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Whistles produced by marine tucuxi dolphins (*Sotalia fluviatilis*) in Guanabara Bay, southeastern Brazil

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Abstract

Underwater recordings of marine tucuxi dolphin (*Sotalia fluviatilis*) sounds were conducted from March 1998 to May 1999 in Guanabara Bay (22°57′S; 43°10′W), southeastern Brazil. The frequency response of the system was 60 Hz–18 kHz (± 3 dB), limited by the cassette recorder. A total of 5086 whistles were analysed. The following acoustic parameters were measured for each whistle: start frequency (kHz), end frequency (kHz), minimum frequency (kHz), maximum frequency (kHz), frequency range (kHz), duration (ms), and number of inflection points. Whistles that presented 0 and 1 inflection point corresponded to 82.6%. Of all whistles, 1372 (26.9%) were tones with harmonics. The whistles duration varied between 10 and 852 ms (102.5 ± 81.0), with the start frequency between 900 Hz and 17.9 kHz (7.9 ± 2.9) and the end frequency from 500 Hz to 18.0 kHz (12.8 ± 4.5). This is the most extensive analysis of tucuxi whistles. Spectrograms and acoustic parameters of the whistles produced by *Sotalia* are presented.

Key words: tucuxi, *Sotalia fluviatilis*, whistles, Brazil, spectrograms, acoustic parameters.

Introduction

The sound emission characteristics and functions of the tucuxi (*Sotalia fluviatilis*) are poorly known. Two ecotypes are considered for this species: the marine tucuxi occurs exclusively in Western Atlantic coastal waters from Santa Catarina (Brazil) to Honduras (da Silva & Best, 1996), while the riverine ecotype is endemic to the Amazon River drainage (da Silva & Best, 1996). Norris *et al.* (1972), studying the river ecotype, first described this species' sound emissions. Nakasai & Takemura (1975) also studied the river ecotype in the Amazon Basin. Since the 1980s, most bioacoustic research on *Sotalia* has focused on echolocation (Wiersma, 1982; Alcuri & Busnel, 1989; Kamminga *et al.*, 1993) and the auditory capacity of this species (Sauerland & Dehnhardt, 1998). Wang (1993) and Wang *et al.* (2001) analysed the species' whistles in Amazon River tributaries. Sound emissions in the marine ecotype were first studied in the 1990s (Pereira, 1997; Figueiredo, 1997; Azevedo, 2000; Monteiro-Filho & Monteiro, 2001). However, the results presented do not effectively characterize the species' sound emissions.

In the present study 5086 whistles of marine tucuxi in its natural environment (Guanabara Bay, Brazil) were analysed, this being the most representative characterization of this species' acoustic signals.

Materials and Methods

Recordings

Acoustic recordings of underwater sounds from marine tucuxi were made over eleven days, from March 1998 to May 1999 in Guanabara Bay

Table 1. Number of inflection points of the marine tucuxi dolphin's whistles in Guanabara Bay (n=5086).

Whistle contour types	n	%
No inflection point—rising frequency	2011	39.5
No inflection point—falling frequency	203	4.0
No inflection point—low frequency range	544	10.7
One inflection point	1443	28.4
Two inflection points	718	14.1
Three inflection points	126	2.5
Four inflection points	29	0.6
Five inflection points	9	0.2
Six inflection points	3	~0.01

Table 2. Descriptive statistics for acoustic parameters of marine tucuxi dolphin's whistles in Guanabara Bay (n=5086). The frequency variables were measured in kHz and the duration in ms.

Acoustics parameters	Range	Mean	Standard deviation	Coefficient of variation
Start frequency	0.9–17.9	7.9	2.9	36.7
End frequency	0.5–18.0	12.8	4.5	35.2
Minimum frequency	0.5–16.5	7.6	2.9	38.2
Maximum frequency	1.6–18.0	13.0	4.1	31.5
Duration	10–852	102.5	81.0	79.4
Inflections	0–6	0.7	0.9	128.6

(22°57′S; 43°10′W), Rio de Janeiro State, southeastern Brazil. The effort was not similar each day. All the field surveys were made from a powered boat, when the weather conditions allowed (Beaufort sea states ≤3). Recordings were made with the engine off. All groups recorded included adults, juveniles, and calves. Group sizes varied from 6 to about 50 individuals (mean=20.4; s.d.=12.8). Recordings were made of dolphin herds engaged in a variety of conditions and activities, including feeding, socializing, traveling, and travel/feeding (derived from Shane, 1990). Underwater sounds of dolphins were recorded at a 3-m depth using a Celesco LC-10 omnidirectional hydrophone (flat frequency response up to 20 kHz), with a custom built preamplifier, and Sony WM-D3 cassette tape recorder. The system frequency response was 60 Hz–18 kHz (± 3 dB), limited by cassette recorder.

