Vocalizations of Amazon river dolphins (*Inia geoffrensis*): Characterization, effect of physical environment and differences between populations

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The vocal repertoire of the Amazon river dolphin and its geographic variations are still poorly known, especially in relation to ecological variables. Here the acoustic characteristics of low frequency pulsed vocalizations, with single or multiple pulses, recorded in two protected areas of the Amazon were described and differences in acoustic emissions related to water properties were analyzed. Both frequency and time parameters differ relative to abiotic condition of water turbidity. Changes in the animals' acoustic behavior might be due to differences in sound propagation between rich-sediment water and clear water. Geographic variation was found in frequency and time parameters, requiring further investigation.
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I. INTRODUCTION

There are several studies characterizing echolocation signals of Amazon river dolphin or boto, *Inia geoffrensis* (de Blanville, 1817) (e.g., Penner and Murchison, 1970; Norris *et al.*, 1972; Evans, 1973; Kamminga, 1979; Wiersma, 1982; Kamminga *et al.*, 1993; Verfuss *et al.*, 1997). The echolocation clicks are characterized by ultrasonic pulses with frequencies ranging from 16 to 150 kHz (Evans, 1973) and dominant frequency between 85 and 100 kHz (Kamminga *et al.*, 1993). Tonal signals have also been reported for this species. Ding *et al.* (1995) and Ding *et al.*(2001) found whistles with simple contours and frequency below 5 kHz; May-Collado and Wartzok (2007) described whistles modulated in broader frequency range of 5.30 and 48.10 kHz.

Caldwell *et al.* (1966) and Caldwell and Caldwell (1967) recorded captive animals and described 12 types of vocalizations grouping them into four categories: single intense clicks, echolocations clicks, jaw-snaps and burst-pulsed signals. The last category was grouped into seven types: "squawk," "screech," "bark," "whimper," "crack," "squeal," and "squeaky squawk."

In several animal taxa, groups geographically separated may be discriminated by their acoustics emissions. In cetaceans, such differences have been considered useful in providing insights into the social organization and association patterns among individuals (Whitehead *et al.*, 1998; Deecke *et al.*, 1999; Miller and Bain, 2000; Yurk *et al.*, 2002; Bazuá-Durán and Au, 2004).

Geographical differences (or macrogeographic variations) are associated with widely separated populations groups over long distances, which do not normally mix; while microgeographic variations are generally assigned to sounds emitted on a local scale among neighboring groups which can potentially intermix (Grimes, 1974; Krebs and Kroodsma, 1980; Conner, 1982; McGregor *et al.*, 2000).

Geographic variations can provide valuable information since they may reflect adaptations to different ecological conditions (Marler, 1960; Ford, 1991), dispersal capabilities of species (Mundinger, 1982; McGregor *et al.*, 2000) and the extent of isolation and genetic divergence between groups or populations (Lemon, 1966; Ford, 2002). In the context of ecology, water abiotic features affect acoustic communication. Sound attenuation and degradation act as environmental constraints on the process of communication (Wiley and Richards, 1982) since they may affect the detection and recognition of emitters by receiver animals (Bradbury and Vehrencamp, 1998; Lugli and Fine, 2003). Given that, it is relevant to investigate how environmental features might act in the evolutionary design of vocalizations and consequently in their biological function.

Most research on dolphin underwater emissions has been conduced in the marine environment (Weilgart and Whitehead, 1997; Stafford *et al.*, 2001; Bazúa-Durán and Au, 2004; Morisaka *et al.*, 2005; Au and Hastings, 2008; Azzolin *et al.*, 2013), and there is still a scarcity of information regarding variation in dolphin acoustic production in freshwater environments. Variations in pulsed vocalizations

