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AMBIENT AND VESSEL NOISE AT CRITICAL FORAGING HABITATS FOR OCEANIC DOLPHINS

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Resumo
Os golfinhos que vivem nas águas oceânicas dos Açores usam consistentemente os montes submarinos para se alimentar à noite. Esses golfinhos dependem inteiramente de cliques de ecolocalização de banda larga e sinais pulsados para navegar, detectar e capturar presas. O ruído subaquático das embarcações pode interferir na capacidade desses golfinhos de se alimentar com sucesso. Neste trabalho, medimos os níveis de ruído na banda de 1-25 kHz em registos acústicos recolhidos em dois montes submarinos (Condor e Gigante) em março-maio de 2008 e abril de 2010-fevereiro de 2011 para avaliar a variação temporal do ruído ambiente, do ruído causado por embarcações, e a sobreposição com os sons usados pelos golfinhos em alimentação. Os níveis médios de ruído por hora variaram de 96 a 127 dB re 1 µPa em ambos os montes submarinos. Os maiores valores de ruído foram registrados durante o inverno e início da primavera, quando o ruído gerado pelo vento foi mais intenso. Com a diminuição da velocidade do vento no verão, a contribuição do ruído das embarcações para o ruído ambiente aumentou. Os golfinhos em alimentação usaram os montes submarinos com maior intensidade de dezembro a maio, coincidindo com os meses mais ruidosos, mas quando esse ruído foi essencialmente causado por fontes naturais. Estudos futuros comparando o mascaramento do vento e do ruído de embarcações contribuirão para melhor compreender os impactos potenciais no comportamento de alimentação dos golfinhos.

Palavras-chave: golfinhos, alimentação, ruído subaquático, ruído de embarcações, Açores

Abstract
Dolphins living in the oceanic waters off the Azores consistently use seamounts to forage at night. These dolphins rely entirely on broadband echolocation clicks and burst-pulsed signals to sense their environment, detect and capture prey. Underwater noise from vessels can interfere with the ability of these dolphins to forage successfully. We measured noise levels in the 1-25 kHz bandwidth from acoustic recordings collected at two seamounts (Condor and Gigante) in March–May 2008 and April 2010–February 2011 to assess temporal variation in ambient and vessel noise and overlap with foraging dolphins. Average noise levels per hour ranged from 96 to 127 dB re 1 µPa in both seamounts. The highest noise values were recorded during winter and early spring, when wind-generated noise was stronger. With the decrease in wind speed in summer, the contribution of vessel noise to background noise increased. Foraging dolphins used Condor and Gigante seamounts more intensively from December to May. The peak in dolphin usage coincided with the noisiest months, but when noise was largely driven by natural sources. Future studies comparing masking of wind and vessel noise will help understanding potential impacts on dolphin foraging behaviour.

Keywords: dolphins, foraging, underwater noise, vessel noise, Azores

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1 Introduction

Seamounts are common topographic features in the Azores [1], an oceanic archipelago located in the mid North Atlantic Ocean. Passive acoustic monitoring (PAM) at two shallow Azorean seamounts, Condor and Gigante, revealed that small delphinids consistently use these seamounts to forage at night [2]. Persistent association of dolphins to these seamounts is likely related to the high densities of micronekton aggregated over the plateau of both seamounts at all times of the year [3]. Such high densities result from the presence of a seamount-associated micronekton community and by the retention of vertically migrating micronekton at the summits [4]. Thus, in the pelagic realm, where prey patchiness is usually high and topography deep, shallow seamounts offer enhanced foraging opportunities for oceanic dolphins, aggregating prey at accessible diving depths [2, 5].

Dolphins rely on broadband echolocation clicks, that vary from tens of kilohertz to well over 100 kHz, and burst-pulsed signals to sense their environment, detect and capture prey. Overlapping high energy noise produced by vessels can interfere with the ability of these dolphins to forage successfully. Vessel traffic is the greatest contributor to noise in the low-frequency band (1 Hz - 1 kHz) [6] but vessels also emit significant energy at higher frequencies (tens of kHz) and, in the case of small vessels, acoustic power increases significantly with speed, especially at higher frequencies [7]. Noise-related auditory masking can affect dolphin echolocation-based foraging by reducing functional acoustic ranges, and impact group coordination during foraging activities. While dolphins are capable of altering the acoustic characteristics (frequency range, amplitude, duration and production rates [8-10]) of their signals in response to vessel noise, most likely to reduce masking, such compensation mechanisms may increase energetic costs and decrease foraging efficiency [11]. In the long-term, these effects can influence population's health, by changing vital rates.