Acoustic analyses

The acoustic recordings were digitized as spectrograms using *Cool Edit Pro 1.2* (*Syntrillium Software Corporation*; sampling at 44.1 kHz, 16 bits, FFT size: 512, Blackmann window). Whistles were defined as continuous, narrow-band sound emissions. For each whistle the following parameters of the fundamental frequency were measured: start frequency (kHz), end frequency (kHz), minimum frequency (kHz), maximum frequency (kHz), frequency range (kHz), duration (ms) and number of inflection points. These parameters were measured with the cursors directly from the spectographic display.

The acoustic characteristics of the whistles were analysed only when all parameters of a spectral contour were distinctly measurable. The descriptive statistics for all measured variables includes the minimum, maximum, means, standard deviation, and coefficient of variation.

Over the whole set of whistles, distributions (Zar, 1999) were calculated for start frequency, end frequency, frequency range, and duration. The paired-sample *t* test (Zar, 1999) was applied to verify if the mean of the end frequency of all whistles analysed was significantly different from the start frequency.

Results

A total of 5086 whistles were recorded over 687 min. Whistles with up to six inflection points were found. Whistles with 0 and 1 inflection point corresponded to 82.6% of all whistles (n=4201). Those with more inflections were emitted infrequently (Table 1). Descriptive statistics of all measured parameters of whistles are shown in Table 2. Representative spectrograms of some whistles can be found in Figure 1.

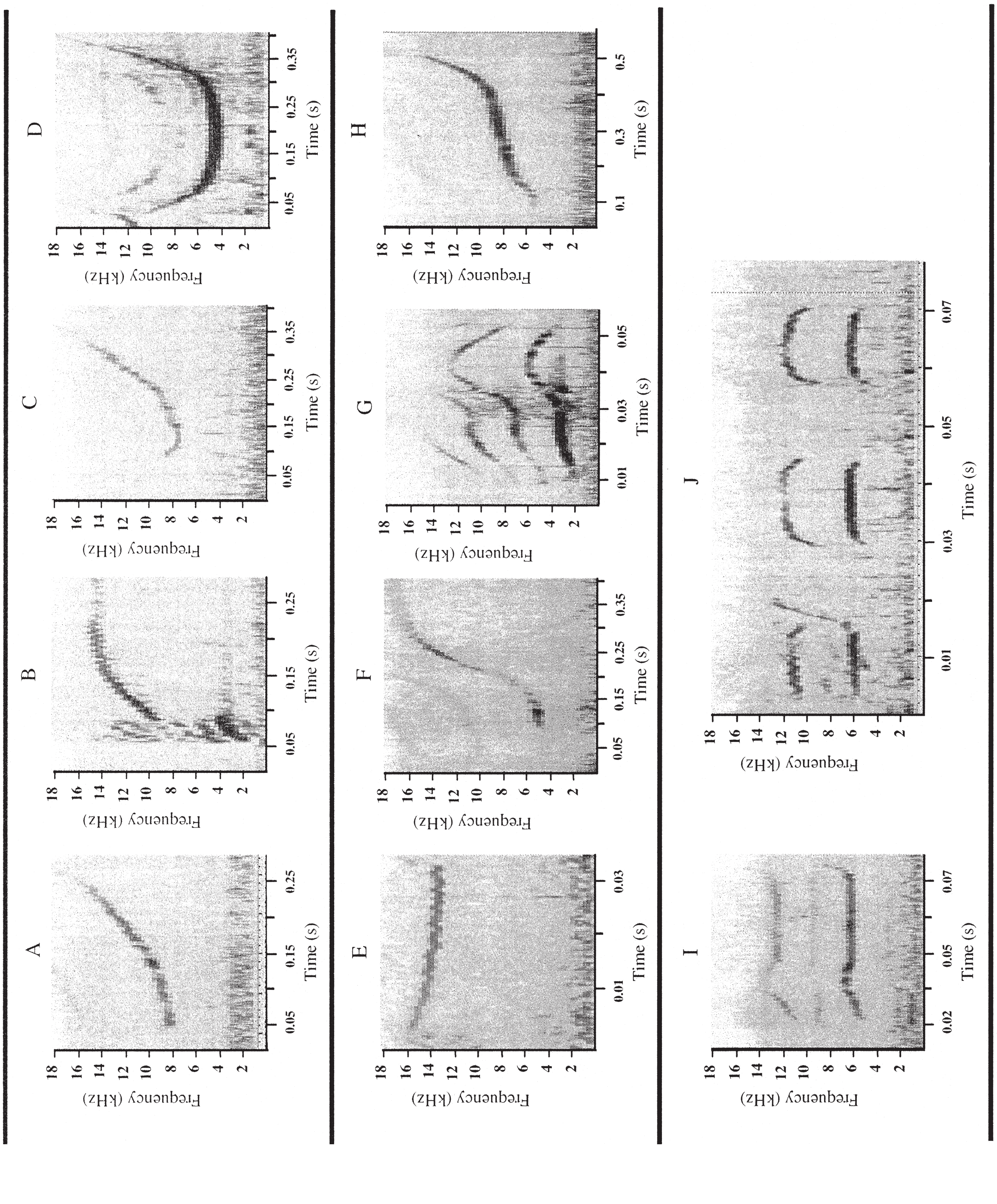
Of all whistles, 1372 (26.9%) were tones with harmonics. Distribution of start frequency values between 4.1 and 12.0 kHz corresponded to 82.4% (Figure 2A). Roughly 75% of the end frequencies were between 10.1 and 18.0 kHz (Figure 2B). Frequency range values presented a relative occurrence of 22.1% up to 2.0 kHz and 87.3% below to 10.0 kHz (Figure 2C). Whistles with duration <300 ms had a relative occurrence of 97.3%; 62.9% of whistles lasted <100 ms (Figure 2D).