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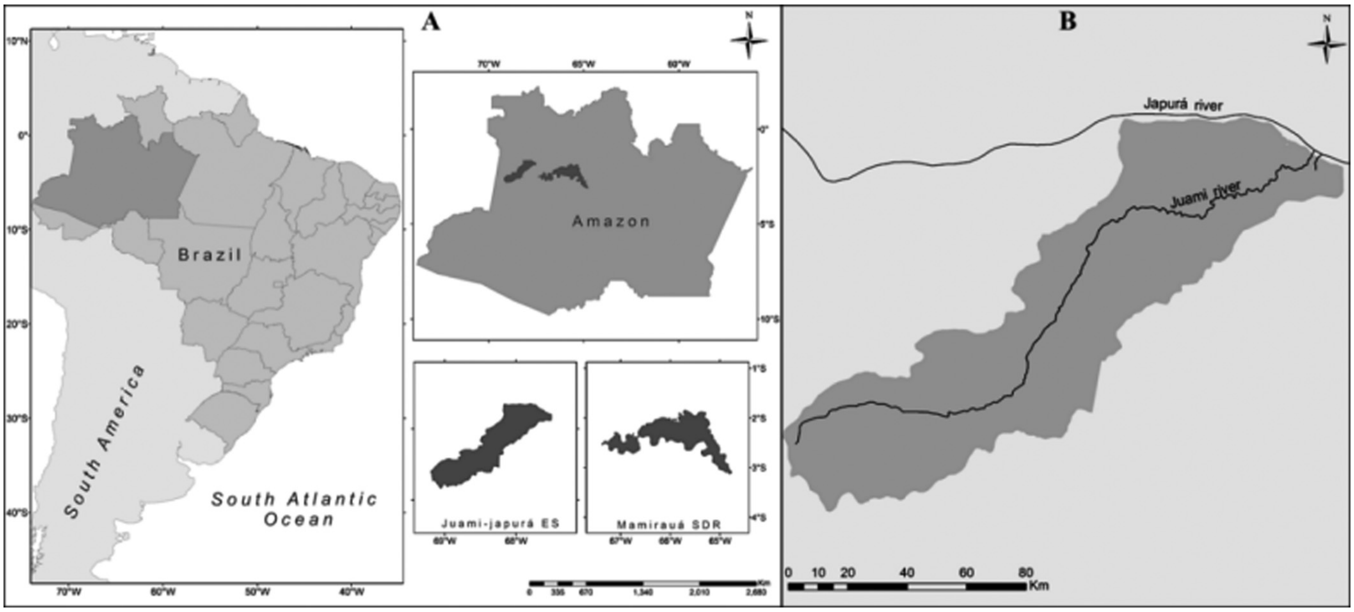

FIG. 1. (A) Study areas in Amazon: Juami-Japurá Ecological Station and Mamirauá Sustainable Development Reserve. (B) Juami and Japurá rivers paths.

have not been broadly studied for Amazon river dolphin from different areas. We aim to contribute to the understanding of the repertoire of this lesser-studied cetacean. This study specifically intends (1) to characterize the low frequency pulsed vocalizations of the Amazon river dolphin at the Juami-Japurá Ecological Station, (2) to document possible effects of water properties in the dolphins' acoustic behavior, and (3) to examine differences in acoustic parameters between two populations.

II. METHODOLOGY

A. Study areas

The Juami-Japurá Ecological Station (JJES) (01°39′S, 68°02′W) is a Brazilian conservation unit located between the interfluve of the Solimões river (the regional designation of that part of the Amazon) and the Japurá river. The JJES area is covered by dense upland ombrophilous tropical forests (Veloso *et al.*, 1991) and the climate is the rainy tropical type (Af subgroup of the Köppen climate classification system). The dry season occurs from July to November (RADAMBRASIL, 1977).

The Mamirauá Sustainable Development Reserve (MSDR) (03°20′S, 64°54′W) is situated in the confluence of the Japurá and Solimões rivers, which are two large "white-water" (rich in sediments) rivers. The reserve is characterized by seasonally flooded forest (Junk, 1983). The weather is tropical humid and the dry season occurs from September to November (Ayres, 1993) (Fig. 1).

Abiotic attributes of the river waters were considered as possible factors in acoustic variation. Amazonian waters have traditionally been classified as white, black, or clear. Sioli (1984) showed that these waters are chemically and physically heterogeneous (Table I). White water rivers carry a high sediment load derived from their headwaters in the Andes. Black and clear water rivers have catchments confined within the Amazonian forest and carry little inorganic sediment (Schmidt, 1973; Devol *et al.*, 1984; Junk and Piedade, 1993).

B. Field sampling and spectrographic analysis

Field sampling was carried out for three days (August 29 to 31, 2012), from 6:00 to 18:00. All recording sessions were performed on a drifting boat with the engine and depth sounder off. Once the animals were sighted, the recordings were carried out until they left the area.

