Final Evaluation Report

Your Details	
Full Name	Túlio Freire Xavier
Project Title	Evaluation of the effects of human sound impacts on acoustic diversity in coral reefs in Northeastern Brazil
Application ID	38537-1
Date of this Report	12/03/2024

1. Indicate the level of achievement of the project's original objectives and include any relevant comments on factors affecting this.

Objective	Not achieved	Partially achieved	Fully achieved	Comments
Recording of at least 80 hours of audio;			■	Sampling sites were selected between Carneiros and Tamandaré beaches, located in the municipality of Tamandaré, Brazil. Carneiros beach experiences intensive tourism throughout the year, attracting a significant number of tourists (Figure 1). The tourism demand is high, resulting in a large concentration of visitors on the beaches. Tamandaré beach, on the other hand, attracts a large number of tourists during the high tourism season, decreasing significantly in the low season, characterised by seasonal tourism. Tourism demand tends to increase in the summer, especially during vacation periods and holidays, but decreases significantly at other times. The level of exposure of coral reefs to these tourism activities is also a factor that can influence the intensity of human impacts on reef ecosystems. In this context, four sampling sites were selected: unsheltered intensive tourism and sheltered intensive tourism at Carneiros Beach, as well as unsheltered seasonal

				tourism and sheltered seasonal tourism at Tamandaré Beach (Figure 1). Data collection was performed in two periods, during the first half of 2023: during the peak of tourism activities (classified as the high tourism season – Figure 4), and when tourism was lowest (classified as the low tourism season). Both collection campaigns were conducted during the dry season. All sampling sites were sampled in both seasons. Sampling consisted of carefully installing the recording equipment at one site at a time, capturing the acoustic soundscape over 10 consecutive hours, from 07:00 to 17:00. This resulted in a total of 80 hours of recorded audio data.
Performing visual censuses;				The fish community was analysed through underwater visual censuses (UVCs) using the belt transect method in all sampling sites. Divers estimated the quantity of fish along a transect (10 x 5m) delimited by a tape measure, identifying the species and determining individual sizes in 2 cm length classes. Five censuses were conducted per audio sampling point, and UVCs were randomly distributed at each sampling site. A total of 937 fish individuals were counted in UVCs. The results indicated that unsheltered sampling sites had higher

				amounts of total fish species and sound-producing species. In terms of total abundance, intensive tourism sites presented the highest values.
Sampling abiotic data of each recording area;				The sample sites were characterised by temperature and depth, with measures taken every half hour of the audio recording time. Depth was obtained in situ using a rope marked by adhesive tape while still submerged in the water. Subsequently, on land, the rope was measured with a tape measure, considering the marking of the adhesive tape as a reference point. Temperature was measured using precision data loggers with an accuracy of 0.1°C, located at the lower end of the sonobuoy (structures were built for recording purposes using PVC pipes, aiming to install the recorder above the water surface, thus avoiding potential damage caused by submerging the equipment – Figure 1 and 2). It was observed that seasonal tourism sites presented the highest temperature values, while intensive tourism sites recorded the highest depth values. During the low tourism season of intensive tourism site (unsheltered conditions), a higher temperature value was observed. On the other hand, in seasonal tourism, this pattern was identified during the low tourism season but in

				sheltered conditions. About depth, intensive tourism sites exhibited a higher value during the low tourism season in sheltered conditions, while seasonal tourism sites showed this characteristic in unsheltered low tourism season sites.
Identify and characterize the acoustic contributors found from the analyzed soundscapes;				The acoustic contributors to soundscapes were characterised through manual screenings based on oscillograms and spectrograms. Contributors were identified according to their nature using Raven Pro 1.6.5 software, considering the categories of biophony, geophony, and anthropophony. Fish vocalisations and crustacean snaps characterised biophony (Figure 5) at all sampling sites. In both tourism seasons, sheltered sites showed the highest numbers of biophony contributors. The sheltered sitesubject to seasonal tourism, during the low tourism season, obtained the highest biophony values, with 208 fish vocalisations and 146 crustacean snaps. In non-sheltered sites, during the high tourism season, an opposite profile was observed, where the intensive tourism site revealed the lowest presence of biophony constituents in the study, evidenced by the record of only 18 fish vocalisations and 34 snaps of crustaceans. In the geophony (Figure 6) acoustic components, sound

				signals from wind, rain, and sea waves were identified. The sites showed similar values regarding the occurrence and diversity of geophony contributors; however, it was observed that wind and sea wave contributors were more numerous at sampling sites where rain occurred. Rain events were the rarest, while wind and sea wave events were the most common. Anthropophony (Figure 7) was represented by jet ski noises, speedboats, paramotor flights with paragliding, regular boats and recreational activities performed by beachgoers. In sheltered locations, the presence of anthropophony contributors was lower compared to unsheltered sites, which exhibited higher values in this aspect. An example is the intensive tourism site, where during the high tourism season, 24 occurrences of jet skis, 18 paramotor flights with paragliding, along with 94 recreational activities by beachgoers, were recorded. During the low tourism season, sheltered sites and the unsheltered seasonal site did not display anthropogenic noise in this study, unlike the unsheltered intensive tourism site, which was the only one to register anthropophony, with six occurrences of jet skis, eight of paramotor flights with paragliding, and 37 recreational

				activities by beachgoers.
Analyze the relationship between the diversity and richness of marine fish with the acoustic complexity of the observed ichthyofauna;				Analysing the relationship between the diversity and richness of reef fish and the acoustic complexity of the ichthyofauna, it became evident that both the obtained ACI values and observed fish sound profiles established a significant relationship with fish diversity and richness (Figure 8). In sampling sites with lower anthropophony incidence, a directly proportional relationship was demonstrated between the diversity and richness of ichthyofauna, with the values of ACI and the quantity of observed fish sound profiles. This indicates that the absence of anthropophony in these areas makes fish vocalisations more prominent and numerous in reef marine soundscapes. Conversely, certain sampling sites experienced a significant decrease, up to 50%, in ACI values of ichthyofauna during high anthropophony moments. This association was particularly pronounced among fish known for sound emission.
Estimate the acoustic complexity of marine soundscapes, identifying interference caused by anthropogenic noise and abiotic				It was evident that the sheltered condition stood out as the most influential predictor in acoustic complexity among variables analysed. Unsheltered sampling sites proved to be more susceptible to receiving a greater influence of anthropogenic

data;				impacts, resulting in lower acoustic complexity values. High tourism season and intensive tourism were identified as the second and third most negatively influential predictors in the acoustic complexity of the sites, respectively. An inversely proportional relationship was observed between temperature and depth with ACI, with temperature being the most influential predictor of acoustic complexity when compared to depth. These predictors were less influential on ACI when compared to categorical variables (Figure 9).
Return of the results obtained to the communities involved;				The scientific outreach actions encompassed the distribution of flyers to tourists and tourism agents at Carneiros and Tamandaré Beaches (Figure 13), as well as the delivery of lectures at the UNINASSAU Poli Digital School in Tamandaré (Figure 14). There was also communication of the data obtained in a public defense, during the master's dissertation defense of the project coordinator. The results were also disseminated through digital media, as well as reported to the managers of the marine protected area (APACC) where the project was conducted, through the activities report of SISBIO (Biodiversity Authorization and Information System).
Exhibit results at important scientific				Presentation of the project results at Brazilian Zoology Congress

meetings and social media;				(Congresso Brasileiro de Zoologia – Figure 15), and divulgation on social media on Instagram of the laboratory associated with the project and the project's administrative NGO.
Preparation of results to be published in a high impact scientific journal.				The project results are undergoing refinements and adjustments for submission to the scientific journal Marine Pollution Bulletin. We are in the process of writing the scientific paper, with the aim of submitting it in the first half of 2024.