By means of the paired-sample *t*-test ($P<0.001$), it was verified that the end frequency was significantly different from the start frequency. The whistles' average end frequency was higher than the average start frequency (Table 1).

Discussion

Studies on bioacoustics of odontocetes in their natural environment have shown a diverse repertoire of whistles, in which some types are common

Figure 1. Spectrogram representation of whistle contour types emitted by marine tucuxi dolphins (*Sotalia fluviatilis*) in Guanabara Bay, Rio de Janeiro, Brazil.


A
B
C
D
E
F
G
H
I
J
Frequency (kHz)
Time (s)

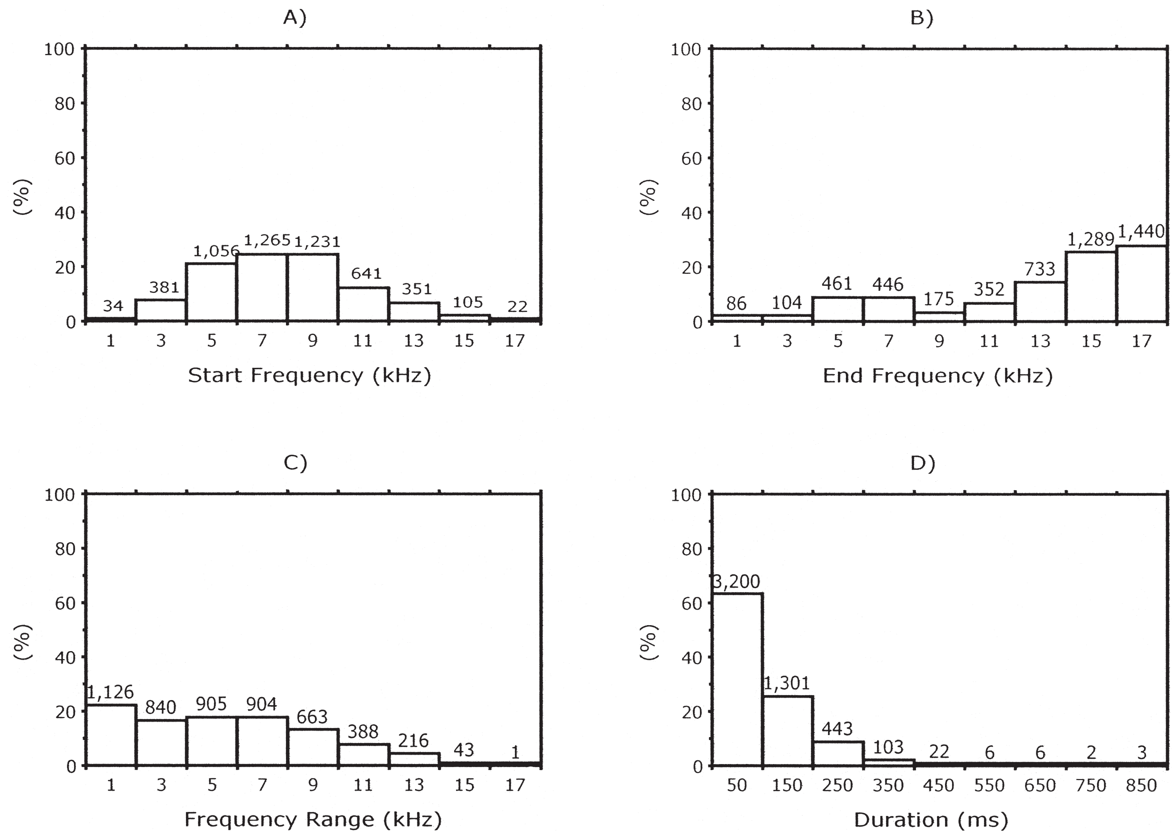


Figure 2. Histograms of the acoustic parameters of marine tucuxi dolphin whistles (n = 5086) in Guanabara Bay (RJ, Brazil). Data labels represent the number of whistles into each category. (A) start frequency; (B) end frequency; (C) frequency range and (D) duration.