The recording system was composed by a Cetacean Research C54XRS hydrophone positioned between 2 and 4 m deep (+3/−20 dB, −185 dB re 1 V/μPa) coupled to a digital Fostex FR-2 LE recorder sampling at 96 kHz/24 bits. The analysis focused on the vocalizations that globally did not exceed the Nyquist frequency of the recording system, thus any aliasing effect was absent on the analyzed signals. The .wav files were analyzed through the spectrogram configured with a FFT length of 2048 samples, 60% overlap and Hamming window of 1024 points generated by software Raven Pro 1.5 (Cornell Laboratory of Ornithology, Cornell University, Ithaca, New York).

The selection of pulsed vocalizations was made based on their signal-to-noise ratio (SNR), which had to be sufficiently high (greater than 10 dB) so that both time and frequency parameters could be clearly measured. The

TABLE I. Ecological attributes of water types (Sioli, 1984).

Abiotic attributes	White water	Black water
pH	Near neutral	Acidic, <5
Electric conductivity	40–1000	<20
Transparency (Secchi depth)	20–60 cm	60–120 cm
Water color	Turbid (muddy)	Brownish
Humic substances	Low	High
Inorganic suspensoid	High	Low
Density	High	Low

vocalizations analyzed were grouped according to the number of pulses: multiple (composed by a series of pulses) or single (just one pulse). The following acoustic parameters were extracted from spectrograms: minimum, maximum, peak and center frequencies, bandwidth (maximum-minimum frequency), duration, number of pulses (just for multiple pulses vocalizations), production rate of pulses (pulses/s), and number of harmonics. The emission rate was calculated by the following ratio: number of vocalizations/min/number of sighted individuals.

The descriptive statistics—mean, standard deviation, minimum and maximum values—were calculated for each parameter.

C. Effect of physical environment and differences between populations

The analysis of possible physical environment effects took into consideration recordings conducted in either white or black water at JJES. Whereas for differences between populations study, it was considered recordings made just in white waters, both at JJES and MSDR.

The Wilcoxon test was performed using R 2.15.3 statistical software (R Core Team, 2013) to analyze the differences in acoustic parameters of vocalizations emitted in the two types of water. The same individuals were eventually recorded in the two water conditions, since they were seen moving freely between black and white waters. The distance between the animals and the boat was controlled in both water conditions, in order that the sampled animals were at a distance of up to 5 m from the boat, thus frequency attenuation was negligible. Descriptive statistics—mean, standard deviation, minimum and maximum values—were calculated for each parameter of vocalizations emitted in both water types.

A principal components analysis (PCA) of measured acoustical parameters was performed to examine the pattern of variability in both conditions of water turbidity. Acoustic features of vocalizations may be highly correlated with one another and the PCA should isolate independent and uncorrelated acoustic variables from the original set of ten extracted parameters.

In the differences between populations analysis, the JJES recordings were compared with results found by Podos *et al.* (2002) (Nyquist frequency of 15–18 kHz; −240 to −165 dB re 1 V/μPa) and Rocha (2009) (Nyquist frequency of 150 kHz; −165 dB re 1 V/μPa) in MSDR. These authors conducted the recordings in white water; therefore just recordings performed under the same type of water in JJES were considered, in order to minimize the environmental effects of water turbidity in the acoustic behavior. In addition, a comparison within MSDR population was performed as a control condition.

The comparisons between the two populations were performed by F-test, which tested the null hypothesis that the variances were equal, and then the t-test to test the null hypothesis of equal means (May-Collado and Wartzok, 2008). The level of significance adopted was $\alpha = 0.05$.

III. RESULTS

A. Acoustic characteristics of pulsed vocalizations

During sampling the dolphin group size ranged from 1 to 4 (2.25 ± 1.09) animals. We analyzed 183 pulsed vocalizations in a total of 6 h, 18 min, and 19 s of recordings. Vocalizations recorded were rapid emissions of frequency-modulated pulses emitted in series (N = 143) or singly (single pulse: N = 49) (Fig. 2), both designs presented harmonic structure The emission rate was 0.09 vocalizations/min/number of sighted individuals. Descriptive parameters are presented in Table II.

B. Effect of physical environment

The Wilcoxon test showed significant differences between the two conditions of water turbidity for the following acoustic parameters: maximum frequency, center frequency, bandwidth, duration and number of harmonics were lower in white water, and production rate of pulses, higher in white water (Table III).

Principal component analysis generated nine statistically independent components for both water turbidity conditions. For white water the first three components accounted 77.21% of data variance, meaning that the complexity of the data set can be reduced to three components with a 22.79% loss of information. Table IV shows each component with its percent variances and the acoustic parameters correlated. All components were loaded negatively with acoustics variables. Component 1 was loaded with low, peak, and center frequencies. Component 2 was loaded with high frequency, bandwidth and number of harmonics. Component 3 was loaded with duration, number of pulses and production rate.

