

Short Note

Acoustic Description of Beach-Hunting Guiana Dolphins (*Sotalia guianensis*) in the Cananéia Estuary, Southeastern Brazil

Nayara C. Tannure,¹ Fernando S. Barbosa,² Diogo D. Barcellos,¹
Beatriz Mattiuzzo,¹ Amanda Martinelli,¹ Laura B. Campos,¹
Valéria R. M. Conversani,¹ and Marcos C. de O. Santos¹

¹*Laboratório de Biologia da Conservação de Mamíferos Aquáticos (LABCMA),
Instituto Oceanográfico, Universidade de São Paulo, São Paulo, Brazil
E-mail: nctannure@gmail.com*

²*Division of Robotics, Perception and Learning (RPL), KTH Royal Institute of Technology, Stockholm, Sweden*

The Guiana dolphin (*Sotalia guianensis*; Van Bénédén, 1864) is a small delphinid found in shallow, coastal, and estuarine waters along the coast of the Atlantic Ocean, from Brazil to Honduras (da Silva et al., 2010). Reaching up to 2 m in length as adults, these dolphins rarely approach boats, do not bow ride, are usually found in murky waters, and have relatively small dorsal fins when compared to their body size—features that challenge researchers who gather baseline information on their behavioral repertoire throughout their distribution (Santos et al., 2000). The Cananéia Estuary (CE) in southeastern Brazil hosts a resident population of ~400 Guiana dolphins (Mello et al., 2019), which has been the focus of long-term investigations for almost three decades (Monteiro-Filho, 1995; Geise et al., 1999; Santos et al., 2000). In the CE, several individuals of the local population have been observed displaying a beach-hunting behavior—that is, when Guiana dolphins closely approach two local sloping beaches for foraging and feeding purposes (Santos, 2010). They do not beach themselves like other odontocetes (Hoesé, 1971; Lopez & Lopez, 1985; Peddemors & Thompson, 1994), but they patrol both beaches on a daily basis and engage in feeding bouts that consist of chasing fish into water as shallow as their body diameter. These dolphins repeat this beach-hunting behavior many times a day (Santos, 2010). As this study population has been photo-identified since 1996 and biopsied since 2002, beach-hunting behavior has been confirmed to be exhibited mainly by adult female dolphins (Santos, 2010).

To better understand the complexity of the beach-hunting behavior displayed by Guiana dolphins in the CE, an investigation of their sound emissions produced during beach hunting will

likely highlight details of this behavior not observable from land. Pivari & Rosso (2005) described and characterized whistles emitted by Guiana dolphins when engaged in beach-hunting behavior. They showed that this population of dolphins produced high rates of whistles when feeding. Moreover, the most common whistles that were recorded had ascendant frequencies and no inflection point. Still, Pivari & Rosso could not discern if feeding bouts were associated with successful prey captures in turbid waters. Also, those authors were focused primarily on whistle descriptions not on echolocation clicks.

Unmanned Aerial Vehicles (UAVs) have been used in several studies of marine mammals such as in the collection of exhalation samples (Acevedo-Whitehouse et al., 2010), for monitoring individual health (Krause et al., 2017), in behavioral observations (Ramos et al., 2018), and for population estimates (Goebel et al., 2015). An advantage of UAVs is the possibility of investigating marine mammals *in situ* with minimal interference on their behavior since UAVs produce less noise than manned aircraft (Goebel et al., 2015).

The goal of the present study is to describe pulsed sounds hypothesized to indicate successful feeding bouts. The successful feeding bouts, defined by observation of dolphins foraging and capturing fish, were documented via an aerial drone in the CE, while the vocal behavior was recorded with two distinct hydrophone systems separate from the drone footage.

