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1 **The newly described Araguaian river dolphins, *Inia araguaiaensis***
2 **(Cetartyodactyla, Iniidae), produce a diverse repertoire of acoustic signals**

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27 **The newly described Araguaian river dolphins, *Inia araguaiaensis* (Cetartiodactyla,**
28 ***Iniidae*), produce a diverse repertoire of acoustic signals**

29

30 **Abstract:** The recent discovery of the Araguaian river dolphin (*Inia araguaiaensis*) highlights
31 how little we know about the diversity and biology of river dolphins. In this study, we described
32 the acoustic repertoire of this newly discovered species in concert with their behaviour in free-
33 ranging, human-habituated individuals. We analysed 393 signals that we classified into 13 types
34 of tonal sounds (n=15) and 66 types of pulsed calls (n=378). The most common sounds were short
35 two-component calls. Thirty-five percent (n=140) of these calls were emitted by calves as they
36 reunited with their mothers suggesting a key role in mother-calf communication. Our findings
37 show that the acoustic repertoire of river dolphins is far from simple. Furthermore, the calls
38 described here are similar in acoustic structure to those produced by social delphinids, such as
39 orcas and pilot whales. Uncovering the context in which these signals are produced may help
40 understand the social structure of this species and contribute to our understanding of the evolution
41 of acoustic communication in whales.

42 **Introduction**

43 River dolphins of the genus *Inia* - commonly known as botos - are evolutionary relics found
44 exclusively in the Amazon, Orinoco, and Tocantins River Basins of South America (Best & Da
45 Silva, 1989, 1993; Hrbek et al., 2014; May-Collado & Agnarsson, 2011; Pilleri & Gühr, 1977;
46 Santos et al., 2012, 2014). Like the franciscana dolphin (*Pontoporia blainvillei*), the baiji (*Lipotes*
47 *vexillifer*), and the Ganges and Indus river dolphins (*Platanista* spp.), botos have flexible necks

48 and backbones, a low and large-based dorsal fin, and a slender rostrum (Best & Da Silva, 1989,
49 1993; Brownwell & Herald, 1972; Cassens, et al. 2000; Crespo et al., 1998; Da Silva et al., 2009;
50 Hamilton et al., 2001; Leatherwoods & Reeves, 1994; Reeves & Martin, 2009;; Zhou 2009). Botos
51 have a preference for habitats with slow currents and high prey concentration such as bays,
52 confluences, small streams, and channels and island margins (Gomez-Salazar et al., 2012a, 2012b;
53 Martin & Da Silva, 2004; Martin, Da Silva & Salmon, 2004; Pavanato et al., 2016). However,
54 residency patterns vary within locations from long-term residency to occasional visitors (Martin
55 & Da Silva, 2004). Although, botos are traditionally considered solitary, with long-term social
56 interactions restricted to mothers and their calves, large aggregations have been documented
57 during foraging and mating events (Best & Da Silva 1989, 1993; Martin, Da Silva & Rothery,
58 2008).

59 The acoustic repertoire of botos has traditionally been thought to be limited to a few sounds
60 (Podos et al., 2002), however, studies of free-ranging and captive botos suggest otherwise. Among
61 some of the sounds reported for botos are burst-pulsed sounds, jaw-snaps, low-frequency sounds,
62 pulsed sounds, echolocation clicks, and whistles (Amorin et al., 2016; Cadwell et al., 1966;
63 Diazgranados & Trujillo, 2002; May-Collado & Wartzok, 2007; Ding et al., 1995; Ding, Würsig
64 & Leatherwoods, 2001; Kamminga et al., 1993; Podos, Da Silva & Rossi-Santos., 2002; Penner
65 & Murchison, 1970). Ding, Würsig & Leatherwoods (2001) also described the emission of low-
66 frequency whistles (up to 5 kHz) for Peruvian botos. However, this discovery was disputed (Podos,
67 Da Silva & Rossi-Santos, 2002) due to the presence of sympatric tucuxi dolphins (*Sotalia*
68 *fluviatilis*) known to emit whistles. Later, May-Collado & Wartzok (2007) confirmed that botos do
69 emit whistles, but at much higher frequencies (up to 48 kHz) than previously thought. These high
70 frequency whistles were recorded from botos at the Yasuni and Napo rivers in Ecuador. Today,

71 there is a consensus that, while botos do emit whistles, these sounds are emitted rarely
72 (Diazgranados & Trujillo, 2002; May-Collado & Wartzok, 2007; Ding, Würsig & Leatherwoods,
73 2001) and likely play a different social role as the one described for delphinids (May-Collado &
74 Wartzok, 2007). Podos, Da Silva & Rossi-Santos (2002) found that the acoustic repertoire of
75 Amazonian botos consisted primarily of pulsed calls with a low emission rate. However, these
76 results were likely limited by the sampling rate of the recorders used by the authors. Amorin *et al.*
77 (2016) studied the same population using a broadband frequency recording system and described
78 a high emission of a variety of pulsed calls.