For black water the first three components accounted 82.39% of data variance, this could mean that the complexity of the data set can be reduced to three components with a 17.61% loss of information. Table V shows each component with its percent variances and the acoustic parameters correlated. Component 1 was loaded negatively with high frequency, duration, bandwidth and number of harmonics. Component 2 was loaded positively with low, peak and center frequencies. Component 3 was loaded positively with number of pulses and production rate.

The correlation circle generated by the PC analysis shows the proximity among the acoustic variables. For white water, the parameters low frequency (LF), center frequency (CF), peak frequency (PF), high frequency (HF), bandwidth (BW), number of harmonics (NH), duration (D) and number of pulses (NP) were better represented, since they are close to the unit circle. HF, BW, and NH are correlated and independent from CF, PF, and LF, which are also correlated. The D and NP showed strongly correlation and are independent from other variables [Fig. 3(A)].

For black water HF, BW, NH, CF, PF, LF, D, NP, and PR were well represented. The parameter production rate (PR) was better represented than in the correlation circle for white water. HF, BW, and NH are strongly correlated and

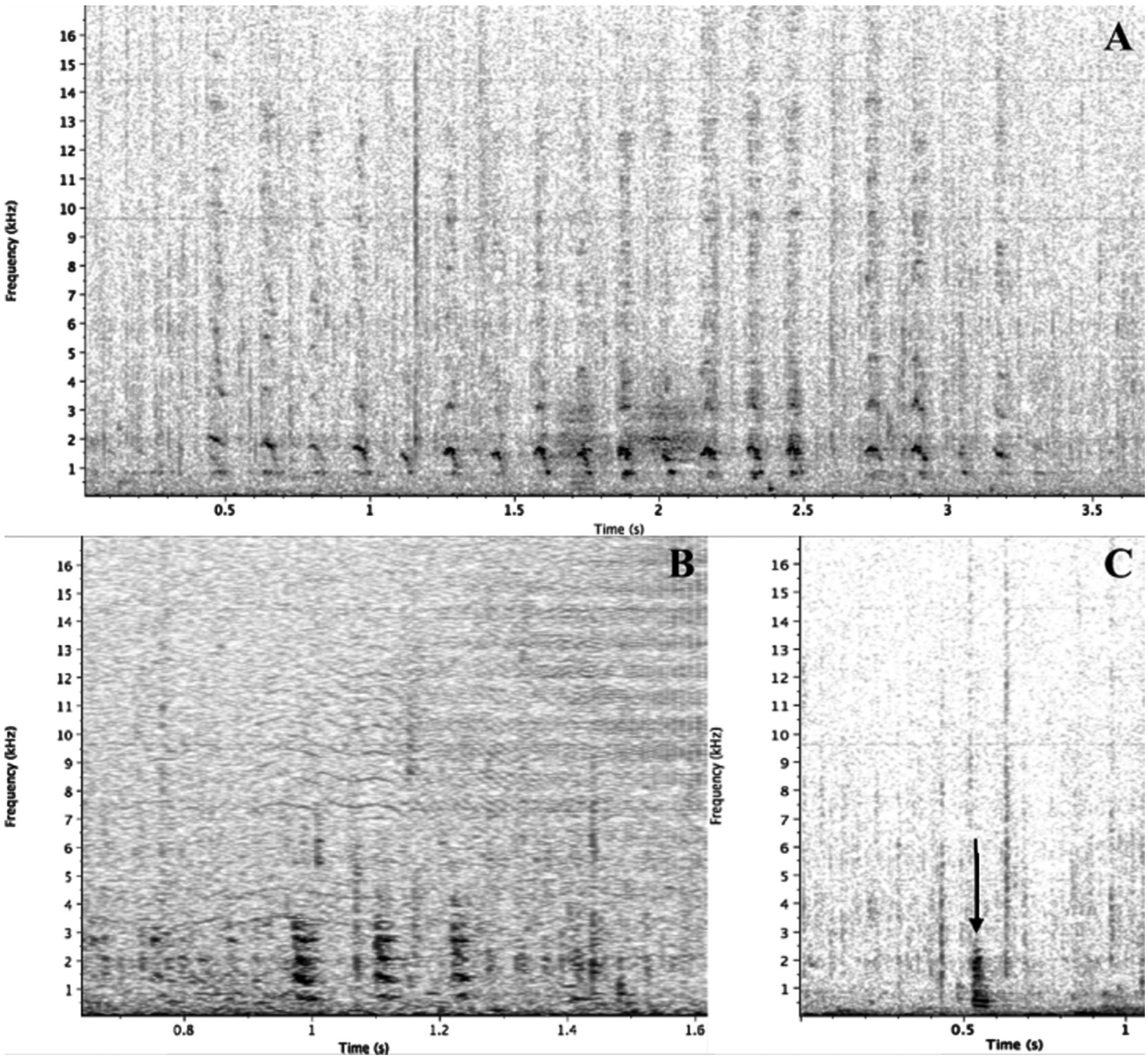

FIG. 2. Pulsed vocalizations of Amazon river dolphin (Spectrogram parameters: FFT length of 2048 samples, 60% overlap and Hamming window). (A) and (B) Multiple pulses (series of pulses). (C) The arrow points to a single pulse.

independent of the CF, LF and PF, also correlated between themselves. LF and PF also showed strongly correlation. The D and NP are correlated and independent from the other variables [Fig. 3(B)].

C. Differences between populations

Table VI presents means and standard deviations for measured vocalizations from JJES and MSDR populations.

TABLE II. Descriptive statistics of acoustic characteristics of *Inia geoffrensis* vocalizations from Juami-Japurá Ecological Station, Amazon, Brazil. (Values presented as mean ± SD and range).