Observations were conducted in July 2017 at Itacuruçá Beach, which is located on the northern edge of Cardoso Island in Trapandé Bay (Figure 1). Observations were conducted from two platforms: (1) an aluminum boat (5 m long), moored 15 m from the beach; and (2) from the

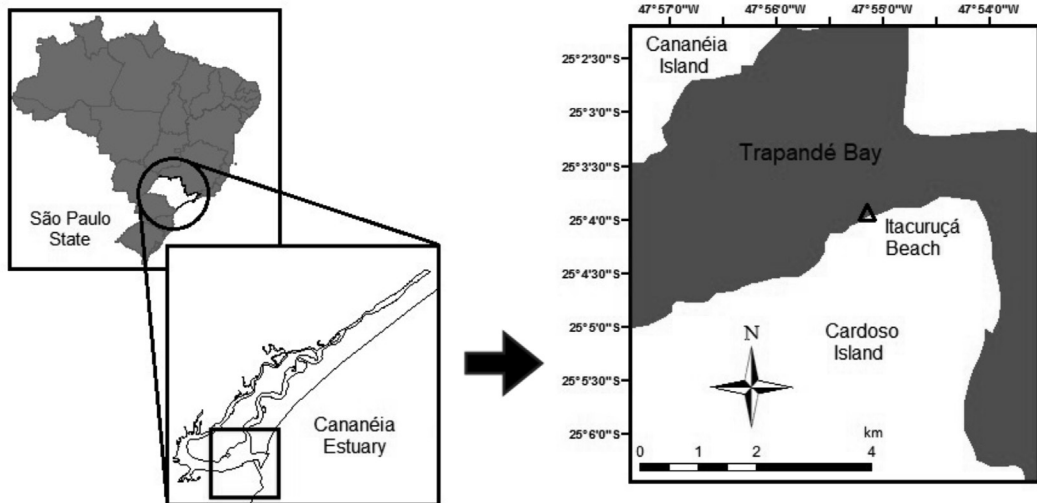


Figure 1. Map showing the study area where beach-hunting Guiana dolphins (*Sotalia guianensis*) were surveyed in southeastern Brazil. The triangle marks where the observations were conducted.

beach, with observers following the Guiana dolphins' movements along the shore. Boat-based observers were responsible for gathering acoustic recordings of these dolphins during feeding bouts, and the land-based observers were responsible for assisting with UAV operations to record successful prey captures by beach-hunting dolphins. The UAV took off from and landed on the shore, with the UAV pilot operating it from the boat.

As local estuarine waters are murky and transparency varies from 1 cm to 4.5 m (Santos & Rosso, 2007), videos were recorded in winter (the dry season) when water was clearer and visibility from above and into the water would be best. During data collection, only one mother and one calf were found engaged in beach hunting. The mother and calf alternated feeding bouts, which allowed the analysis of individual feeding bouts with no overlap. We used a UAV (DJI Phantom 3 Standard) to observe Guiana dolphin beach-hunting behavior. Flights were performed at heights between 15 to 20 m above water level to avoid interference on the natural behavior of the dolphins. Videos of beach-hunting behavior were obtained with the UAV's original integrated camera, with a resolution of 2.7K HD (2,704 × 1,520 pixels) at 29.97 frames per second.

Video files containing feeding bouts were analyzed visually using the software *Blender*, Version 2.78 (Blender Foundation, Amsterdam, Netherlands). Videos were zoomed in and analyzed frame by frame for visual confirmation of prey capture. The feeding bouts were then categorized as *success* (Figure 2) when it was clear that

the prey was captured, *failure* (Figure 3) when it was clear that the prey escaped from the predator, or *inconclusive* when it was not possible to confirm that the prey was captured or escaped.

Two systems were used for audio recordings. The first included an HTI (High Tech, Inc., Long Beach, MS, USA) portable hydrophone with a sensitivity of -201 dB re 1 V/ μ Pa (8.9 V/bar) and a frequency response of 2 Hz to 30 kHz \pm 3 dB. Sounds were recorded on a Sony Linear PCM Recorder with 16-bit resolution and a 96-kHz sample rate. The second recording system was a DSG-ST HTI-99-HF (Loggerhead Instruments, Sarasota, FL, USA) with a sensitivity of -201 dB re 1 V/ μ Pa (8.9 V/bar) and a frequency response from 2 Hz to 125 kHz with a 16-bit resolution and 288-kHz sample rate. The HTI portable hydrophone remained with the team on the boat, while the DSG-ST HTI-99-HF was fixed approximately 15 m away from the beach at 1.6 m depth. The HTI/Sony recording system allowed the vessel team to listen to sound emissions in real time. The fixed DSG recorder gathered high-frequency data. The acoustic recorders and the UAV video camera were time synchronized to facilitate an easy alignment of audio and video data during analyses.