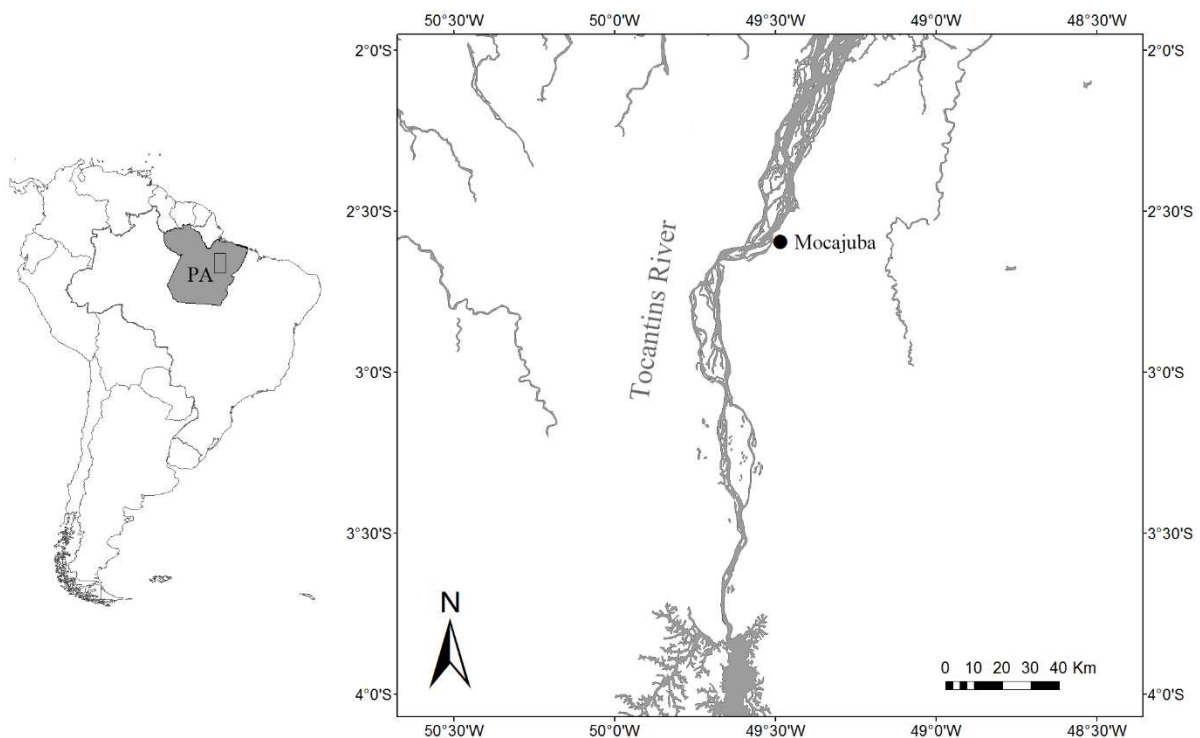
79 A major constraint in studying river dolphins is that they usually do not perform
80 conspicuous surface displays combined with the difficulty of identifying individuals in the field
81 (Best & Da Silva, 1989, 1993; Brownwell & Herald, 1972; Cassens, et al. 2000; Crespo, Harris &
82 González, 1998; Da Silva, 2009; Hamilton et al., 2001; Leatherwoods & Reeves, 1994; Reeves &
83 Martin, 2009; Zhou 2009). Here we studied the acoustic repertoire of free-ranging Arauguaian
84 botos that regularly visit a fish market in Mocajuba in Northern Brazil (Santos et al., 2014). This
85 semi-controlled setting gave us the unique opportunity to combine acoustic technology with
86 underwater behavioural observations.

87 **Material & Methods**

88 *Study area*

89 This study took place along the Tocantins River in the town of Mocajuba in Pará State,
90 Brazil (Fig. 1). The Tocantins River is classified as a clearwater river with a small floodplain as
91 the river runs through a narrow valley. There are large sandbanks in the river's main channel where
92 herbaceous vegetation may occur, there are floating vegetation, and submerged aquatic
93 macrophytes where there is light penetration (Junk et al., 2011). At its lower reaches, water cycles
94 in this region are very dynamic with a greater rainfall from November to April, with the highest

95 waters on March, rainfall declines from May to October, with lowest waters on September
96 (Ribeiro, Pretere & Juras, 1995). There is also a daily cycle of tide pulses (Goulding et al., 2003;
97 Ribeiro, Petrere & Juras, 1995). Mocajuba has a fish market that serves as the main place to acquire
98 fish products for the city and the riverside communities. The wastes of the market and the provision
99 of fish by locals attracts botos to the pier. This set up together with low turbidity waters during the
100 dry season allows great proximity to botos enabling us to identify individuals and observe their
101 behaviour in detail (Fig. 2).



