The use of Passive Acoustic Monitoring as an auxiliary tool for monitoring Marine Protected Areas

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ABSTRACT

Marine Protected Areas (MPAs) in Brazil, like the "Refúgio de Vida Silvestre do Arquipélago de Alcatrazes"(REVIS de Alcatrazes), contain great species diversity. For conservation purposes, investing in local monitoring and surveillance is necessary. In this sense, Passive Acoustic Monitoring (PAM) has been used to collect acoustic data from marine environments. Therefore, this study assessed the frequency of vessels in the mentioned MPA in 2019 using PAM. Audio records collected by a hydrophone anchored at Saco do Funil (24°05'S; 45°41'O), located around 500 m from the main island of the archipelago, were used. Each audio file underwent a visual inspection of the spectrograms to detect the acoustic signals. The noise related to vessels transit was identified in 10% of the analyzed files, of which approximately 46% of the occurrences did not correspond to visits by the MPA management office. The area was most frequented from 6 am to 2 pm. The occurrence of non-official and unauthorized vessels was mostly concentrated from 3 am to 6 am and at 0 am. The study also underscored the biological significance of the MPA, revealing this area potential to be regularly visited by baleen whales in July and toothed whales throughout the analyzed months. So far, this is the only known surveillance investigation that used the PAM in MPAs along the Brazilian coast. Improvement and expansion of this technique use may lead using acoustics as an important auxiliary tool in monitoring MPAs on the Brazilian coast.

Keywords: Acoustic signals classification, Occurrence of boats, Occurrence of cetaceans, Monitoring and surveillance efforts, Biodiversity conservation

INTRODUCTION

Marine Protected Areas (MPAs) are important for biodiversity protection; as well as for helping to increase the biological productivity on the surrounding areas and gathering resilience to marine ecosystems (Lester et al., 2009;

Worm et al., 2006). Therefore, investing in local monitoring and surveillance efforts is necessary for MPAs roles fulfillment.

The "Refúgio de Vida Silvestre do Arquipelago de Alcatrazes" (REVIS de Alcatrazes) and the "Estação Ecológica Tupinambás" (ESEC Tupinambas) are Marine Protected Areas (MPAs) managed by the regional office of the Chico Mendes Institute for Biodiversity Conservation (ICMBio) in São Sebastião, Brazil. These MPAs were established with the aim to preserve the local biodiversity, unique

natural environments, and ecosystem services (Brasil, 2016). Spanning approximately 70,000 hectares, they are situated 11 kilometers off the coast of São Sebastião, in the northern region of the state of São Paulo, Brazil.

Monitoring and surveillance of MPAs, especially those far from the coast, present significant challenges (Kachelriess et al., 2014). To enhance these efforts, Passive Acoustic Monitoring (PAM) has been used for vessel traffic monitoring in MPAs worldwide (Kline et al., 2020; Sorensen et al., 2010; Kaplan and Mooney, 2015). This scientific tool consists in gathering data from marine environments by recording their acoustic landscapes, which includes sounds from anthropogenic sources (anthropophony), biogenic sources (biophony), and environmental sources (geophony) (Mellinger et al., 2007). The PAM approach enables the surveying of marine environments in scenarios of impractical visual surveys, such as during adverse weather conditions, unfavorable oceanographic circumstances, or in the absence of natural light (Mellinger et al., 2007; Johnston et al., 2015). It is a non-optical, non-invasive, and non-destructive method (Zimmer, 2013).

PAM is also a valuable tool for monitoring the biota within a MPA. This is possible due to the significant role of sound as a primary mean of communication among marine organisms, thanks to the low attenuation of sound waves in the marine environment (Urick, 1975). Cetaceans (whales and dolphins) and some fish species use sound for feeding, reproduction, environmental perception, communication, and socialization strategies (Thomson and Richardson, 1995; Bass and McKibben, 2003).

Since December 2018, the quoted MPA management has authorized leisure activities, including scuba diving, within the REVIS de Alcatrazes. The implementation of PAM in this area could bring subsidies for a better cost-benefit ratio for the surveillance of protected areas unauthorized use, especially on days and times when it is impossible for research or surveillance vessels to remain in the MPA (Kline et al., 2020). Additionally, it may be possible to track potential changes in the local acoustic landscape over time, as well as to evaluate the occurrence area of marine organisms that commonly emit sounds. The presence of cetaceans in diversity and abundance has been pointed out as an indicator of the quality of marine ecosystems (Moore, 2008). They play crucial ecological roles, including vertical and horizontal transport of nutrients and organic matter, facilitation of mixing processes, carbon sequestration and storage, and regulation of biological communities by controlling the population stock of their prey species (Bowen, 1997; Lutz et al., 2014; Roman et al., 2014). Along the coast of São Paulo, 32% of the cetacean species described by the Society for Marine Mammalogy (Committee on Taxonomy, 2022) have been reported, six species being year-round residents of the local coastal belt and another five being seasonal migrants (Santos et al., 2019). Despite the relatively limited number of species, their presence throughout the year may represent a local indicator of environmental quality.

