Characteristics of whistles from resident bottlenose dolphins (*Tursiops truncatus*) in southern Brazil

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Little is known of the whistles produced by bottlenose dolphins in the South Atlantic Ocean. A total of 788 whistles were recorded from free-ranging bottlenose dolphins in Patos Lagoon estuary, southern Brazil. The mean number of whistles emitted per minute per animal was 0.8. Bottlenose dolphins emitted a varied repertoire of whistles, in which those with more than one inflection point were the most frequent and there was no predominance of ascending or descending whistles. Whistles recorded had a great frequency range, between 1.2 and 22.3 kHz. Whistle duration was 553.3 (±393.9 ms) and 66.6% of the whistles lasted <800 ms. Differences in the mean values of the whistles' characters were found between this study and other values previously reported for *Tursiops*. Bottlenose dolphins in the Patos Lagoon estuary emitted repeated whistle contours and individuals may be sharing some whistle types, as it has been suggested for *Tursiops*. *© 2007 Acoustical Society of America.* [DOI: 10.1121/1.2713726]

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I. INTRODUCTION

Bottlenose dolphins (*Tursiops* spp.) are cosmopolitan in distribution. *Tursiops truncatus* is found in most of the world's warm temperate to tropical seas, in coastal and offshore waters, while *T. aduncus* is limited to the coastal waters of the Indian and Western Pacific Ocean (Wells and Scott, 2002). The whistles of bottlenose dolphins, especially *T. truncatus*, have been studied extensively from captive or temporally restrained animals (e.g., Caldwell *et al.*, 1990; McCowan and Reiss, 2001; Watwood *et al.*, 2004) and free-ranging individuals (e.g., Sayigh *et al.*, 1990; Janik, 2000). These authors have reported mainly on signature whistle hypothesis, mimicry, and evidences for vocal learning.

Acoustic parameters of whistles, such as frequency and duration components and number of inflection points, have been used for characterization of whistles of delphinid species, allowing comparisons among groups and populations (Wang *et al.* 1995; Rendell *et al.* 1999; Bazúa-Duran and Au, 2004). However, only a few populations of free-ranging bottlenose dolphins have had their whistles characterized in terms of frequency and duration ranges, geographic variation, and others (e.g. Steiner, 1981; Schultz and Corkeron, 1994; Wang *et al.*, 1995; Morisaka *et al.*, 2005). Little is known of the whistles produced by bottlenose dolphins in the South Atlantic Ocean. The only published account by Wang *et al.* (1995), revealed values for ten variables of 110 whistles of bottlenose dolphins in Argentina. The authors reported frequency parameters ranging between 1.17 and 17.11 kHz and mean duration of 1.14 s (±0.49).

In southern Brazil, the Patos Lagoon estuary and adjacent coastal waters are inhabited by a small resident population of bottlenose dolphins, estimated at 83 individuals (95% CI=78 to 88) (Dalla Rosa, 1999). The dolphins are frequently found near the estuary mouth, and use the area for feeding, traveling, socializing, and resting (Möller, 1993). The average group size is four individuals (Dalla Rosa, 1999). Newborn calves are common in spring and summer (Möller, 1993). This paper describes the characteristics and presents sonograms of whistles recorded from free-ranging bottlenose dolphins in Patos Lagoon estuary.

II. METHODOLOGY

Acoustic recordings of underwater sound produced by bottlenose dolphins were made at Patos Lagoon estuary, southern Brazil (Fig. 1), between 4 and 7 March 2002. All surveys were carried out under similar weather conditions (Beaufort sea states ≤2), in a small outboard-powered boat about 6 m in length. Dolphin group was an aggregation of two or more dolphins in apparent association within 100 m of each other. Trying to maximize data representativeness, we avoided oversampling groups/individuals during surveys, recording groups at different localities. Acoustic recordings were made with the engine off and were monitored by head-