Here, we measured broadband underwater noise levels, collected at Condor and Gigante seamounts during March–May 2008 and April 2010–February 2011, to assess temporal variation in ambient and vessel noise and overlap with foraging dolphins.

2 Methodology

2.1 Data collection

Acoustic recordings were collected using bottom-moored Ecological Acoustic Recorders (EARs) [12], deployed on Condor and Gigante seamounts in the Azores (Fig. 1), at an approximate depth of 190 m (Table 1). The EAR is an autonomous system that consists of a Sensor Technology SQ26-01 hydrophone with a flat frequency response (±1.5 dB) from 18 Hz to 28 kHz and a response sensitivity between -193 and -194 dB re 1 V/µPa. A Burr-Brown ADS8344 A/D converter was used with a zero-to-peak voltage of 1.25, and a total system gain of 47.5 dB re 1µPa. The EARs were programmed to record 30 s every 10 min or 90 s every 15 min at a sampling rate of 50 kHz, providing an effective recording bandwidth of 25 kHz at a 5% or 10% duty cycle, respectively (Table 1).

Table 1 - Summary of acoustic recordings on Condor and Gigante seamounts. The table indicates the time period, duty cycle (sec on/min off), hydrophone sensitivity (dB re 1 V/µPa), number of days and hours of recordings of each deployment.

Location	Period	Duty cycle	Sensitivity	Nº days	Nº hours
Condor	Mar - May 2008	30 s/10 min	-193.14	75	88.6
	Apr - Sep 2010	90 s/15 min	-194.17	159	379.8
	Sep 2010 - Feb 2011	90 s/15 min	-194.17	153	366.1
Total				**387**	**834.5**
Gigante	Mar - May 2008	30 s/10 min	-193.64	72	85.7
	Jul - Sep 2010	90 s/15 min	-193.14	71	167.6
	Sep 2010 - Feb 2011	90 s/15 min	-193.14	159	379.8
Total				**302**	**633.1**

