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Effects of anthropogenic noise on the acoustic behaviour of *Sotalia guianensis* (Van Bénéden, 1864) in Pipa, North-eastern Brazil

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This study investigated the emission of subaquatic noise from recreational tourism motorboats, schooners and a sea-bottom mounted water pump. Analyses demonstrated alterations in several whistle (IF: $t = 2.42$, $P = 0.015$; FF: $t = -2.22$, $P = 0.025$) and calls patterns (MIF: $t = -3.13$, $P = 0.001$; MAF: $t = -3.49$, $P = 0.0005$; FD: $t = -2.21$, $P = 0.027$; D: $t = 2.89$, $P = 0.004$), caused primarily by motorboats. Duration of clicks was also modified (D: $t = -3.85$, $P = 0.0001$), mainly by the water pump. The frequency range of all noises (0.43–35.8 kHz) overlaps that used by dolphins (1–48 kHz), causing sound emissions changes, with a considerable increase in number of whistles and a reduction in clicks trains. These changes may be a strategy developed by these dolphins to overcome the noise band. Mitigation measures, such as boating regulations and environmental education for the local community, boaters and tourists are needed to conserve the species. The Guiana dolphin population is apparently already suffering, evidenced by diminished residence time and reduced number of individuals entering the inlet during the presence of pleasure craft.

Keywords: vessel noise, North-eastern Brazil, Guiana dolphin, *Sotalia guianensis*, Pipa beach, acoustic behaviour

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INTRODUCTION

The disordered growth of the human population in coastal areas, in addition to recreational, artisan and commercial fishing (Wells *et al.*, 1998), as well as ship and tourist boat traffic has been increasing for decades and, consequently, bringing impacts to marine life (Wells & Scott, 1997). In addition to these processes, chemical and sound pollution have reached increasingly higher levels, causing serious disturbance and even damage, primarily to cetaceans that use hearing and sound emission as their main means of communication and environment exploration through biosonar (Ketten, 1992; Richardson *et al.*, 1995; Tyack, 2000; Hildebrand, 2009).

Hearing in cetaceans is one of the most important senses and a good auditory apparatus is essential for the life of species, especially for predation, sensing the environment and social interactions (Ketten, 1992; Prideaux, 2003). Decreased auditory sensitivity caused by physical damage or masking noise compromises individuals and may subsequently affect an entire population (Richardson *et al.*, 1995; Prideaux, 2003). Using the acoustic impact assessment model, Erbe (2002) showed that whale-watching boats interfere in killer whale – *Orcinus orca* (Linnaeus, 1758) – communications, cause behavioural changes and may even generate temporary or permanent hearing losses in resident populations.

Other studies demonstrated that behavioural and sound emission changes can be due to the presence of watercraft. Parijs & Corkeron (2001) observed that Indo-Pacific humpback dolphins – *Sousa chinensis* (Osbeck, 1765) – exhibit an increase in number of whistles immediately after boats pass through their habitats.

The *Sotalia guianensis* dolphin (family Delphinidae) is also known as the Guiana dolphin. It is a small animal (mean of 1.80 m) that primarily inhabits estuaries, bays, inlets and mangrove areas (Da Silva & Best 1996; Rosas *et al.*, 2003). Its worldwide distribution ranges along the Atlantic Ocean, from Honduras, in Central America, to the state of Santa Catarina, southern Brazil (Da Silva & Best, 1996; Flores & Da Silva, 2009).

As a consequence of its coastal distribution, the species has been constantly approached by dolphin-watching tourism boats, and some studies have demonstrated the impact suffered by this species on the Brazilian coast (Santos *et al.*, 2006; Rezende, 2008; Tosi & Ferreira, 2008). Santos *et al.* (2006) report that boats approaching dolphins in Pipa beach, Rio Grande do Norte state, may induce subtle behavioural alterations, especially in regard to displacement. At the same site, Tosi & Ferreira (2008) observed that approaching boats had an influence on individuals, evidenced by the increase in respiratory synchronism, reported as a defence strategy against the presence of these vessels.

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Filla & Monteiro-Filho (2009) found Guiana dolphins from the region of Cananéia, São Paulo state react less negatively the longer boats remain in the area, due to habituation. However, boats approaching to within 50 m of dolphins were responsible for most of the negative responses like trying to withdraw from the boat and these were interpreted as being a defence behaviour, through which the animals seek protection, especially for the youngest, by moving far away.