Previous studies conducted in the REVIS de Alcatrazes using PAM have only focused on the methodology description and improvement (Sanchez-Gendriz and Padovese, 2017). In this article, we used a PAM acoustic device within the REVIS de Alcatrazes to characterize the presence of cetaceans and vessel sounds, thereby contributing to the description of the local acoustic landscape within the MPA, in addition to assist in the ongoing surveillance efforts of the MPA.

METHODS

DATA ACQUISITION

A hydrophone was installed at the entrance of Saco do Funil (24°05'S; 45°41'O), in the REVIS de Alcatrazes, near the main island of the archipelago (PAM in Figure 1) at a depth of 12 meters in a region with a water column of 21 meters, to establish the Passive Acoustic Monitoring (PAM) methodology. Recordings were captured using an Ocean Digital Spectrogram Recorder (DSG) manufactured by Loggerhead Instruments. The hydrophone used was a High Tech Inc. model HTI-96 MIN, with a sensitivity of -201 dBV re µPa, ± 3 dB, capable of capturing sounds in the frequency range from 2 Hz to 30 kHz. The DSG recorder was set to a gain level

of 33 dB (168 dB re 1 µPa). A recording duration of one minute was programmed with a four-minute interval between recordings, with a sampling rate of 96 kHz. The DSG data collected were decompressed and converted into WAV files using SoundTrap Host software, version 1.2.9.29427.

A total of 288 audio files were generated per day, corresponding to a record duration of 4 hours and 38 minutes. This study analysis focused on a selection of audio files captured over a period of 101 days, from March 2019 to April 2020. Throughout the 14-month period of recordings, data from the following months and number of days per month were sampled: 30 days in April, 30 days in July, 26 days in October, and 15 days in December.
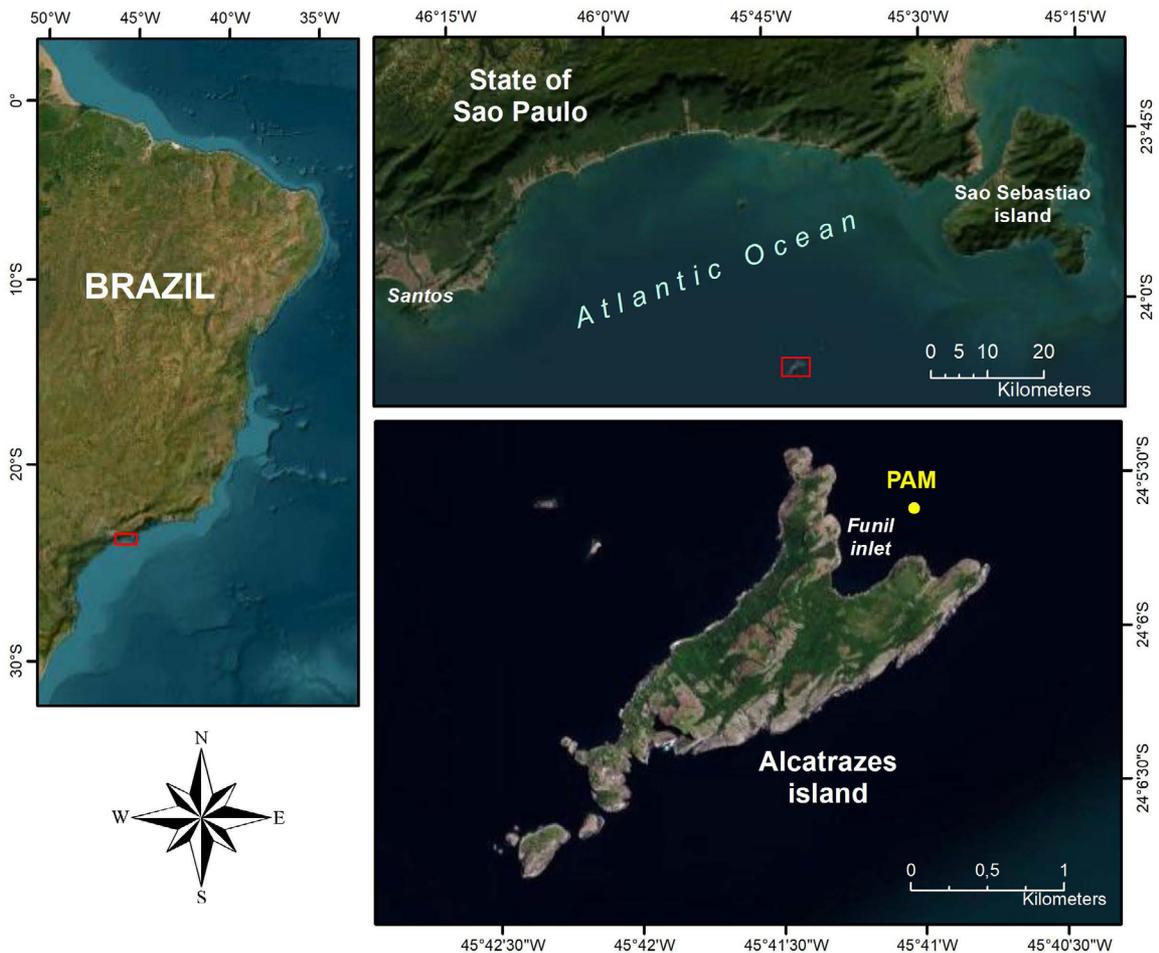