to several species (Dreher & Evans, 1964). Our findings showed that marine tucuxi produce whistles with similar shape to others delphinids as was pointed-out by Pereira (1997). In general, whistles of marine tucuxi in Guanabara Bay are simple in form. Some other delphinid species produce whistles longer in duration and contain a greater number of inflection points (Matthews *et al*., 1999). Our results showed that, although this population has a varied repertoire of whistles, those with 0 and 1 inflection point are preferably emitted. This feature is related to the short duration of whistles analysed, which may have limited the number of frequency modulations.

Analysis of acoustic variables of whistles emitted by tucuxi in Guanabara Bay showed higher frequency and longer duration than those reported in the literature for this species. Figueiredo (1997), who analysed marine tucuxi's ascending frequency whistles in Sepetiba Bay (Rio de Janeiro State), reported frequency variations between 0.1 and 17.5 kHz and durations between 3 and 399 ms (n=688). Norris *et al*. (1972) described whistles about 0.2 s long, with most frequencies between 10 and 15 kHz (n=not provided). Nakasai & Takemura (1975) found whistles from 0.1 to 0.5 s and frequencies ranging from 5 to 16 kHz, with a higher occurrence between 10 and 12 kHz (n=not provided). Therefore, the wider variation of *Sotalia fluviatilis* whistle duration and frequency variables in Guanabara Bay seems to result from a larger sample size, which provided more representative information on the acoustic parameters of the species' sound emissions.

In works of Wang (1993) and Wang *et al*. (2001) one finds more detailed information on the acoustic variables of the whistles of the *Sotalia* riverine ecotype. In the 155 whistles analysed by those authors, some frequency parameters showed higher values than the ones from Guanabara Bay, reaching 23.8 kHz. Differences seem to be the result of the differences between frequency range measured, i.e., our recording system upper limit was only 18 kHz. The end frequency of some whistles was 18 kHz, indicating that these signals surpassed the upper limit of the recording system. The duration of the whistles in Guanabara Bay is much shorter than those reported by Wang (1993). This author pointed-out an average duration of about 400 ms. Maybe this difference in duration is related to different behavioural contexts or to the inclusion of several chirps in the present analysis. Despite differences in recording and analysis, the hypothesis of the existence of actual differences in whistles characteristics between the riverine and marine ecotypes must be investigated. The two ecotypes live in different habitats and ecology could exert a considerable influence on the evolution of sound communication (Van Parijs *et al*., 2000).

The end frequency of marine tucuxi whistles in Guanabara Bay was on average higher than the start frequency. Studies conducted with tucuxi have shown that the species preferably emits whistles of rising frequency. Norris *et al*. (1972) noticed only rising whistles. Wang (1993) and Wang *et al*. (2001), also studying the river ecotype, found the mean end frequency was higher than the mean start frequency. In Sepetiba Bay, one of the gathering areas of marine tucuxis on the coast of Rio de Janeiro State, Simão *et al*. (1998) pointed-out that 79.6% of the whistles analysed showed rising frequency. Nevertheless, the relation between start and end frequency may vary among populations of the same species (Wang *et al*. 1995). The statement that tucuxi's whistles in Guanabara Bay are mainly of rising frequency represents an important characteristic of this population and, consequently, may be a tool to differentiate *S. fluviatilis* populations.

Extremely varied whistles were found, with high variation coefficients for the acoustic parameters. Whistles frequency parameters presented the lower variation coefficients. Duration and number of inflections presented the highest variation coefficients, showing a rather high variability in these whistles' acoustic parameters. This high variability in duration and number of inflections may be the result of an individual modulation of these parameters, to transmit information in different contexts or individual differentiation among dolphins, as has been suggested for some delphinids (Steiner, 1981; Wang *et al*., 1995).

This is the most representative characterization of tucuxi's whistles. The acoustic parameters of this signal must be investigated in other tucuxi's populations. The intra-specific variability and exact social function of the whistles are still unknown and future studies need to be developed to understand these bioacoustical features.

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