Because wildlife-watching tourism in Brazil is undergoing a process of constant change, this study aims to propose possible solutions to mitigate and prevent disturbance and/or damage inflicted on dolphins, thereby contributing to their conservation, particularly in areas where Guiana dolphins are a tourist attraction.

The present study seeks to characterize the frequency parameters produced by different tour boat motors in the area, examine whether noises have an influence on the acoustic expression of dolphins and determine which anthropogenic underwater noise has the greatest effect on the sounds emitted by these animals.

This investigation tested the hypothesis that different sound categories are emitted by dolphins in the presence and absence of boats, and that these variations are influenced by the type of noises present in the area.

MATERIALS AND METHODS

Study area

The study area consists of two inlets, Madeiro and Curral, belonging to the district of Pipa in the municipality of Tibau do Sul. It is located in the southernmost part of Rio Grande do Norte state (06°13′23.9″S 35°04′14.8″W), ~90 km from Natal, the state capital, North-eastern Brazil (Figure 1).

The inlets exhibited high water turbidity, since they are high energy beaches, with constant movement of suspended sediment. Both inlets are surrounded by cliffs with a mean height of 30 m, protecting the region from winds and coastal currents and resulting in a relatively stable area, affected only by tides and rainfall (IDEMA, 2003).

Data collection

Dolphin and boat motor sounds were recorded on 11 collection days between April and June 2009. Sampling effort was 49 h 48 m with a daily mean of 4.5 h. The collections were considered satisfactory when the weather conditions were < 2 on the Beaufort scale.

Recordings were made from a 5-m fibreglass motorboat equipped with a Mercury 60HP 4-stroke outboard motor. Sounds were recorded using an HTI SSQ 94 hydrophone (frequency response up to 24 kHz) positioned at a depth of 1.5 m connected to a digital recorder (M-Audio Microtrack II, Cumberland, RI) with 16 bits of precision at a sampling rate of 96 kHz.

The boat initially approached at low speed and the engine was turned off during recordings. Recording sessions took place when dolphins were less than or equal to 100 m away, concluding when individuals swam beyond that distance and/or were no longer visible.

Recordings were initiated 2 h before commercial tours began (around 8:00 h), extending until they were half completed (around 13:00 h) in order to determine the influence of boat noise on sound emissions of dolphins present in the area. On three days, recordings were also made after the end of the tours, at 16:00 h. It was, therefore, possible to record dolphin sound emissions without noise interference as well as sounds and noises that occurred simultaneously.

Two motorboats were analysed: (motorboat one: Yamaha 115HP 2-stroke gasoline engine; motorboat two: Mercury 60HP 4-stroke gasoline engine) and two schooners (both equipped with 6MWM D229 diesel engines), randomly chosen as a sample of the boats used in the area. Data were collected regarding the presence and type of vessel (schooner or motorboat) in the area during recordings in order to complement analyses on the influence of tour boats on dolphin behaviour.

The three sound categories that are used in this study followed Monteiro-Filho & Monteiro (2001).

Analysis

To analyse any acoustic signal it is important to consider time and frequency. The time domain represents the amplitude as a function of time and in the frequency domain, the amplitude displayed as a function of frequency (Au & Hastings, 2008). Because of this relevance this study analysed both domains, such as previously applied to analysis of anthropogenic sounds in the cetacean soundscape ecology in Brazilian waters (Rossi-Santos, 2015). Time representation is a signal usually referred to as the waveform, while the frequency representation of a signal is usually referred to as the frequency spectrum (Au & Hastings, 2008).

Recordings were analysed with RAVEN PRO® 1.4 software. The following parameters were determined for each boat: minimum frequency (MIF), maximum frequency (MAF), frequency variation (FV). Parameters calculated from sound emissions of dolphin calls were minimum frequency (MIF), maximum frequency (MAF), frequency variation (FV) and duration (D), and for whistles the same frequencies were measured in addition to initial frequency (IF) and final frequency (FF). All the parameters were calculated considering the fundamental note.

Sauerland & Dehnhardt (1998) reported that the dominant frequency for the species' clicks is around 88 kHz. The maximum frequency values for clicks trains in this study always reached the maximum value of the recorder (48 kHz); thus, this frequency parameter was not considered in our analyses. Therefore, herein we utilized the minimum frequency (MIF) and click train duration (D) as click parameters for analysis.