Figure 1. Map of the study area with yellow dot described as PAM representing the location where the sound emission recording equipment was attached. The upper panels show the REVIS de Alcatrazes location in relation to Brazil and the state of São Paulo. The bottom panel emphasizes the position of the PAM device in proximity to the main island of the Alcatrazes Archipelago, Alcatrazes Island.

PROCESSING AND DATA ANALYSIS

The audio files with one minute in length recorded every 5 minutes underwent a manual inspection process involving the spectrograms visual examination. Each file individually was carefully analyzed using a Hann type window spectrogram, with a 90% overlap, 1024 FFT points (Fast Fourier Transform), and a resolution of 48 kHz. The initial screening of the audio files was carried out using Raven Pro 1.5 software (Bioacoustics Research Program, Cornell University, 2015). This visualization technique

enabled the identification of various acoustic signals within the recordings.

This study focused on the identification of the acoustic signals produced by boats and cetaceans. After visual identification of these signals, we also listened to the audio files to confirm the presence of boats or cetaceans whenever it was possible.

CLASSIFICATION OF OCCURRENCES

The acoustic signals from the vessels were categorized into three types:

Tourism signals detected in days and times of authorized presence of boats for diving operations.

Surveillance and research – ICMBio signals recorded on days and times of authorized presence of ICMBio research and surveillance vessels.

Other Activities signals observed on days and times not documented in the MPA's records. This category may include vessels passing through, research or surveillance vessels not listed in the MPA's visitor log, as well as potential fishing activities.

The acoustic signals from cetaceans were classified into signals produced by toothed whales or odontocetes or by baleen whales or mysticetes. Echolocation clicks (Au, 1993) and social signals such as whistles (Au and Hastings, 2008) were attributed to odontocetes. As for mysticetes, different types of signals produced at fundamental frequencies below 1kHz were considered (Thomson and Richardson, 1995).

The detection was recorded in binary form (0 = Absent; 1 = Present) within one-hour time intervals (comprising 12 files of 1 minute each). A single signal occurrence within the analyzed hour was sufficient to categorize the source as "present". Histograms were generated to analyze the distribution of cetacean and boat occurrences on different days of the week and times of the day.

Baleen whales and various types of boats produce low-frequency acoustic signals, which can travel longer distances than the high-frequency whistles and echolocation clicks of toothed whales. In case of no obstruction such as high concentrations of suspended organic matter or nearby sound sources, the sounds from mysticetes and boats can be detected by a hydrophone up to 5 to 8 kilometers away. In contrast, sounds from odontocetes can only be detected up to 3 to 5 kilometers away by the hydrophone.

Cetacean sounds are emitted in a unidirectional manner, which minimizes the chances of interference from sound refraction off the seabed. The hydrophone was positioned in a coastal area with a maximum depth of 21 meters and a narrow temperature range between surface and bottom. Based on the temperature profile from the World Ocean Atlas 2023 (WOA23) climatology, the average temperature in this area ranged from 23.6°C at the surface to 22°C at 21 meters depth. Consequently, it is likely that the water column stratification did not significantly impact the propagation of the recorded sound.

STATISTICAL ANALYSIS

The distribution of boat's signals occurrences per day was tested for its conformity to a Poisson distribution, which is a random distribution (Sokal and Rohlf, 1981). The null hypothesis assumed that vessel occurrences follow a Poisson distribution, i.e. it occurs randomly. To test this hypothesis, we employed Pearson's χ^2 test, comparing expected and observed frequencies for this distribution.

The expected frequencies for the Poisson distribution were estimated using Equation 1, in which $\bar{x}$ denotes the mean of the frequency distribution i.e. the average frequency at which the event tends to occur within the analyzed period; r represents the frequency class; and n is the sample size.

$$f_{exp} = \frac{n \times \bar{x}^r}{r! e^{\bar{x}}} \qquad (1)$$

If the null hypothesis was rejected in the chi-square test, the coefficient of dispersion (CD) was calculated using equation 2 to classify the distribution as clumped or uniform, following Sokal and Rohlf (1981). In equation 2, s represents the standard deviation of the sample and $\bar{x}$ denotes the mean of the sample. A CD value greater than 1 indicates a more clumped distribution, while a CD value of less than 1 suggests a tendency towards uniformity or repulsion.

