

Possible occurrence of signature whistles in a population of *Sotalia guianensis* (Cetacea, Delphinidae) living in Sepetiba Bay, Brazil

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According to the “signature whistle” hypothesis, dolphins emit stereotypic sequential whistles whose function is to transmit the identity and location of the whistling animal. However, it has also been proposed that the information signature may be expressed by distinct acoustical features within a single type of whistle shared by a population of dolphins. In an attempt to detect signature whistles from *Sotalia guianensis* living in Sepetiba Bay, Rio de Janeiro, Brazil, 12 h of vocalizations were recorded. Following analysis of the spectrograms, the whistles were classified according to visual inspection and the contour similarity method. Although the identities of the whistling animals were not established, 202 whistle sequences were selected and classified by visual inspection into 27 different types of potential signature whistles. However, there was a large discrepancy between this classification method and that obtained using the quantitative contour similarity method. The arguments in support of the premise that *S. guianensis* produces signature whistles are discussed and the limitations of the classification systems employed are examined.

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I. INTRODUCTION

Small cetaceans often communicate through whistles (Hermam and Tavolga, 1980). In fact, a varied repertoire of whistles has been described for the gray dolphin, *Sotalia guianensis* (Monteiro-Filho and Monteiro, 2001; Azevedo and Simão, 2002; Erber and Simão, 2004), lately classified as the marine ecotype of *S. fluviatilis* (Cunha *et al.*, 2005).

The “signature whistle” hypothesis was initially raised by Caldwell and Caldwell (1965) following observations of five captive *Tursiops truncatus* dolphins. According to these authors, each animal tended to emit a unique and distinct type of whistle independent of the circumstances. The individual whistle of each animal was characterized by a specific contour (or stereotype) with a unique pattern of low and high frequency modulations (Tyack, 1986; Caldwell *et al.*, 1990; Sayigh *et al.*, 1990). According to Caldwell *et al.* (1990), the stereotypic contour could be repeated several times within a whistle, the repeated elements being known as “loops” and each of the repeated sequences constituting a signature whistle. The basis of the hypothesis is that the individually distinctive attributes of signature whistles transmits the identity and location of the whistler.

Evidence based on vocal mimicry suggests that the signature whistle contour produced by a dolphin results mainly from vocal learning (Reiss and McCowan, 1993; McCowan and Reiss, 1995; Tyack, 1997; Miksis *et al.*, 2002; Fripp *et al.*, 2005) in which infant dolphins develop their unique

signature whistles for use throughout life (Caldwell *et al.*, 1990; Sayigh *et al.*, 1990). Variations of the whistles may serve other functions including the maintenance of group cohesion since, in captivity, the whistles are produced almost exclusively by dolphins isolated from the group (Janik and Slater, 1998).

Most research on signature whistles has been conducted with the species *T. truncatus*, although individual whistles have also been detected in emissions of captive (Caldwell *et al.*, 1973) and free (Herzing, 1996) populations of *Stenella frontalis*, *Lagenorhynchus obliquidens* (Caldwell and Caldwell, 1971), *Delphinus delphis* (Caldwell and Caldwell, 1968), and possibly in *Sousa chinensis* (van Parijs and Corkeron, 2001). The objective of the present paper was to investigate the possible occurrence of signature whistles in a population of *Sotalia guianensis* living freely in their natural habitat, Sepetiba Bay.

II. METHODS

A. Collection of data

Field studies were conducted in Sepetiba Bay, Rio de Janeiro, Brazil (between latitudes 22° 54' and 23° 04' S, and longitudes 43° 34' and 44° 10' W; Fig. 1) over 22 different days within the period May 1994 to February 1999. Vocalizations of the population of *S. guianensis* in this area were recorded from a stationary boat, located ~20 m from the dolphin group, using a Cetacean Research Technology (Seattle, CA) model C54 hydrophone placed 3 m below the water surface. The output of the hydrophone was connected to a pre-amplifier and to a Sony WM-D3 professional walkman (4 tracks; 2 channels; 1% total harmonic distortion; fre-