To examine whether boat noises influence dolphin sound emissions, based on the means of each parameter, calculated from sound classes in the presence and absence of noise a Kolmogorov–Smirnov normality test of the data and a Mann–Whitney analysis with 0.05 significance were conducted for each parameter.

Kruskal–Wallis was used to determine if the noise influence varies according to the type of producer (motorboat, schooner and other noises), followed by *a posteriori* analysis using comparisons between pairs to show which noise has the greatest influence.

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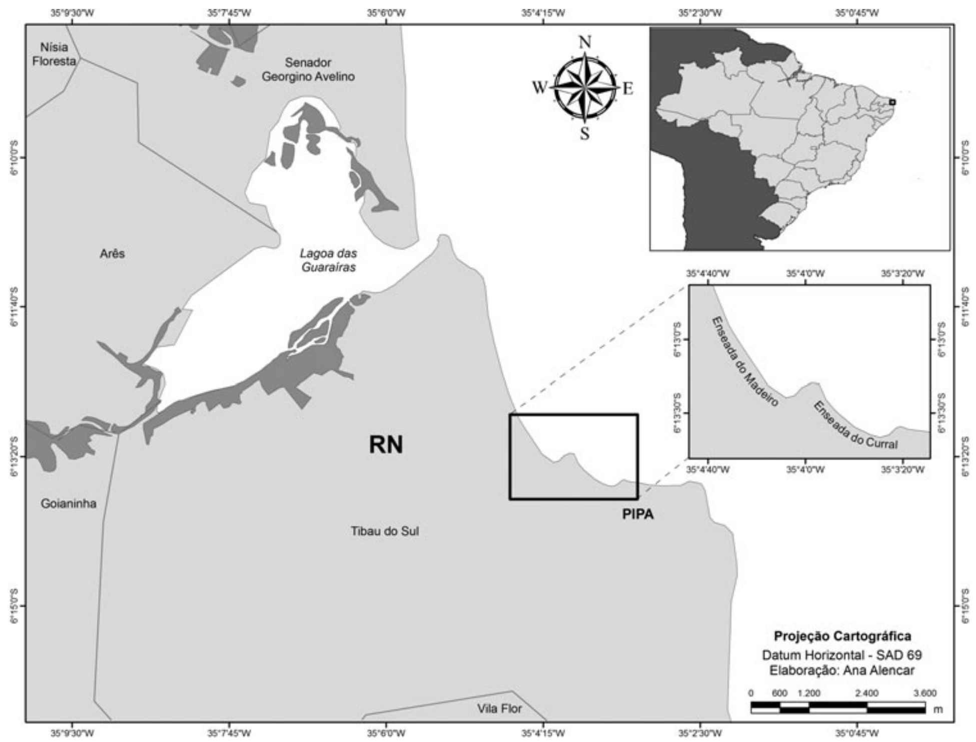

Fig. 1. Study area located at Pipa beach, municipality of Tibau do Sul, Rio Grande do Norte state, Brazil. (Map elaboration by Ana Alencar.)

RESULTS

The total recording time was 18 h 49 m, consisting of 260 sessions, 109 (42%) of which included the presence of boats. The current dolphin-watching tourism boat fleet in Pipa consists of six motorboats and four schooners making an average of four and three trips daily, respectively. Including all commercial tours, total tour time averages 6 h a day, 7 days a week, enabling a total noise recording time of 6 h 20 m. The median number of dolphins present during recordings was three individuals (two adults and one infant).

The recorded boats emit sounds with a mean peak frequency of around 10 kHz. However, noises produced, in addition to fundamental sounds, also contain harmonics (multiple values of the fundamental note), which reach higher frequencies, reverberating in the acoustic environment. Accordingly, the range used by the noises encompasses frequencies between 0.42 and 15.3 kHz and if considering the reverberation the range reaches to 35.82 kHz.

During some recording sessions, generally conducted after tourist activities ended, the presence of a different noise from that produced by boats was recorded, exhibiting a narrow frequency and little reverberation. This noise was identified as originating from water tubes coming from the shore to a building, these being a water suction pump located 2.5 km away from our study site, installed underwater by the rocky shore of a luxury hotel in the region. We then analysed and described this new pattern of noise for the species along with the boat noise description (Table 1).