RESULTS

A total of 2424 hours of audio recordings were screened, and results consider boat and cetacean detections apart.
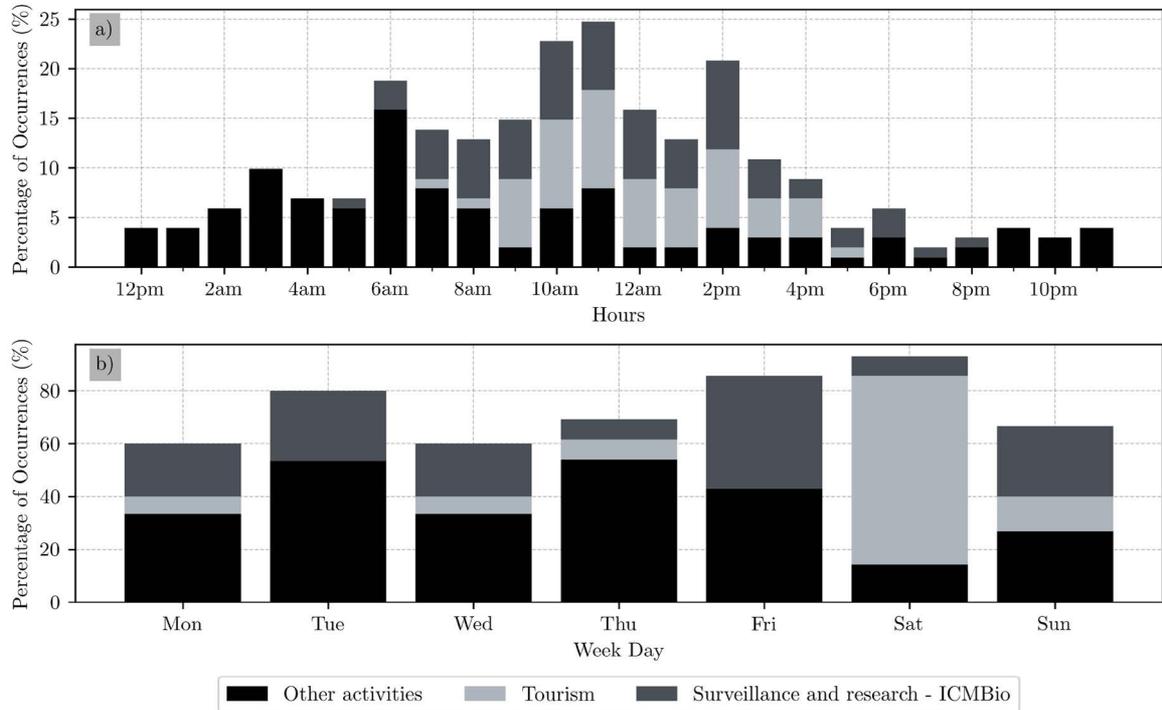
$$CD = \frac{s^2}{\bar{x}} \qquad (2)$$

Figure 2. Frequency of boat signals occurrences (a) on an hourly basis and (b) by day of the week recorded at the REVIS de Alcatrazes in 2019. Detected signals for the respective classes, namely, "Tourism", "Surveillance and Research – ICMBio", and "Other Activities", are highlighted in light gray, dark gray, and black, respectively.

BOAT DETECTIONS

The noises attributed to the boats were identified in 243 hours (10% of the total hours analyzed). Of these, 113 hours (approx. 46%) did not correspond to the visits recorded by the MPA management office. Of the 101 days analyzed, 74 exhibited vessel occurrences (73%). Among these, 38 were not included in the MPA files, representing 51%.

By employing Pearson's χ^2 test with a 95% confidence level, we rejected the null hypothesis suggesting that the observed distribution does not adhere to a Poisson distribution for occurrences within the "other activities" category across the entire analyzed period. The coefficient of diffusion revealed that the observed distribution exhibits a slight degree of aggregation (CD = 2.6). The gathered results show relevant evidence that these events do not occur randomly and are not completely independent of each other. In other words, the occurrence of one event can influence the probability of other events occurring.

Considering each month individually (Figure 3), July had the highest percentage of hours per month regarding boat noise (10.8%) while April showed the lowest values (9.2%). In April, most of the occurrences coincided with the MPA records (Figure 3, panel a), and only 24% of the occurrences were related to "other activities". In contrast, in July, despite having a higher incidence of boat-related noise, it was primarily concentrated on a few days (Figure 3, panel b). Furthermore, July exhibited the highest number of occurrences linked to

"other activities" throughout the entire analyzed period, with only 25% of the days with boat noise appearing in the MPA visit log.

The months of October and December fell in between (Figure 3, panels c and d), showing intermediate figures in terms of the percentage of hours with boat occurrences and the percentage of days in which "other activities" were recorded: 9.9% and 45% in October, and 10.3% and 50% in December respectively.