2. Describe the three most important outcomes of your project.

a). The results obtained in the project reveal a complex interaction between biophony and anthropophony components in reef acoustic soundscapes. Anthropophony has emerged as a critical factor in shaping marine soundscapes, especially in unsheltered intensive tourism sites. The significant relationship between fish diversity and richness and acoustic complexity underscores the central role of fish in structuring marine sounds. The factors (shelter condition, tourism season and tourism type) played shaped acoustic diversity the most, and the anthropogenic sound impact on observed acoustic soundscapes. In addition to anthropophony, abiotic factors such as temperature and depth also influenced acoustic complexity, but to a lesser degree.

b). The study also revealed the importance of preserving marine soundscapes in high tourist activity areas, where anthropophony is intense and disruptive. It is essential to consider acoustic conservation integral to marine ecosystem management and conservation strategies. Building upon these results, future research can further explore mechanisms for mitigating anthropophony and evaluate their effectiveness.

c). Another significant outcome of the project was the outreach activities aimed at providing feedback to the local population, disseminating the results within the scientific community. These efforts included presenting the project results at the Brazilian Zoology Congress and publicising information through social media platforms. Additionally, the scientific outreach actions encompassed the distribution of flyers to tourists and tourism agents at Carneiros and Tamandaré Beaches, as well as the delivery of lectures at the UNINASSAU Poli Digital School in Tamandaré.

3. Explain any unforeseen difficulties that arose during the project and how these were tackled.

During the project execution, as previously informed in the project updates, we encountered an issue in one of the data collection areas of the research. The managers responsible for granting access to the protected area of Tamandaré implied restrictions in our access to the fully protected site. This unexpected situation prevented data collection in the protected area during the project execution period. It is important to highlight that we complied with the requirements for the necessary permissions established by the responsible authorities. However, due to factors beyond our control and understanding, it was impossible to carry out the data collection activities in the protected area of Tamandaré as initially planned.

To address the issue encountered in data collection, we decided to increase the number of underwater records two-fold in the open area of Tamandaré. In this way, we sought to compensate for the lack of data from the fully protected area. However, to ensure a valid comparison between high and low human sound impact moments, we conducted collections in the open area at different times (high and low tourism season). We selected a peak impact period, such as holidays or weekends, when there is higher human activity and, consequently, greater anthropophony. Conversely, we chose a low-impact time, such as a regular day or the low tourist season, when human noise is reduced. This approach allowed us to capture the similarity found in the closed area, where we differentiated between an impacted environment and an environment less affected by human activity.

We also encountered difficulties distributing flyers about the project's results to tourism agents. They showed some resistance, as anthropophony is closely linked to tourism activities, which in turn is related to their work. To overcome this, we made clear that we did not intend to jeopardise their work; instead, we hope our results could lead to actions to improve their activities regarding their noise impacts. We believe that, in the end, they understood the importance of our work and the results obtained.

4. Describe the involvement of local communities and how they have benefitted from the project.

As an integral part of the project "Assessment of the Effects of Human Sound Impacts on the Acoustic Diversity of Coral Reefs in the Brazilian Northeast," two significant actions of environmental education and scientific divulgation were carried out, aiming to inform and actively engage the involved communities. These activities sought to raise awareness among tourists, local residents, and students about the impacts of human noise on coral reefs. Besides these actions, other activities related to the topic in question also occurred, as mentioned below.

Scientific outreach action at Carneiros and Tamandaré beaches (January 2024):

During the last week of January 2024, a scientific outreach took place at Carneiros and Tamandaré beaches, collection sites for the project (Figure 13). During this initiative, informational flyers were developed (Figure 11 and 12) addressing the project and its objectives and raising awareness among tourists and tourism agents about human sound impacts on marine ecosystems. The visual artwork of the flyers was produced by a graphic designer artist contracted for the service. Two hundred of these flyers were produced and printed for this action.

The flyers were distributed to the target audience at the beaches, where the purpose of the flyers was explained. This action was of utmost importance, allowing us to inform and raise awareness among the main stakeholders responsible for human noise and its impact on coral reefs. The public's involvement underscored the interest and importance of promoting positive and informative interaction, highlighting the significance of raising awareness about coral reef preservation.

The flyer was divided into three sections. In the first section, we provided information about marine bioacoustics and the sound components of a reef marine soundscape. The second section covered anthropophony and how it increasingly affects the health of reefs and associated organisms. Finally, in the third section, we informed about how we can mitigate these impacts, with conservation strategies and public awareness messages, encouraging them to implement these mentioned conservation strategies.

Lecture at UNINASSAU Poli Digital School in Tamandaré (February 2024):

In early February 2024, a didactic intervention was conducted at the UNINASSAU Poli Digital School, located in Tamandaré. The contact with the school was facilitated through one of the project members, Thiago Henrique Sousa, who also resides in the vicinity of the study area. Following this contact, the school showed significant interest in hosting an intervention to disseminate the results of our research, making it possible to carry out this event.

During this activity, a lecture was presented to the students at the final grades of elementary school, addressing the project, its actions, applications, and the results obtained so far. Project member Thiago Henrique Sousa also executed this action. Their enthusiasm highlighted the active participation of the students during the presentation. At the end of the lecture, informational flyers were distributed to reinforce the knowledge acquired about sound impacts on coral reefs and the project's initiatives. The students who attended the lecture also received the produced flyers and provided excellent feedback on the intervention moment (Figure 14).

As mentioned, the researcher Thiago Henrique Sousa resides in Tamandaré and began his involvement in the project during its execution. His participation in the project was fundamental as we had the opportunity to integrate a local native into the scientific actions of the project. Thiago was trained in bioacoustic analyses, increasingly integrating himself into the study field, and disseminating the results of our project to the local community. This integration of a local researcher not only enriched our project but also fostered greater community engagement and understanding. This is a significant step forward in bridging scientific research with local knowledge and community involvement, ultimately leading to more effective conservation efforts.

Additionally, in October 2023, the defense of the master's thesis of the project's coordinator, Túlio Freire Xavier, occurred, with Beatrice Padovani, one of the most influential researchers in marine ecology studies in Costa dos Corais Marine Protected Area (APACC), where the project was conducted (Figure 1), serving as a member of the dissertation defence committee. During this meeting, there was a highly productive exchange related to the project's themes and discussions on ways to apply the research findings to conservation processes for the observed acoustic soundscapes. Additionally, the researcher expressed interest in a collaboration to evaluate anthropophony impacts in the study area.