Based on between-boat comparisons, it was observed that variations in frequencies (including reverberation) emitted by motorboats are greater than those emitted by schooners. Furthermore, there are differences between types of outboard engines, since motorboat 1 used a 2-stroke engine, exhibiting higher means at all frequencies, whereas motorboat 2, which is driven by a 4-stroke engine, displays lower mean frequencies (Table 1).

Analysis of dolphin sounds generally demonstrated an overlap of frequency ranges between noises and their sound emissions, which ranged from 1 to 48 kHz, considering all sound categories recorded. Spectrograms (Figures 2A, B) show dolphin sound emission occurring simultaneously with the noises and no noise.

For a better comparison of the influence of anthropogenic noise on each sound emission class, the parameters calculated were separated according to the absence and presence of noise (Table 2).

There was a considerable increase in the number of whistles during the presence of noise, from 1146 whistles in the absence of noise to 2112 when it was present. However, the number of click trains sequences decreased from 524 in the absence of sounds and to 349 in the presence of noise. There was no difference in the number of calls during the presence (144) and absence (145) of sounds.

Table 1. Mean values of parameters obtained from the acoustic noise produced by boats and a water pump in Pipa beach, Rio Grande do Norte, Brazil. Frequency is in kHz.

	MIF	MAF	FV
Motorboat 1	2.88	35.82	35.04
Motorboat 2	0.79	28.1	27.31
Schooner 1	0.42	25.71	25.28
Schooner 2	0.52	22.00	21.47
Water pump	1.84	8.14	6.30

MIF, Minimum Frequency; MAF, Maximum Frequency; FV, Frequency Variation.

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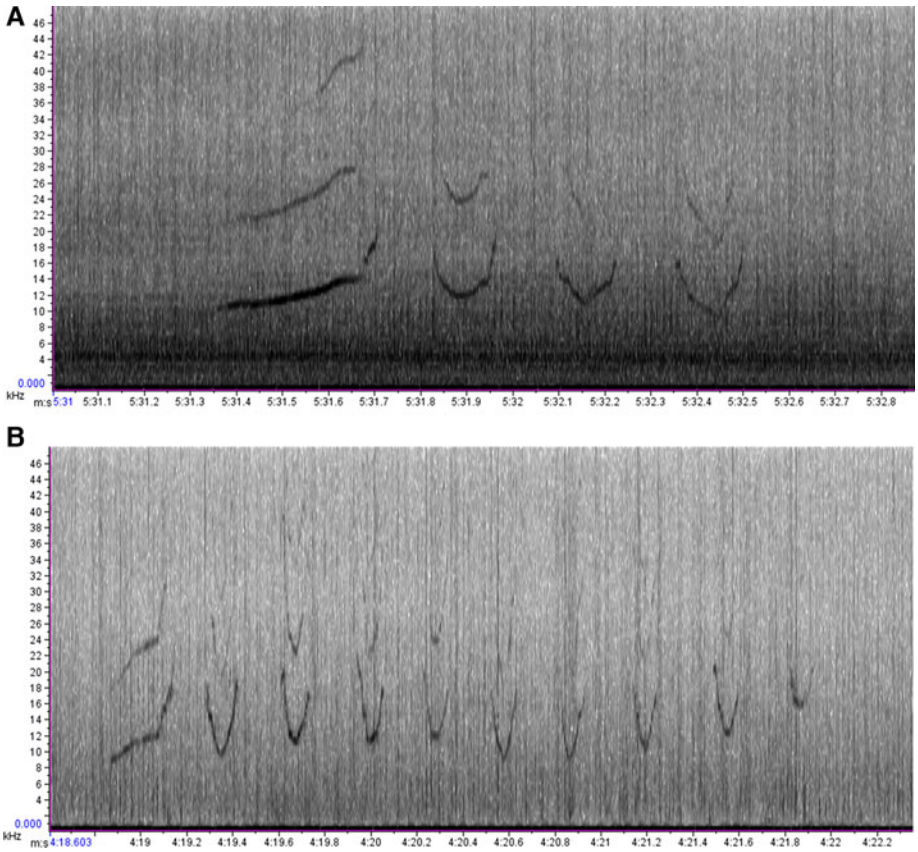

Fig. 2. Spectrogram of anthropogenic noise and dolphins' sound emissions recorded at Pipa beach, Rio Grande do Norte, Brazil. (A) noise of a motorboat together with whistles of dolphins. (B) whistles without anthropogenic noise.

