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## SOUNDS PRODUCED BY TUCUXI (*SOTALIA FLUVIATILIS*) FROM THE NAPO AND AGUARICO RIVERS OF ECUADOR

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**ABSTRACT:** The acoustic structure and repertoire of the tucuxi (*Sotalia fluviatilis*) remain poorly studied. This lack of information limits our understanding of how acoustic signals evolved and the factors that promote variation across and within populations. Using a broadband recording system, we recorded 30 whistles from tucuxis in the Napo and Aguarico Rivers, Ecuador. Our results show that Ecuadorian tucuxis emit a variety of sounds including whistles, echolocation clicks, and pulse sounds. Whistles structure varied with respect to other populations described in previous studies, providing preliminary evidence of geographic variation. In addition, this study provides evidence of high order harmonics in whistles (up to 80kHz) highlighting the importance of broadband recording systems.

**RESUMEN:** La estructura acústica y el repertorio de sonidos del tucuxi (*Sotalia fluviatilis*) continúan siendo poco estudiados. Esta carencia de información limita nuestro entendimiento de cómo evolucionan las señales acústicas y de los factores que promueven variaciones inter e intra poblacionales. Usando sistemas de grabación de banda ancha registramos 30 silbidos de tucuxi en los ríos Napo y Aguarico, Ecuador. Nuestros resultados muestran que los tucuxi ecuatorianos emiten una variedad de sonidos incluyendo silbidos, clicks de ecolocalización y pulsos. La estructura de los silbidos varió con respecto a otras poblaciones descritas en estudios anteriores, proporcionando evidencia preliminar de variación geográfica en los sonidos de comunicación de esta especie. Además, este estudio proporciona evidencia de armónicos de alto orden en silbidos (hasta 80kHz) destacando la importancia de los sistemas de grabación de amplia banda.

**KEYWORDS:** Communication, echolocation, pulsed sounds, Delphinidae, tucuxi, *Sotalia fluviatilis*.

### Introduction

The tucuxi, *Sotalia fluviatilis* lives in freshwater systems of South America (Flores and da Silva, 2009). Like its marine congener, the Guiana dolphin *S. guianensis* (Monteiro-Filho *et al.*, 2002; Cunha *et al.*, 2005; Caballero *et al.*, 2007), it is known to produce a variety of sounds, including echolocation clicks, whistles, and burst pulse or graded signals described variously as squawks, screech, bark, whimper, crack, squeal, and squeaky-squawks (*e.g.* Caldwell and Caldwell, 1967; Wiersma, 1982; Kamminga *et al.*, 1983; Wang *et al.*, 1995; 2001). Most of our knowledge on tucuxi sound production (in the wild) comes from studies in the Brazilian Amazon River and tributaries (*e.g.* Podos *et al.*, 2002; Azevedo and Van Sluys, 2005), Colombia (Diazgranados and Trujillo, 2002<sup>4</sup>; Diazgranados *et al.*, 2002<sup>5</sup>), and one study in Perú (Wang *et al.*, 1995; 2001). Very little is known about their acoustic behavior in other parts of their distribution. Here we report on several types of sounds produced by tucuxi in the Ecuadorian Aguarico and Napo rivers, right on the border with Perú, and compare our results with available information from other populations.

### Material and Methods

This study took place in the Napo and the Aguarico rivers on 17 August 2005. The location of the recorded animals is shown in Figure 1. Acoustic signals were recorded using a broadband system consisting of a RESON hydrophone (-203dB re 1V/μPa, 1Hz to 140kHz) connected to an AVISOFT recorder and Ultra Sound Gate 116 (sampling rate 400-500kHz 16bit), which sent the signals to a laptop computer. Recordings were made continuously, but segmented in 3min files. The predominant behavior was noted for every other 3min file. When animals were not in sight during a 3min scanning period, the behavior was noted as unknown.

Five behavioral categories were defined: (1) Feeding/Foraging, animals actively searching, pursuing, and/or consuming prey, (2) Social activities, animals interacting among themselves or with the boto, *Inia geoffrensis* (*e.g.* body contact, tail slapping) and following the boat or other group members, (3) Traveling, dolphins swimming either slowly or fast while maintaining a defined direction, (4) Resting, animals showing little movement always within the same area

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<sup>4</sup> DIAZGRANADOS, C. AND TRUJILLO, F. (2002) Vocal repertoire of the freshwater dolphins *Inia geoffrensis* and *Sotalia fluviatilis* in Colombia, South America (Abstract 5aAB11). Page 2400 in Proceedings, First Pan-American/Iberian Meeting on Acoustics, December 2002, Cancún, Mexico. *Journal of the Acoustical Society of America* 112(5)(Pt. 2).