5. Are there any plans to continue this work?

Plans for the continuation of the project are already in progress. Unlike the current project, our objective is to extend our sampling across the entire APACC, expanding beyond the regions located solely in the state of Pernambuco - Brazil, to also encompassing sites in the state of Alagoas - Brazil, where APACC has a significant territorial extension. The overarching aim is to assess how anthropophony affects Brazil's largest marine protected area in terms of spatial dynamics. To achieve this, we will incorporate recordings from various random sampling sites throughout the APACC into the dataset obtained in our initial project. We aim to gain insights into how anthropophony manifests spatially through analysis and screening of this expanded dataset. In the future, data collection for this expanded proposal will be carried out, we plan to perform recordings at 15 sampling sites along the APACC in Alagoas and Pernambuco, Brazil.

Currently, we are refining results obtained in the project to which this final report refers to, for publication of these findings, as aforementioned. We aim to primarily focus on a temporal approach to the behavior of anthropophony impacts observed in marine acoustic soundscapes. Subsequently, we plan to analyse and process the data obtained from the spatial approach by the APACC, for future publication of these results in high-impact journals.

6. How do you plan to share the results of your work with others?

The processes of sharing the results of our work are already underway. In addition to exposing the findings to the communities involved, recently, from February 26th to 29th, 2024, the project was officially presented at the Brazilian Congress of Zoology (Figure 15 and 16). This initiative constituted a crucial opportunity to share the results and conclusions with the scientific community. The presentation highlighted the methodologies employed, the challenges encountered, and the insights provided by our study. It was greatly rewarding to receive positive feedback from the scientists who attended the study presentation, emphasising how interesting and innovative the application of acoustic tools for impact assessment is. Congratulations were extended for the initiative of conducting a project with such a theme, which is still relatively new in Brazil, especially in the Northeast region.

These results were divulged through the laboratory's Instagram account (@labpier.ufpe) to which the project is linked, and the administrative NGO (@institutonautilus). The post can be viewed through the link below:

https://www.instagram.com/p/CygvNZcPtbM/?utm_source=ig_web_copy_link&igshid=MzRlODBiNWFlZA==

The master's dissertation presented and produced by the coordinator of the aforementioned project has also been published in the digital repository of the Federal University of Pernambuco, and is available for public access through the following link:

https://repositorio.ufpe.br/handle/123456789/54183

Future divulgation of the project's results would involve the NGO Instituto Nautilus, which plans to share the findings with stakeholders from various conservation units. Currently, the NGO holds a position on the consultative council of the Recife de Fora Marine Park and the Corumbau Extractive Reserve in Bahia – Brazil, where tourism also plays a significant role. Furthermore, Instituto Nautilus maintains strong relationships with managers of marine protected areas along the Brazilian coast, owing to its involvement in other conservation-focused research projects like the Budiões Project. Leveraging these connections, the NGO aims to organise awareness-raising meetings concerning the impacts of anthropogenic noise in different areas of interest. Furthermore, there will be publication in a high-impact scientific journal and continuity of the research subject.

7. Looking ahead, what do you feel are the important next steps?

Looking to the future, I believe that the next most important steps, in addition to the stage of publishing this data, would be the continuation and expansion of this

project, aiming to increasingly reach the target audience of these issues, generating more awareness about the topic. In this way, our efforts can make a significant difference in mitigating the impacts mentioned here.

To achieve this, actions such as establishing acoustic monitoring programmes that use detection technologies to record and analyse underwater sounds are crucial to understanding the extent and patterns of sound impacts in the area. Additionally, public awareness campaigns about the impacts of human noise on the marine environment and conservation measures are essential. Providing information about sensitive areas and regulations through signage, brochures, and educational programmes is also paramount.

Our research group aims to maintain continuity in expanding and applying research areas, making increasing efforts to preserve the health of coral reefs.

8. Did you use The Rufford Foundation logo in any materials produced in relation to this project? Did the Foundation receive any publicity during the course of your work?

The Rufford Foundation logo was featured in all materials produced for scientific divulgation and environmental education related to the project. These materials included the flyers used to raise awareness about the impacts of human noise on reef environments at the study sites, slide presentations used for educational interventions to divulge project results in the final grades of elementary school, and other presentations related to the project. The poster presented at the Brazilian Congress of Zoology also prominently displayed the Rufford Foundation logo and the arts of divulgation through social media. It's important to note that in all these activities, it was made clear that The Rufford Foundation provided financial support to the project.

9. Provide a full list of all the members of your team and their role in the project.

João Lucas Leão Feitosa (Ph.D. in Oceanography and Professor at the Federal University of Pernambuco- UFPE) - Contributed to this project by conducting data analysis related to the results, providing advisoryduring the project execution and administration, and writing manuscripts related to the project.

Luísa Valentim Melo de Vasconcelos Queiroz Véras (Ph.D. in Animal Biology-UFPE) - Assisted in project data collection.

Maria Laís Martins Vieira (Ph.D. candidate in Animal Biology-UFPE) - Assisted in project data collection.

Alexandre da Gama Fernandes Vieira Júnior (Ph.D. candidate in Animal Biology-UFPE) - Assisted in project data collection.

Thiago Henrique Sousa (Master's degree candidate in Animal Biology-UFPE) - Assisted in collecting project data and activities to return the results obtained to the communities where the project occurred.

10. Any other comments?

On behalf of the entire project team, I would like to express our deepest appreciation for the generous financial support provided by The Rufford Foundation. Without your invaluable assistance, the realisation of our project would have been significantly hindered. Your steady commitment to funding conservation and research initiatives like our own is truly commendable, and we are immensely grateful for your belief in our work.

I want to express our sincere gratitude to the Federal University of Pernambuco and the LabPIER for their continuous support and guidance throughout the project. Their resources, facilities, and expertise have facilitated our research endeavors, and we are indebted to them.

I also want to take this opportunity to thank each and every member who contributed to the project. Your dedication, hard work, and expertise were indispensable in achieving our goals, and the collaborative spirit that you brought to the team was truly inspiring. It is through your collective efforts that we were able to overcome challenges and make meaningful strides towards our objectives.

Lastly, I will be attaching a selection of images that document the journey of our project, capturing the various stages of our research process and showcasing the results we have achieved over the course of this past year.