Following Christiansen et al. (2016), the UAV was acoustically documented at elevations of 10, 15, 20, 25, and 30 m to assess its potential impact on Guiana dolphins. For these measurements, the portable hydrophone was held between 10 and 15 cm below the sea surface, simulating the depth at which Guiana dolphins attempt to catch

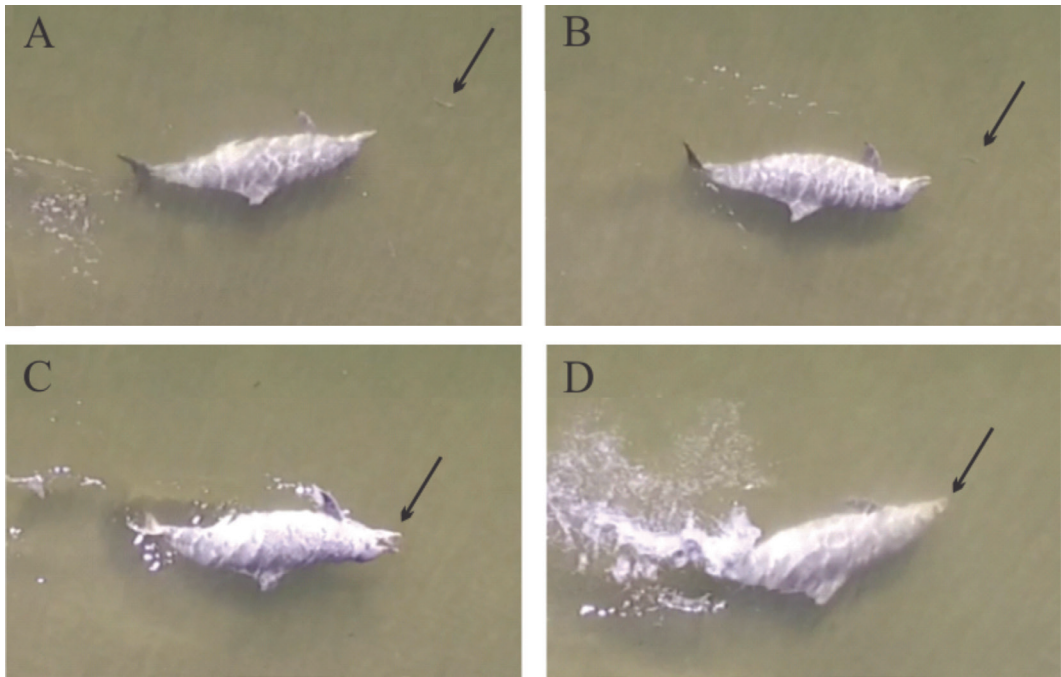


Figure 2. Frames from a successful feeding bout. The arrows indicate prey position in each frame. It is possible to observe the Guiana dolphin following the prey in A and B, while C and D display the successful capture.