Regarding the frequency of boat occurrences throughout the day over the entire analyzed period, there is a notable peak during the early morning to early afternoon, from 6 am to 2 pm. The percentage of boat noise during this time frame fluctuated from 12% at 8 am and 1 pm to 24% at 11 am (Figure 2, panel a). Occurrences of the category "other activities" were identified at all hours of the day, with a pronounced prevalence from midnight to 8 am, reaching a maximum of 16% at 6 am. Occurrences related to tourism, surveillance, and research were observed from 5 am to 8 pm, with the most significant concentrations from 7 am to 4 pm. The peak occurred at 17% at 10 am, 11 am, and 2 pm.

In terms of the distribution of boat occurrences on days of the week for the entire analyzed period, there were no significant variations in the total number of occurrences on different days (Figure 2, panel b). Occurrences of the "other activities" and "surveillance and research – ICMBio" categories displayed relatively uniform frequencies throughout all days of the week, without any particular day standing out. As expected, most of the "tourism" occurrences happened during the weekend, with a peak on Saturday.
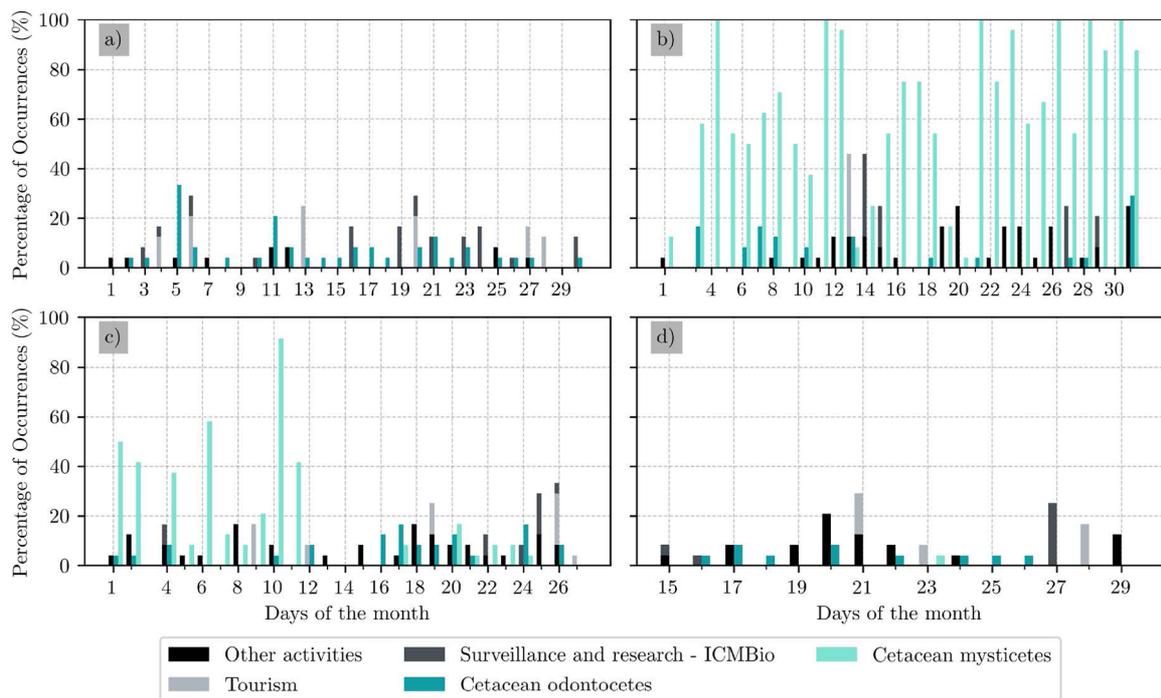