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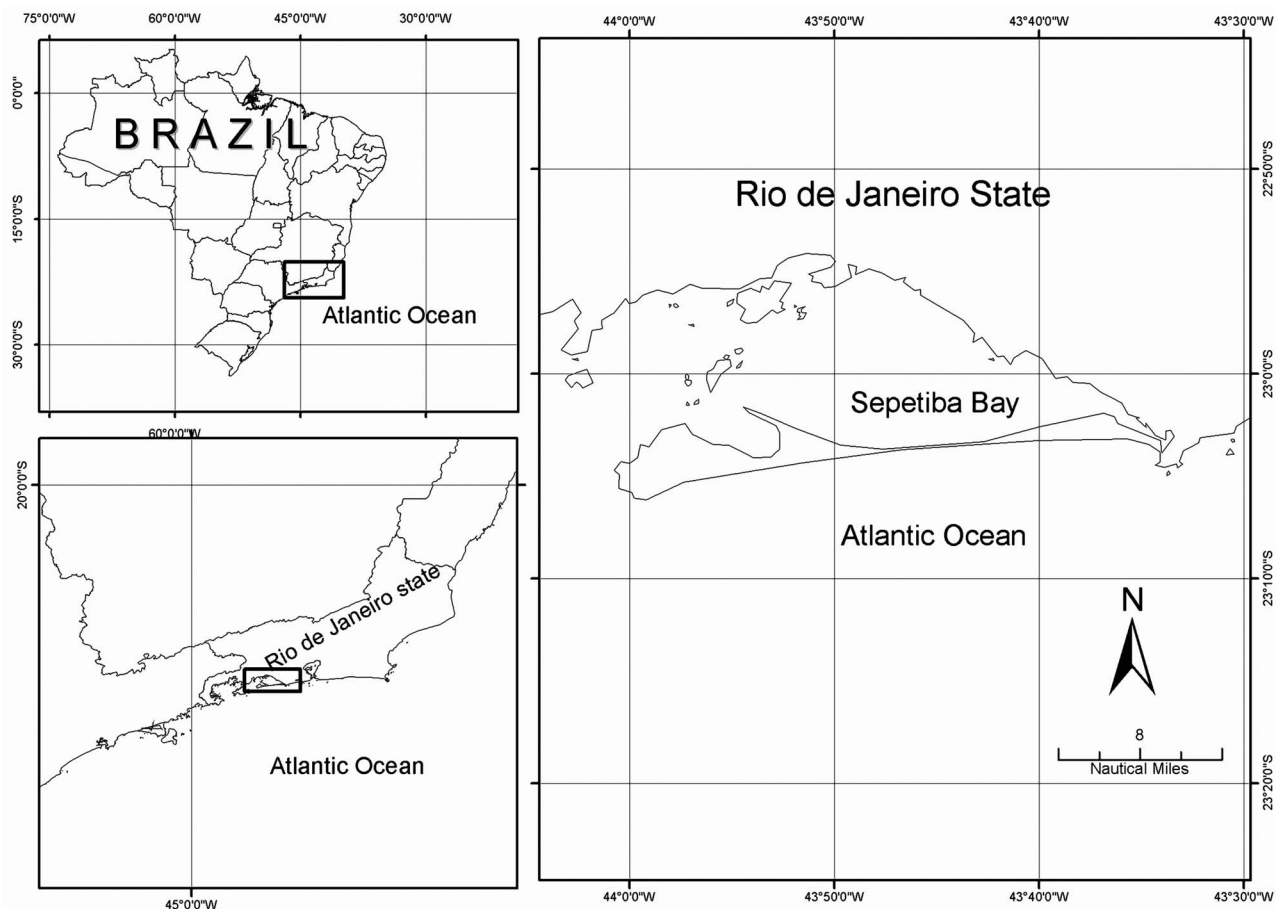


FIG. 1. Geographical location of Sepetiba Bay.

quency response 60–16 000 Hz \pm 3 dB) equipped with Sony UCX-S chromium oxide recording tape. A total of 12 h of collective vocalizations, in which the sounds produced by individual animals were not distinguishable, were recorded and analyzed. In parallel with the recordings, information about the climatic conditions, the locations and times of the sightings, and observations concerning the groups of dolphins were noted on field-work forms and on a handheld mini-recorder.