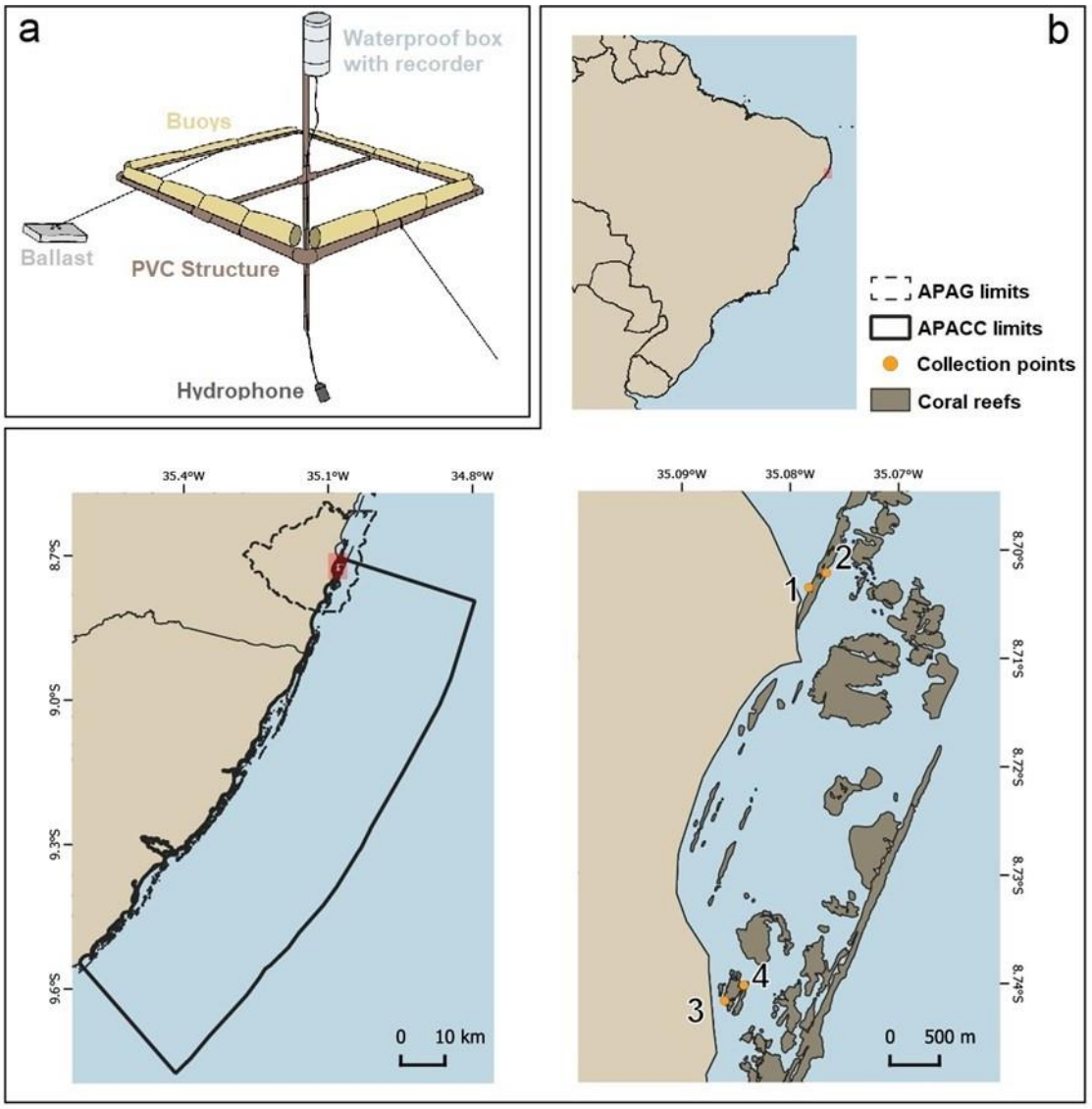

Figure 1. Location of coral reefs in the study area, Carneiros (1 and 2) and Tamandaré beach (3 and 4), northeast Brazil. And structure designed for the execution of passive acoustic monitoring sets. a – Structure of the sonobuoy used in the study. b – Selected sampling sites, unsheltered intensive tourism – 1 (104 m from the coast) and sheltered – 2 (340 m from the coast), and unsheltered seasonal tourism – 3 (114 m from the coast) and sheltered – 4 (358 m from the coast). The dashed and underlined delineations on the map represent APAG and APACC, respectively. The orange points represent the study collection sites, and the regions filled with dark beige color represent the coral reefs.

Figure 2. Sonobuoy used in the study in the data site collection.

Figure 3. Underwater view of the study collection area.

Figure 4. Land view of the study collection area.

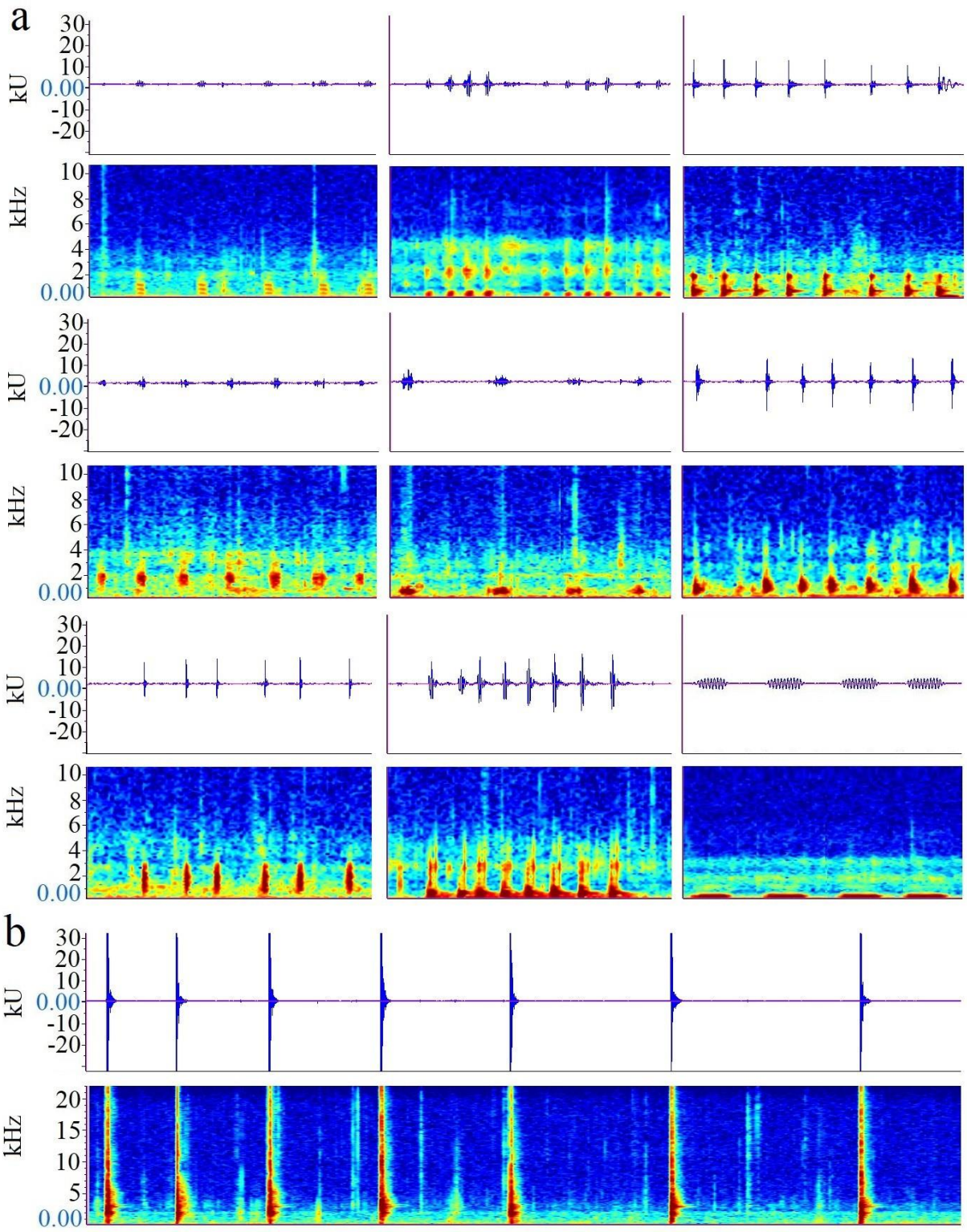

Figure 5. Spectrograms and oscillograms of biophony representatives (a: Sound profiles of fish; b: Snaps of crustaceans).