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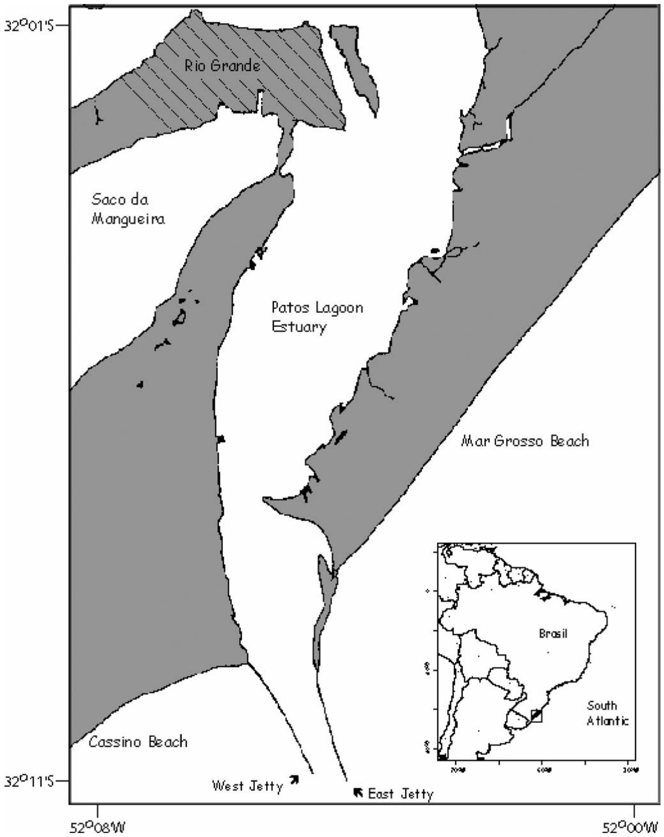

FIG. 1. Map of the Patos Lagoon Estuary, southern Brazil, where acoustic recordings of underwater sound produced by bottlenose dolphins were made.

phones. Whenever dolphin sounds became weak, we stopped recording and repositioned the boat. The recording system consisted of a High Tech Inc. hydrophone (model HTI-96-MIN, frequency response: 5 Hz to 30 kHz ±1.0 dB, −165 dB *re*: 1 V/μPa) and a digital audio tape recorder SONY TCD-D8 with upper frequency limit of 24 kHz (sampling rate of 48 kHz).

DAT recordings of each group sampled were redigitized using the program Cool Edit Pro (Syntrillium Software) at a sampling rate of 48 kHz, 16-bit resolution. Whistles were defined as continuous, narrow-band sound emissions with or without harmonics (Popper, 1980). Whistles were analyzed using Cool Edit Pro with a FFT size of 512 points, an overlap of 50%, and using a Hamming window.

The contour of each whistle was determined by visual analyses of the frequency modulation by at least two authors and was then categorized into the following broad classes: ascending (whistles rising in frequency and no one inflection point), descending (whistles falling in frequency and no one inflection point), ascending-descending (initial rising in frequency, one inflection point, then falling in frequency), descending-ascending (initial falling in frequency, one inflection point, then rising in frequency), constant (whistles in which the frequency changes 1000 Hz or less during more than 90% of duration), and multi (Fig. 2).

Seven acoustic parameters from the fundamental component of each whistle were measured: starting frequency (SF), ending frequency (EF), minimum frequency (MinF), maximum frequency (MaxF), frequency range (MaxF-MinF), duration (DUR), and number of inflection points (defined as points where the whistle contour changed from ascending to descending or vice versa). The frequency variables were measured in kHz and the duration in milliseconds. We calculated the mean frequency (MeF) as the average of SF, EF, MinF, and MaxF. These whistle parameters were chosen to be consistent with previous studies of bottlenose dolphins (e.g., Wang *et al.*, 1995; Morisaka *et al.*, 2005) and other dolphin species (e.g., Bazúa-Duran and Au, 2004; Azevedo and Van Sluys 2005). We only used whistles for which all parameters of a spectral contour were distinctly measurable.

The descriptive statistics for all measured variables includes the minimum values, maximum values, 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 analyzed was significantly different from the start frequency.

III. RESULTS

Eleven groups of bottlenose dolphins were recorded. Group size ranged from 2 to 15 members, including adults, juveniles, and mother-calf pairs. We estimate that about 40 different dolphins were recorded and, probably, some individuals were recorded more than one time. Animals were engaged in feeding, traveling, travel/feeding, and resting behaviors. A total of 982 whistles were recorded over 288 min, which represents 0.8 whistles per minute per individual. Of that total ($N=982$), 788 whistles had adequate signal quality for acoustical analysis. From the 788 whistles, 394 (50%) were tones with harmonics. Whistles with up to 14 inflection points were found, but those with zero up to four inflection points corresponded to 94% of all whistles.