<sup>5</sup> DIAZGRANADOS, M.C., MEJÍA, P. AND ACOSTA, A. (2002) Effect of boat traffic on the vocal and surfacing behavior of river dolphins: A key for abundance estimation methods (Abstract 5pAB3). Page 2431 in Proceedings, First Pan-American/Iberian Meeting on Acoustics, December 2002, Cancún, Mexico. *Journal of the Acoustical Society of America* 112(5)(Pt. 2).

and diving for short periods of time in relative synchrony with other group members, and (5) Milling, animals moving slowly but changing direction constantly with variable diving periods. In addition, group size and composition, photo-identification photographs, and GPS data were also collected.

Seven sightings of tucuxi were made and recordings were obtained from all. Six sightings consisted of solitary animals and one of a mixed group of five tucuxis and two botos. A total of 53 files (each 3min long) were obtained accounting for approximately 2.65h of recorded time. Sounds were broadly categorized as: whistles, click trains, and burst sounds. Whistles were defined as narrowband and frequency modulated sounds (Richardson *et al.*, 1995). Click trains and burst sounds were differentiated based on mean interclick interval (ICI), clicks having a mean ICI longer than 10ms and burst pulses less than 10ms (see Lammers *et al.*, 2004).

Both whistles and pulsed sounds were manually analyzed using the program Raven 1.1 (Cornell Laboratory of Ornithology, New York) and Cool Edit 96 with a Hann sample window of 522, FFT (Fast Fourier Transformation) size of 1024 points, and overlap of 50%. The following standard acoustic parameters were measured for whistle fundamental (not considering harmonics): starting frequency (SF), ending frequency (EF), minimum frequency (MinF), maximum frequency (MaxF), delta frequency (DF = MaxF - MinF), and duration (ms). For clicks and burst trains the following parameters were measured #clicks/train, click repetition rate (#clicks/s), interclick interval (ms), duration (s), and dominant frequency (kHz) for selected individual clicks within each click train.

Because the waveform of each individual click within a click train tends to be repetitive and stereotyped (Au *et al.*, 1974) we selected two clicks from six click trains to measure dominant frequency. The relative background energy at each frequency was subtracted from the analyzed clicks.

In addition, using available published information about the mean and standard deviation for each whistle parameter (Table 1) we did pairwise comparisons between tucuxi populations. We first tested the null hypothesis that the variances are equal using the F-test and then the t-test to test the null hypothesis of equal means at the level of significance of 0.05 (Ambrose and Ambrose, 1995).

**Results**

**WHISTLES**

A total of 30 good quality whistles were recorded from two of the seven sightings (Table 1). Nine of the whistles were recorded from a solitary tucuxi engaged in milling behavior at the intersection of the Napo and Aguarico rivers. The other 21 whistles were recorded from the mixed-species group when the animals were foraging.

About 63% of these whistles contained harmonics (one to seven harmonics), but in only 48% of the whistles harmonics were clear enough for measurements. Harmonics minimum frequency ranged from 10.89 to 50.95kHz, maximum frequency from 23.06 to 83.5kHz, and frequency with peak energy from 11.23 to 83.5kHz (Figure 2a).