Figure 3. Daily percentage of hours boats and cetaceans were detected throughout the sampled months (a – April; b – July; c – October; d – December) within the REVIS de Alcatrazes. The detected boat signals for "Tourism", "Surveillance and Research – ICMBio", and "Other Activities" categories are colored in light gray, dark gray, and black, respectively. The detected signals for baleen whales (cetacean mysticetes) and toothed whales (cetacean odontocetes) are highlighted in light blue and dark blue, respectively.
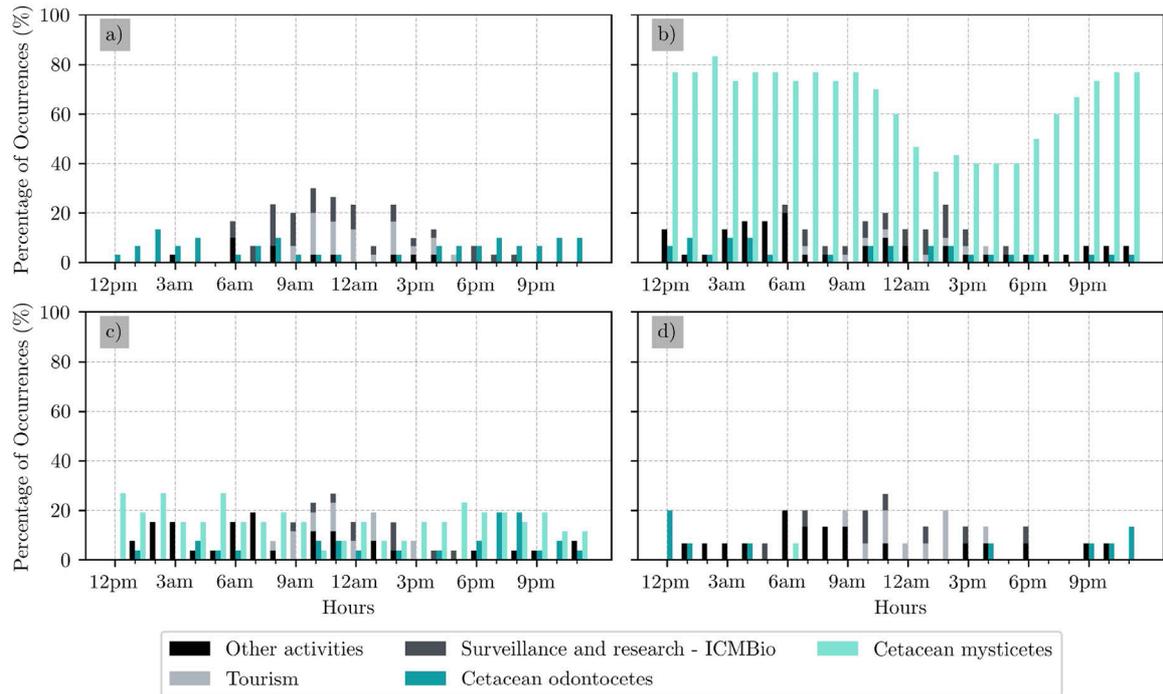
Figure 4. Frequency of occurrences of boats and cetaceans signals on an hourly basis in the sampled months (a – April; b – July; c – October; d – December) within the REVIS de Alcatrazes. The detected boat signals for "Tourism", "Surveillance and Research – ICMBio", and "Other Activities" categories are colored in light gray, dark gray, and black, respectively. The detected signals for baleen whales (cetacean mysticetes) and toothed whales (cetacean odontocetes) are highlighted in light blue and dark blue, respectively.

CETACEAN DETECTIONS

The MPA was of great importance for the cetaceans. The occurrence of toothed whales was recorded in all months analyzed. Acoustic signals from odontocetes were detected in 54 of the 101 days and in 108 of the 2424 hours analyzed. Baleen whales occurred on 30 days in July, 16 days in October, and one day in December. Acoustic mysticete signals were present in 565 hours of the 2424 hours analyzed.

April exhibited the highest daily detection rate per month for odontocetes. Acoustic signals from toothed whales were recorded on 22 of 30 days in April 2019, accounting for 73% of this period (Figure 3, panel a). Two prominent peaks in daily occurrences were observed during this month, one on the 5th of April and the other on the 11th of April, representing 33% and 21% of the hours of those respective days. The remaining days of the month had a relatively uniform distribution of occurrences. As depicted in Figure 4 (panel a), these events concentrated from

12 am to 4 am and from 4 pm to 11 pm. This pattern contrasts with the occurrence of boats.

There were no records of mysticetes in April. In contrast, July marked the period with the highest daily occurrence rate of baleen whales and the lowest percentage of toothed whales. Acoustic signals from mysticetes were consistently present in all analyzed days, comprising 100% of the daily hours on six days in July (Figure 3, panel b). Excluding July 1, 13, 19, and 20, the daily occurrence rate of these signals exceeded 25%. They occurred throughout the hours, with occurrence rates consistently exceeding 70% from midnight to 10 am, as illustrated in Figure 4 (panel b). After 10 am, there was a gradual decline in this percentage, reaching a minimum of 36. 7% at 1 pm and subsequently increasing after 6 pm. After 9 pm, the occurrence rates again exceeded 70%. Odontocetes were identified on 11 of the 30 days in July, representing 36.7% of this period (Figure 3, panel b). The highest daily percentage of acoustic signals from these animals occurred

on July 31, with occurrences of 29% hours on that day. These occurrences were evenly distributed throughout hours of the day, with no discernible predominant occurrence during any specific time (Figure 4, panel b).

In October, odontocetes were present in 13 of the 26 days analyzed, while mysticetes were detected in 16 days, respectively corresponding to 50% and 61.5% of the period (Figure 3, panel c). Occurrences of odontocetes were evenly distributed throughout the month. The highest percentage of daily occurrence was 16. 7%, on October 17 and 24. Odontocetes occurred in 15 of the 24 hours of the day, considering occurrences of every day of the month, with a significant concentration of acoustic signals from these animals at night, particularly from 6 to 11 pm (Figure 4, panel c). Mysticetes showed concentrated occurrences from October 1 to 11, with a few additional instances observed from October 17 to 24. On October 10, the highest percentage of daily hours with mysticetes acoustic signals was recorded, comprising 91.7% hours of the day. Although these signals are present at all times of the day, their pattern of occurrence over the hours was less distinct than in July (Figure 4, panel c).