Whistle duration was 553.3 ms (±393.9 ms) and 66.6% of the whistles lasted <800 ms. The average minimum frequency was 5.96±2.15 kHz and 83.6% of the whistles had MiF between 2.1 and 8.0 kHz. The maximum frequencies averaged 12.21±3.20 kHz and values between 12.1 and 16.0 kHz corresponded to 64.2%. The frequency range of whistles averaged 6.25±3.34 kHz. The average mean frequency was 8.70±2.15 kHz and 67.4% of the whistles had MeFs ranging from 6.1 to 10.0 kHz. Descriptive statistics of all measured whistle parameters are shown in Table I. The paired-sample *t* test ($t=0.526$; df=787; $P=0.599$) indicated that the end frequency (8.37±3.70) was not significantly different from the start frequency (8.28±3.11).

Whistles categorized as multi (more than one inflection point) were the most common and corresponded to 31.5% of all whistles. Ascending-descending (23.5%), ascending (17.3%), and descending (14.2%) whistles also were frequently emitted. Descending-ascending (7.4%) and constant (6.1%) whistles were less frequent. Descriptive statistics for acoustic parameters of bottlenose dolphin's whistles for each whistle category are shown in Table II.

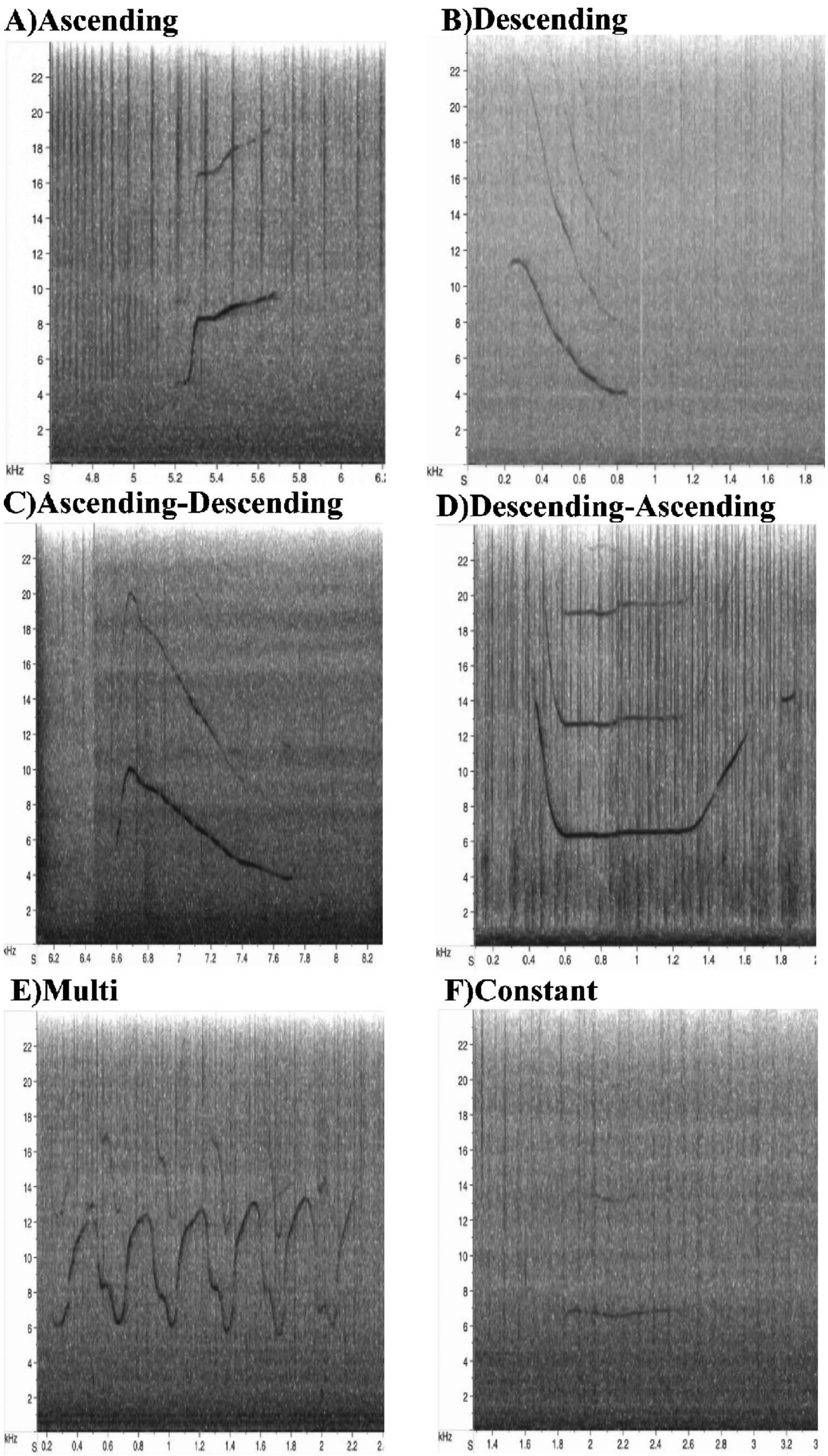

FIG. 2. The six classes to which bottlenose dolphin whistles contours were categorized. *X* axis=time (s), *Y* axis=frequency (kHz).

TABLE I. Descriptive statistics for acoustic parameters of bottlenose dolphin whistles in the Patos Lagoon estuary, southern Brazil (N=788). The frequency variables were measured in kHz and the duration in milliseconds.

Acoustic parameters	Range	Mean (±S.D.)	Coefficient of variation (%)
Starting frequency	3.1–20.8	8.28 (3.11)	37.6
Ending frequency	2.8–22.3	8.37 (3.70)	44.2
Minimum frequency	1.2–17.2	5.96 (2.15)	36.1
Maximum frequency	3.6–22.3	12.21 (3.20)	26.2
Frequency range	0.1–16.6	6.25 (3.34)	53.4
Mean frequency	3.5–18.0	8.70 (2.15)	24.7
Duration	48–2458	553.3 (393.9)	71.2
Inflections	0–14	1.42 (1.85)	92.5

Similar whistle contours were found in 101 whistles, totaling 435 whistles (55.2%) with at least one repetition. Whistle contours were repeated in different groups and different days. The most repeated whistle contours occurred 25 times, and seven had at least ten repetitions.

IV. DISCUSSION AND CONCLUSIONS