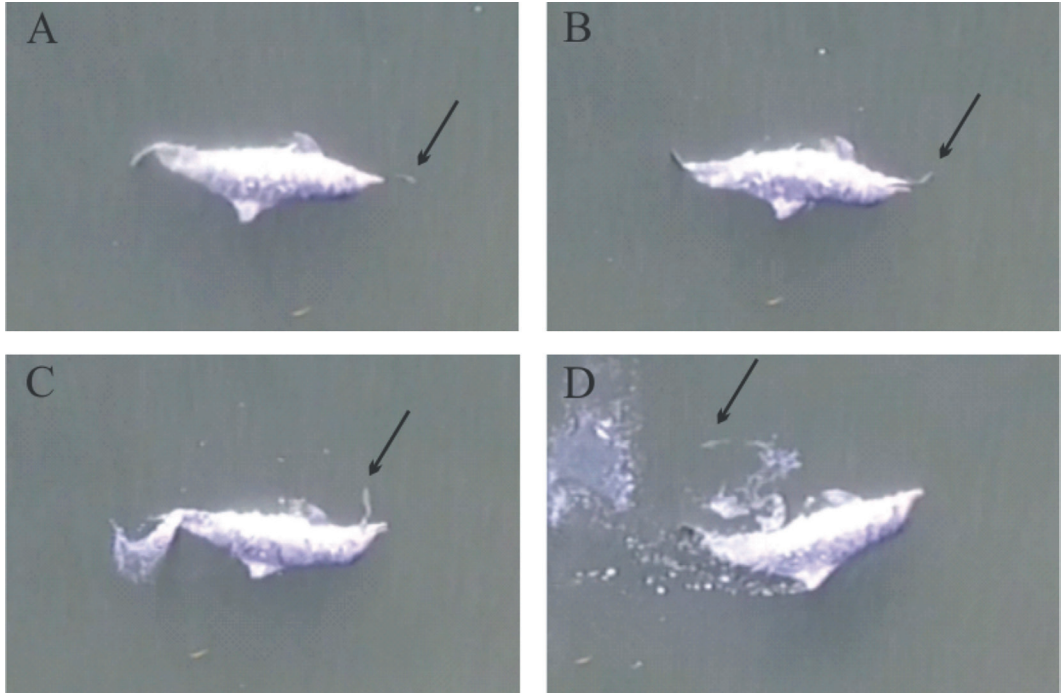


Figure 3. Frames of a failed feeding bout. The arrows indicate prey position in each frame. It is possible to observe the Guiana dolphin following the prey in A and B, while C and D display the evasion of prey.

prey. These audio data were used to identify the noise produced by the drone when analyzing the sonogram.

Acoustic files were analyzed visually using *Raven Pro*, Version 1.5 (Cornell Laboratory of Ornithology, Ithaca, NY, USA), and only echolocation trains associated with successful feeding bouts were analyzed. Echolocation clicks of successful feeding bouts were selected with sound recordings gathered immediately before each feeding bout and 5 s after the prey capture event. As the Guiana dolphins were moving in relation to the hydrophone and were never directed toward the hydrophone during recordings, absolute values of total energy and peak-to-peak (PtP) could not be obtained. Therefore, PtP was normalized (PtP [N]) by dividing each value of PtP by the maximum value in each feeding bout dataset so it could be used as a qualitative variable to describe the feeding bout. For each successful feeding bout, the following details in the echolocation clicks were evaluated: the total energy (dB) contained in the selected interval, the inter-click interval (ICI) (s), the number of clicks per second, the buzz duration (ICI < 10 ms) (s), and PtP (N). All sound emission types (e.g., whistles, echolocation clicks, and burst pulses) documented in the 20 s after feeding bouts were analyzed with a presence table.

In the present study with Guiana dolphins, adapted from the hunting behavior analysis presented by Griffin et al. (1960) when studying bats, *prey pursuit* was defined as starting with the *search phase* when the dolphin approaches the beach, which is followed by the *approach phase* when the chase of the prey occurs, and then by the *post-capture phase*, the time at which adult dolphins swam to deeper waters after capturing their prey. In this scenario, the prey capture is the event that separates the approach phase from the post-capture phase. In our acoustic analyses, a feeding bout consists of the two last phases of the hunting behavior: (1) approach and (2) post-capture (see Figure 4).

To isolate the approach phase from the post-capture phase, all datasets were submitted to a cluster analysis of K-means as proposed by Bow (1984). For this analysis, we individually compared the ICI, total energy, and PtP (N) to feeding bout duration to categorize each feeding bout into the approach and post-capture phases of interest. The Shapiro-Wilk test was used to evaluate the normality of total energy, PtP (N), and ICI. The Spearman's test was used to create a correlation matrix to evaluate the relationship between ICI, total energy, PtP (N), and phase duration (i.e., feeding bout, approach, and post-capture). The Spearman's correlation test was used to verify the relationship between buzz duration and approach phase duration.