Pairwise comparisons suggest tucuxi populations vary

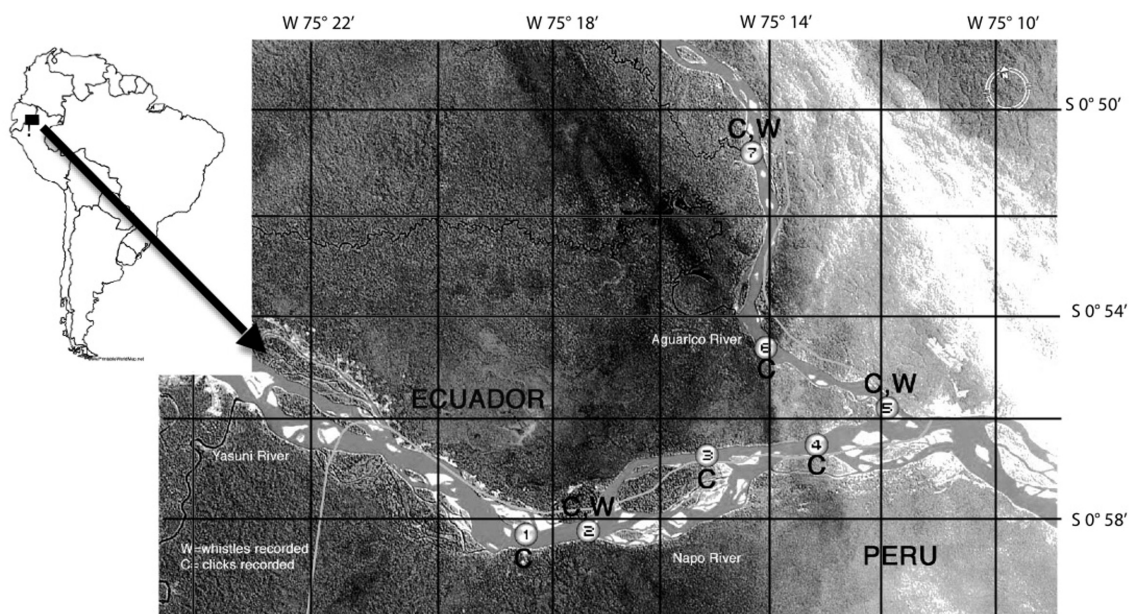


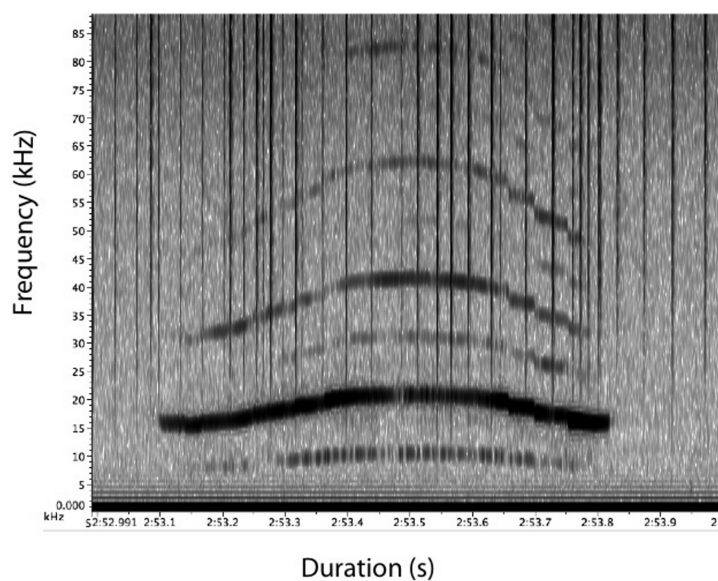
Figure 1. Geographical position of each tucuxi sighting and type of sounds recorded in each sighting (C = clicks/bursts, W = whistles).

in whistle parameters (Table 2). Tucuxis from the Mamirauá Reserve whistle significantly lower in frequency than those from the Marañon-Tigre rivers and the Pacaja River. Maximum whistle frequency was significantly higher in tucuxis from Pacaja River than those from other populations (all comparisons were significant except for the Marañon-Tigre rivers and Mamirauá Reserve). Start frequency is significantly higher in Aguarico - Napo Rivers compared to

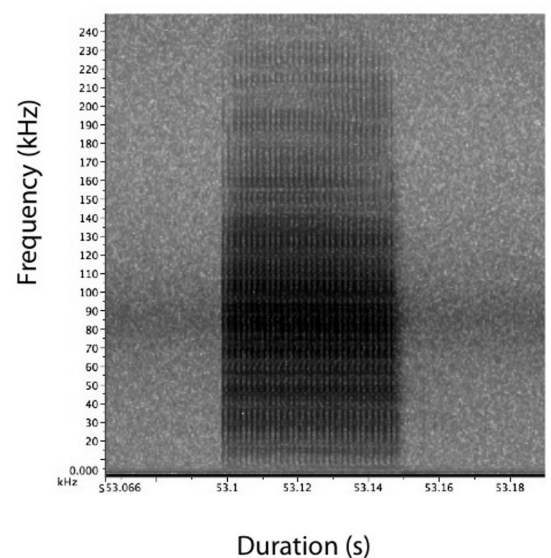
Mamirauá Reserve, but no significant differences were found for any other comparisons. Ending frequency was significantly higher in tucuxis from the Pacaja River compared to the other populations. Whistles were longer in tucuxis from Mamirauá Reserve compared to those from the Pacaja and Aguarico-Napo rivers. Finally, whistles were more frequency modulated in tucuxis from the Marañon-Tigre rivers compared to those of the Aguarico-Napo Rivers and Pacaja River.

