As reported in our latest updates, we have successfully completed the data collection activities for our project and have now moved on to the data analysis phase. In this new progress update, we present the first insights and results from our ongoing data analyses. Data processing analyses have been satisfactorily completed, and the statistical analyses are being finalized. Below, we provide a detailed explanation of the methodology used, as well as preliminary results and conclusions.

Data collection.

Data collection took place in January and February of 2023 and 2025, at Carneiros, Tamandaré, São José da Coroa Grande, Maragogi, and Japaratinga beaches. This sampling period corresponded to the dry season of the austral summer, always during the peak tourism season. Recordings were consistently made during the period of greatest tourist activity at each location, between 10:00 a.m. and 2:00 p.m. Acoustic data were obtained using a Zoom H2N recorder (16-bit stereo, WAV format, 44.1 kHz sampling rate) paired with an Aquarian Audio H2A hydrophone (sensitive from 10 Hz to 100 kHz; -180 dB re: 1 V/μPa). This setup was housed within cost-effective "sonobuoy" systems adapted from Borie. The sonobuoy structure featured a waterproof PVC box mounted at the top to protect the recorder approximately 0.5 m above the waterline, safeguarding it against accidental immersion. The hydrophone was fixed to the lower end of the unit, submerged at a depth of roughly 0.5 m. The midsection of each sonobuoy consisted of a square flotation frame (0.5 m per side) made from PVC tubing and kept stable by four anchoring weights (15 kg each) connected via tensioned ropes of up to 3 meters. This configuration minimized lateral drift and tilting, ensuring steady and consistent positioning during recordings and reducing the potential for acoustic distortion caused by movement.

Recordings were performed at each of 25 sampling sites with a single recording session conducted per season. Each session consisted of continuous sound monitoring for one consecultive hour. At the surface, an observer continuously monitored anthropogenic activities capable of producing underwater noise, facilitating precise attribution of detected sounds to their corresponding sources. All procedures complied with national ethical and environmental standards and were authorized under permit number 82961–1, issued by MMA/ICMBio – Government of Brazil.

Data and statistical analyses.

Recordings were screened using Audacity software (v.2.2) to exclude segments potentially affected by noise generated during sonobuoy installation. Following this screening, 50 minutes of audio from each site were selected for subsequent analyses. The Acoustic Complexity Index (ACI) was applied to assess the influence of sound pollution sources on the complexity of marine soundscapes. This index was selected because it measures changes in sound intensity across frequency bands over time, making it suitable for comparing of different marine soundscapes. The ACI was obtained using Kaleidoscope Pro 4.5.5 software, with a sampling rate of 44.1 kHz, 16-bit stereo audio, an FFT size of 2048 points, and a frequency resolution of 21.5 Hz (continuous temporal step).

The analysis used two separate Acoustic Complexity Index measures: Low ACI (0.05–3 kHz), which includes the primary frequency bands of fish sounds and most anthropogenic noise, and High ACI (3–22.05 kHz), covering higher frequency components present in the soundscape. In addition, sound pressure level (SPL) analyses were also performed in Kaleidoscope Pro 4.5.5. For each site, the root mean square (RMS) values of SPL were calculated in third-octave bands, specifically at the central frequencies of 0.025, 0.063, 0.125, 0.25, 1, 2, 10, and 20 kHz. This approach allowed for a detailed characterization of the intensity of both biological and anthropogenic sounds within the soundscape, providing quantitative information on the sound energy present at each frequency band. Based on the sampling conducted in the study, from the total of one hour of recordings, 50 minutes were analyzed by calculating the ACI and SPL. To enable a more detailed analysis while maintaining temporal resolution throughout the recording period, each 50-minute file used for analysis was segmented into 100 new files of equal duration, resulting in 30-second segments. These segments were then analyzed individually and considered for the characterization of the respective site.