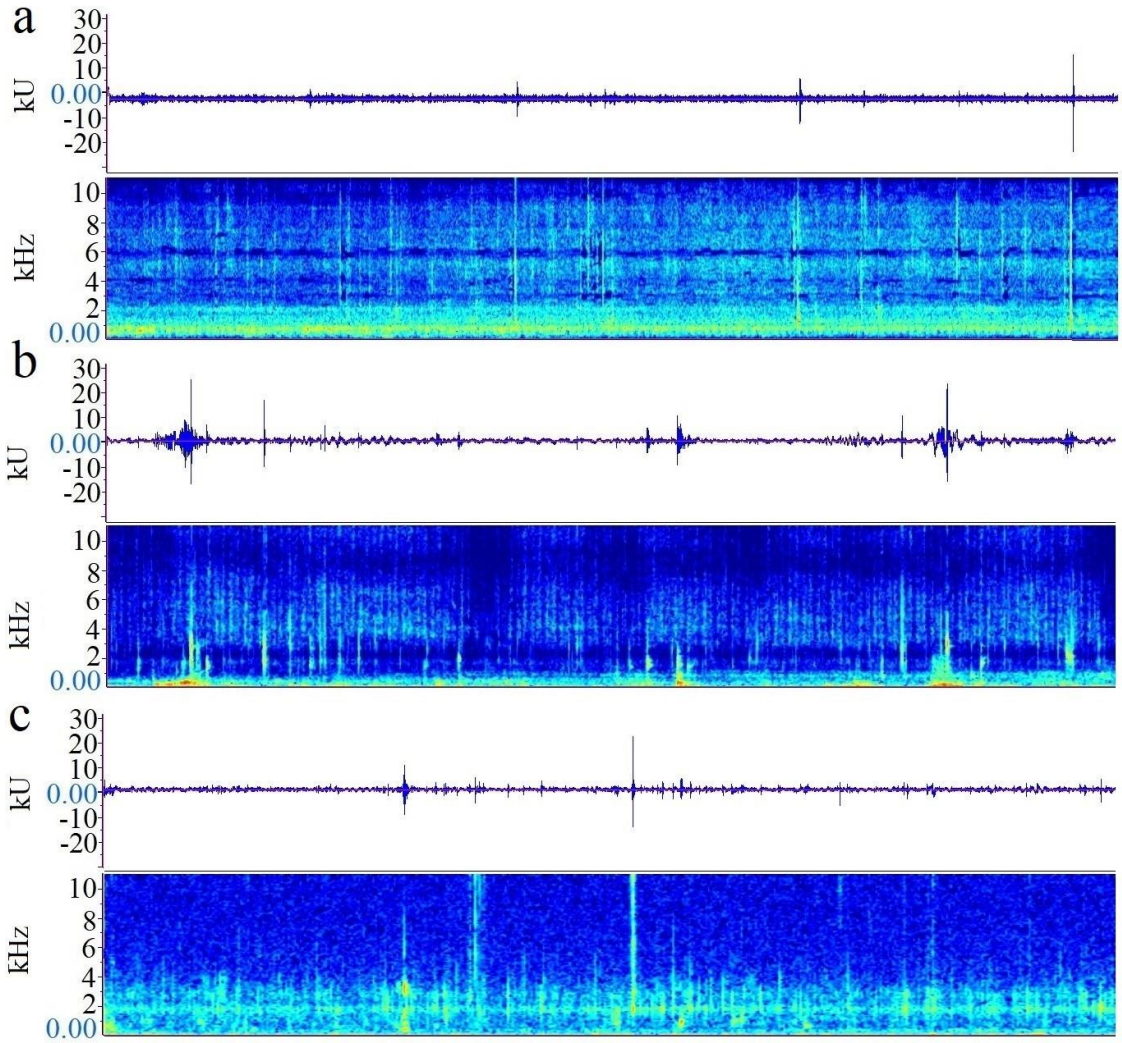

Figure 6. Spectrograms and oscillograms of geophony representatives (a: Wind; b: Rain; c: Sea waves).