In December, mysticetes acoustic signals were exclusively detected at 6 am of December 23, encompassing the entire period of analysis (Figure 3, panel d). On the other hand, acoustic signals from odontocetes were identified on 8 of the 16 days in December, accounting for 53.3% of the analyzed period (Figure 3, panel d). However, the occurrence rate for these 8 days was relatively low, fluctuating from 4.2% to 8.3% hours per day. These occurrences were predominantly concentrated during the nighttime hours, specifically from 9 pm to 1 am (Figure 4, panel d).

DISCUSSION

The results are highly promising regarding the use of PAM to support MPAs management. An initial assessment of boat occurrence frequency was conducted, along with the presence of baleen and toothed whales. These two detection categories are crucial for enhancing the efficiency of MPA management in Brazil, considering their unique characteristics related to the protection of natural resources.

The use of tools such as Raven Pro 1.5 software, which generates spectrograms for each recorded audio file, enabled the distinction of acoustic signals from boats and cetaceans near the hydrophone, despite a time-consuming analysis. Histograms illustrating these signals occurrence throughout the month and at different times of the day were constructed for REVIS de Alcatrazes. The histograms advantage lies in their practical data representation, offering the potential for application in forthcoming monitoring reports of MPAs using PAM. It would be useful to invest in future studies that apply a machine learning method to automatize the process of detecting signals and, possibly, generating the histograms in near real-time.

The acoustic signals of boats categorized as "Other Activities" did not conform to a Poisson distribution (associated with random events). However, caution should be taken when interpreting the results as they may encompass both periodic and non-periodic activities (Ihler et al., 2006). The coefficient of diffusion suggesting a slightly clustered distribution could be linked to the permanence of the vessels at the site. However, to validate this hypothesis, further studies on the occurrence and positioning of boats are essential. These studies should combine different techniques, such as visual boat detection by a surveillance team in the area or the installation of motion-detecting cameras, as demonstrated in Fraser et al. (2020).

Weather and sea conditions appear to have had a noticeable impact on boat occurrences in the area, particularly in July. During this month, the northern coast of São Paulo experienced the highest number of cold fronts. Notably, on the 4th and 16th, when intense cold fronts moved into the area, there was a significant reduction in boat occurrences within the area (Figure 3, panel b). The Center for Weather Forecasting and Climate Studies (CPTEC, in Portuguese, Centro de Previsão de Tempo e Estudos Climáticos) also recorded cold fronts on the northern coast on April 28/29, July 27, July 6, and October 19. However, the relation between the absence of boats and the

presence of cold fronts is not as clearly defined as observed during the more intense fronts in July.

The trends revealed by the histograms depicting the frequency of vessel occurrences have proven to be a valuable tool for advising the MPAs management on optimizing the distribution of monitoring and surveillance efforts to maximize the detection of potentially illegal activities (Kline et al., 2020). In this study, July was the month with the highest occurrence of vessels regarding the total hours analyzed, with a higher percentage from the "other activities" class. In Brazil, July is typically linked to school vacations, similarly to December. Additionally, it coincides with winter, which is characterized by a great cold fronts incidence, comparable with the fall season — with also frequent cold fronts— and the lowest average temperatures in the southeast region of Brazil. On the other hand, April exhibited the lowest number of occurrences related to "other activities". This month experienced fewer cold fronts and is within the closed season for fishing shrimp (Brasil 2008). Shrimp represents one of the primary fishing resources on the north coast of the state of São Paulo (Alves et al., 2009).

Another significant pattern to take into consideration for MPA management is the clustering of boats linked to "other activities" during the evening and early morning, specifically from midnight to 8 am, with a peak at 6 am. Regarding the day of the week, occurrences — except for those from the "tourism" category, which were more prevalent on Saturdays — exhibited considerable variability. This fluctuation is unsurprising, given that boats engaged in fishing, sightseeing, or naval activities typically do not adhere to a fixed day of the week for sailing.

Only vessel occurrences with confirmed acoustic signals, determined by visual spectrogram inspection and clear signal listening, were considered in the analyses. Intense low-frequency biological signals (biophony) or environmental signals (geophony) occurred at specific times of the day, potentially causing oversight of noises from distant vessels.

For future investigations, we propose to complement the analysis with more sophisticated methods. Merchant et al. (2012) explored the

acoustic data using the AIS system to assess the contribution of vessel noise. Vessels could be identified within the MPA limits using high-definition satellite images, as proposed by Corbane et al. (2010). Kline et al. (2020) used acoustic parameters such as frequency and intensity variations of noise tones and sound attenuation in the environment to investigate vessel passages. PAM proved to be an extremely important tool to manage MPAs with unavailable surveillance on a 7day-24h rate.