	Multiple pulses (n = 134)	Single pulses (n = 49)	Total (n = 183)
Minimum frequency (kHz)	0.52 ± 0.24 [0.06–1.39]	0.64 ± 0.34 [0.12–1.39]	0.52 ± 0.24 [0.06–1.39]
Maximum frequency (kHz)	3.37 ± 2.88 [1.67–17.10]	2.88 ± 1.73 [1.76–12.35]	3.37 ± 2.88 [1.67–17.10]
Peak frequency (kHz)	1.29 ± 0.39 [0.09–2.11]	1.43 ± 0.46 [0.23–2.11]	1.29 ± 0.39 [0.09–2.11]
Center frequency (kHz)	1.32 ± 0.33 [0.09–2.77]	1.45 ± 0.42 [0.23–2.77]	1.32 ± 0.33 [0.09–2.77]
Bandwidth (kHz)	2.85 ± 2.87 [0.85–16.62]	2.25 ± 1.62 [0.85–11.14]	2.85 ± 2.87 [0.85–16.62]
Duration (s)	0.26 ± 0.35 [0.03–2.49]	0.06 ± 0.04 [0.03–0.22]	0.26 ± 0.35 [0.03–2.49]
Number of pulses	5.46 ± 3.71 [2.00–19.00]	1.00 1.00	4.27 ± 3.74 [1.00–19.00]
Production rate of pulses (pulses/s)	21.40 ± 8.48 [4.36–37.31]	19.13 ± 8.08 [4.65–40.00]	20.79 ± 8.44 [4.36–40.00]
Number of harmonics	3.30 ± 1.60 [1.00–8.00]	3.00 ± 1.54 [1.00–9.00]	3.22 ± 1.59 [1.00–9.00]

TABLE III. Acoustic characteristics of *Inia geoffrensis* vocalizations in different conditions of water turbidity from Juami-Japurá Ecological Station and p- values of Wilcoxon test. Significant p values are shown in bold. (Values presented as mean ± SD and range).

	White water (turbid) (n = 98)	Black water (brownish) (n = 85)	p-value
Minimum frequency (kHz)	0.50 ± 0.23 [0.18–1.34]	0.54 ± 0.26 [0.06–1.39]	0.637
Maximum frequency (kHz)	2.33 ± 0.50 [1.67–5.09]	4.56 ± 3.87 [1.76–17.10]	**<0.0001**
Peak frequency (kHz)	1.25 ± 0.31 [0.52–2.06]	1.34 ± 0.46 [0.09–2.11]	0.166
Center frequency (kHz)	1.26 ± 0.23 [0.80–1.97]	1.40 ± 0.41 [0.09–2.77]	**0.007**
Bandwidth (kHz)	1.83 ± 0.52 [0.85–4.62]	4.03 ± 3.86 [1.25–16.62]	**<0.0001**
Duration (s)	0.18 ± 0.12 [0.03–0.58]	0.36 ± 0.48 [0.03–2.49]	**0.017**
Number of pulses	4.60 ± 3.38 [1.00–16.00]	3.88 ± 4.09 [1.00–19.00]	0.084
Production rate of pulses (pulses/s)	25.34 ± 5.58 [11.24–37.31]	15.55 ± 8.13 [4.36–40.00]	**<0.0001**
Number of harmonics	2.68 ± 1.16 [1.00–8.00]	3.84 ± 1.79 [2.00–9.00]	**<0.0001**