Bottlenose dolphins in Patos Lagoon estuary emitted a varied repertoire of whistles, in which those with more than one inflection point were the most frequent. This is in accordance with previous studies of free-ranging bottlenose dolphins, which reported mean inflection points between 0.78 (Morisaka *et al.*, 2005) and 2.86 (Steiner, 1981). Whistles recorded in our study had a great frequency range, but, in general, were similar to published frequency ranges for this genus. Schultz and Corkeron (1994) reported bottlenose dolphin whistles with a low frequency of 0.8 kHz in Morenton Bay (Australia), and Wang *et al.* (1995) found high frequency reach up to 21.6 kHz. The range of duration of bottlenose dolphin whistles sampled was also in agreement with previous studies. Duration generally varies greatly among bottlenose whistles, with changes as great as 0.37 s (Morisaka *et al.*, 2005) to 1.30 s (Wang *et al.*, 1995). Both parameters, duration, and inflection points had the highest coefficients of variation. This high intraspecific variability in both duration and number of inflection points may result from an individual modulation of these parameters so that information may be transmitted from different contexts or from different individuals (Steiner, 1981; Wang *et al.*, 1995; Rendell *et al.*, 1999; Bazúa Duran and Au, 2004).

Some whistle characters observed in this study differed significantly from those values previously reported for *Tursiops* spp. (Table III). The duration of whistles recorded at Patos Lagoon estuary differed from all areas, except for one location in Japan. Comparisons of the number of inflection points and frequency variables showed similarities and differences with other populations of *T. truncatus* and *T. aduncus*. Some studies have indicated that species-specific variables have low intraspecific and high interspecific variation (Steiner, 1981; Wang *et al.*, 1995), such that we would expect to observe similarities with *T. truncatus* rather than with *T. aduncus*. These species are closely related (Rice, 1998), potentially explaining the increase in intraspecific variability for some comparisons. Other, nonheritable, factors also may be causing increased intraspecific variability. Variation of acoustic whistle parameters may be related to adaptation to background noise (Rendell *et al.*, 1999). For example, Wang *et al.* (1995) suggested that in bottlenose dolphin whistles, higher frequencies, longer durations, and greater numbers of inflections are associated with localities of higher background noise. Additionally, social relationship and behavioral states at recording time may also be responsible for differences and similarities among the studies. Spinner dolphins show high variation in whistle duration (Bazúa Duran and Au, 2002), which might be attributed to differences in group size and general behavioral states.