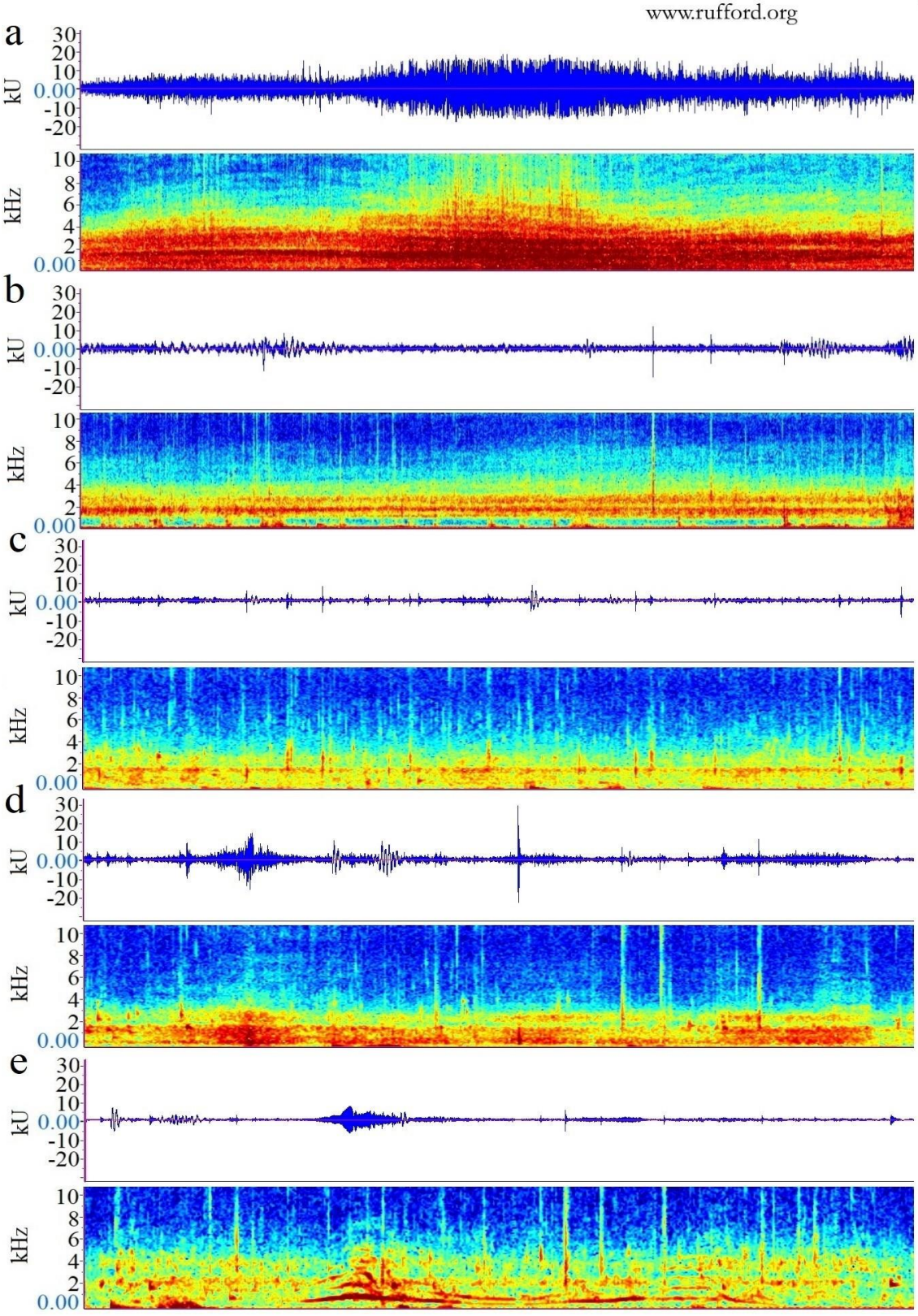

Figure 7. Spectrograms and oscillograms of anthropophony representatives (a: Jet ski; b: Speedboat; c: Paramotor with paraglider; d: Boat; e: Recreational activities carried out by bathers).

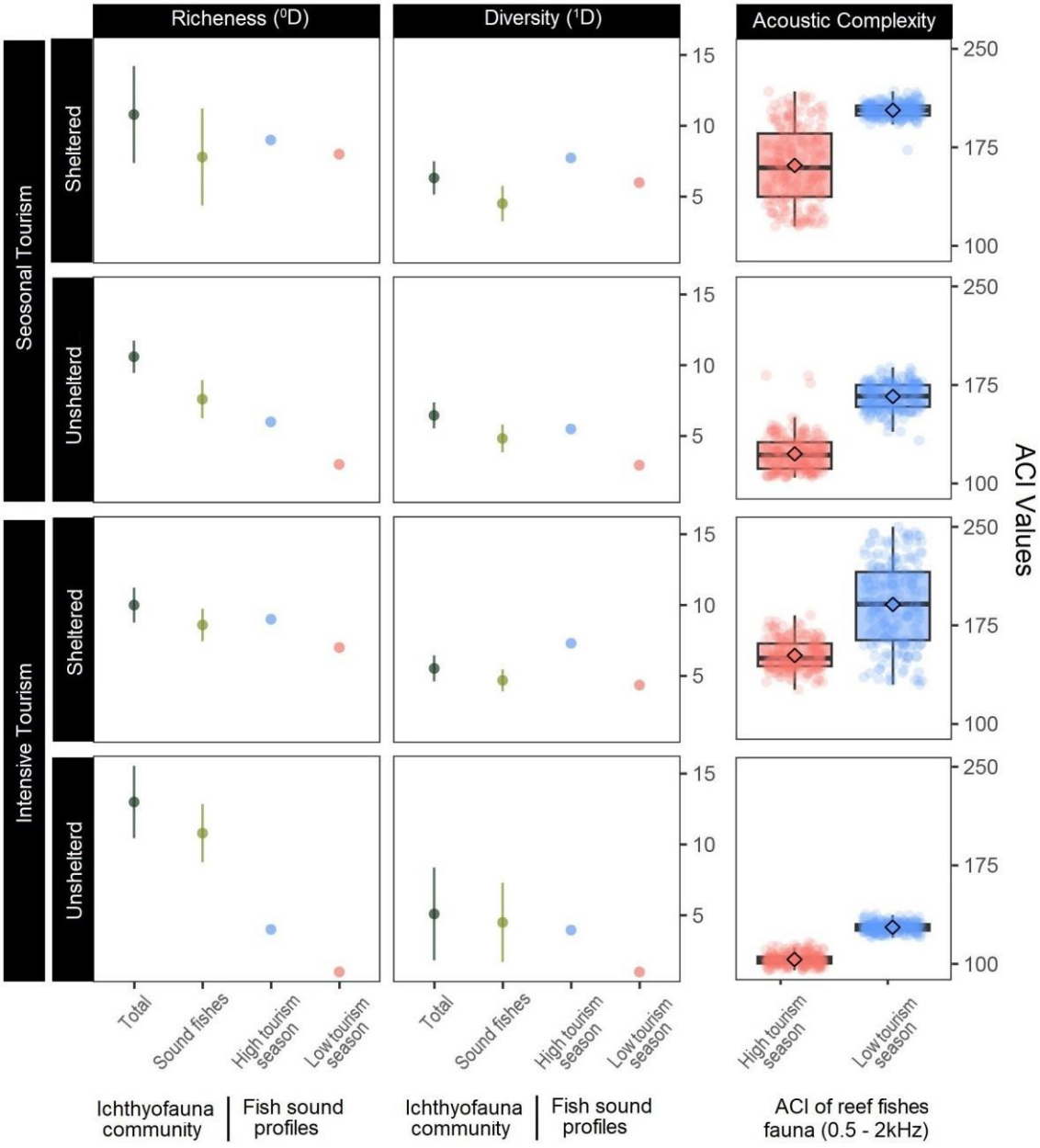

Figure 8. Analysis of the relationship between the reef fish community, in terms of its richness and diversity, and the respective sound profiles and acoustic complexity of the fish fauna observed in the 4 sample sites analyzed in high and low tourism seasons. The Box plot in the panel (central line: median; box limits: first and third quartile; ends of lines: minimum and maximum) represents the distribution of ACI values from the reef ichthyofauna.