102

103 **Figure 1.** Location of the Mocajuba fish market at the margins of the Tocantins River

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106

107 **Figure 2.** Mocajuba's fish market, clear and shallow waters allow for detailed observation of
108 Araguaian botos' behaviour. (A): Taken from drone footage by our team led by Gabriel Melo-
109 Santos. (B) Photo by Rodrigo Tardin.

110

111 *Data collection*

112 Acoustic and behavioural data was collected in visits that ranged from three to 15 days
113 during October to December 2013, March 2014, June 2015, July, September and December 2016.
114 The presence of botos at the market depends on the market opening hours, which is the time when
115 the animals are fed (Santos et al., 2014). Therefore our observations took place in the morning.
116 Behavioural observations were collected in a continuous all-events sampling (Mann, 1999). For
117 each session, we collected the following data: number of individuals present, age class (adult,
118 juvenile, calf), and sex (based on the presence of mammary slits). In addition, animals were
119 identified based on natural marks on the dorsal and ventral parts of the body, given that the botos
120 in the market frequently swim upside down (Santos et al., 2014). Photographs of their bodies were
121 taken with a Nikon 3200 SLR Camera (Nikon Corp., Tokyo, Japan) and a 70x300mm zoom lens
122 (Nikon Corp., Tokyo, Japan). Underwater video was collected with a GoPro Hero 4 (GoPro Inc.,

123 San Mateo, USA) held on hand (Fig. 5). Notes and drawings of the marks and their locations were
124 also taken if we were unable to take pictures. We held permits to perform this study issued by
125 SISBio (number 52892) from the Brazilian Mistry of Environment.

126 Sound recordings were taken continuously in synchrony with behavioural observations.
127 We used three recording systems along the study: (1) an Aquarian hydrophone (Anacortes,
128 Washington, USA) connected to a Tascam DR1 digital recorder (22kHz sampling rate), (2) a CR1
129 hydrophone (Cetacean Research Technology, Seattle, USA) connected to a pre-amplifier and a
130 Tascam DR-44WL (96kHz sampling rate) and (3) a Soundtrap (Ocean Instruments, New Zeland,
131 576kHz, sampling rate).

132

133 *Data analysis*

134 All recorded signals were inspected using a spectrogram analysis in Raven Pro 1.5 (Cornell
135 Laboratory of Ornithology, New York, USA). Only whistles and pulsed calls with good signal to
136 noise ratio were selected for further analysis. Signals were assigned visually a *posteriori* into
137 categories based on their shape of their contours (Fig.6). Other defining characteristics of the
138 classification of botos sounds were duration - short (<200ms) versus long (>200ms) signals - and
139 the presence of nonlinear phenomena: (a) subharmonics - signals with additional spectral
140 components in the harmonic stack, generally in multiples of $\frac{1}{2}$ or $\frac{1}{3}$ of the fundamental
141 frequency- and (b) biphonation - signals with the presence of two independent fundamental
142 frequencies (Tokuda et al., 2002; Wielden et al., 1998). Pulsed calls produced in a succession
143 where considered a single signal if they were separated by less than 200 ms. Using a rarefaction
144 curve (Magurran, 2004), we evaluated how much of the acoustic repertoire was registered during