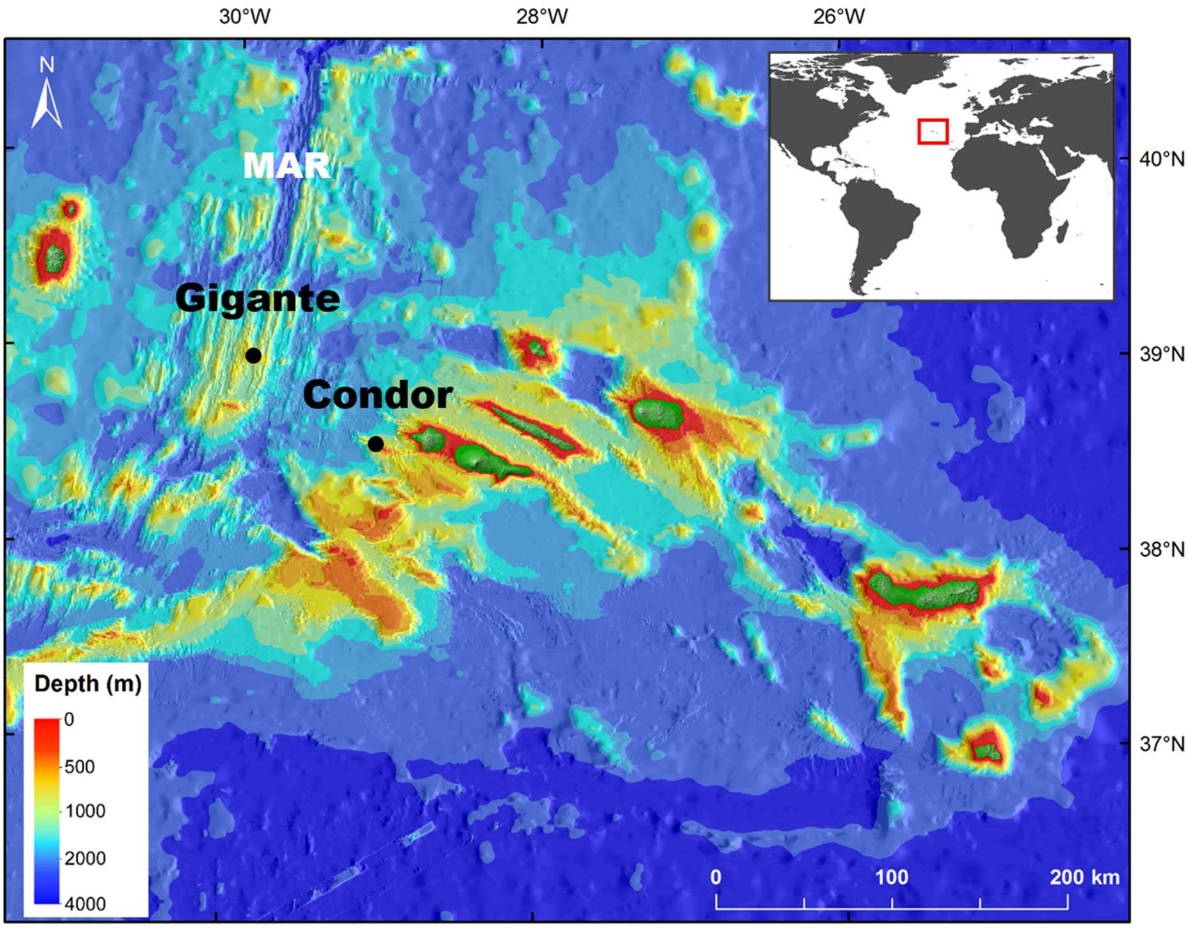

Figure 1 - Map of the study area indicating the locations where Ecological Acoustic Recorders (EARs) were deployed (black dots): Condor and Gigante seamounts in the Azores. MAR: Mid-Atlantic Ridge (MAR). Azores bathymetry data credits: [13].

2.2 Data analysis

For dolphin detection, acoustic data were processed using Triton, a custom Matlab script [14], to compute long-term spectral averages (LTSAs) with a frequency and time resolution of 20 Hz and 15 s, respectively. LTSAs provides a compressed spectrogram view allowing efficient visual examination of long datasets [15]. For each 1 h long LTSA segments, ones or zeros representing presence or absence of dolphin signals were assigned. When dolphin signals were detected within a LTSA segment, 30% of the files with the strongest signals (indicated by dB intensity) were selected for visual inspection of the spectrograms to classify dolphin vocalizations and detect potential foraging activity. Dolphin acoustic presence was analysed using the proportion of dolphin positive hours per day (DPH), calculated as the number of hours with at least one dolphin detection divided by the number of hours recorded on that day. Dolphin foraging activity was examined by calculating the proportion of foraging positive hours per day (FPH), i.e., the number of hours with at least one foraging signal divided by the number of hours with dolphin detections on that day.

Acoustic recordings were processed in Matlab using the PAMGuide package [16] to compute broadband (1-25 kHz) sound pressure levels (SPLs, in dB re 1 μPa) with a 1-s time segment averaged to 15-s resolution via the Welch method. We then calculated the adaptive threshold level (ATL) [17, 18] to determine the contribution of intermittent vessel noise to general background noise levels. The ATL works on the assumption that the minimum recorded SPL over a given period is representative of background sound within that period [17]. Time with levels above the threshold was summed and divided by the total recording time to obtain the Percentage of Time with noise levels Above the Threshold Level (PT-ATL) [18]. Wind speed data were obtained from Weather Underground historical data (www.wunderground.com).

Data were pooled by month of the year (hereafter called sampling periods) within each seamount, as most months were only monitored once during the study period and we could not assess monthly or inter-annual variation in the data.

PT-ATLs were compared among seamounts by using a Wilcoxon rank sum test and a Spearman correlation test was used to detect correlation between SPL metrics (mean, median, 5th, 75th and 95th percentiles), wind speed and PT-ATL.