The t-test showed that minimum frequency, maximum frequency, peak frequency and duration of multiple pulses were lower for JJES population. No significant differences were found for numbers of harmonics and number of pulses. In relation to single pulses, the duration was significantly different between JJES and MSDR. The comparison within MSDR population (Podos *et al.*, 2002; Rocha, 2009) did not show significant differences for available parameters duration and number of pulses (Table VII).

IV. DISCUSSION

A. Acoustic characteristics of pulsed vocalizations

The vocalizations recorded either contained single or multiple pulses and presented harmonic structure. Podos *et al.* (2002) also found the same types. Most of our recordings presented multiple pulses (N = 134), Podos *et al.* (2002) also observed most vocalizations containing multiple pulses (designated by them as notes) (N = 216).

Other studies recorded these pulsed signals for Amazon river dolphins. Caldwell and Caldwell (1970) observed these vocalizations (which they called "squeals") consisting of a series of pulses, during transportation of two individuals for a "Sea World" in Los Angeles. Diezgranados and Trujilo (2002) recorded these emissions for two populations in the Orinoco river basin at Colombia.

Although this species is mostly solitary, temporary aggregations may be formed in foraging contexts. Podos *et al.* (2002) observed the described vocalizations during foraging behavior, when such pulsed signals possibly occurred. Besides that, pulsed emissions are associated with relations of proximity among individuals, as in agonistic interactions among males for access to females (Herzing, 2000).

Burst-pulses sounds in general are not well studied, although they seem to have a predominatly communicative function (Herman and Tavolga, 1980). It would be important to know more about these emissions in the various odontocete species, in different environments and activities.

B. Effect of physical environment

Characteristics of acoustic signals are affected by environmental conditions, hence communication mechanisms have evolved to adapt to different abiotic conditions (Morton, 1975; Wiley and Richards, 1978; Sugiura *et al.*, 1999).

Our results revealed that frequency and temporal structures of pulsed vocalizations of the Amazon river dolphin, changed in relation to the abiotic conditions of water turbidity. Since the target animals were at a distance of up to 5 m from the boat, and consequently the frequency attenuation was negligible, the observed differences between the two conditions of water resulted from a change in the acoustic behavior on the part of the animals.

TABLE IV. Principal components analysis (PCA) loadings of acoustic parameters for white water, their eigenvalues and their percent variance explained for pulsed vocalizations prodiced by Amazon river dolphins. High loadings (>absolute 0.30) are highlighted in bold for each component (PC).

	PC1	PC2	PC3
Low frequency	**−0.472145337**	−0.183588	−0.22093725
High frequency	0.126262856	**−0.61419763**	0.07352735
Peak frequency	**−0.391884223**	−0.28491097	−0.18673492
Duration	0.349690306	0.02659087	**−0.52766409**
Center frequency	**−0.412980066**	−0.33067891	−0.28878499
Bandwidht	0.325356746	**−0.50490441**	0.16523445
Number of pulses	0.340221298	0.03617269	**−0.59361029**
Number of harmonics	0.305023634	**−0.37507474**	0.09920811
Production rate	0.008967804	−0.03014725	**−0.39945779**
% of variance	31.38	25.34	20.49
Cumulative %	31.37	56.72	77.21

TABLE V. Principal components analysis (PCA) loadings of acoustic parameters for black water, their eigenvalues and their percent variance explained for pulsed vocalizations prodiced by Amazon river dolphins. High loadings (>absolute 0.30) are highlighted in bold for each component (PC).