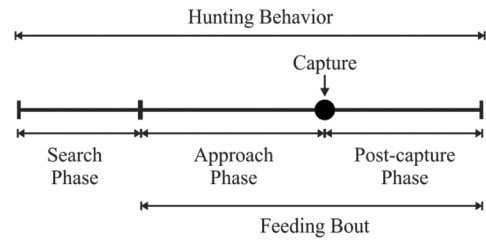


Figure 4. Phases of hunting behavior and feeding bout used in this study. Adapted from Griffin et al. (1960).

A total of nine feeding bouts rendered clear images of confirmed prey capture and good quality audio from which 4,045 (mean \pm SD = 449 \pm 335) clicks were analyzed. The approach phase lasted 3.60 \pm 1.45 s, with 288 \pm 260 emitted clicks and 75.2 \pm 44.3 clicks per second, with a mean ICI of 18 \pm 11 ms, a maximum ICI of 204 \pm 164 ms, and a minimum ICI of 2 \pm 4 ms. Buzzes recorded had a mean duration of 1.22 \pm 1.06 s, with a mean ICI of 4 \pm 1 ms. No significant correlation was observed between buzz duration and approach phase duration.

UAV noises were observed occupying frequencies below 10 kHz in the spectrogram considering all tested heights, but its intensity decreased with height and was nearly indistinguishable above 20 m. It is important to point out that this region has intense boat traffic, so UAV disturbance could be masked by other anthropogenic and natural sounds and, therefore, may have had no influence on Guiana dolphin behavior.

The analyses of sonograms showed that after the detection of prey, beach hunters start approaching the prey by emitting sounds with progressively smaller ICIs until immediately before the capture attempt when they emit a buzz with an ICI of less than 10 ms (Figure 5). Clicks and whistles were the most frequent emissions in the post-capture period (Table 1). None of the emission types was observed during the post-capture phase in all nine analyzed feeding bouts, although the most common emissions were whistles and echolocation clicks. Cluster analysis showed that only ICI vs feeding bout duration can be used to isolate the approach from the post-capture phase (Figure 6). Spearman's correlation test results are presented in Table 2.

In all feeding bouts, none of the variables analyzed showed significant correlation between themselves (Table 2). However, ICI and feeding bout duration, ICI and PtP (N), and total energy and PtP (N) were significantly correlated in at least four of the nine successful feeding bouts and the two documented foraging phases (Table 2). The Spearman's correlation (Table 2) and the cluster

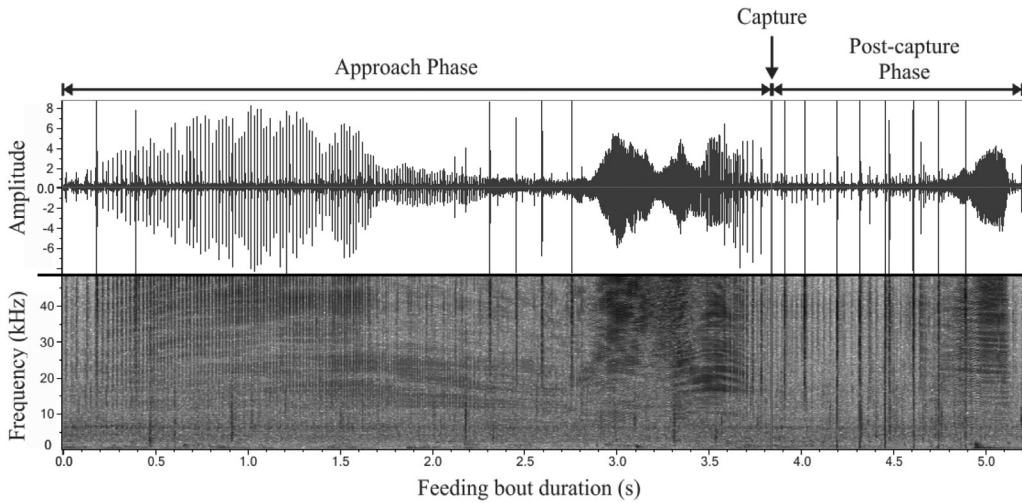


Figure 5. A sonogram of a successful feeding bout by a beach hunter Guiana dolphin. The waveform (upper) shows the amplitude vs feeding bout duration (s), and the spectrogram (lower) represents the frequency (kHz) vs feeding bout duration (s) (brightness: 50, contrast: 50, and spectrogram window size: 1,360).