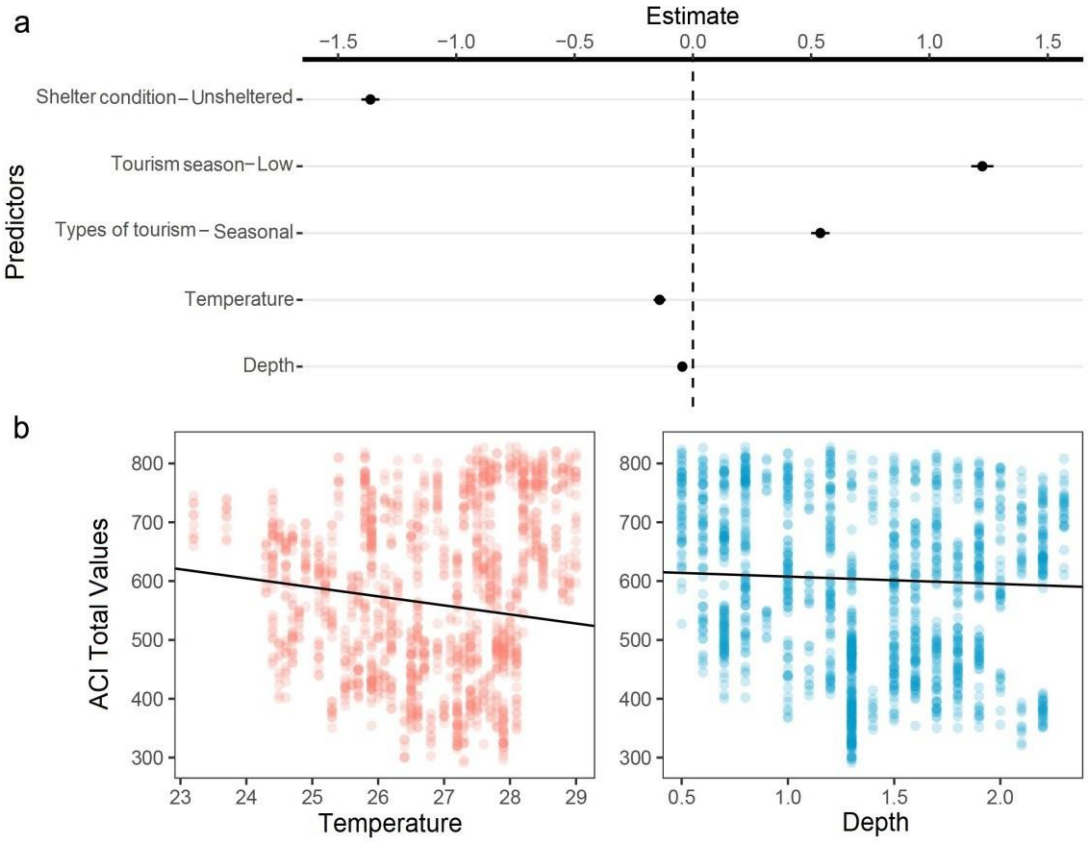

Figure 9. Generalized Linear Model Analysis, showing the relationship of predictors to the Acoustic Complexity of the sample sites analyzed. a – Categorical variables (Shelter condition, Season, Type of tourism). b – Continuous variables (Temperature and Depth). The estimate refers to the estimate of the coefficients associated with each predictor variable in the model. These coefficients represent the relative contribution or effect of each variable on the response of the model's dependent variable.

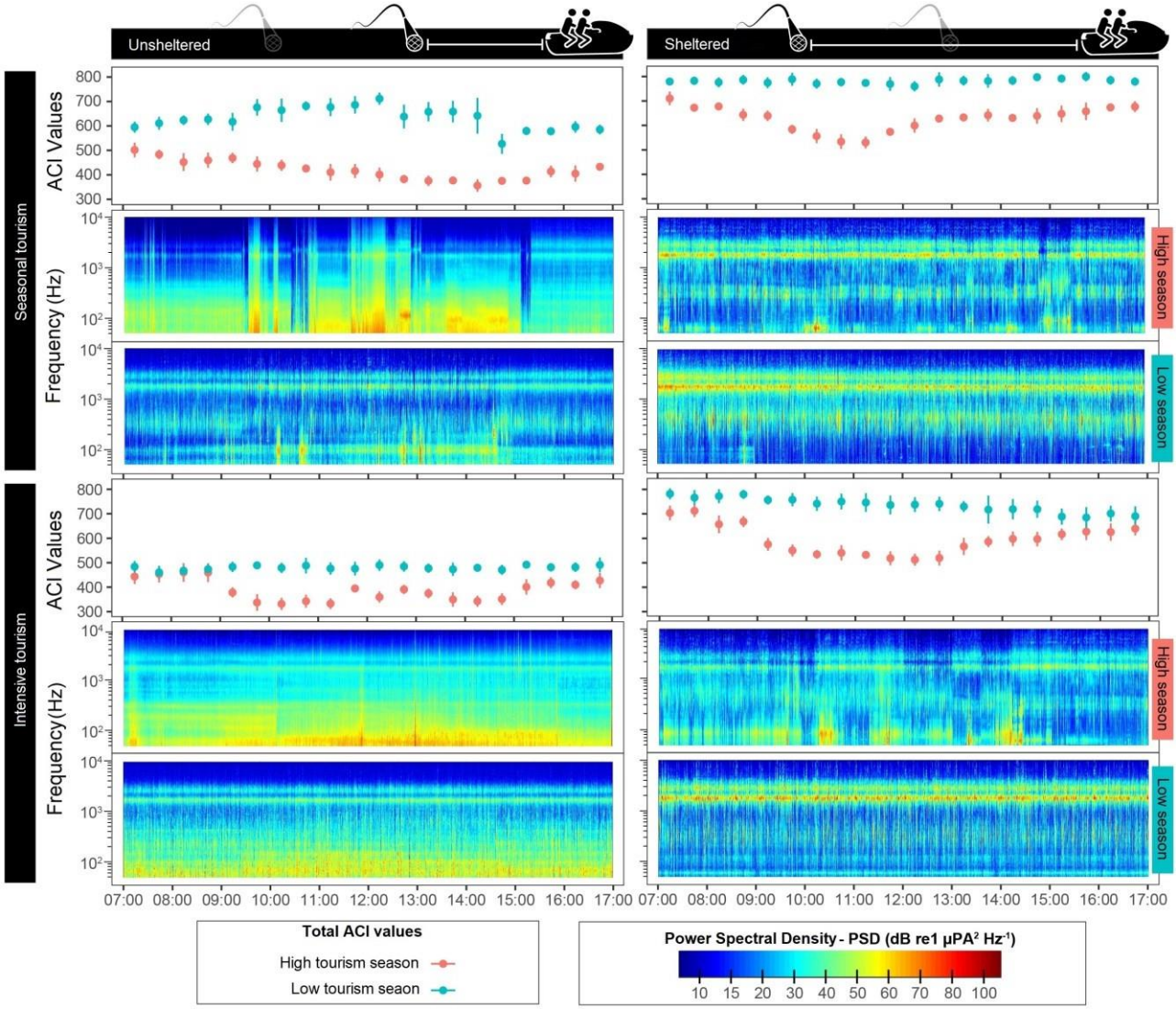

Figure 10. Spectrograms and total values of the Acoustic Complexity Index, in relation to the temporal variation of the sample sites analyzed, in high and low tourism seasons. The blue dots represent the total ACI values, with their respective variations, on a temporal scale, in the low tourism season, while the blue dots represent the values in the high tourism season. The PSD values are represented on a color scale in the spectrograms. The representative scale indicates values of PSD along the color gradient scale, serving as a reference point for the PSD values.

Figure 11. The front of the informational flyers produced to raise awareness about the impacts of anthropogenic noise on coral reefs.

Figure 12. The back of the informational flyers produced to raise awareness about the impacts of anthropogenic noise on coral reefs.

Artist's portfolio: https://eduardolopes1a1l66ca.myportfolio.com

Figure 13. Scientific divulgation action at Carneiros and Tamandaré beaches.

Figure 14. Lecture at UNINASSAU Poli Digital School in Tamandaré.