Recorded vocalizations were digitized, oscillograms and spectrograms were generated, and quantitative sound parameters were determined (via Blackman-Harris type fast Fourier transform with a window of 1024 points and 75% overlap) using COOL-EDIT PRO software version 1.2 (Syntrillium Software, Phoenix, AZ). All spectrograms were inspected visually in order to identify stereotypic whistles in sequence. It was impossible to identify the whistler dolphin for each emission. Therefore, a signature whistle was established as a multi-loop one. Once one multi-loop whistle was identified, all one-loop whistles of same contour were considered as part of the sample. Spectrograms corresponding to each of the whistles thus identified were copied, saved in the form of pcx files and labeled with a randomly produced identification number. Each of the selected whistles was analyzed with respect to the number of loops and the presence of a harmonic or lateral band. The following quantitative parameters were extracted from the first loop of each whistle: duration,

initial and final frequencies, minimum and maximum frequencies, number of inflexion points, and time intervals between loops.

B. Classification of whistles according to the visual inspection method

The spectrograms of all selected whistles were printed and classified into groups according to the visual perception of the loop contours as determined by two independent researchers. During the classification procedure, the researchers had no access to any other information concerning the whistles. However, since the whistles could not be associated with any particular individual animal, it was not necessary to enlist the participation of a third independent person (unconnected with the project) in order to avoid any tendencies in the classification (McCowan and Reiss, 2001). The two independent classifications obtained were then compared, and whistles with uncertain categorization, together with those that were differently categorized by the two researchers, were disregarded.

C. Classification of whistles according to the contour similarity method

A quantitative method for the classification of whistles emitted by *T. truncatus* has been proposed by McCowan (1995), in which 20 frequency readings were determined for

each whistle contour. The frequencies were obtained by dividing the duration of the loop by 19 and by considering the initial and final frequencies. The frequency measurements were used to produce Pearson's correlation matrix, which was then submitted to principal component analysis to reduce the number of collinear variables. Factors with a value greater than 1.0 were used in the *K*-means cluster analysis to define the different groups of whistles. Finally the cross-validation of whistle types was conducted using stepwise discriminant analysis.

Since the whistle emissions of *S. guianensis* are considerably shorter (mean value=0.102 s; [Azevedo and Simão, 2002](#)) than those produced by *T. truncatus* (mean value =0.960 s; [Caldwell et al., 1990](#)) the limitations of the hardware and software employed in the present study rendered it impractical to extract 20 frequency readings. For this reason, all the steps were performed taking into consideration 15 frequency readings taken from the first loop of the whistles.

Solutions of the *K*-means cluster analyses were produced in the range $n-2 \leq k \leq n+2$, where *n* is the number of groups obtained by the visual method and *k* is the number of groups formed by the cluster analysis. Statistical analyses were performed using STATISTICA for WINDOWS 5.1 software and FITOPAC 1.0 (G. J. Shetherd, UNICAMP, Campinas, São Paulo, Brazil).

In addition the coefficient of frequency modulation (COFM) was calculated for all of the whistles. COFM represents the total magnitude of variation of frequencies in each whistle ([McCowan and Reiss, 1995](#)) and was calculated on the basis of the 15 frequency points measured for each whistle according to a modified version of the [McCowan and Reiss \(1995\)](#) equation

$$\text{COFM: } \frac{\sum_{n=1}^{14} |y_{n+1} - y_n|}{10},$$

where Y_n is the frequency (in kilohertz) at the *n*th frequency point measured.

III. RESULTS

The spectrograms of 346 stereotypic whistles were selected by the visual inspection method from the 12 h of recordings of gray dolphins living freely in Sepetiba Bay, Rio de Janeiro, Brazil, although 144 whistles were later eliminated during the process of visual classification. The 202 remaining whistles had been recorded on 15 of the 22 days of field work (Table I) when the dolphins were engaged in cruising (48%) or random/collective hunting (30%) mainly.

Application of the visual inspection method allowed the division of these 202 whistles into 27 types (Fig. 2); the quantitative parameters are shown in Table II. Seventeen types of whistles (44.5% of the total) were exclusively formed by multi-loops and were recorded on a single day (Table I). Moreover, the time intervals between whistles corresponding to each of these 17 types were very short. These factors all together suggested that each one of these whistle types was emitted by individual dolphins and had the great potential to be signature whistles.

TABLE I. Dates when whistles of types 1–27 were recorded.