3 Results

Broadband (1-25 kHz) hourly average SPLs ranged from 99.2 to 126.8 dB re 1 μPa in Condor seamount and from 96.2 to 117.7 dB re 1 μPa in Gigante seamount (Fig. 2a). Overall, SPLs varied over the sampling periods, with the highest levels recorded in winter (December 2010 to February 2011) and spring (March-May 2008 in Gigante and April-May 2010 in Condor) periods (Fig. 2a). However, the average sound levels in Condor varied in no obvious high or low peak in the sampling period.

For both seamounts, the average wind speed was higher in December 2010 to February 2011 and in March-April 2008, and lower in May 2008 and in April-November 2010 (Fig. 2b).

PT-ATLs differed between seamounts ($W=31$, $p=0.01$). Gigante had slightly the highest percentage of boat noise (5.3 ± 1.7% s.d.) than Condor (3.3 ± 2.8% s.d.), and values per sampling period varied between 0.7 to 9.4% in Condor and 3.1 to 8.7% in Gigante. In Condor, PT-ATL peaked during July and August 2010 and in April 2008 (Fig. 2c). In Gigante, PT-ATL peaked during July and September 2010 but differences between the other sampling periods were not as obvious as in Condor (Fig. 2c).

Median, 75th and 95th percentiles SPLs per sampling period were positively correlated with wind speed in Condor, while all SPL metrics were positively correlated with wind speed in Gigante (Figs. 2a, b). Regarding PT-ATL, only the 5th percentile SPLs per sampling period were negatively correlated with PT-ATL in Condor, whereas in Gigante all SPL metrics, except the 95th percentile, were negatively correlated with PT-ATL (Table 2; Figs. 2a, c).

Table 2 – Results of Spearman correlation test (r_s). Significant term ($p<0.05$) is shown in bold.

	Wind speed		PT-ATL	
SPLs	**Condor**	**Gigante**	**Condor**	**Gigante**
Average	r_s=0.53, p=0.053	r_s=0.90, **p<0.001**	r_s=-0.06, p=0.834	r_s=-0.69, **p=0.02**
Median	r_s=0.68, **p=0.01**	r_s=0.81, **p=0.002**	r_s=-0.53, p=0.05	r_s=-0.73, **p=0.02**
5th Percentile	r_s=0.31, p=0.273	r_s=0.69, **p=0.02**	r_s=-0.66, **p=0.01**	r_s=-0.80, **p=0.005**
75th Percentile	r_s=0.79, **p=0.001**	r_s=0.86, **p=0.001**	r_s=-0.43, p=0.124	r_s=-0.76, **p=0.009**
95th Percentile	r_s=0.77, **p=0.001**	r_s=0.95, **p<0.001**	r_s=-0.22, p=0.453	r_s=-0.45, p=0.173