Table 1. Presence of three distinct sound emissions emitted by beach-hunting Guiana dolphins (*Sotalia guianensis*) during the post-capture phase in nine successful feeding bouts in the Cananéia Estuary, southeastern Brazil. Emissions recorded during each phase are marked with an x.

Feeding bout	0-5 s			5-10 s		
	Whistle	Burst pulse	Click	Whistle	Burst pulse	Click
1	x		x	x		x
2	x		x	x		x
3	x					
4	x	x	x	x	x	x
5			x			x
6			x			x
7		x	x			x
8		x	x			x
9	x			x	x	

Feeding bout	10-15 s			15-20 s		
	Whistle	Burst pulse	Click	Whistle	Burst pulse	Click
1	x		x	x		
2	x		x	x		x
3			x			x
4	x	x	x	x		x
5			x			x
6		x	x			x
7	x		x	x	x	x
8			x			x
9	x		x	x		x

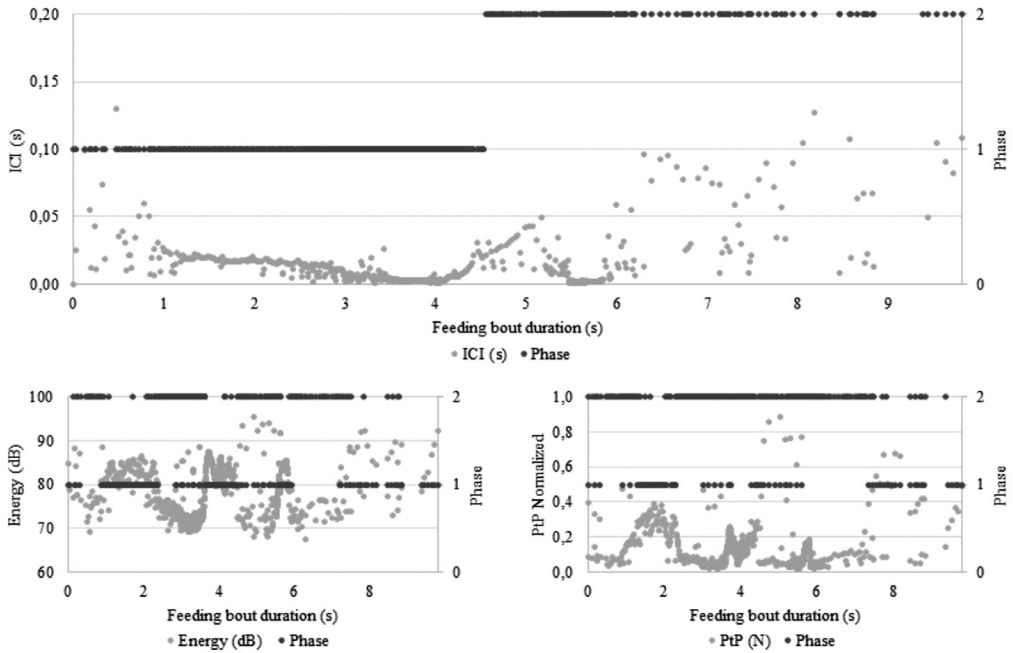


Figure 6. Phases identified by cluster analysis of ICI (upper), energy (lower left), and PtP (N) (lower right) vs feeding bout duration (s) of a beach hunter Guiana dolphin.

analyses (Figure 6) suggest that only the approach phase data can be used to verify the correlation of a parameter with the feeding bout duration.

When comparing the complete feeding bout (i.e., approach + post-capture phases) correlation matrices with the approach phase correlation matrices, the results are contradictory: the feeding bout data mistakenly suggest the increase of ICI values over time, while the approach data suggest a decrease of ICI over time. Studies of the pulsed emissions of other odontocetes and bats suggest a decrease in ICI as the foraging animal approaches its prey (see Griffin et al., 1960; Kaveh & Farhodi, 2013; Wisniewska et al., 2014; Geberl et al., 2015). When searching for prey, individuals emit clicks with high energy and high ICI until a prey item is located and the approach phase begins. Once the prey has been found and is approached, the ICI decreases with a decrease in distance to the prey. Immediately prior to prey capture, foraging individuals emit clicks with gradually lower energy and decreasing ICI. Our results corroborate these observations and suggest that the correlation tests for the feeding bout can lead to an inaccurate conclusion. Therefore, the use of a cluster analysis is strongly recommended.