Bottlenose dolphins in the Patos Lagoon estuary emitted repeated whistle contours. Several authors (e.g., Caldwell *et al.*, 1990; Sayigh *et al.*, 1990; Janik, 2000; Watwood *et al.*, 2004) have suggested that the production of repeated whistles by bottlenose dolphins may indicate the use of sig-

TABLE II. Minimum, maximum, mean, and standard deviation values for acoustic parameters of bottlenose dolphin whistle categories in the Patos Lagoon estuary, southern Brazil. The frequency variables were measured in kHz and the duration in seconds.

Parameters	Ascending (N=137)	Descending (N=112)	Ascending-descending (N=185)	Descending-ascending (N=58)	Constant (N=48)	Multi (N=248)
Duration	0.05–1.15	0.07–1.07	0.12–1.29	0.2–1.53	0.05–0.82	0.18–2.46
	0.30±0.19	0.41±0.20	0.49±0.22	0.44±0.28	0.26±0.18	0.88±0.47
Starting frequency	3.2–12.9	4.4–20.8	3.6–16.5	3.9–17.1	3.5–14.4	3.1–17.7
	6.9±2.30	11.07±3.15	8.1±2.72	9.4±3.20	6.9±3.01	7.9±2.92
Ending frequency	6.0–20.4	3.2–14.2	2.8–15.6	3.8–22.3	3.5–14.5	2.9–21.0
	12.41±2.86	5.34±1.64	7.2±3.26	9.5±3.70	7.0±2.99	8.5±3.37
Minimum frequency	3.2–12.9	3.2–14.2	1.4–12.9	3.2–12.3	3.4–14.0	1.2–17.2
	6.9±2.30	5.34±1.64	6.1±2.09	6.0±2.16	6.6±3.04	5.6±1.90
Maximum frequency	6.0–20.4	4.4–20.8	5.8–20.3	6.8–22.3	3.6–14.5	7.1–21.0
	12.41±2.86	11.07±3.15	13.2±2.74	11.4±3.11	7.2±3.03	13.1±2.66
Mean frequency	4.7–15.0	4.1–15.2	4.5–13.4	5.5–15.7	3.5–14.2	4.7–17.9
	9.5±2.19	8.2±1.88	12.6±1.94	9.1±2.33	6.9±3.01	8.8±1.88
Frequency range	1.1–12.8	2.8–16.6	1.2–15.2	1.5–15.3	0–1.0	1.1–15.4
	5.3±2.80	5.9±3.17	7.1±3.03	5.4±2.99	0.6±0.32	7.6±2.93
Inflections	0	0	1	1	0	2–14
						3.5±2.06

TABLE III. Mean and standard deviation of some whistle parameters of bottlenose dolphins from previous studies. The two-sided *t*-test (Zar. 1999) was performed to compare whistle parameters with this study. Italic numbers represent significant differences ($P<0.01$). An asterisk indicates data not reported by the authors.