The Mann–Whitney *U* test showed the presence of noise influenced the initial and final frequency parameters of whistles (IF: $U = 115434$, $P = 0.029$; FF: $U = 116027$, $P = 0.050$); however, it did not alter the remaining parameters (MIF: $U = 120295$, $P = 0.770$; MAF: $U = 120295$, $P = 0.350$; FV: $U = 120871$, $P = 0.950$; D: $U = 117456$, $P = 0.160$).

For click trains, the Mann–Whitney only revealed differences between the presence and absence of noise in the parameters duration (D: $U = 78403.50$, $P = 0.0001$), without altering all frequency parameters (MIF: $U = 91218.00$, $P = 0.950$; MAF: $U = 84492.50$, $P = 0.057$; FV: $U = 89733.50$, $P = 0.640$). In calls, all frequency and duration parameters

Table 2. Mean, standard deviation and amplitude of the acoustic parameters of *Sotalia guianensis* whistles, calls and recorded during the absence and presence of noise between the months April and June 2009, in Pipa beach in the state of Rio Grande do Norte, Brazil. Frequency is in kHz and duration in seconds.

	IF	FF	MIF	MAF	FV	D
Whistle without noise	11.50 ± 5.02	18.80 ± 4.60	10.20 ± 3.76	19.50 ± 4.40	9.30 ± 0.10	0.19 ± 0.10
	(0.93–47.5)	(3.20–36.50)	(0.70–25.10)	(3.20–47.50)	(1.30–44.10)	(0.02–2.66)
Whistle with noise	11.80 ± 4.69	19.10 ± 4.62	10.40 ± 4.01	19.60 ± 4.40	9.20 ± 4.76	0.20 ± 0.12
	(0.93–47.50)	(1.30–38.50)	(0.90–28.20)	(5.20–47.50)	(0.30–44.40)	(0.02–0.87)
U	115434	116027	120295	120295	120871	117456
P	0.029*	0.050*	0.770	0.350	0.950	0.160
Calls without noise	–	–	7.10 ± 4.28	9.50 ± 4.59	2.45 ± 1.01	0.22 ± 0.14
	–	–	(0.56–16.90)	(1.80–19.60)	(0.72–6.57)	(0.04–1.09)
Calls with noise	–	–	8.70 ± 4.50	11.50 ± 4.64	2.70 ± 1.08	0.18 ± 0.09
	–	–	(0.93–19.80)	(2.90–23.20)	(1.03–7.10)	(0.03–0.65)
U	–	–	8259.00	8087.500	8785.000	8261.000
P	–	–	0.002*	0.000*	0.019*	0.002*
Clicks without noise	–	–	6.40 ± 3.04	–	–	1.75 ± 1.38
	–	–	(1.00–17.10)	–	–	(0.14–10.27)
Clicks with noise	–	–	6.50 ± 3.23	–	–	2.18 ± 1.90
	–	–	(1.10–20.50)	–	–	(0.29–15.70)
U	–	–	91218.00	–	–	78403.500
P	–	–	0.95	–	–	0.000*

IF, initial frequency; FF, final frequency; MIF, minimum frequency; MAF, maximum frequency; FV, frequency variation; D, duration.
*Significant values.

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Table 3. Means and standard deviation of parameters of three sound classes that were influenced by separate noises in presence of the water pump, the boat and the schooner recorded between April and June 2009, in Pipa beach, Rio Grande do Norte, Brazil.