To compare soundscape parameters and fish sound characteristics among the different sampling sites and categories, the data for RMS SPL and ACI values at each site were first tested for normality using the Shapiro-Wilk test. As the assumptions of normality were not met, even after log-transformation, non-parametric statistical analyses were performed. Differences among groups were assessed using the Kruskal-Wallis test (‘kruskal.test’ function), followed by pairwise comparisons with Dunn’s post hoc test (‘dunnTest’ function from the FSA package). All statistical analyses were performed in R version 4.1.3.

Preliminary results.

Analyses of the ACI and RMS data (Box 1; Fig. 1 e 2) showed that:

Low ACI (0.05–3 kHz)

Low ACI values varied among the sampled sites. The highest mean Low ACI values were observed at SCG 1 (207.9 ± 11.1), Tamandaré 8 (200.9 ± 11.2), and Tamandaré 9 (192.5 ± 10.5). In contrast, the lowest values were recorded at Tamandaré 6 (141.5 ± 10.1), Tamandaré 3 (143.3 ± 11.4), and Maragogi 1 (144.4 ± 13.8). At the Carneiros sites, values ranged from 149.4 ± 9.6 (Carneiros 3) to 183.2 ± 9.8 (Carneiros 5). At Maragogi and Japaratinga, values ranged from 144.4 ± 13.8 (Maragogi 1) to 161.7 ± 9.2 (Maragogi 4), and from 154.3 ± 5.6 (Japaratinga 3) to 172.1 ± 11.3 (Japaratinga 1), respectively.

High ACI (3–22.05 kHz)

For High ACI, the highest value was observed at SCG 1 (1350.4 ± 84.2), followed by SCG 3 (1142.3 ± 56.0), SCG 2 (1136.6 ± 66.5), Tamandaré 8 (1127.6 ± 131.1), and Carneiros 3 (1111.5 ± 77.8). The lowest High ACI values occurred at Tamandaré 3 (668.7 ± 122.3), Japaratinga 2 (791.5 ± 224.2), Tamandaré 5 (787.0 ± 74.0), Maragogi 3 (830.4 ± 118.2), and Maragogi 1 (818.5 ± 115.4). At the other sites, values ranged from 874.9 ± 90.7 (Maragogi 2) to 1111.5 ± 77.8 (Carneiros 3).

Sound pressure levels analyses:

- 0.025 kHz: The highest mean values were recorded at Tamandaré 4 (116.0 ± 6.8), Carneiros 5 (115.3 ± 4.8), Carneiros 3 (113.3 ± 4.4), and Carneiros 1 (113.0 ± 3.5). The lowest values were observed at SCG 1 (81.6 ± 5.4), Tamandaré 10 (82.6 ± 5.5), and Carneiros 2 (82.6 ± 5.8).
- 0.063 kHz: The highest value was found at Tamandaré 7 (121.9 ± 3.9), followed by Carneiros 5 (119.8 ± 4.1) and Maragogi 2 (117.3 ± 2.0). The lowest values were observed at SCG 1 (85.5 ± 4.4), Carneiros 2 (89.2 ± 4.4), and Japaratinga 1 (89.3 ± 2.6).
- 0.125 kHz: The highest values were found at Carneiros 5 (119.9 ± 4.4) and Maragogi 2 (118.9 ± 1.8), while the lowest were at Tamandaré 10 (85.3 ± 3.7) and Japaratinga 1 (87.4 ± 3.6).
- 0.25 kHz: Carneiros 5 had the highest value (118.2 ± 3.7), followed by Maragogi 2 (117.2 ± 1.6) and Carneiros 1 (112.7 ± 2.2). The lowest values were recorded at Tamandaré 9 (89.9 ± 7.4) and Japaratinga 2 (98.0 ± 9.6).
- 1 kHz: Values ranged from 89.8 ± 3.4 (Tamandaré 9) to 109.8 ± 2.0 (Carneiros 3).