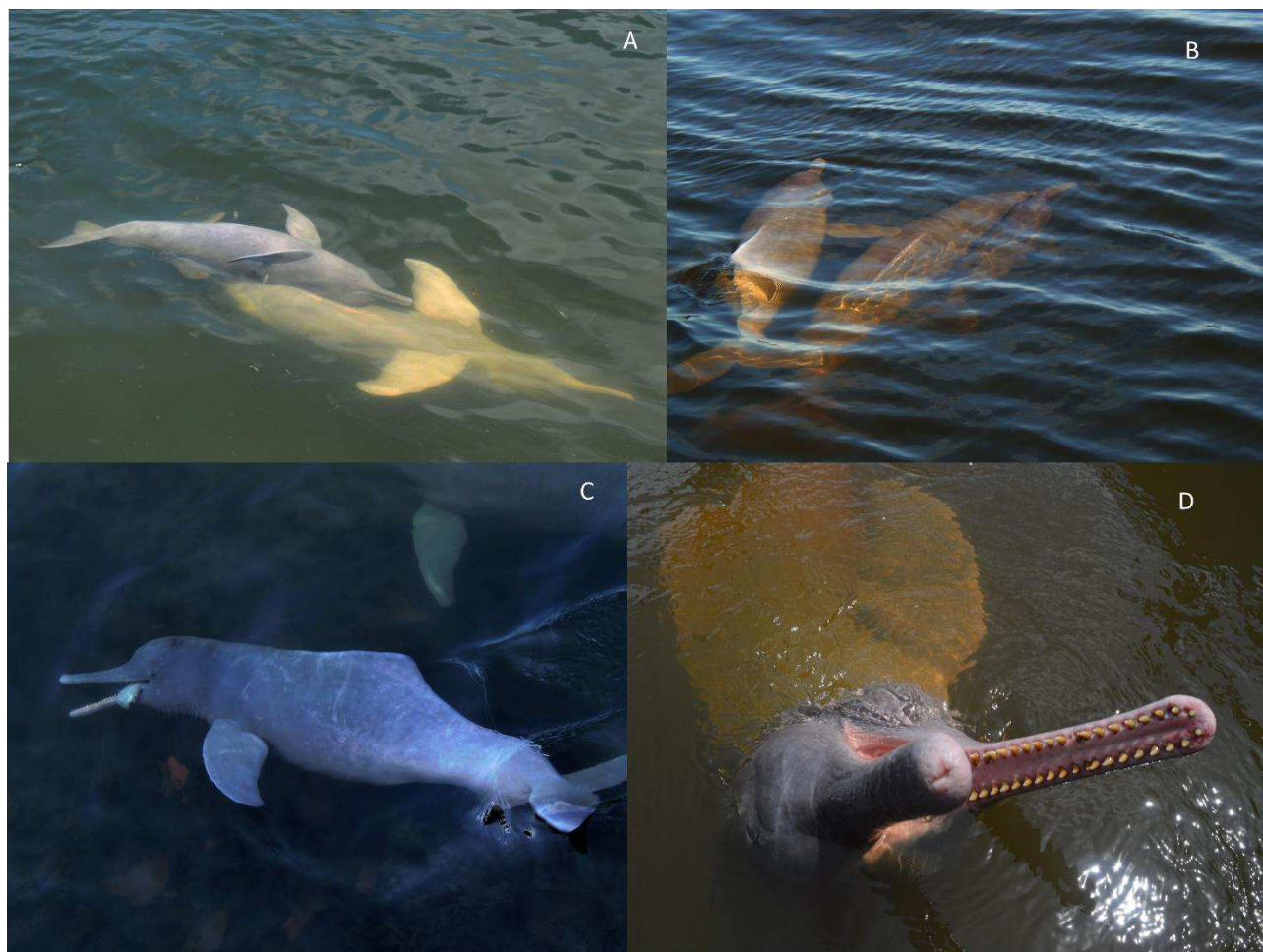
145 our sampling period. Using a Whittaker diagram (Magurran, 2004), we assessed the occurrence of
146 the signals recorded as part of these animal's repertoire. Analyses were conducted in R.

147

148

149 **Results**

150 Botos were observed on 32 days (sightings happened everyday) and we collected 20.2
151 hours of acoustic recordings. Group sizes ranged between 3 to 12 individuals. These animals
152 repeatedly visited the market allowing us to photo-identify the animals and often following specific
153 individuals. We were able to identify nine individuals by their natural marks, five adult females,
154 one adult male, one juvenile female, one female calf and one male calf. Only two behaviours were
155 observed: socialization and feeding (Fig.3). Social interactions consisted of animals having
156 physical contact with one another and swimming alongside each other. Although, occasionally
157 animals would bite the neck of another when waiting to be fed. While we did not specifically test
158 for associations between individuals, the most stable associations appeared to be between mothers
159 and their calves. Feeding behaviour consisted of animals soliciting food with the head out of the
160 water and open-mouthed or poking humans with their snout. However, with the help of underwater
161 cameras we were able to match some of the observations to the vocalizing animals (see below).