Studies of odontocete and bat acoustic behavior have described a reduction of energy used in their sonar when approaching prey (Au, 2018), which

validates our observations since the correlation between ICI vs PtP (N) and total energy vs PtP (N) were primarily positive. This positive correlation between two variables means that the decrease of one is followed by a decrease of the other.

Although the correlation strength observed in ICI vs feeding bout duration, ICI vs PtP (N), and total energy vs PtP (N) were not strong (> 0.75) in every feeding bout (Table 2), correlation indexes greater than or equal to 0.70 are rare in behavioral sciences due to the greater individual variability (Margulis, 2010). In our study, the correlation strength ranged from 0.21 to 0.81, suggesting a great plasticity in this delphinid species.

When comparing the standard deviation with the mean values of phase duration, emitted clicks, clicks per second, ICI, and buzzes during the approach phase, the high deviation suggests that there is great variation among the analyzed feeding bouts. This may be a result of the low number of successful feeding bouts recorded. However, it is possible to discern that the foraging behavior of Guiana dolphins is initiated by an echolocation train with high energy clicks that show decreasing values of ICI as the predator approaches the prey. After prey capture, there is an increase in ICI values.

As we documented, ICI may vary during the capture phase; this may occur because of

Table 2. Spearman's correlation matrix for the nine successful feeding bouts of beach-hunting Guiana dolphins. The analyzed variables are total energy (dB), ICI (s), PtP (N), and phase duration (s), divided into feeding bout, approach, and post-capture phases. Significant correlations ($p < 0.05$) are shown in gray and correlation indexes are marked in bold.

N	Feeding bout						Approach						Post-capture					
	Energy (dB)	ICI (s)	PtP (N)	Duration (s)	Energy (dB)	ICI (s)	PtP (N)	Duration (s)	Energy (dB)	ICI (s)	PtP (N)	Duration (s)	Energy (dB)	ICI (s)	PtP (N)	Duration (s)		
1	Energy (dB)	0.4523	0.3377	0.0626		0.0625	0.6905	0.5646		0.5914	0.7713	0.4453						
	ICI (s)	0.0678	0.0014	9.30E-17	-0.2380		0.0023	0.0689		0.9878	0.2375							
	PtP (N)	0.0865	0.2827	0.0016	0.0516	0.3800		-0.0374		-0.0020	0.6031							
	Duration (s)	0.1671	0.7139	0.2789	0.0746	0.1184	-0.1831	0.0979		0.1510	-0.0668							
2	Energy (dB)	0.6723	0.3132	0.9814		0.5531	0.4670	0.6103		0.4072	0.6604	0.8947						
	ICI (s)	-0.0313	2.80E-02	4.27E-37	-0.0637		0.3651	0.4315	-0.0856		0.0002	0.0012						
	PtP (N)	0.0746	0.3366	2.09E-06	0.0781	-0.0972		1.17E-07	0.0454	0.3733	0.4924							
	Duration (s)	-0.0017	0.7921	0.4455	-0.0548	0.0844	0.6423	-0.0137		0.5093	0.0709							
3	Energy (dB)	0.6997	0.7762	0.9396		0.9880	0.9278	0.7468		0.2307	0.6655	0.9243						
	ICI (s)	-0.0302	7.31E-07	7.43E-02	0.0015		2.01E-10	8.88E-15	-0.1628		0.1616	0.0009						
	PtP (N)	-0.0222	0.4781	0.0506	0.0087	0.6479		7.02E-16	-0.0591	0.1896	0.1416							
	Duration (s)	0.0059	0.3399	-0.1520	-0.0311	-0.7045	-0.7343	-0.0130		0.4303	0.5448							
4	Energy (dB)	0.7370	0.1317	0.8403		0.6384	0.7893	0.4542		0.1580	0.1412	0.9041						
	ICI (s)	-0.0152	0.0791	1.82E-22	0.0299		0.2052	0.0008	-0.0910		0.0275	0.9378						
	PtP (N)	0.0681	0.0793	0.0007	0.0170	-0.0806		0.6947	0.0949	0.1417	6.03E-07							
	Duration (s)	0.0091	0.4550	0.1532	-0.0476	-0.2102	0.0250	0.0078		0.0050	0.4046							