- 2 kHz: Carneiros 3 (117.1 ± 1.1), SCG 2 (117.2 ± 1.3), and SCG 1 (117.8 ± 2.1) recorded the highest values; the lowest were at Japaratinga 2 (100.2 ± 4.7) and Tamandaré 9 (102.1 ± 3.4).
- 10 kHz: The highest values occurred at SCG 2 (100.0 ± 2.0), SCG 3 (99.8 ± 1.9), Carneiros 3 (99.6 ± 2.3), and Carneiros 1 (98.8 ± 2.1). Tamandaré 9 (78.1 ± 2.8), Tamandaré 5 (79.7 ± 3.1), and Maragogi 1 (85.7 ± 5.5) had the lowest values.
- 20 kHz: The maximum values were observed at SCG 2 (92.6 ± 2.6), SCG 3 (92.7 ± 2.3), Carneiros 3 (92.6 ± 2.8), and Carneiros 1 (91.8 ± 2.5), and the lowest at Tamandaré 9 (73.4 ± 3.5) and Tamandaré 5 (73.5 ± 2.3).

Box 1. Mean and standard deviation (± SD) of the Acoustic Complexity Index and Sound Pressure Level measured at each site. Each cell shows the average value for each parameter, followed by its respective standard deviation. The abbreviation "SCG" refers to sites located at São José da Coroa Grande beach. Low ACI corresponds to the frequency range of 0.05–3 kHz, while High ACI corresponds to the frequency range of 3–22.05 kHz.

Sites	**Low ACI**	**High ACI**	**0.025 kHz**	**0.063 kHz**	**0.125 kHz**	**0.25 kHz**	**1 kHz**	**2 kHz**	**10 kHz**	**20 kHz**
Carneiros 1	155.0 ± 9.0^{ab}	1107.2 ± 82.5^{cd}	113.0 ± 3.5^{e}	114.9 ± 3.1^{e}	115.4 ± 3.1^{e}	112.7 ± 2.2^{e}	109.2 ± 1.8^{e}	116.1 ± 1.2^{f}	98.8 ± 2.1^{g}	91.8 ± 2.5^{h}
Carneiros 2	174.2 ± 21.8^{cd}	1075.5 ± 143.3^{c}	82.6 ± 5.8^{a}	89.2 ± 4.4^{a}	85.2 ± 4.7^{a}	93.3 ± 4.9^{a}	95.8 ± 4.5^{a}	108.4 ± 5.1^{a}	87.5 ± 6.2^{a}	80.8 ± 6.6^{a}