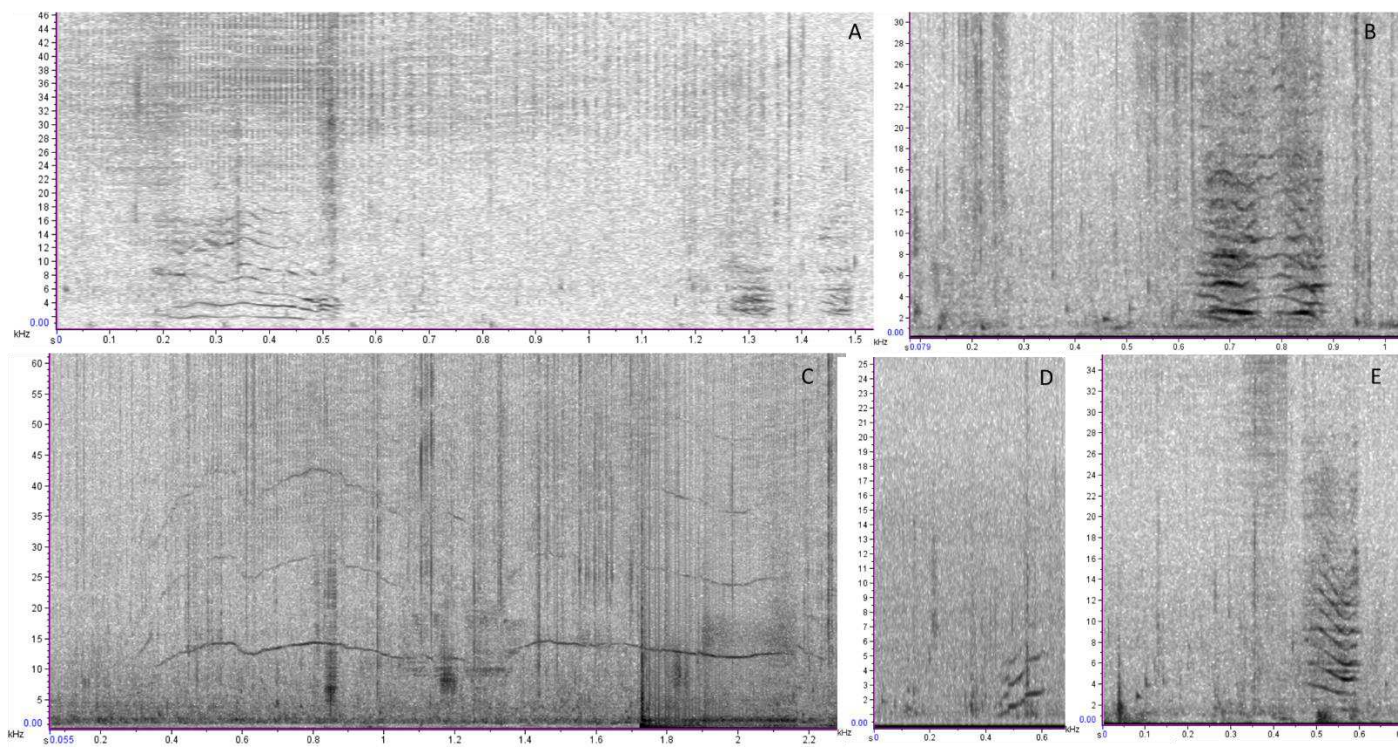
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163 **Figure 3.** The two behaviours observed during this study were socialization and feeding. (A)
164 and (B): botos engaged in social activity, slow-swimming and physical contact, (C): boto feeding
165 on a fish and (D): waiting to be fed. Photos (A), (B) and (C) by Gabriel Melo-Santos and (D) by
166 Luiza Pereira.

167

168 Based on signal quality we selected at total 393 acoustic signals and classify them into six
169 major sound types and 78 sub-categories. The six sound types were: long-two-component calls,
170 long calls with subharmonics, short calls with biphonation (short-two-component calls), short calls
171 without non-linear phenomena, short-calls with subharmonics, and tonal sounds (Fig. 4, Table 1).
172 While we found a diversity of calls the rarefaction curve indicates that 20 hours of acoustic
173 sampling was not sufficient to capture most of the acoustic repertoire of these animals (Fig.5).

174 However, botos do seem to produce some signals more abundantly than others (Fig. 6). The long-
175 calls with subharmonics (n=11) and whistles (n=15) were rarest and the short-two-component calls
176 were the most commonly produced (n=246). Interestingly, 35% (n=140) of these were short two-
177 component calls. Some of these calls were produced by calves as observed by the bubble emission
178 from the blowhole, and their emission was followed by physical contact with their mothers (Fig.7).
179



181 **Figure 4.** Examples of acoustic signals recorded during our study:(A)- Long call with
182 subharmonics followed by two short two-component calls; (B) -Long two-component call; (C) -
183 Narrow-banded frequency modulated whistle and the longest sound registered in this study; (D) –
184 Short call with no non-linear phenomena. E – A short call with subharmonics.

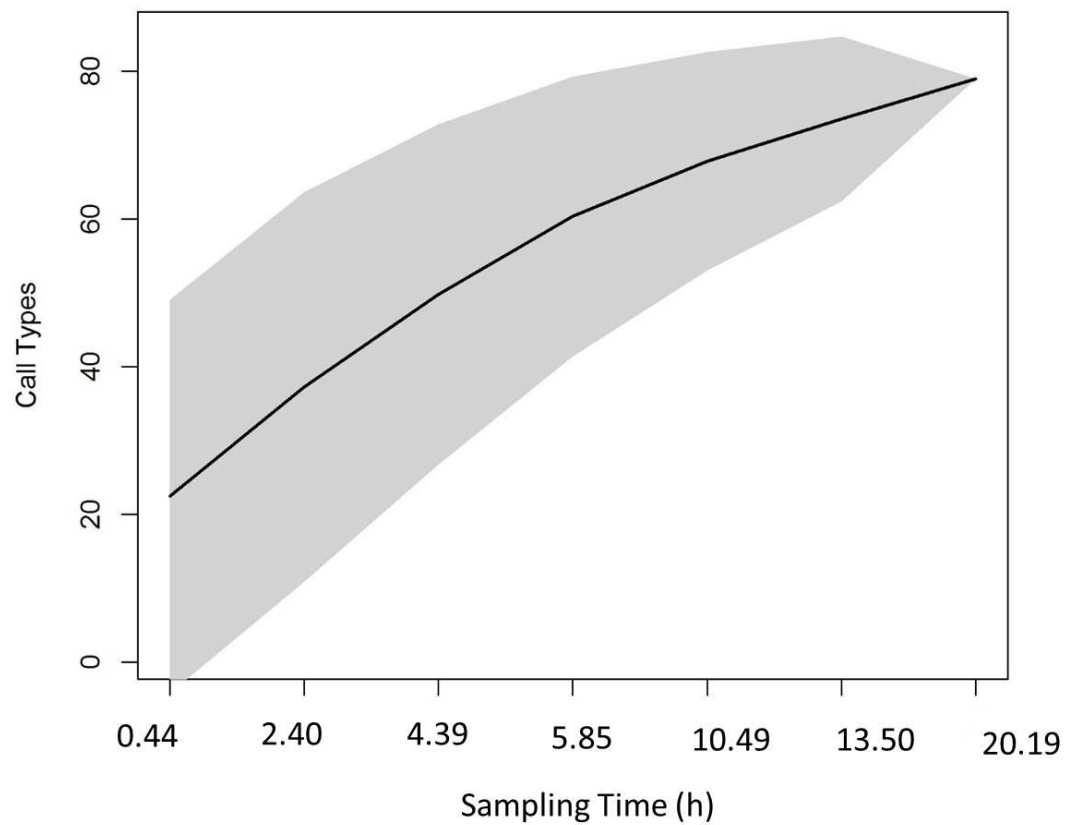
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189 **Table 1.** Major classification categories of signals recorded from the Araguaian river dolphin at
 190 the Mocajuba fish market.