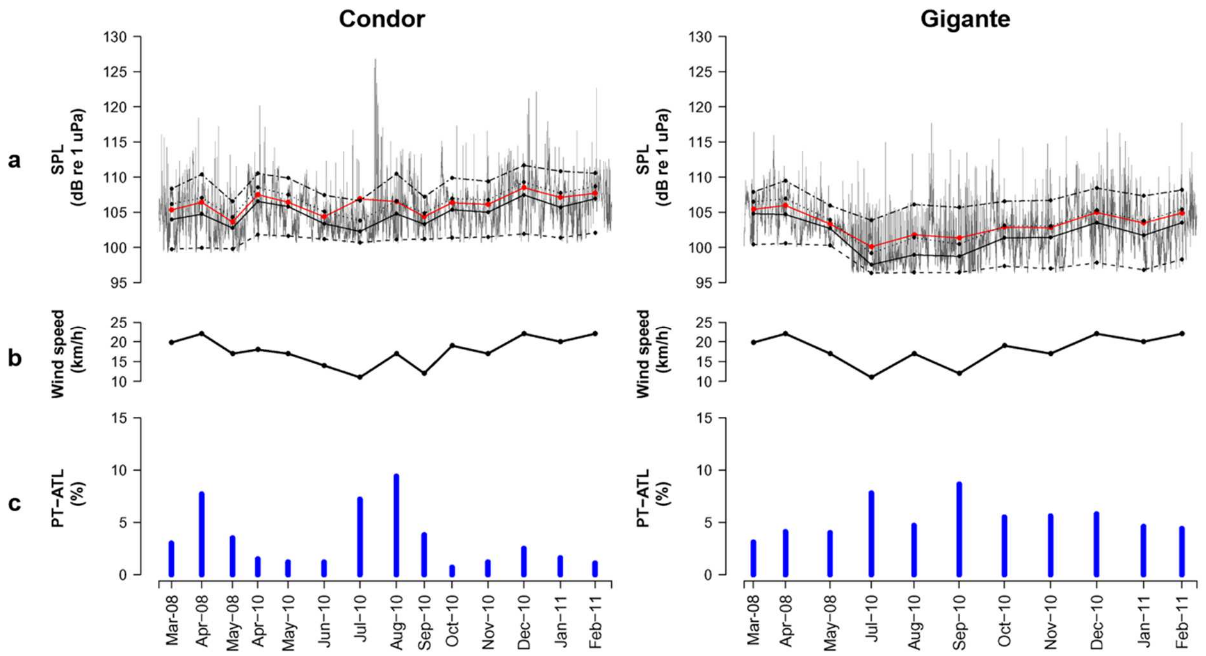

Figure 2 - (**a**) Broadband sound pressure levels (SPLs) between 1 and 25 kHz in Condor and Gigante seamounts: hourly (grey lines) and per sampling period averages (red lines), medians (black lines) and 5th, 75th and 95th percentiles (dashed black lines). (**b**) Wind speed averages per sampling period and seamount. (**c**) Percentage of time with vessel noise levels above the threshold level (PT-ATL) averages per sampling period and seamount.

Dolphins were acoustically detected in all years, months and nearly every day at both seamounts (Fig. 3). DPH did not differ between the two seamounts but varied significantly across sampling periods, being higher in winter (January and February 2011) and in early spring (March 2008 in Condor) periods and lowest in late spring and summer periods (Fig. 4a). Foraging signals (buzzes and bray calls) were recorded in >87% of the days dolphin were present (Fig. 3). FPH did not vary significantly between seamounts nor among sampling periods (Fig. 4b). On average, dolphins foraged 3.9 ± 2.7 (s.d.) hours per day at Condor and 4.8 ± 3.2 hours per day at Gigante, with a maximum of 19 and 16 hours at Condor and Gigante, respectively. There was a strong diel pattern in dolphin acoustic occurrence and behaviour, with higher detections of foraging and echolocation vocalizations during the night.