Carneiros 3	149.4 ± 9.6^{ab}	1111.5 ± 77.8^{cd}	113.3 ± 4.4^{e}	115.5 ± 4.0^{e}	114.2 ± 2.8^{e}	112.5 ± 1.9^{e}	109.8 ± 2.0^{e}	117.1 ± 1.1^{f}	99.6 ± 2.3^{g}	92.6 ± 2.8^{h}
Carneiros 4	160.9 ± 5.9^{bc}	928.2 ± 77.0^{ab}	100.4 ± 8.6^{c}	101.3 ± 7.9^{c}	102.0 ± 6.5^{c}	103.4 ± 5.3^{c}	102.6 ± 2.4^{c}	112.7 ± 1.4^{d}	93.1 ± 1.9^{d}	85.4 ± 2.7^{d}
Carneiros 5	183.2 ± 9.8^{d}	948.8 ± 95.3^{ab}	115.3 ± 4.8^{e}	119.8 ± 4.1^{f}	119.9 ± 4.4^{f}	118.2 ± 3.7^{f}	108.5 ± 2.0^{f}	112.8 ± 1.8^{d}	89.6 ± 3.4^{b}	81.9 ± 3.3^{b}
Tamandare 1	152.9 ± 18.1^{ab}	973.6 ± 135.0^{ab}	84.4 ± 5.0^{a}	94.9 ± 6.2^{b}	93.0 ± 5.6^{b}	93.1 ± 4.3^{b}	98.6 ± 3.5^{b}	105.2 ± 5.4^{b}	86.8 ± 5.7^{a}	80.5 ± 6.1^{a}
Tamandare 2	173.7 ± 11.1^{cd}	1074.5 ± 101.5^{bc}	96.6 ± 3.5^{b}	96.7 ± 3.8^{b}	95.1 ± 3.7^{b}	103.9 ± 2.9^{b}	103.1 ± 1.6^{b}	114.4 ± 1.4^{e}	92.8 ± 2.8^{d}	85.6 ± 3.3^{d}
Tamandare 3	143.3 ± 11.4^{a}	668.7 ± 122.3^{a}	106.3 ± 11.5^{d}	108.8 ± 7.1^{d}	110.0 ± 4.1^{d}	104.5 ± 4.2^{d}	97.5 ± 4.5^{d}	106.2 ± 2.2^{b}	86.4 ± 5.0^{a}	82.0 ± 6.2^{a}
Tamandare 4	148.1 ± 10.6^{ab}	875.2 ± 77.9^{ab}	116.0 ± 6.8^{e}	112.8 ± 9.6^{e}	111.8 ± 8.3^{e}	112.0 ± 6.3^{e}	107.9 ± 5.0^{e}	114.3 ± 2.7^{e}	93.6 ± 3.7^{e}	87.1 ± 4.3^{e}
Tamandare 5	171.0 ± 12.0^{bcd}	787.0 ± 74.0^{a}	100.0 ± 2.8^{c}	107.1 ± 3.0^{d}	107.9 ± 4.3^{d}	105.1 ± 3.5^{d}	97.5 ± 4.0^{d}	104.2 ± 2.6^{b}	79.7 ± 3.1^{c}	73.5 ± 2.3^{c}
Tamandare 6	141.5 ± 10.1^{a}	936.8 ± 73.6^{ab}	104.1 ± 5.8^{c}	106.1 ± 5.3^{d}	106.8 ± 5.5^{d}	108.3 ± 4.5^{d}	107.1 ± 3.2^{d}	113.6 ± 1.9^{e}	90.3 ± 3.0^{e}	83.4 ± 2.9^{e}