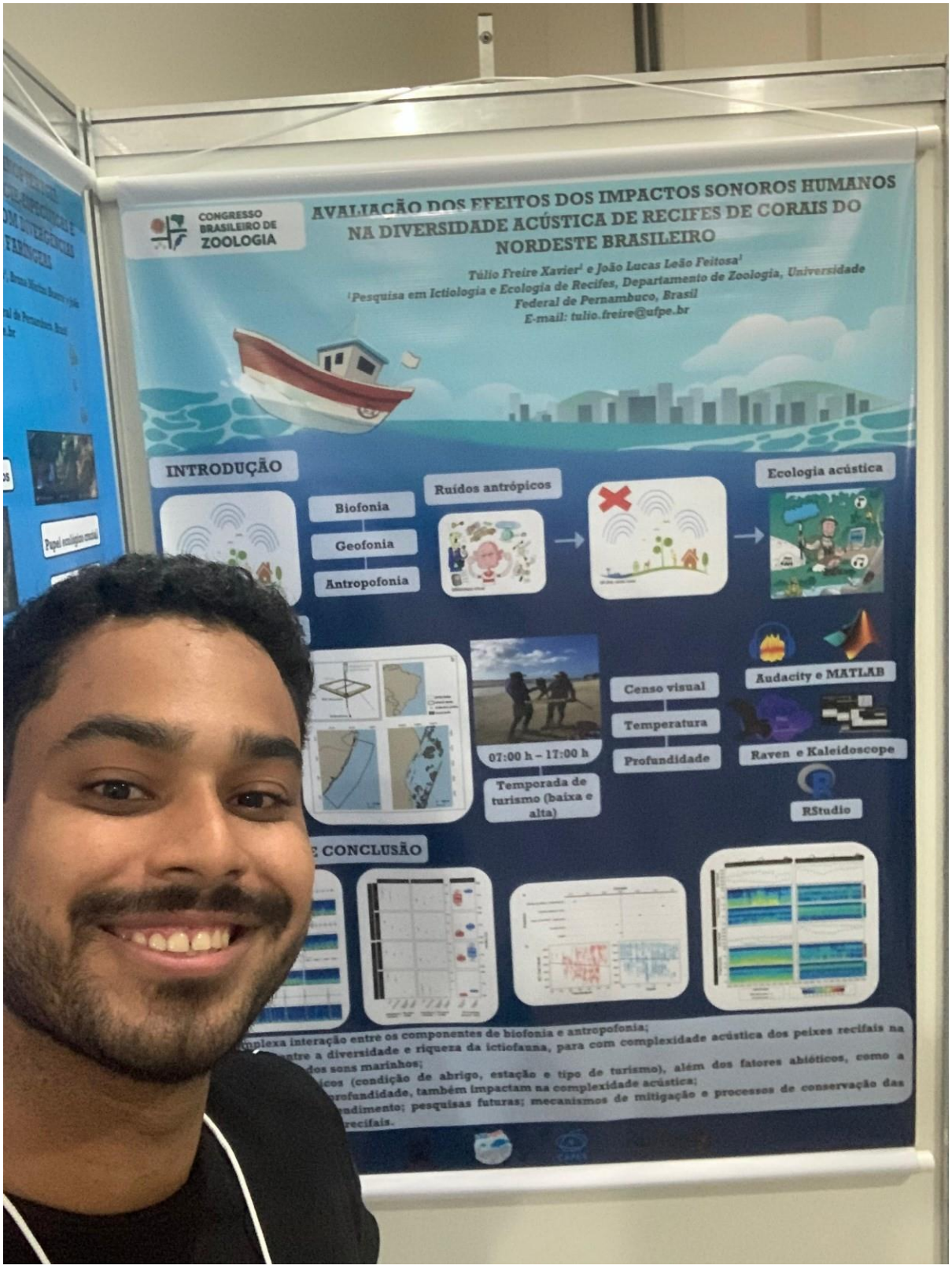

Figure 15. Presentation at the Brazilian Zoology Congress (Congresso Brasileiro de Zoologia) 2024.

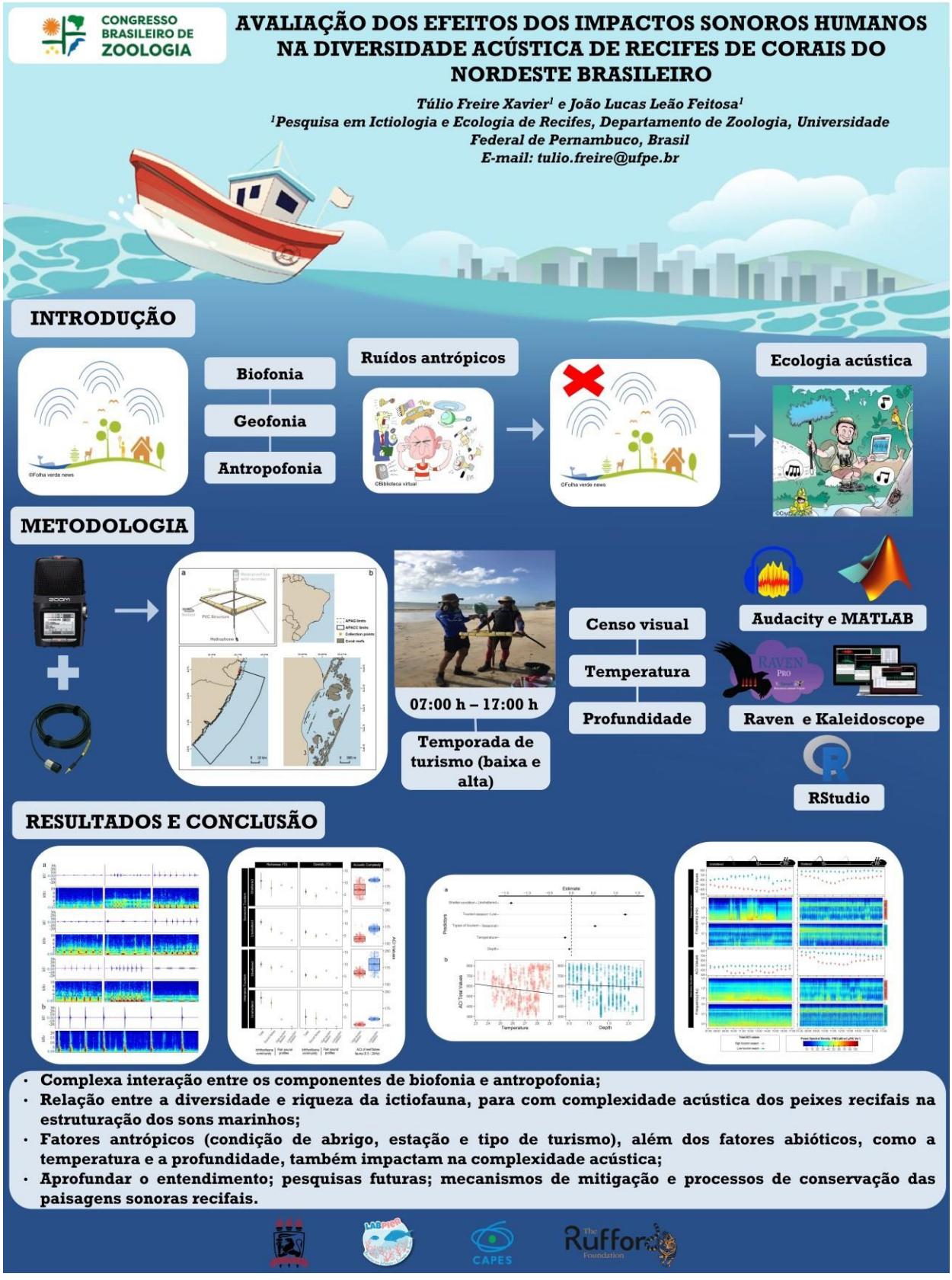

Figure 16. Poster presented at the Brazilian Zoology Congress (Congresso Brasileiro de Zoologia) 2024.