Type of whistles	Date of recording
1	27/05/1994
2	11/02/1998
3	04/06/1995
4	04/06/1995
5	09/06/1998
6	22/09/1994
7	22/12/1997
8	22/12/1997
9	10/03/98; 21/01/1999
	21/05/1994; 22/09/1994; 27/08/1995; 02/04/1997; 22/12/1997; 01/03/1998; 10/03/1998; 25/03/1998; 09/08/1998; 21/01/1999
10	
11	04/06/1995; 18/12/1998; 21/01/1999
12	22/12/1997
13	22/12/1997
14	01/03/1998; 09/06/1998; 21/01/1999
15	04/06/1995; 27/08/1995
16	10/03/1998; 26/11/1998
17	01/03/1998
18	22/12/1997
19	27/08/1995; 01/03/1998; 21/10/1999
20	22/09/1994; 27/08/1995; 22/12/1997; 10/03/1998
21	25/03/1998
22	21/01/1999
23	22/12/1997; 10/03/1998; 25/03/1998; 12/05/1998
24	22/12/1997
25	22/12/1997; 10/03/1998; 25/03/1998; 12/05/1998
26	22/09/1994
27	22/12/1997

Analysis of the five solutions of the *K*-means cluster analysis with $25 \leq k \leq 29$ (where *k* is the number of groups formed by the cluster analysis) showed that classification by the contour similarity method was not in accord with that deriving from the visual inspection method. However, when *k*=28, the two methods exhibited some similarity in relation to 17 possible signature whistles identified by the visual inspection method (Table III), although large discrepancies could still be observed between the two classifications.

IV. DISCUSSION

The fact that 27 distinct types of whistles were detected in the population of *S. guianensis* of Sepetiba Bay underlines the profuse vocal repertoire of this species, as the mean size group was of 30 animals, and confirms the previous findings of the authors' research group ([Azevedo and Simão, 2002](#); [Erber and Simão, 2004](#)). In contrast, [Monteiro-Filho and Monteiro \(2001\)](#) reported only four types of whistles in a population of *S. guianensis* living in the estuarine complex of Cananéia (São Paulo, Brazil). This discrepancy may be attributed to the recording equipment used by the earlier authors, as its frequency response had an upper limit of 8000 Hz in comparison with 16 000 Hz for the equipment used in the present study. Since the whistles detected in our studies exhibited average frequencies in the region of 7800 Hz, equipment specification is clearly a factor of considerable importance.

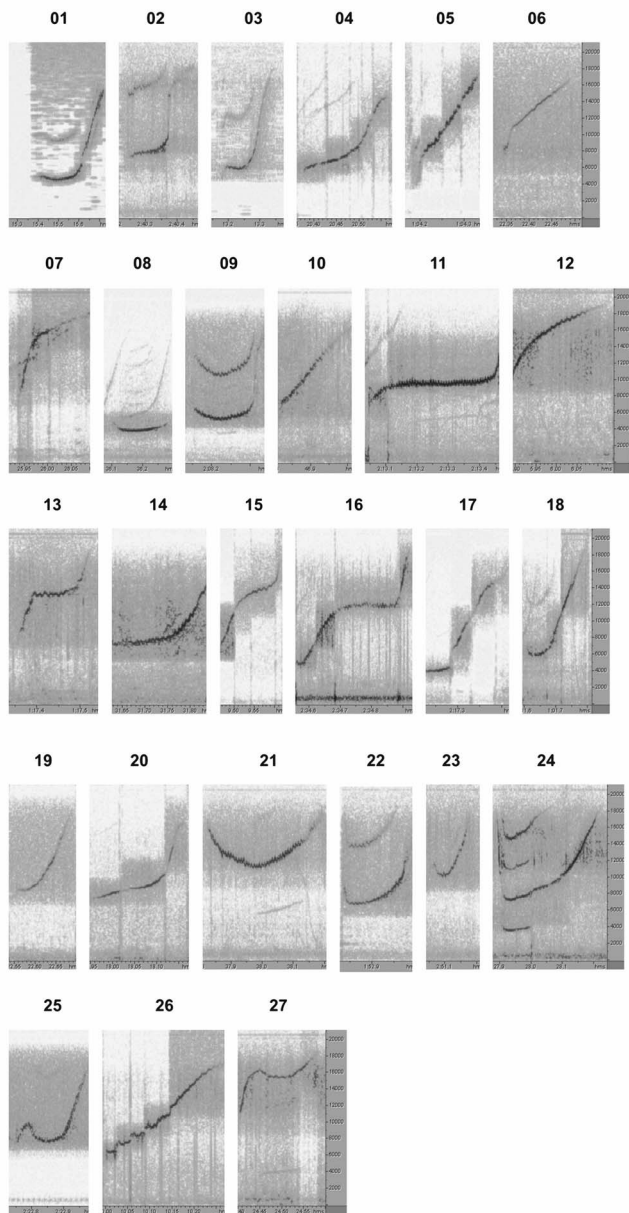


FIG. 2. Spectrograms of the 27 types of potential signature whistles classified by the visual inspection method produced by *Sotalia guianensis* living in Sepetiba Bay, Rio de Janeiro, Brazil.