**Table 1.** Frequency and time parameters measured on *Sotalia fluviatilis* whistle fundamentals from the Napo and Aguarico Rivers, Ecuador in comparison with other studies.

	MinF (kHz)	MaxF (kHz)	DeltaF (kHz)	SF (kHz)	EF (kHz)	Duration (s)	#Inflection Points	Source
<i>Mean</i>	10.61	17.69	7.22	12.82	13.57	0.374	0.731	n=30
<i>SD</i>	3.19	4.64	3.56	5.50	3.36	0.249	0.874	Aguarico/Napo Rivers
<i>Range</i>	5.17-15.04	7.79-28.84	1.76-19.42	5.17-28.83	6.84-20.51	0.007-0.785	0-2	Ecuador (this study)
<i>CV%</i>	30.0	26.2	49.3	42.9	24.7	66.6	119.7	
<i>Mean</i>	10.93	19.95	9.02	11.36	19.63	0.381	0.44	n=61
<i>SD</i>	3.39	2.43	3.59	3.81	2.41	0.172	0.74	Pacaja River, Northern
<i>Range</i>	5.19-18.88	12.3-23.87	1.9-15.2	5.19-20.62	12.3-23.07	0.067-0.814	0-3	Brazil
<i>CV%</i>	31	12.2	39.8	33.5	20.7	45.2	168.2	(Azevedo and Van Sluys, 2005)
<i>Mean</i>	9.18	15.65	-----	9.70	14.64	0.630	-----	n=50
<i>SD</i>	3.05	2.49	-----	3.64	2.66	0.320	-----	Mamirauá Reserve,
<i>Range</i>	-----	-----	-----	-----	-----	-----	-----	Amazonian
<i>CV%</i>	33.2	15.9	-----	37.6	18.2	50.8	-----	Brazil
								(Podos <i>et al.</i> , 2002)
<i>Mean</i>	10.210	15.410	-----	10.760	14.350	0.410	1.38	n=155
<i>SD</i>	3.10	3.11	-----	3.53	2.89	0.210	2.19	Marañon and Tigre
<i>Range</i>	3.65-18.14	8.28-23.86	-----	3.64-21.21	7.89-23.11	0.06-1.04	0-16	Rivers, Amazonian, Peru
<i>CV%</i>	30.39	20.18	-----	32.77	20.15	51.10	158.4	(Wang <i>et al.</i> , 1995; 2001)



a.



b.

**Figure 2.** Examples of whistle contour (a) and burst sound (b) recorded from tucuxi in this study.



**Table 2.** Significant pairwise comparisons of *Sotalia fluviatilis* whistle parameters.

Statistic	MinF (kHz)	MaxF (kHz)	SF (kHz)	EndF (kHz)	Duration (s)	#Inflection Points	Population
<i>t</i> -student <i>df</i>	n.s.	6.94 100.8	n.s.	13.6 135.7	n.s.	4.7 213	Marañon and Tigre Rivers vs. Pacaja River
<i>t</i> -student <i>df</i>	2.1 203	n.s.	n.s.	n.s.	n.s.	----	Marañon and Tigre Rivers vs. Mamirauá Reserve, Amazonian
<i>t</i> -student <i>df</i>	n.s.	2.45 31.9	n.s.	n.s.	n.s.	2.71 94.7	Marañon and Tigre Rivers vs. <b>Aguarico and Napo Rivers</b>
<i>t</i> -student <i>df</i>	2.86 112	9.35 107	n.s.	10.2 103.6	5 75.6	----	Pacaja River vs. Mamirauá Reserve, Amazonian
<i>t</i> -student <i>df</i>	n.s.	2.37 32.2	n.s.	5.5 31.4	n.s.	n.s.	Pacaja River vs. <b>Aguarico and Napo Rivers</b>
<i>t</i> -student <i>df</i>	n.s.	2.15 33.4	2.58 37.4	n.s.	4 69.9	----	Mamirauá Reserve, Amazonian vs. <b>Aguarico and Napo Rivers</b>

n.s. = not significant results at the 0.05 level of significance.

#### CLICK TRAINS

A total of 22 click trains from four solitary tucuxis were selected for measurements based on their signal/noise quality. Clicks were emitted by one animal when milling and by the other three during foraging. No clicks were analyzed from the mixed-species group because of overlap between click trains. We also did not include click trains from the other two solitary tucuxis due to high background noise. Click trains contained from seven to 99 clicks (mean = 36.86, SD = 27.92) with a mean duration of 2.58±1.89s (range 0.497 to 7.539). Click repetition rate was 15.35±6.38 clicks per second and mean ICI was 67.8 (SD = 25.2). Click dominant frequency was 88.35 kHz (SD = 3.01) and mean duration 109.2ms (SD = 31.97).