	IF	FF	MIF	MAF	FV	D
Whistle with water pump	11.26 ± 3.66	18.27 ± 4.18	10.59 ± 3.29	18.56 ± 3.91	7.97 ± 4.42	0.20 ± 0.12
	(3.63–21.79)	(4.18–31.34)	(3.29–19.87)	(3.91–31.34)	(1.01–23.59)	(0.02–2.66)
Whistle with motorboat	11.43 ± 4.74	19.22 ± 4.65	10.58 ± 4.02	19.72 ± 4.43	9.14 ± 4.80	0.19 ± 0.12
	(1.13– 47.48)	(2.87–38.59)	(1.13–28.17)	(4.43–47.48)	(1.61–44.40)	(0.02–0.87)
Whistle with schooner	10.59 ± 4.81	19.30 ± 4.67	9.98 ± 4.14	19.72 ± 4.45	9.72 ± 4.70	0.19 ± 0.12
	(0.92–37.24)	(1.33–34.53)	(0.92–24.60)	(4.45–37.24)	(2.63–30.62)	(0.02–0.87)
H	17.121	11.527	10.079	16.621	30.114	1.404
P	0.000*	0.031*	0.060	0.055	0.053	0.490
Call with water pump	–	–	–	–	–	–
	–	–	–	–	–	–
Call with motorboat	–	–	8.52 ± 4.38	11.40 ± 4.62	2.88 ± 1.14	0.18 ± 0.09
	–	–	(0.92–19.83)	(2.98–23.22)	(1.02–7.09)	(0.03–0.65)
Call with schooner	–	–	9.54 ± 4.86	11.76 ± 4.77	2.22 ± 7.08	0.16 ± 0.08
	–	–	(2.15–19.54)	(4.77–22.09)	(0.70–3.70)	(0.05–0.39)
H			1.582	0.404	9.722	2.517
P	–	–	0.453	0.816	0.007*	0.280
Click with water pump	–	–	8.84 ± 3.15	–	–	3.11 ± 1.88
	–	–	(3.15–19.73)	–	–	(0.47–09.14)
Click with motorboat	–	–	5.96 ± 3.23	–	–	2.17 ± 1.55
	–	–	(1.43–20.55)	–	–	(0.30–15.69)
Click with schooner			6.40 ± 2.62	–	–	1.67 ± 1.33
			(1.02–13.18)	–	–	(0.29–09.33)
H	–	–	38.602	–	–	35.447
P	–	–	0.08	–	–	0.000*

*Significant values.

change in the presence of noise (MIF: $U = 8259.00$, $P = 0.002$; MAF: $U = 8087.50$, $P = 0.000$; FV: $U = 8785.00$, $P = 0.019$; D: $U = 8261.00$, $P = 0.002$).

The means of dolphin sound patterns in the presence of motorboat, schooner and water pump noise were separated in order to determine which of the three had more influence on the three sound classes (Table 3). Water pump noise is not present in analyses of calls, since they were not emitted in the presence of this noise.

The Kruskal–Wallis demonstrated that whistles exhibit differences in IF and FF parameters for the different types of noise (IF: $H = 17.121$, $P = 0.000$; FF: $H = 11.527$, $P = 0.003$). The *a posteriori* showed the motorboat had the greatest influence. Analyses of click trains revealed a difference between types of noises in parameter D (D: $H = 35.44704$, $P = 0.000$). The *a posteriori* for click trains parameters indicated they were more influenced by the water pump (Table 3).

The Kruskal–Wallis for calls showed no difference between types of noise for MIF and MAF (MIF: $H = 1.582$, $P = 0.453$; MAF: $H = 0.404$, $P = 0.816$; D: $H = 2.517$, $P = 0.280$). However, a difference was recorded for frequency variation (FV: $H = 9.722$, $P = 0.007$). The *a posteriori* confirmed the difference between the motorboat and schooner, the former exerting the greatest influence (Table 3).

DISCUSSION

Dolphin-watching tourism has been growing steadily, with positive and negative repercussions. If applied in a well-organized operation it may promote an increase in environmental responsibility and generate income for local populations (Corkeron, 1995). However, when uncontrolled, these activities may cause short- and long-term damage to the animal populations of the region (Constantine, 2001).

Guiana dolphin watching in Pipa occurs daily and the boats used for this activity generate significant sound pollution, since they used a wide frequency range, considering the harmonics and the reverberation of the noises produced. Reverberation occurs when the difference in time between the emission and the sound reflection is very short, enhancing sound propagation in a certain acoustic enviroment (Rossing, 2007).

Between-boat comparisons demonstrated that the schooners, equipped with low rotation engines (centre of the boat), seem to be less harmful than high rotation engines (stern) when maximum noise frequency values are involved. The 4-stroke motorboat engine emits lower frequency ranges than the 2-stroke version. A lower frequency range can cause less impact because dolphins are able to adjust and use higher frequencies and also depends on the hearing curve that is less sensitive to lower frequencies.

The different frequency parameters recorded in the boats under study confirm the findings of Au & Green (2000). The authors believe the smaller boats produce sounds of equal or greater intensity than large boats. This occurs because the number of rotations per minute (RPM) required by a high rotation engine with small propellers to overcome thrust must be much greater than the RPM needed for inboard motors with larger propellers. Thus, outboard motors can generate more noise and possibly more injuries to marine life. Moreover, wood hulls are excellent sound conductors, preventing engine noise from being dissipated in the water (Filla & Monteiro-Filho, 2009).