Most of the previous investigations of signature whistles have involved captive dolphins in which the identity of the vocalizing animal could be readily established (Caldwell *et al.*, 1990; Sayigh *et al.*, 1990). In the few studies relating to free animals, the whistling dolphins were identified either by sub-aquatic filming or after an intense chase of a focal animal (Smolker *et al.*, 1993; Herzog, 1996). In our work it was not possible to establish the identity of the whistling individual since our intention was to interfere as little as possible with the natural behavior of the animals. Furthermore, filming groups of *S. guianensis* would be impracticable since the waters of Sepetiba Bay (Rio de Janeiro, Brazil) are turbid (maximum visibility of ~ 2.5 m) and gray dolphins are shy animals that tend to avoid proximity to humans.

Hence, among the three characteristics of a signature whistle, namely, stereotypic contour, loop sequences, and individuality (Caldwell *et al.*, 1990), only the first two could be used during the investigation of such sound emissions in the repertoire of this species, resulting in 202 whistle sequences that could constitute signature whistles.

The method of categorizing whistle contours used in the present study was based on that of Janik and Slater (1998) in which visual classification was performed by independent researchers who had no knowledge of the identity and behavior of the whistling animals. By using this strategy, 27 different types of whistles with stereotypic contours, most of which presented multiple loops (74,7%), were identified by the researchers. Although the authors could not confirm that these vocalizations were indeed signature whistles, there are some strong indications supporting this supposition. First, each of the 17 types that presented the highest potential to be signature whistles was detected separately in a single day of recording. Second, these 17 types presented a short time interval between whistles, suggesting that each type of whistle was produced by only one animal. Third, as stated by Tyack (1997), signature whistles allow the individuals to maintain contact with one another, for example, when they are feeding or when one animal is approaching a group. In the present study, 78% of the selected potential signature whistles were recorded in the occasions when the dolphins were cruising or hunting, evidence that is highly consistent with the functions proposed for such type of vocalization. However, Jones and Sayigh (2002) and Cook *et al.* (2004) recorded more signature whistles when *T. truncatus* free-ranging dolphins were socializing. Once only 7.5% of the *Sotalia guianensis* recordings were obtained during socializing events, it is impossible to affirm that the same had not occur for this species in Sepetiba Bay. Finally, our previous studies concerning the gray dolphins of Sepetiba Bay have indicated the existence of an affinity between partners (Simão *et al.*, 2000). According to Beecher (1989), such a relationship between animals is only possible if they are able to recognize distinct individual signs. In the case of dolphins, the hypothesis is that these signs are expressed in the form of signature whistles (Tyack, 1997).

The results of our study are supported by the observations of Ding *et al.* (2001) who, following comparison between whistles produced by different dolphin populations and species, reported the repetition of identical whistles in the repertoire of *S. guianensis*.

The COFM values have demonstrated that the whistles produced by *S. guianensis* are as complex as those of *T. truncatus*, since the COFM value of the former was 0.98 and that of the latter is reported to be 0.88 (McCowan and Reiss, 1995).

The small number of whistles selected (202 sequences in 12 h of recorded vocalization) was expected because the study involved wild animals performing their natural activities. According to Janik *et al.* (1994) and Janik and Slater (1998) signature whistles are produced in all behavioral contexts, but they are more frequent when the animal is isolated from its group, and this is a rare situation in nature. Furthermore, it is believed that when the stress level is reduced and

TABLE II. Quantitative measurements (mean values) of the 27 potential signature whistles classified according to the visual inspection method.