Vocalization type	Number of sub-categories	Number of sounds produced
Long two-component calls - pulsed calls longer than 0.200s, with biphonation as the most marking characteristic, may exhibit subharmonics	9	18
Long calls with subharmonics- calls longer than 0.200s, may exhibit biphonation	5	11
Short two-component calls - pulsed calls shorter than 0.200s, with biphonation as the most marking characteristic, may exhibit subharmonics	29	246
Short calls - signals shorter than 0.200s with no non-linear phenomena	7	29
Short calls with subharmonics - calls shorter than 0.200s, may exhibit biphonation	15	74
Whistles - tonal narrow-banded signals longer than 0.100s, may exhibit harmonics	13	15
Total	78	393

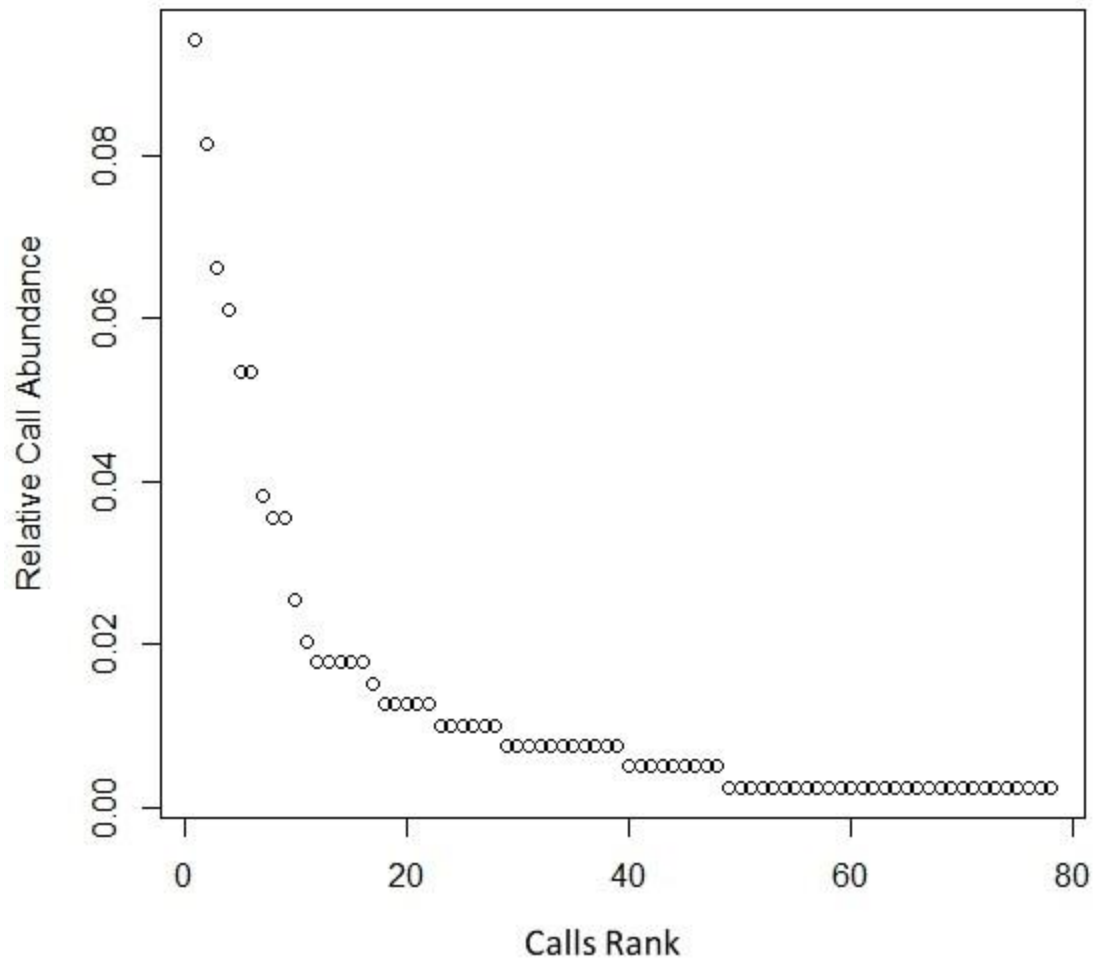
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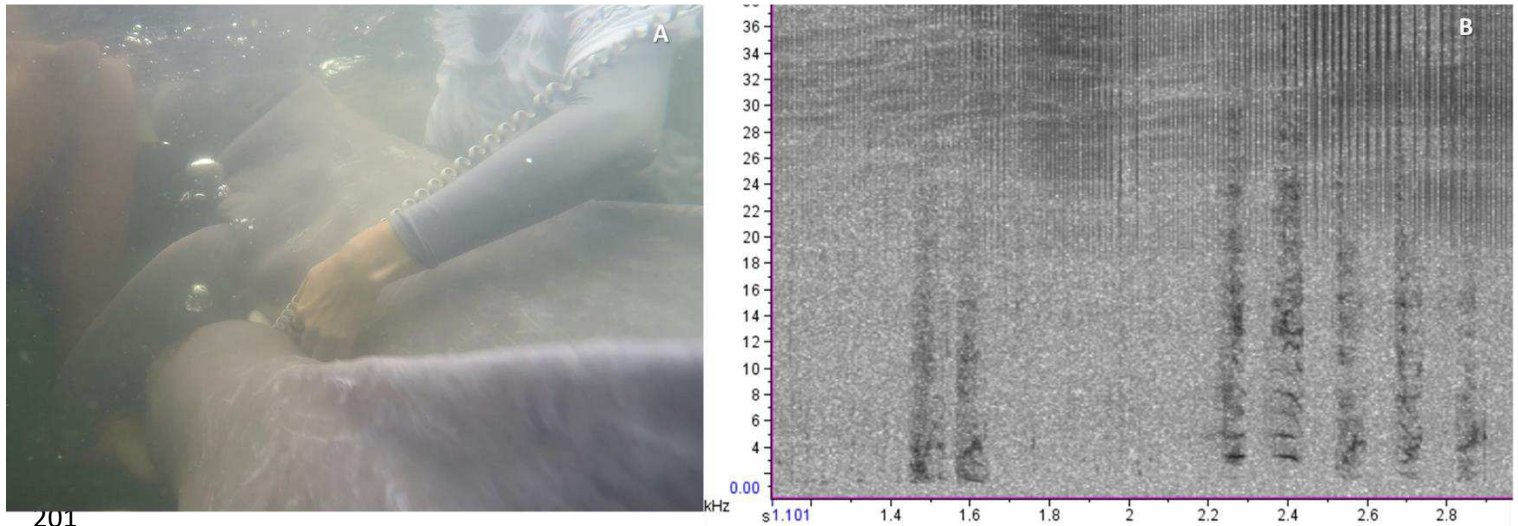
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194 **Figure 5.** Rarefaction curve showing the cumulative number of call types detected with
195 increasing sampling time (hours of recordings analysed). The curve suggests that 20 hours of
196 acoustic sampling is not enough to capture most of the acoustic repertoire of the Araguaian river
197 dolphin.



198