Signal parameters are influenced by the distance and orientation of the vocalizing animal to the recording hydrophone. Lower frequencies are less attenuated over distance than higher frequencies. The orientation of the animal to the recording device changes the signal properties as well, as higher overall amplitudes and more high frequency energy is expected when the animal's vocal beam is on axis with the recorder (Au, 1993). Signals obtained from random axis orientations may have distorted asymmetric wave forms, which include reverberations caused by reflections within the head, from the external environment or even both (Au *et al.*, 1978).

Although we know that the number of harmonics in a spectrogram is a whistle variable that is defined by whistle directionality (Lammers & Au, 2003) and by the upper frequency limit of the recording system, thus it is not the best variable to be used when referring to the effects of anthropogenic noise on the acoustic behaviour of animals, this was the tool we had to start this study in this unique area for *S. guianensis* conservation. The results obtained when comparing values using the number of harmonics seen in the spectrogram has little biological relevance for dolphin studies and does not provide a strong explanation for the noise interference. For future studies we assume and recommend to remove this parameter from the analysis so as not give so much emphasis on the reverberation aspect. In this way, we plan to develop new research efforts utilizing additional analysis with more robust parameters, such as: Signals Intensity, Source Pressure Level, Signal to Noise Ratio, Root Mean Squared, Peak-to-Peak and Centre Frequency.

In contrast to the boats, the water pump exhibits a narrow frequency range and no harmonics. Peak frequency noise is around 2 kHz. We could observe that the water pump is used to remove salt water from the sea to supply a hotel swimming pool. It is generally turned on in the late afternoon, after commercial tours, thereby increasing exposure of the dolphins to anthropogenic noise.

Considering many associated factors can influence engine noise including type and power, speed and boat building material (Ng & Leung, 2003; Constantine *et al.*, 2004; Filla & Monteiro-Filho, 2009), dolphin-watching vessels in Pipa beach exhibit characteristics that may harm dolphins in the area, primarily when different engines are used, such as 2-stroke and 4-stroke versions and high power. Acoustic monitoring is therefore needed to evaluate this damage.

A number of studies have revealed that dolphins seem to respond to the presence of boats by emitting more whistles (Parijs & Corkeron, 2001; Scarpaci *et al.*, 2001). In the present study, boat tours to observe Guiana dolphins in their natural habitat in Pipa beach cause modifications in their standard sound emissions. Similar to the bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821) (Scarpaci *et al.*, 2001), Guiana dolphins practically doubled whistle production when boat noise occurred in the same area as the individuals.

Frequency ranges of the boats in Pipa are generally similar to those used by dolphins and the phenomenon of reverberation caused by engine noise increases frequency overlap even more. This overlap can generate masking, occurring when an anthropogenic noise covers or 'masks' the sounds produced by dolphins (Foote *et al.*, 2004; Nowacek *et al.*, 2007). At certain moments, generally during motor acceleration, masking occurs in such a way as to preclude determining any other type of sound other than engine noise. However, at other times, even with interference, it was possible to identify the fundamental note and record the dolphins' sound parameters.

All sounds produced by dolphins in Pipa registered an increase in at least two acoustic parameters in the presence of sounds, with whistles (IF and FF) and calls (MIF, MAF, FV and D) exhibiting changes primarily in their frequency values. Based on this result, it can be hypothesized that the large amount of noise present in the area causes modifications in the dolphins' acoustic niche, evidenced by sound emissions at higher frequencies. Thus, there is an attempt to avoid the higher ranges used by boats.

Data obtained here agree with the hypothesis of Parks *et al.* (2009), who believed that cetaceans, such as the North Atlantic right whale – *Eubalaena glacialis* (Müller, 1776) – modify their calls with an increase in frequencies, depending on where they are, to overcome background and anthropogenic noise from the different areas they inhabit throughout the year.

The Mann–Whitney test showed no differences in frequency parameters in clicks values during the presence and absence of noise. A wide range of frequencies are used in dolphin click emissions, irrespective of the existence of noise, varying between 1 and 48 kHz. It will probably be unnecessary to modify the frequency niche of this sound, because dolphins already use this wide range for echolocation.

Duration was the only parameter altered in the click category. This increased during the presence of noise, probably to overcome the noise barrier, since frequencies remained unchanged. Producing a longer lasting sound can permit greater echolocation accuracy during masking moments, due to sound interference.