#### BURST SOUNDS

Only one short burst sound (50ms) was produced by a solitary tucuxi; it consisted of 30 clicks with a mean interclick interval of 2ms. A total of 26 burst sounds (with good signal noise ratio) were analyzed from the mixed-species group (Figure 2b). Animals were engaged in foraging activities within a small area continuously during the recording period. We do not know if both or only one species emitted these sounds. However, our recordings of boto dolphins from the Yasuní River did not contain burst sounds. Of all burst trains only one had an ICI of 1ms, for all others the ICI was 2ms. Overall, burst trains contained 26.9 (SD = 13.7) clicks per train with mean duration of 46ms (SD = 22.8). Mean dominant frequency was 77.62 kHz (SD = 11.85).

#### Discussion

Ecuadorian tucuxis emitted a variety of sounds including whistles, pulsed and echolocation clicks. The acoustic structure of these sounds is similar to that described in previous studies (e.g. Caldwell and Caldwell, 1967; Wiersma, 1982; Wang *et al.*, 1995; 2001). However, whistle structure comparisons between this study and others, suggest these sound may vary geographically as reported in its sister species the marine *S. guianensis* (e.g. May-Collado and Wartzok, 2009; Rossi-Santos and Podos, 2006; Azevedo and Van Sluys, 2005). This is interesting, as one would expect freshwater environments to be relatively homogenous in their acoustic properties. However, differences in 'micro-habitat' (e.g. rapids, lakes, etc.) may influence whistle structure as well as the degree of contact (or isolation) between these populations as it has been shown in *S. guianensis*, where adjacent populations are more similar in their whistle parameters (particularly frequency) (Azevedo and Van Sluys, 2005; Rossi-Santos and Podos, 2006; May-Collado and Wartzok, 2009). In addition, *S. guianensis* shows an overall pattern of increasing in frequency from southern to northern populations (Azevedo and Van Sluys, 2005; Rossi-Santos and Podos, 2006; May-Collado and Wartzok, 2009).

The whistles recorded from the mixed species group were more likely emitted by tucuxis and not by botos. May-Collado and Wartzok (2007) contrasted the differences between these whistles and those of botos from the Yasuní River, located about 14km upstream from this study area, and found significant differences in the contour and acoustic parameters of the two species.

In addition, these 21 whistles had similar contours to those described for other tucuxi populations and the sister species *S. guianensis* (e.g. Monteiro-Filho and Monteiro, 2001; Podos *et al.*, 2002; Azevedo and Van Sluys, 2005; Azevedo and Simão, 2002; May-Collado and Wartzok, 2009) (Figure 2a).

This is the first time that whistles with high frequency harmonics have been reported in *S. fluviatilis*. These high frequency whistle harmonics may not be exclusive to this Ecuadorian population but may have been undetected in other studies due to the limitations in the maximum frequency of the recording equipment. Until now all *S. fluviatilis* acoustic studies have used recording systems limited to 25kHz. The fundamental frequency did not exceed this 25kHz limit, but until we have full frequency range recordings from other *S. fluviatilis* populations, the production and role of high frequency whistle harmonics will remain unknown. The presence of high order harmonics in whistles has been recently described for its sister species *S. guianensis* (May-Collado and Wartzok, 2009). In the distantly *Stenella longirostris* and *Orcinus orca* high-frequency harmonic whistles are associated with direction and coordination as the animals travel from one area to another (Miller, 2002; Lammers and Au, 2003).

Click repetition rate, duration, and dominant frequency values were similar to those described in previous studies (e.g. Norris *et al.* 1992; Kamminga *et al.* 1993). However, further comparisons are limited due to differences in data analysis approaches and recording systems. Finally, this study provides the first descriptions of tucuxi burst pulses. Similarly to burst pulses of spinner and spotted dolphins (Lammers *et al.* 2003), tucuxis emit burst pulses that are predominantly ultrasonic. However, there is contrast in the context in which they are produced: while in spinner and spotted dolphins burst pulses have been recorded during social events, in this study tucuxis emitted burst pulses when solitary and in the presence of botos during foraging events. However, this may be due to a small sample size.

This study provides insights on the sound repertoire of tucuxis in Ecuador and provides new information on the emission of high order harmonics, and geographical variation. Future studies should use recording systems with a broader bandwidth of at least 150kHz to ensure the inclusion of high order harmonics and burst pulses and thus gain more information about their role in dolphin communication.

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