Tamandare 7	154.4 ± 11.5^{ab}	926.9 ± 67.7^{ab}	112.6 ± 4.0^{e}	121.9 ± 3.9^{g}	116.9 ± 3.6^{g}	116.0 ± 3.1^{g}	106.3 ± 3.1^{g}	114.4 ± 2.0^{e}	86.8 ± 2.2^{a}	80.9 ± 2.2^{a}
Tamandare 8	200.9 ± 11.2^{ef}	1127.6 ± 131.1^{de}	94.3 ± 4.9^{b}	96.1 ± 4.5^{b}	99.4 ± 4.5^{b}	98.3 ± 4.5^{b}	100.2 ± 2.4^{b}	111.8 ± 2.5^{e}	90.0 ± 4.2^{e}	82.1 ± 4.5^{e}
Tamandare 9	192.5 ± 10.5^{de}	952.1 ± 76.4^{ab}	85.4 ± 4.3^{a}	91.9 ± 6.2^{a}	94.4 ± 5.7^{a}	89.9 ± 7.4^{a}	89.8 ± 3.4^{a}	102.1 ± 3.4^{a}	78.1 ± 2.8^{a}	73.4 ± 3.5^{a}
Tamandare 10	176.9 ± 18.9^{d}	1103.3 ± 135.6^{cd}	82.6 ± 5.5^{a}	90.8 ± 5.4^{a}	85.3 ± 3.7^{a}	92.1 ± 4.5^{a}	95.6 ± 4.3^{a}	109.1 ± 4.0^{c}	89.1 ± 5.1^{b}	82.3 ± 5.9^{b}
SCG 1	207.9 ± 11.1^{f}	1350.4 ± 84.2^{f}	81.6 ± 5.4^{a}	85.5 ± 4.4^{a}	89.3 ± 4.2^{a}	100.1 ± 4.0^{a}	104.7 ± 2.4^{a}	117.8 ± 2.1^{g}	97.6 ± 3.0^{f}	90.7 ± 3.1^{g}
SCG 2	150.4 ± 7.1^{ab}	1136.6 ± 66.5^{e}	112.0 ± 4.6^{e}	114.7 ± 3.6^{e}	114.2 ± 2.5^{e}	111.7 ± 1.9^{e}	109.7 ± 2.0^{e}	117.2 ± 1.3^{g}	100.0 ± 2.0^{g}	92.6 ± 2.6^{h}
SCG 3	152.7 ± 7.4^{ab}	1142.3 ± 56.0^{e}	110.5 ± 4.3^{e}	115.8 ± 3.6^{e}	115.8 ± 3.6^{e}	113.4 ± 3.0^{e}	110.2 ± 2.9^{e}	116.7 ± 1.5^{g}	99.8 ± 1.9^{g}	92.7 ± 2.3^{h}
Maragogi 1	144.4 ± 13.8^{a}	818.5 ± 115.4^{a}	108.8 ± 9.6^{d}	112.5 ± 8.4^{d}	112.7 ± 5.5^{d}	109.7 ± 5.9^{d}	103.9 ± 5.7^{d}	110.1 ± 5.2^{c}	85.7 ± 5.5^{a}	78.5 ± 4.6^{a}
Maragogi 2	155.6 ± 12.4^{ab}	874.9 ± 90.7^{ab}	111.3 ± 1.9^{e}	117.3 ± 2.0^{f}	118.9 ± 1.8^{f}	117.2 ± 1.6^{f}	105.8 ± 1.7^{f}	114.4 ± 1.3^{f}	91.5 ± 2.2^{f}	84.8 ± 2.0^{g}
Maragogi 3	147.5 ± 21.8^{ab}	830.4 ± 118.2^{a}	107.5 ± 3.4^{d}	114.5 ± 4.2^{e}	114.9 ± 5.1^{e}	114.7 ± 4.3^{e}	104.7 ± 4.0^{e}	111.3 ± 3.6^{e}	88.7 ± 3.7^{b}	81.8 ± 3.9^{b}
Maragogi 4	161.7 ± 9.2^{bc}	906.5 ± 101.6^{ab}	98.0 ± 5.8^{c}	104.7 ± 4.2^{c}	99.8 ± 5.0^{c}	103.1 ± 3.0^{c}	103.2 ± 1.7^{c}	113.3 ± 1.5^{d}	90.8 ± 2.1^{e}	83.4 ± 2.3^{e}
Japaratinga 1	172.1 ± 11.3^{bcd}	958.2 ± 56.7^{ab}	86.2 ± 2.7^{a}	89.3 ± 2.6^{a}	87.4 ± 3.6^{a}	95.1 ± 4.3^{a}	99.7 ± 2.3^{a}	110.3 ± 1.9^{d}	89.2 ± 2.5^{a}	81.1 ± 2.7^{a}
Japaratinga 2	161.7 ± 24.0^{bc}	791.5 ± 224.2^{a}	96.4 ± 11.7^{b}	99.6 ± 11.9^{b}	100.5 ± 9.4^{b}	98.0 ± 9.6^{b}	95.6 ± 8.6^{b}	100.2 ± 4.7^{a}	85.8 ± 9.4^{a}	82.7 ± 11.3^{a}
Japaratinga 3	154.3 ± 5.6^{ab}	998.2 ± 65.1^{b}	111.9 ± 3.2^{d}	109.9 ± 1.5^{d}	109.4 ± 1.9^{d}	108.9 ± 1.4^{d}	108.9 ± 1.7^{d}	114.2 ± 1.3^{f}	92.3 ± 2.1^{f}	85.7 ± 2.3^{g}