199 **Figure 6.** Whittaker diagram displaying the occurrence of calls emitted by Araguaian botos with
200 most calls produced rarely.



201

202 **Figure 7.** (A): Vocalizing calf as indicated by the bubbles blowing from its blowhole and
203 associated short-two-component call, taken from video footage by our team. (B) Spectrogram of
204 calls produced by a calf of Araguaian boto, followed by a bubble stream.

205

206 Discussion

207 Our results show that the Araguaian river dolphin has a more diverse acoustic repertoire
208 than previously documented for the genus *Inia* (Amorin et al., 2016; Cadwell et al., 1966;
209 Diazgranados & Trujillo, 2002; May-Collado & Wartzok, 2007; Ding et al., 1995, 2001;
210 Kamminga et al., 1993; Podos, Da Silva & Rossi-Santos, 2002). Early studies described members
211 of the genus *Inia* as silent animals (Podos et al., 2002) or with a limited acoustic repertoire (Amorin
212 et al., 2016; Cadwell et al., 1966; Diazgranados & Trujillo, 2002; May-Collado & Wartzok, 2007;
213 Ding et al., 1995; Ding, Würsig & Leatherwoods, 2001; Kamminga et al., 1993; Podos, Da Silva
214 & Rossi-Santos, 2002). However, here we show that the acoustic repertoire of *Inia* dolphins is
215 diverse and likely as complex as the acoustic repertoire of delphinids.

