

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