Figure 1. Boxplots showing the distribution of ACI values across all sampling sites, for two frequency ranges: High ACI (3–22.05 kHz, upper panel, green) and Low ACI (0.05–3 kHz, lower panel, blue). Each box represents the interquartile range (IQR), the horizontal line within each box indicates the median, the diamond denotes the mean, and whiskers show the range within 1.5 times the IQR. Dots represent individual segment values. Sites are arranged by location along the x-axis. The abbreviation "SCG" refers to sites located at São José da Coroa Grande beach.

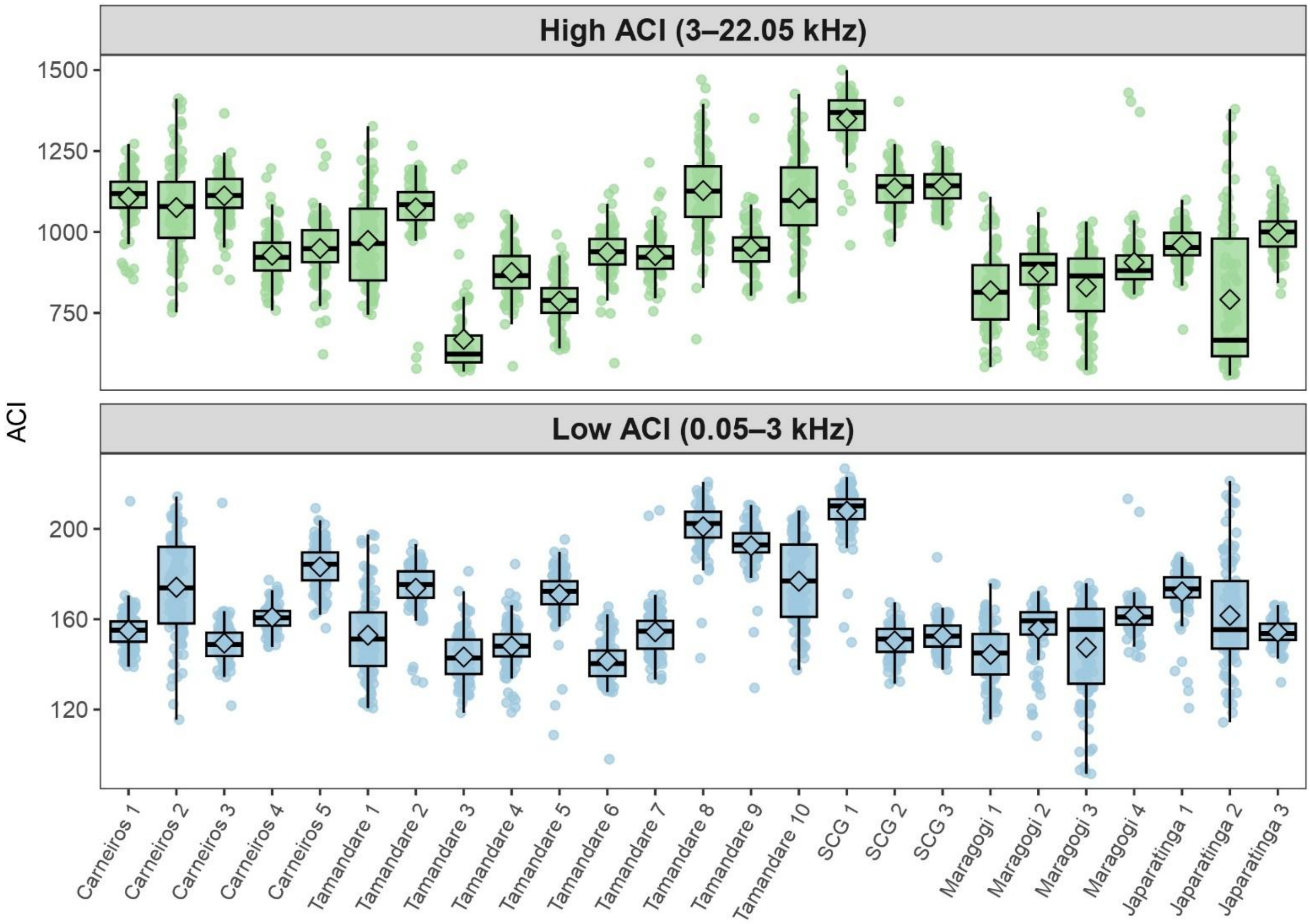
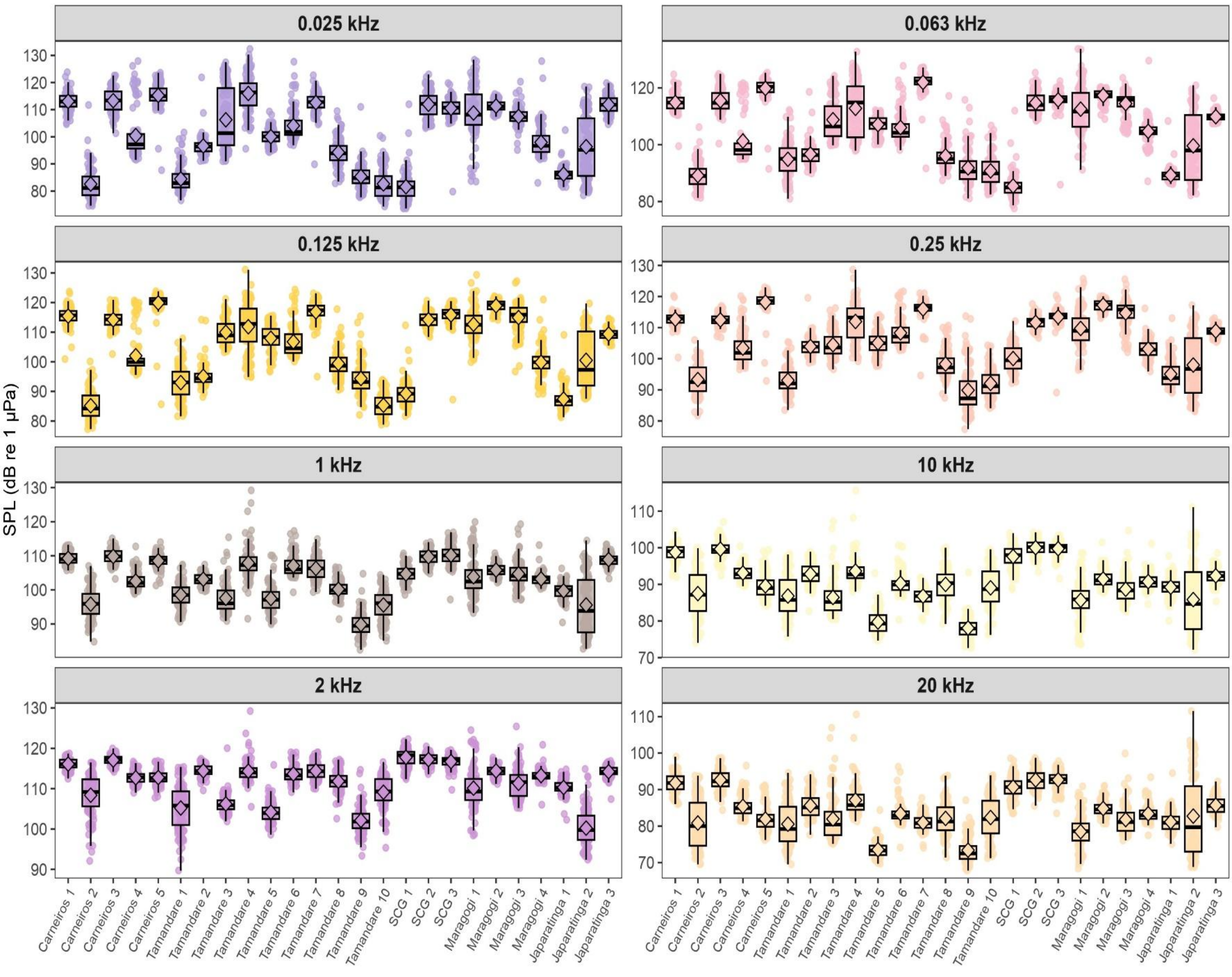