Location	SF	EF	MinF	MaxF	DUR	I	N	Study
Patos Lagoon estuary, Brazil[a]	8.28 (3.11)	8.37 (3.70)	5.96 (2.15)	12.21 (3.20)	0.55 (0.39)	1.42 (1.85)	788	This study
Argentina[a]	*9.24 (2.74)*	*6.63 (2.29)*	*5.91 (1.50)*	*13.65 (1.54)*	*1.14 (0.49)*	1.58 (1.24)	110	Wang *et al.* (1995)
Texas, USA[a]	8.01 (2.81)	8.16 (3.78)	5.77 (1.84)	*11.32 (3.31)*	*0.68 (0.40)*	*2.09 (2.54)*	2022	Wang *et al.* (1995)
North Atlantic Ocean[a]	*11.26 (3.99)*	*10.20 (3.65)*	*7.33 (1.66)*	*16.24 (2.69)*	*1.30 (0.63)*	*2.86 (2.45)*	858	Steiner (1981)
Sado estuary, Portugal[a]	*5.8 (1.8)*	*12.1 (4.4)*	*15.0 (2.7)*	*5.4 (1.2)*	*0.86 (0.40)*	*	735	dos Santos *et al.* (2005)
Gulf of California[a]	*12.10 (2.89)*	9.19 (3.44)	*6.91 (2.11)*	*13.68 (1.72)*	*0.66 (0.35)*	1.15 (1.32)	110	Wang *et al.* (1995)
Eastern Tropical Pacific Ocean[a]	*11.2 (4.6)*	*9.0 (3.7)*	*7.4 (2.2)*	*17.2 (3.1)*	*1.4 (0.7)*	*3.7 (3.0)*	157	Oswald *et al.* (2003)
Moreton Bay, Australia[b]	*	*	*	*	*0.38 (0.21)*	*	404	Schultz and Corkeron (1994)
Shark Bay, Australia[b]	*3.84 (1.42)*	*7.56 (3.80)*	*3.57 (0.97)*	*10.57 (3.02)*	*0.68 (0.35)*	1.63 (1.53)	658	Wang *et al.* (1995)
Japan[b]	*10.33 (2.41)*	8.87 (2.21)	*7.37 (1.54)*	*11.62 (2.00)*	0.62 (0.34)	*0.88 (0.79)*	215	Wang *et al.* (1995)
Mikura I., Japan[b]	*7.17 (2.85)*	*9.82 (4.18)*	5.98 (2.44)	12.21 (3.20)	*0.39 (0.33)*	1.22 (1.39)	851	Morisaka *et al.* (2005)
Ogasawara I., Japan[b]	*6.91 (3.12)*	*10.35 (4.86)*	5.61 (2.06)	12.34 (4.93)	*0.44 (0.44)*	1.19 (1.50)	247	Morisaka *et al.* (2005)
Amakura-Shimoshima I., Japan[b]	*6.74 (2.82)*	8.06 (3.80)	*5.63 (2.21)*	*9.39 (3.90)*	*0.37 (0.25)*	*0.78 (0.88)*	515	Morisaka *et al.* (2005)

[a]Tursiops truncatus.
[b]Tursiops aduncus.

nature whistles, although this hypothesis is not wholly supported (McCowan and Reiss, 2001). Like in other populations, bottlenose dolphins from the Patos Lagoon estuary live in fission-fusion societies where individual association patterns are fluid (Dalla Rosa, 1999). Therefore, signature whistles could be used to individual recognition or group cohesion (e.g., Caldwell *et al.*, 1990; Sayigh *et al.*, 1990; Janik and Slater, 1998; Watwood *et al.*, 2004). However, our method of data collection did not allow us to identify the whistler, therefore we cannot evaluate the signature whistle hypothesis with this data set.

It has been suggested that bottlenose dolphins imitate the whistles of conspecifics (Janik, 2000). But whistles produced by bottlenose dolphins may come from a common shared whistle repertoire and what appears to be imitation simply refers to animals repeating the same call type, what might serve as contact calls or to coordinate group movements or group formation (Watwood *et al.*, 2004). In this way, individuals in the Patos Lagoon estuary may be sharing some whistle types, as it has been suggested for *Tursiops* elsewhere.

This is the first description of the whistle repertoire of bottlenose dolphins in Brazilian waters and the second in the South Atlantic Ocean. We recorded and analyzed whistles from free-ranging bottlenose dolphins engaged in different behaviors. The whistle repertoire of bottlenose dolphins in the Patos Lagoon estuary seems to be varied, as it has been observed for *Tursiops* in other areas (e.g., dos Santos *et al.*, 2005). Bottlenose dolphins from the Patos Lagoon estuary produced stereotyped whistles in which the acoustic parameters were similar to published ranges for the genus. But, some differences were found between whistle characters of bottlenose dolphins from Patos Lagoon estuary and those values previously reported for *Tursiops* spp. Besides biological differences, the comparisons with previously published whistle characteristics may have been affected, in part, by methods and equipment used to record dolphin sounds in each study. So, care must be taken in order to avoid speculative conclusion about intra- and interspecific variability in *Tursiops* whistles.

There was no predominance of ascending or descending whistles and the mean of the SF and EF values were similar. The relationships between start and end frequency may vary between bottlenose populations (Wang *et al.*, 1995; dos Santos *et al.*, 2005). The statement that bottlenose whistles in Patos Lagoon estuary are mainly balanced in frequency represents an important characteristic of this population and, consequently, may be a tool to discriminate *Tursiops* populations along the Brazilian coast. Additionally, production of repeated whistles was verified in these free-ranging dolphins, but further studies are needed to clarify its function.

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