Types	Samples (<i>n</i>)	Duration (ms)	Fi ^a (kHz)	Ff ^b (kHz)	Fmi ^c (kHz)	Fma ^d (kHz)	No. of loops	COFM ^e
1	12	0.286	6.1	15.2	5.6	15.2	1.2	1.09
2	6	0.180	7.2	17.9	7.2	17.9	1.8	1.07
3	7	0.258	4.3	15.4	4.3	15.2	2.1	1.28
4	6	0.768	6.1	14.8	6.1	14.8	1.8	0.87
5	2	0.212	2.3	17.6	2.3	17.6	3.5	1.53
6	2	0.162	6.7	17.4	6.7	17.4	2.0	1.07
7	3	0.127	8.4	17.8	8.4	17.8	2.0	0.93
8	4	0.194	4.5	4.5	4.1	4.5	1.8	0.09
9	6	0.221	8.6	17.5	5.8	17.5	1.3	1.49
10	38	0.161	8.8	16.9	8.8	16.9	2.3	0.83
11	4	0.282	9.7	16.0	9.7	16.0	1.8	0.63
12	6	0.151	9.0	17.5	9.0	17.5	2.0	0.85
13	4	0.122	9.6	17.5	9.6	17.5	1.8	0.80
14	5	0.253	7.8	16.4	7.8	16.4	1.6	0.86
15	6	0.175	5.9	17.2	5.9	17.2	2.0	1.13
16	23	0.219	8.4	17.2	8.4	17.2	2.0	0.85
17	3	0.238	4.3	14.9	4.3	14.9	1.7	1.05
18	2	0.225	6.8	17.6	6.8	17.6	2.0	1.09
19	4	0.132	8.0	16.3	8.0	16.3	2.0	0.83
20	6	0.170	6.6	17.2	6.6	17.2	2.0	1.06
21	4	0.352	16.5	18.0	12.1	18.0	1.8	1.16
22	8	0.203	9.1	15.0	6.9	15.0	1.6	1.01
23	25	0.144	12.2	17.0	10.0	17.0	1.4	0.95
24	6	0.341	14.8	17.3	7.6	17.3	1.5	1.72
25	5	0.243	6.9	16.3	6.9	16.3	1.6	1.50
26	7	0.237	6.8	17.8	6.8	17.8	2.1	1.13
27	7	0.162	11.3	17.6	11.3	17.6	1.4	0.75

^aFi=initial frequency.

^bFf=final frequency.

^cFmi=minimum frequency.

^dFma=maximum frequency.

^eCOFM=coefficient of frequency modulation.

the contextual behavior is more diverse, as in animals living freely in the wild, the vocal repertoire is more varied (McCowan, 1995; Smolker and Pepper, 1999). An additional factor that influenced the quantity of whistles selected was the high number of sequences that had to be eliminated either because there was background noise interference or because of their low energy.

The quantitative contour similarity method of McCowan (1995) was employed to compare the similarity between the whistle types selected for two main reasons: First, the technique employs applicable calculus and second the technique allows the categorization of whistles that share similar contours but may present differences with respect to total duration, real frequency, or those that are expanded or compressed with respect to frequency and time. The latter criteria appear to be very important in the classification of whistles, since it has been demonstrated that the signature whistles of *T. truncatus* may vary in duration, frequency, number of loops, etc., while still maintaining the highly distinct pattern of the loop contour (Caldwell *et al.*, 1990).

The results of the authors revealed a large disparity between the visual inspection and the contour similarity methods. Janik (1999), following comparison between different

whistle classification methods, reported a similar discrepancy between these two methods. According to this author, the main problem with the contour similarity method appears to be associated with the normalization of the duration and the number of frequency measurements taken for each contour. It is likely that 20 frequency measurements are insufficient to determine the rapid modulations in frequencies that occur in some contours. In order to overcome this problem, modifications were introduced into the method by extracting 60 (McCowan and Reiss, 2001) or 100 (Watwood *et al.*, 2004) frequency points per whistle contour. Following these adjustments, the two classification systems were statistically equivalent and the results produced were more consistent. According to Janik (1999) and Sayigh *et al.* (2007), the contour similarity method is not as reliable as the human observer. Indeed, the authors demonstrated that the whistle contours classified by the visual method were consistently produced by only one isolated animal, thus proving that human observation could recognize meaningful vocalizations, while quantitative techniques could not perceive the differences. Since only 15 frequency measurements could be extracted for each whistle contour in the present study, the

TABLE III. Comparison between the two methods of whistles' classification. Each column represents a whistle type created by McCowan's (1995) method. Each number in columns represents a particular whistle. The visual inspection method's whistle types that are considered more potential signature whistles are bold and, if split, are marked with a similar letter.