Figure 2. Boxplots showing the distribution of root mean square (RMS) sound pressure level (SPL, dB re 1 µPa) values at each site, for eight third-octave frequency bands (from 0.025 to 20 kHz). For each panel, boxplots and dots represent the distribution of SPL values for all 30-second segments at each site. The horizontal line in each box indicates the median, the diamond represents the mean, and whiskers indicate the range within 1.5 times the IQR. Sites are arranged by location along the x-axis. The abbreviation "SCG" refers to sites located at São José da Coroa Grande beach.



Preliminary conclusions and insights.

The sites that were most affected by effect of noise from tourist activities are those that exhibit:

- Lower values of Low ACI and High ACI, as reduced acoustic complexity indices generally indicate lower diversity of natural sounds, potentially reflecting sound pollution and a reduction in biological complexity.
- Higher SPL values (especially in the frequency bands typical of boat and human activity noise, usually between 0.05 and 2 kHz), since high SPL levels in this range suggest a significant presence of anthropogenic noise.

In this context, it is identified that, considering each of the 25 sites:

Most affected:
Low Low ACI, low High ACI, and high SPL in the lower frequency bands.

- Tamandaré 3: Low ACI (143.3), High ACI (668.7 – the lowest value among all sites), relatively high SPL in the lower bands (mean between 104 and 110).
- Tamandaré 6: Low ACI (141.5), High ACI (936.8), moderate SPL (104–108).
- Tamandaré 5: Low ACI (171.0), High ACI (787.0), high SPL in the lower bands.
- Japaratinga 2: Low ACI (161.7), High ACI (791.5), low SPL but both ACIs are low.
- Maragogi 1: Low ACI (144.4), High ACI (818.5), high SPL (between 108 and 112 in the lowest bands).

Intermediate:
Moderate ACI and intermediate SPL.

- Carneiros 4, Tamandaré 1, Carneiros 3, Maragogi 4, Tamandaré 4, Japaratinga 3, Maragogi 3, SCG 2/3.

Least affected:
High Low ACI, high High ACI, and low SPL.

- SCG 1: Low ACI (207.9), High ACI (1350.4), low SPL in the lower bands.
- Tamandaré 8: Low ACI (200.9), High ACI (1127.6), low SPL.
- Carneiros 5: Low ACI (183.2), High ACI (948.8), high SPL but high ACI values.
- Tamandaré 10: Low ACI (176.9), High ACI (1103.3), low SPL.
- Tamandaré 9: Low ACI (192.5), High ACI (952.1), low SPL.

And when considering the beaches/regions in general, the ranking from most affected to least:

Tamandaré

Reason: Tamandaré has several sites with low Low ACI values (e.g., Tamandaré 3: 143.3; Tamandaré 6: 141.5), low High ACI values (e.g., Tamandaré 3: 668.7), and, in many sites, high SPLs in the lower frequency bands.
Conclusion: This is the most impacted region by anthropogenic noise, especially at Tamandaré 3, 5, 6, and parts of Tamandaré 4.

2. Maragogi

Reason: Maragogi has sites with consistently low Low ACI values (Maragogi 1: 144.4; Maragogi 3: 147.5), relatively low High ACI values, and high SPLs in some lower frequency bands.
Conclusion: This is the second most impacted region, particularly at Maragogi 1, 3, and

3. Japaratinga

Reason: The sites show intermediate to low values for both Low and High ACI, especially Japaratinga 2, but with some variation.
Conclusion: Moderate impact, closer to Maragogi than to the less impacted regions.

4. Carneiros

Reason: Carneiros has some sites with slightly below-average Low ACI values (e.g., Carneiros 3: 149.4; Carneiros 4: 160.9), but most sites show intermediate or high ACI values and SPLs that are generally lower than those in Tamandaré and Maragogi.
Conclusion: This region has a lower impact than Tamandaré, Maragogi, and Japaratinga.

5. SCG (São José da Coroa Grande)

Reason: SCG 1, 2, and 3 present the highest values of both Low and High ACI (e.g., SCG 1: Low ACI 207.9; High ACI 1350.4), and low SPLs in the lower frequency bands.
Conclusion: This is clearly the least impacted region by anthropogenic noise.

With the completion of the analysis phases, we are now beginning preparations to soon initiate dissemination activities, including environmental education actions with all targeted stakeholders, as planned in the project.