	PC1	PC2	PC3
Low frequency	0.1924846	**0.47375263**	0.1151421
High frequency	**−0.4295928**	0.29368068	−0.1600795
Peak frequency	0.1862886	**0.49642005**	0.0843992
Duration	**−0.4518404**	−0.07211979	0.4146143
Center frequency	0.0545982	**0.5490476**	0.1764814
Bandwidht	**−0.4436124**	0.26256534	−0.1682912
Number of pulses	−0.3474042	−0.1007463	**0.6738237**
Number of harmonics	**−0.3231144**	0.21923466	**−0.2230625**
Production rate	0.3386311	0.09522865	**0.4677882**
% of variance	39.55	30.57	12.27
Cumulative %	39.55	70.12	82.39

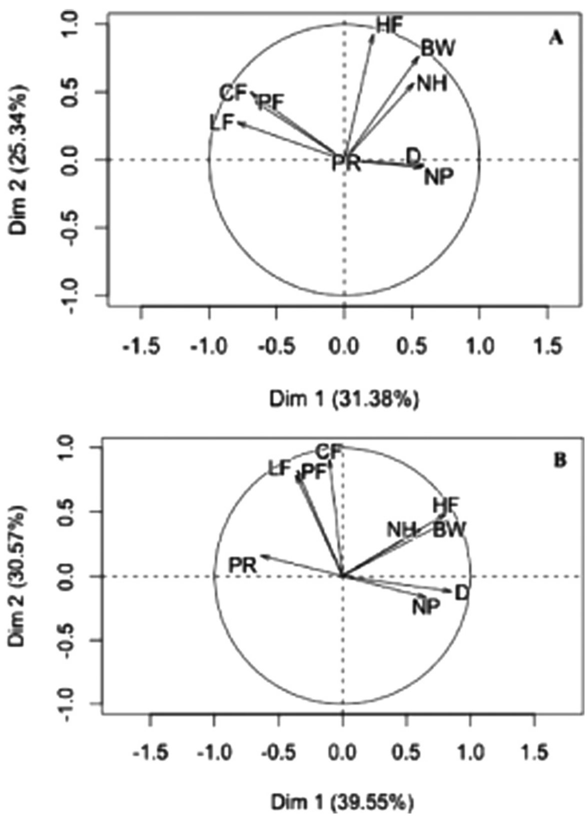

FIG. 3. Correlation circle of Principal Component Analysis showing the position of acoustic parameters in the two-dimensional spaces (Dim) of the two principal components. (A) White water; (B) black water. LF = low frequency; HF = high frequency; CF = center frequency; PF = peak frequency; BW = bandwidth; NH = number of harmonics; NP = number of pulses; D = duration; PR = production rate of pulses.

White water presents much higher quantities of particles in suspension than black water (Sioli, 1956). Signals emitted in rich sediments water (white water) have more attenuation and geometric spreading along their propagation (Stoll, 1985; Kibblewhite, 1989; Bradley and Stern, 2008). The scattering process is also higher in this water type, since sound energy bends as soon as it hits a particle (diffraction) (Medwin, 2005). The maximum frequency, center frequency, bandwidth and number of harmonics were significantly lower in white water than black water. Considering that lower frequencies present greater wavelength, this emission change would ensure that acoustic information is reliably transmitted and increases the active space of the signal under conditions of higher attenuation, spreading and scattering (Hamilton, 1980).

Vocalizations should be heard by nearby animals (Smith, 1996; Lammers *et al.*, 2003) thus, any possibly losses would affect any messages encoded. The lower value of duration, higher production rate and higher emission rate in white water, may be an adaptation to the propagation conditions. The abiotic condition of black water enables emission with higher duration, lower production rates and lower vocalizations per minute per number of individuals. Since this type of water permits better sound propagation and allows somewhat better visibility, the animals may invest less in their emissions.

After data reduction through PCA, the vocalizations required three main structural components for white water and black water to be described reasonably. As showed in the correlation circle, different water conditions lead to different grouped and restricted frequency parameters. Low frequency, center frequency and peak frequency are independent from high frequency and bandwidth. It is not surprising that high frequency, bandwidth and number of harmonics are associated, since the highest frequency is dependent on the number of harmonics within the vocalization, which also occurred for duration and number of pulses.

Moreover, the PCA showed that Amazon river dolphins modulate the extracted acoustics parameters in different water conditions. High frequency, number of harmonics and bandwidth are more correlated in black water than white water. Besides that, peak frequency and low frequency are strongly correlated in black water, whereas in white water the peak frequency is strongly correlated with center frequency. In addition, the parameters duration, number of pulses and production rate are best represented in the correlation circle of black water. It is likely that these variables carry additional information and may be used by animals in this low-sediment condition water.

C. Differences between populations

Acoustic geographic variations may be viewed as results of adaptations to differences in environmental conditions or

TABLE VI. Means and standard deviations for measured vocalizations emitted by Amazon river dolphin (*Inia geoffrensis*) from Juami-japurá Ecological Station in comparison with other studies.