Whistle types by McCowan's method																											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
161	135 ^a	204 ^b	103 ^c	252	174	62 ^d	326	281	7	77 ^f	17	63	218	283	60 ^d	149	25	29	133 ^a	36	3	145	233	21	2	13	48
344	157 ^a		110 ^c		178	65 ^d		282	8	78 ^f	18	147 ^a	219	286	195 ^b	235	49	171	137 ^a	104 ^c	24	254	234	126	41	37	167
345			112 ^c			66		284	9	79 ^f	21	148 ^a	220		196 ^b	236	50	185	187	109 ^c	80 ^f	255 ^f	237	139	43	39	265
346			113			67 ^d		336 ^c	11	156 ^e	22	152 ^a	221		198 ^b	244	52	250	193	242	81 ^f	256	238	140	44	76	266
						68 ^d		338 ^c	12	158 ^e	23		264		199 ^b		53	251	210	258	115		239	150	45	93	267
						69 ^d			14		38				203 ^b		54	269	340	280	160 ^e		240	180	72	128	309
						197 ^b			19		51				205 ^b		55	273	341	317 ^a	210		241	182	73	129	310 ^a
						201 ^b					175		87		206 ^b		144	293			297		243	183	74	303	311 ^a
											333 ^c		88		208 ^b		168	298					306	184	75	335 ^c	312 ^a
											334 ^c		89		209 ^b		304	302						188	114		313 ^a
													211		322 ^b		325	305						189	127		314 ^a
													223				337 ^e	320						190	131		315 ^a
													263											192	136 ^f		318 ^a
													271												191		331
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divergence between the two classification methods was already expected.

McCowan and Reiss (2001) investigated whistles produced by captive *T. truncatus* belonging to three different social groups and submitted to two different conditions similar to those predicted in the signature whistle hypothesis (voluntary group separation and temporary forced separation). No stereotypic individual whistles were detected in any of these experiments, with almost all of the individuals producing just one type of whistle characterized by ascending frequency. The authors think that this common whistle could have individual acoustic variations, which might serve as signature information, similar to the situation found with other non-human animals.

In contrast to these authors, a number of recent studies have corroborated the signature whistle hypothesis. For example, Watwood *et al.* (2005) compared signature whistles produced by temporarily restrained *T. truncatus* with whistles produced by free swimming animals. The authors concluded that the types of stereotypic whistles produced by the restrained animals were not a consequence of their confined condition since such whistles were also produced significantly by free interacting animals. Only two of the animals involved in these experiments produced whistle contours similar to those reported by McCowan and Reiss (2001). Sayigh *et al.* (2007) explained the results presented by McCowan and Reiss (2001) as a product of the normalization of whistles' duration that would cause a contour distortion and by the fact that only captive animals were used in

the experiment, as Miksis *et al.* (2002) observed that captive-born dolphins can incorporate features of trainers' whistles into their signature whistles.

In the present study, the authors also found a type of whistle (number 10; Fig. 2) similar to that described by McCowan and Reiss (2001) for *T. truncatus*. This type of whistle, which is very simple and presents an ascending contour, has been found in the repertoire of other dolphin species such as *Delphinapterus leucas* (Sjare and Smith, 1986) and *Delphinus delphis* (Moore and Ridgway, 1995) and some other *T. truncatus* populations (Tyack, 1986; Janik *et al.*, 1994; Cook *et al.*, 2004). In this study, whistle number 10 was detected on 11 different days of recorded vocalizations and may be common among the population studied. Whistles of this type that are shared by different species are unlikely to be involved in the transmission of individual information as previously suggested by McCowan and Reiss (2001).

The results presented here agree with signature whistle hypothesis corroborating the suggestion of Sayigh *et al.* (2007) that "individually distinctive signature whistles would appear to be a more promising mechanism for individual recognition than a shared whistle containing subtle signature information, as proposed by McCowan and Reiss (2001)." Further studies involving captive individual dolphins should be conducted in order to confirm the emission of signature whistles by *S. guianensis*. Such a study is feasible since there are two estuarine dolphins in captivity in the Dolphinarium Münster (Munster, Germany; Liebschner *et al.*, 2005).

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