5	Energy (dB)	0.0017	5.45E-96	6.23E-16	1.62E-06	1.70E-91	3.27E-14	0.0003	1.83E-07	0.0002
	ICI (s)	-0.1676	0.7742	0.1888	-0.2183	0.1999	2.62E-27	-0.4747	0.0020	3.53E-17
	PtP (N)	0.6122	0.0093	0.5443	0.6310	-0.0443	0.1006	0.5369	-0.2771	0.0003
	Duration (s)	0.2888	-0.0424	0.0196	0.2940	-0.0567	0.4787	-0.7252	0.3204	
6	Energy (dB)	1.84E-10	9.35E-205	0.0039	1.64E-09	6.00E-118	1.70E-12	0.0001	5.48E-79	1.72E-08
	ICI (s)	-0.2516	0.0160	5.64E-25	-0.3062	0.0107	1.31E-72	-0.2070	0.0074	0.0447
	PtP (N)	0.8083	0.1592	0.4177	0.7946	0.1082	0.0907	0.8142	0.1441	4.08E-17
	Duration (s)	0.1681	-0.3603	-0.0270	0.3401	-0.6802	0.0719	0.3678	0.4782	
7	Energy (dB)	0.7202	4.17E-157	0.0018	0.0002	8.98E-146	0.0140	0.1473	0.0003	0.3712
	ICI (s)	-0.1454	0.0005	0.0372	-0.2105	0.0457	2.97E-10	0.2080	0.0949	0.8021
	PtP (N)	0.7932	0.1272	0.0038	0.7923	0.0761	0.1088	0.6926	0.2388	0.4319
	Duration (s)	0.1145	-0.0766	0.1063	0.0935	-0.2839	0.0611	0.1292	-0.0364	0.1137
8	Energy (dB)	0.8117	0.2491	0.1194	0.9309	0.1916	0.0488	0.3104	0.8548	0.1276
	ICI (s)	0.0180	0.0006	0.0198	0.0067	0.0097	0.7673	-0.3576	0.3466	0.8548
	PtP (N)	0.0868	-0.3928	0.3206	0.1013	-0.3674	0.0279	0.0667	-0.3333	0.8548
	Duration (s)	-0.1171	0.1745	0.0749	-0.1523	0.0230	0.1697	0.5152	-0.0667	
9	Energy (dB)	1.52E-09	9.37E-08	4.01E-07	0.3855	0.0005	0.8517	0.1453	0.0187	0.0008
	ICI (s)	0.4245	0.0045	3.12E-18	0.3428	0.0083	0.0435	0.1242	0.7237	0.0297
	PtP (N)	0.3946	0.2976	0.5276	0.2910	0.2240	0.0002	0.3544	-0.0302	0.1197
	Duration (s)	0.3833	0.5385	0.2404	-0.3282	-0.3798	-0.4553	0.2799	0.1845	0.1326

adjustments related to the environment or individual preferences in foraging strategies (Ey & Fischer, 2009). Similarly, we recorded buzzes during all analyzed feeding bouts, except in one, which is similar to what Wisniewska et al. (2014) found for echolocation clicks in prey capture by false killer whales (*Pseudorca crassidens*) and bottlenose dolphins (*Tursiops truncatus*). Further investigations should address the potential role of buzzes in prey capture.

This was the first attempt to describe feeding bouts of beach-hunting Guiana dolphins in the CE. Mixing data from aerial images and acoustics proved to be a promising technique for describing the whole process of prey capture by these dolphins. Further investigations should address possible individual variations as well as cooperative groups hunting throughout the whole estuary.

Acknowledgments

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