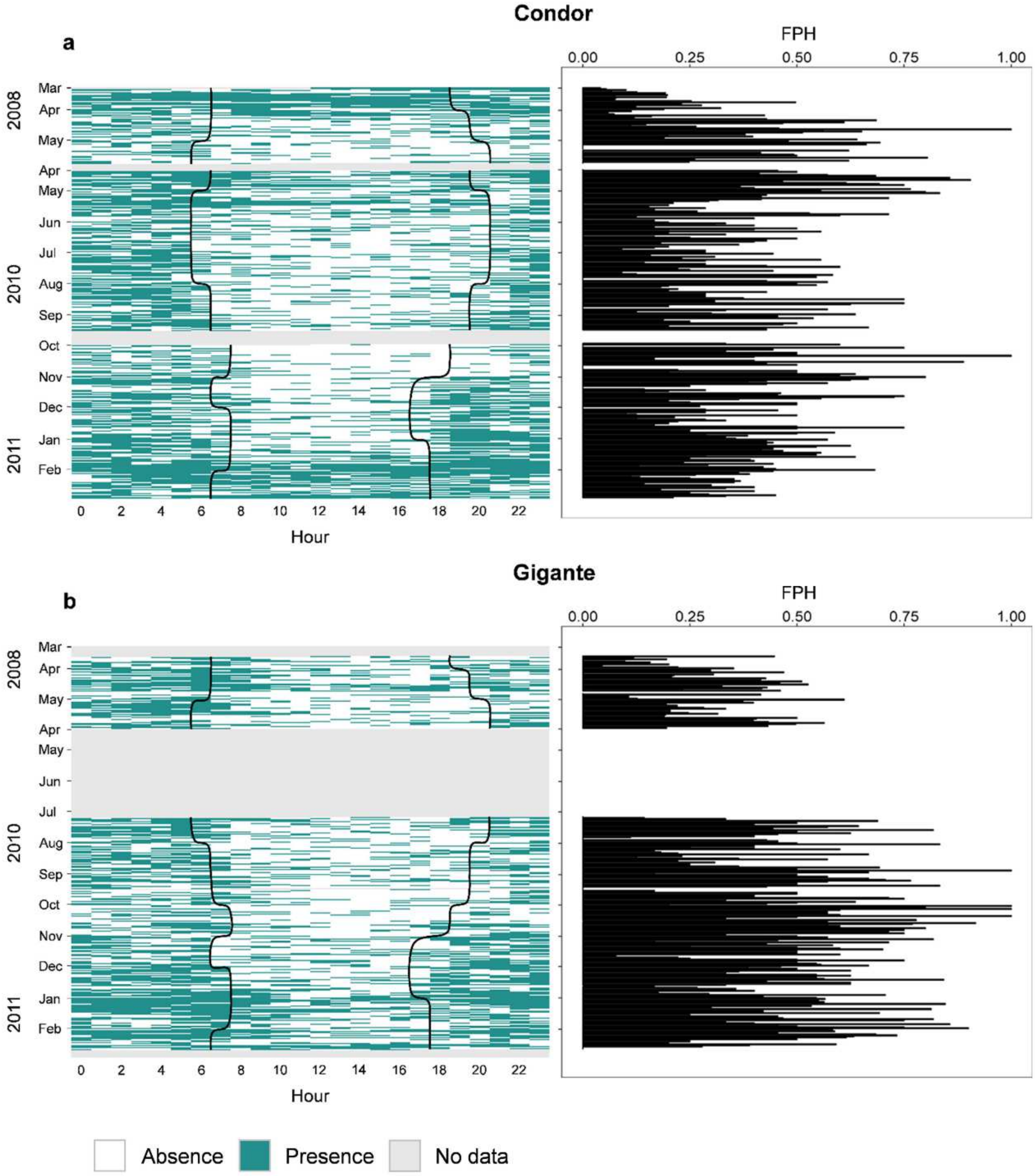

Figure 3 - Daily dolphin detections per hour of day (left plots) and daily proportion of dolphin foraging positive hours (FPH) (right plots) in Condor (a) and Gigante (b) seamounts. Each rectangular cell in the left plots represents acoustic presence (green) or absence (white) for each hour and day of the study period. Periods of missing data are shown in grey. Vertical black lines indicate sunrise and sunset times. Figure reprinted from Cascão et al. [2].

There was a small overlap between the highest PT-ATL values and the lowest DPH and FPH values in the summer periods and in April 2008 (in Condor) (Figs. 4a, b), although this pattern is clearer in Condor than in Gigante.