Concerning the presence of acoustic signals from toothed whales, they occurred in all analyzed months on at least 36% of the days in each month, underscoring the significance of the MPA for these apex predators. Odontocete species previously documented in the archipelago vicinity include the rough-toothed dolphin, *Steno bredanensis* (Figueiredo et al., 2020); the Atlantic spotted dolphin, *Stenella frontalis* (Santos et al., 2010; Figueiredo et al., 2020); and the common dolphin, *Delphinus delphis* (Tavares et al., 2010; Santos et al., 2010). The concentration of most acoustic signals in low-light conditions may be attributed to the odontocetes dependence on sound for feeding and orientation during nighttime (Wood and Evans 1980). A follow-up survey or replication study might help to clarify why toothed whale detections were lower in winter. Could this be due to a seasonal change in habitat use, or is it simply a result of methodological noise from a one-season sample?

The fact that odontocetes were detected for 108 hours over 54 days, in contrast to mysticetes, which were detected for a much longer period of 565 hours over a similar number of days, could be attributed to several factors. Odontocetes use sound intermittently for navigation, hunting, or communication (Au, 1993), typically in shorter bursts compared to mysticetes. Conversely, mysticetes produce long and complex songs that can last for extended periods, particularly during the breeding season (Payne and McVay, 1971). Moreover, the low-frequency sounds emitted by baleen whales travel longer distances than the higher-frequency sounds produced by toothed whales. Additionally, the number of humpback whales in the surveyed area has recently increased due to the recovery of the southern ocean stock

following the end of the commercial whaling era (Paschoalini et al., 2021).

Baleen whales were observed during the winter and spring, represented by the months of July and October. This pattern reflects the migratory behaviour of most species within this group. During winter and spring, these cetaceans inhabit tropical and subtropical regions for breeding, birthing, and nurturing their young (Stern and Friedlaender, 2017). In contrast, during the summer, they migrate to temperate and polar regions for feeding (Stern and Friedlaender, 2017). Despite their migratory behavior signifying their presence in the region for only part of the year, their acoustic signals persisted for extended duration at the site during these periods. This possibly underscores their substantial use of the area. Reported migratory species off the coast of São Paulo state encompass: the southern right whale (*Eubalaena australis*), the common minke whale (*Balaenoptera acutorostrata*), the Antarctic minke whale (*Balaenoptera bonaerensis*), and the humpback whale *(Megaptera novaeangliae)* (Paschoalini et al., 2021).

The detection of baleen whale sounds on December 1 suggests the potential presence of Bryde's whales (*Balaenoptera edeni*). This species has previously been observed feeding in the area, typically during the summer and fall months (Zerbini et al., 1997; Siciliano et al., 2004; Figueiredo et al., 2020).

Furthermore, it has been noted that the centroid of the fundamental niches for *Steno bredanensis*, *Stenella frontalis*, and *Balaenoptera edeni* may be situated near the archipelago (Figueiredo et al., 2020). Most likely attributable to the heightened level of protection of this MPA in recent decades, it has evolved into a region for the generation and export of energy and matter. This has, in turn, drawn cetaceans to its vicinity, as the area is sufficiently rich to sustain their regular visits.

This study limitation was not identifying sound emissions regarding lower taxonomic levels such as cetacean suborders. Further investigations should advance on identifying those species emissions. It is also important to invest in future studies that monitor the cetaceans responses to boat presence, particularly following the opening of the MPA to tourism. These animals may transition from avoiding boats to actively "surfing" on the waves generated by moving vessels (Richardson and Wursig, 1997).

CONCLUSIONS

In this study, we employed Passive Acoustic Monitoring (PAM) as a methodology to investigate the occurrence of boats and cetaceans in a Marine Protected Area (MPA) by situated quite close to the shoreline. This approach involved identifying acoustic signals using data obtained from a hydrophone positioned near the Alcatrazes Archipelago. By these acoustic signals analysis, we generated histograms, providing insights into the occurrences temporal distribution. Statistical tests, including the dispersion coefficient and expected frequency for a Poisson distribution, were employed to evaluate potential vessel permanence at the site. This methodology serves as a straightforward alternative for assessing permanence of the boats at the site and the occurrence of cetaceans within MPAs. This investigation unveiled discernible patterns in boats occurrences linked to "other activities", notably concentrated during the evening and early morning hours. Additionally, distinctions between months with varying vessel frequencies were established, with fluctuations correlating to the presence of cold fronts, closed seasons, or school vacations. PAM proved to be an extremely important tool to manage MPAs with unavailable surveillance in a 7day-24h rate. The study also underscored the biological significance of the MPA, revealing the potential of the area in sustaining regular visits by baleen whales in July and toothed whales throughout the analyzed months. While our methodology provides crucial initial insights, it is essential to acknowledge its limitations. More advanced studies incorporating technologies such as Automatic Identification Systems (AIS), visual identification, or high-definition satellite imagery together with acoustic data are indispensable for a comprehensive understanding of boats and cetacean dynamics.

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AUTHOR CONTRIBUTIONS

A.C.B.M.: Conceptualization; Formal analysis; Investigation; Visualization; Writing – Original draft.

S.N.G.: Funding acquisition; Project administration; Resources.

M.C.O.S.: Conceptualization; Supervision; Funding acquisition; Project administration; Resources; Validation; Writing – review & editing.

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