Although the pump displayed a narrow frequency range and little reverberation, this characteristic does not seem to interfere in clicks trains, given that the frequency parameters of this sound category remained unchanged. However, the uninterrupted noise of the pump appeared to have a greater influence on clicks, since duration increased in the presence of noise.

In addition to these parameters, production of this sound category fell considerably during the presence of noise. Thus, dolphins seem to avoid using this sound during these moments. This fact may be related to dispersion of fish during the approach of boats and/or visual identification, thereby avoiding energy expenditures with more intense echolocation to overcome anthropogenic noise. It is also possible that dolphins are distracted by boats, or need to pay more attention to the boats than to feeding.

In contrast to clicks, the sound parameters of whistles were significantly altered in the presence of boat noise. The *a posteriori* showed that the increase in values observed at IF and FF are related to the presence of motorboats, likely due to their high frequency values when compared with schooners. Since IF exhibit lower frequency values than FF, the former are more susceptible to higher noise levels (mean = 10 kHz). Furthermore, the number of whistles produced in the presence of motorboats was greater when compared with schooners. This may reflect the larger number of motorboats in the area and greater number of tours these boats make. Calls showed alterations only with respect to frequency variation and between boats. An increase in the parameter occurred for this sound category, as well as in whistles, in the presence of motorboats.

Accordingly, it is difficult to determine which noise causes the greatest impact on the sound parameters of dolphins in Pipa, given that the pump affected clicks more, while the boats exerted greater influence on the other categories. However, motorboats tend to have more influence than schooners, since they accounted for the greatest impact on whistles and calls. Moreover, irrespective of source, the presence of these sounds alters the sound emissions of Guiana dolphins in Pipa, generating concern for creating impact reduction measures.

The harm caused to dolphins by noise can be auditory and/or behavioural (Richardson *et al.*, 1995; Rezende, 2008). Daily exposure to moderate to high-intensity sounds generates temporary hearing losses that can eventually become permanent (Pavan, 2002; Wartzok *et al.*, 2005). Based on a study using a photo-identification technique, dolphins visit the inlet every day and an average total population of 105 individuals was estimated in the area, which varies between 88 and 129 through the year, with a quarter of the population presenting high fidelity (Link, 2000; Silveira, 2006; Ananias *et al.*, 2008; Paro, 2010). Thus, it seems likely that some individuals are exposed to these noises daily, possibly sustaining damage from this interference.

Impacts caused by tour boats in Pipa are still unclear. Studies in the region have revealed a number of behavioural modifications and the present study showed changes in some sound emission patterns. All previous investigations describe short-term alterations – there are still no long-term studies on the vessels' interference in dolphins. Monitoring of this population is needed to minimize these impacts, mainly those that can generate long-term damage.

According to Constantine (2001), boats cause negative long-term effects when they affect important behaviours for the conservation of the population, such as foraging and reproduction. The decrease in clicks trains during the presence of noise must be monitored to determine whether this interference is compromising foraging activity, since, although this may only affect a few individuals in the short term, it may compromise the entire population in the long term, decreasing survival or altering their living area.

There are no studies in long-term estimations of population density in the region; however, direct information from local fishermen and tour boat owners revealed that residence time and the number of individuals entering the inlets has declined in recent years (Izac, personal communication). Cases of marine mammal species abandoning areas as a result of negative impacts are not rare. Stevens & Boness (2003) observed that the South American fur seal – *Arctocephalus australis* (Zimmermann, 1783) – seems to abandon optimal reproduction areas, due to human disturbances in these areas. Thus, measures must be taken to discourage dolphins in Pipa from leaving this important feeding and reproduction area (Nascimento, 2006).

Tosi & Ferreira (2008) conducted an impact study of boats in the Pipa area during a period in which boat traffic was controlled. They found that behavioural changes were fewer than those observed before controls were established. However, these measures are no longer in force and tour boat traffic is very heavy. Further studies to determine the impact of boats owing to different types of motors used, based on comparisons of these motors at a same speed, may identify the one that has the least impact on local marine life.

Attempting to convince boat owners to replace old motors with less powerful, 4-stroke engines, in addition to performing regular maintenance, is essential to reducing noise. Furthermore, environmental education programmes involving the local community and tourists are needed to show the importance of conserving marine life, mainly because, once enlightened, these individuals often become monitors of tour boat activities.

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