	Multiple pulses						Single pulses	
	Minimum frequency (kHz)	Maximum frequency (kHz)	Peak frequency (kHz)	Number of harmonics	Duration (s)	Number of pulses	Duration (s)	Source
Mean	0.5	2.33	1.25	2.68	0.18	4.6	0.05	n = 98 - Juami-japurá Ecological Station, Amazon, Brazil (This study).
SD	0.23	0.5	0.31	1.16	0.12	3.38	0.01	
Mean	—	—	—	—	0.72	4.18	0.10	n = 240 - Mamirauá Reserve, Amazon, Brazil (Podos *et al.*, 2002)
SD					0.45	2.35	0.07	
Mean	1.3	17.0	3.1	3.5	0.79	3.3	—	n = 39 - Mamirauá Reserve, Amazon, Brazil (Rocha, 2009)
SD	1.1	7.5	2.9	4.6	0.81	4.0		

TABLE VII. Pairwise comparisons of *Inia geoffrensis* pulsed vocalizations parameters obtained in this study with results presented in available literature. Significant p - values are shown in bold.

	Populations					
	JJES and MSDR (Rocha, 2009)		JJES and MSDR (Podos *et al.*, 2002)		MSDR (Rocha, 2009) and (Podos *et al.*, 2002)	
Multiple pulses	t Test	p-value	t Test	p-value	t Test	p-value
Minimum frequency (kHz)	−4.503	**<0.0001**	—	—	—	—
Maximum frequency (kHz)	−12.204	**<0.0001**	—	—	—	—
Peak frequency (kHz)	−3.975	0.0003	—	—	—	—
Number of harmonics	−1.099	0.278	—	—	—	—
Duration (s)	−4.683	**<0.0001**	−17.156	**<0.0001**	−0.527	0.601
Number of pulses	1.926	0.056	1.124	0.262	1.337	0.188
Single pulses						
Duration (s)	—	—	−10.799	**<0.0001**	—	—

be a by-product due to the isolation and genetic divergence among populations (Ford, 1991; Foster and Cameron, 1996).

Our recordings and those made by Podos *et al.* (2002) and Rocha (2009) were carried out in the dry season with the same water turbidity and seasonal rivers dynamics. Pairwise comparisons showed significant differences in both frequency and time parameters, which may indicate geographic variation between populations. Frequency parameters presented lower means in emissions recorded in JJES than those recorded in MSDR. Differences in frequency parameters are usually associated with variation between species or between populations and are generally related to anatomical variables such as body size or noise levels conditions (see Rendell *et al.*, 1999).

Temporal parameter (duration) was also significantly different between populations. Differences in duration were also documented for whistles of Hawaiian spinner dolphin (Bazúa-Durán and Au, 2004) and *Tursiops truncatus* (Janik *et al.*, 1994; Wang *et al.*, 1995), and could be associated with different individuals engaged in different activities during the recording sessions. The comparison of duration parameter between the same population in MSDR—Podos *et al.* (2002) vs Rocha (2009)—could be considered as a control condition for supporting the geographic variation, since no significant difference was observed.

Different group sizes may have significant influence in the sound emission of the animals and thus, can be another factor to explain the geographic variation (Norris *et al.*, 1994; Herzing, 2000). In this study, *Inia geoffrensis* group size ranged from 1 to 4 individuals, while in the work of Rocha (2009), it ranged from 1 to 15 and for Podos *et al.* (2002) it was from 1 to 14 individuals. Therefore, the variation of acoustics parameters may reflect the isolation of populations, behavior context and adaptation to the environmental conditions (other than turbidity) such as shape, depth and geology of rivers, temperature of water, underwater vegetation density and noise levels. Thus, understanding differences in signaling of distinct populations requires a variety of multidisciplinary approaches.

V. CONCLUSIONS

This is the first work to describe pulsed vocalizations signals of Amazon river dolphin in the Juami-Japurá Ecological Station. Repertoire characteristics may provide baseline information for further approaches concerning differences between populations, acoustic ecology, taxonomy, and behavior studies.

Abiotic underwater features play an important role in the process of communication system. The variation of acoustic parameters in different conditions of water turbidity demonstrates that these aspects of the animals' acoustic behavior might be sensitive to abiotic features of their environment. More observational and experimental studies are needed to determine how pervasive the effect of turbidity is upon vocalizations characteristics and they should include qualitative and quantitative analysis of other pulsed vocalizations emitted by Amazon river dolphins.

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