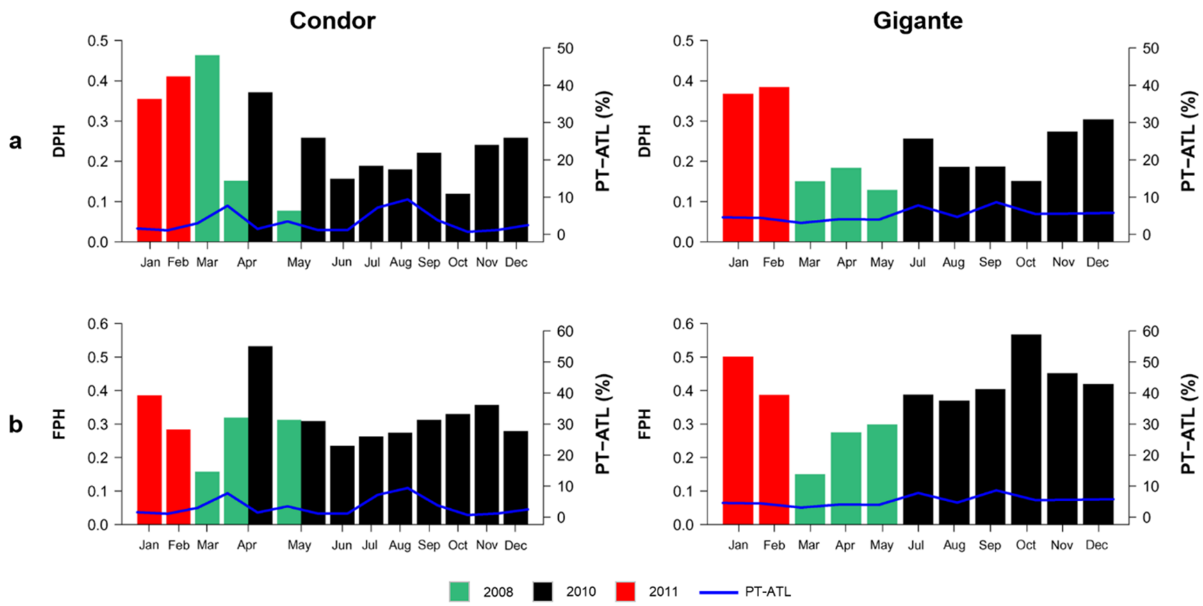

Figure 4 - (**a**) Daily proportion of dolphin positive hours (DPH) and the percentage of time with vessel noise levels above the threshold level (PT-ATL) per month and year of sampling in Condor and Gigante seamounts. (**b**) Daily proportion of foraging positive hours (FPH) and PT-ATL per month and year of sampling in Condor and Gigante seamounts.

4 Discussion

This preliminary study explores the underwater noise levels at Condor and Gigante seamounts, two important foraging habitats for oceanic dolphins in the Azores [2], by assessing temporal variation of wind-driven noise and vessel noise, and the overlapping with foraging dolphins.

Hourly average noise levels ranged from 96 dB re 1 µPa (Gigante seamount) to 127 dB re 1 µPa (Condor seamount). The highest noise values were recorded during winter and early spring, when wind-generated noise was stronger. With the decrease in wind speed in summer, the contribution of vessel noise to background noise increased. Overall, broadband noise levels were positively correlated with wind-driven noise in both seamounts, but negatively correlated with the percentage of time with intermitted vessel noise (PT-ATL) in Gigante (except for the 95th percentile level) and with the 5th percentile PT-ATL in Condor, most likely due to the low PT-ATL values.

The contribution of vessel noise to background noise levels found in this study is relatively low, with the maximum PT-ATL values being approximately 9% for both seamounts. Gigante seamount shows a slightly higher presence of boats than Condor, most likely due to traffic routes used by commercial shipping and the presence of commercial fishing year-round in Gigante. Some of the PT-ATL peaks (April 2008, July 2010) were related to scientific cruises carried out in both seamounts. For instance, if we had eliminated recordings coinciding with these cruises, the maximum hourly average noise level in Condor would have been 123 dB re 1 µPa. The PT-ATL peak in August 2010 at Condor most likely is due to maritime touristic activities (shark diving and big game fishing), as Condor seamount was closed as a marine reserve since June 2010.

Foraging dolphins used Condor and Gigante seamounts more intensively from December to May. The peak in dolphin usage coincided with the noisiest months, but when ambient noise was largely driven by local wind noise, that dominates the mid-frequency band (500 Hz - 25 kHz) [19]. Thus, dolphin's vocalizations could be masked by wind noise. Dolphins may alter their signal characteristics in the presence of vessel noise as an anti-masking strategy [8-10], but little is known about how dolphins adjust their signals in response to natural ambient noise fluctuations. Only one publication was found showing that dolphins increased the end frequency of their whistles in elevated natural noise conditions, and suggesting that it may be a modality for improving transmission efficiency [10]. Furthermore, our results show that the potential temporal overlap of dolphins with vessel noise is generally small and even if both co-occur, the low noise levels produced by vessels are unlikely to cause significant masking of dolphin echolocation signals.

Condor and Gigante seamounts are located in offshore waters, far from areas used by whale-watching boats, where vessel noise is higher [20]. Future studies should investigate masking from wind and vessel noise in areas intensively used by whale-watching boats to understand potential impacts on dolphin foraging behaviour.

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