216 While pulsed calls were the most commonly produced sounds, tonal sounds were also
217 produced. These findings agree with previous descriptions of whistle emission from Peruvian

218 (Ding, Würsig & Leatherwoods, 2001) and Ecuadorian botos (May-Collado & Wartzok, 2007)
219 and other river dolphins like the Franciscana and the baiji (Cremer et al., 2017; Wang, Wang &
220 Akamatsu, 1999; Wang et al., 2006). In these studies, the function of emitted whistles was unclear.
221 May-Collado & Wartzok (2007) found that botos emitted whistles in a different social context than
222 in delphinids, keeping distance between each other, rather than promoting social interactions as in
223 marine dolphins.

224 Among pulsed calls, the short-two-component call was the most commonly produced
225 sound. These calls were emitted in what appear to be mother-calf interactions. Our video footage
226 and some underwater follows show bubbles emanating from calves' blowholes while they emitted
227 these calls as they approached their mothers after a short separation (see Supplementary Material).
228 Bubble streams are often used as a cue to identify vocalizing animals (Bebus & Herzing, 2015;
229 Fripp, 2005; Jones, 2014) and in this case the bubble stream revealed that the calves were
230 producing the calls and did so in a repetitive fashion. These vocal patterns are similar to what has
231 been described for calves of bottlenose dolphins, which use signature whistle as contact calls,
232 where calves increase whistle emission as they approach their mothers (Smolker, Mann & Smuts,
233 1993). Given the strength of mother-calf associations in botos (Best & Da Silva, 1989, 1993) and
234 the characteristics of their habitat, a shared signal that enhances mother-calf recognition may be
235 key as they move through murky waters and complex underwater vegetation. The complex
236 structure of botos' might also have led to evolution towards signals with short duration, longer
237 signals might suffer interference of echoes caused by obstacles (sandbanks, underwater vegetation,
238 riverbed, even the water surface). Notwithstanding, social signals produced by *Inia* sister taxa
239 *Pontoporia* who also evolved in riverine environments are also short (Cremer et al., 2017).

240 Several species of toothed whales emit calls of similar acoustic nature as the ones described
241 here for botos (Filatova et al., 2012; Fitch et al., 2002; Ford, 1989; Deecke et al., 1999, 2010, 2011;
242 Garland et al., 2015; Marcoux et al., 2012; Miller & Bain, 2000; Papale et al., 2015; Pérez et al.,
243 2017; Sjare & Smith, 1986; Vergara & Barrett-Lennard, 2008; Vergara, Michaud & Barrett-
244 Lennard, 2010; Yurk et al., 2002; Zwamborn & Whitehead, 2017). For example, the calls of killer
245 (*Orcinus orca*), pilot (*Globicephala* spp.) whales have been shown to contain non-linear features
246 suggesting they may carry information on group identity and maintaining social cohesion (Deecke
247 et al., 2010; Pérez et al., 2017; Yurk et al., 2002; Zwamborn & Whitehead, 2017). Similarly,
248 Marcoux, Auger- Méthé & Humphries (2012) show evidence that narwhal (*Monodon Monoceros*)
249 calls might be related to specific groups or individuals. Non-linear calls have also been reported
250 to convey individuals' identity and/or emotional state (Fitch, Neubauer & Hetzel, 2002; Papale et
251 al., 2015). Given these similarities we propose these two-component signals evolved early in the
252 evolutionary history of toothed whales as social contact signals, likely for mother-calf interactions
253 and later in the lineage leading to delphinids it evolved into a group recognition signal.

254

255

256 **Conclusions**

257 We show that the acoustic repertoire of botos is far from been simple. The Araguaian river
258 dolphins studied at Mocajuba fish market produce a diverse acoustic repertoire, as we found 78
259 sound types, mostly pulsed calls, and our analysis indicate that there is more to discover.
260 Notwithstanding, these sounds are mostly complex in structure presenting nonlinear phenomena.
261 The animals we studied are habituated to humans, which provided a unique opportunity to shed
262 light on the acoustic and social behaviour of this understudied species. Under relatively controlled

263 conditions we identified more than half of the studied animals and recorded their acoustic and
264 underwater behaviour. When possible, we matched recordings with video footage of calves as they
265 reunited with their mothers. During this reunions calves appeared to use the two-component calls
266 as contact calls, nevertheless further investigation is needed to understand the importance of these
267 calls for mother-calf interactions. Furthermore, given that Araguaian river dolphin calls are similar
268 in acoustic structure to those of delphinids, we proposed that these signals evolved early in the
269 evolutionary history of toothed whales as social calls, likely as mother-calf contact calls, and that
270 later in the lineage leading to dolphins its function evolved to group/family call recognition.

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277

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