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Effects of the Aguirre Power Plant on the Marine Soundscape: a New Mangrove Function in Jobos Bay National Estuarine Research Reserve, Puerto Rico: a Preliminary Study

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Abstract—**Jobos Bay National Estuarine Research Reserve (JBNERR) has flora and fauna adapted to a tropical climate. Within the reserve lies the Aguirre Power Plant Complex, which produces a great deal of noise that could place significant stress on marine life and cover a significant area. To test this hypothesis, underwater sound frequencies were recorded at several points of different proximity to the power plant using a hand-held sound recorder with a hydrophone attachment. Each recording was two minutes in duration and positioned one meter above the ocean floor. Results revealed anthropogenic noise from the power plant is strongly present in the 0.01–200 Hz frequency range in an area up to 1.5 km from the power plant. However, because sound waves travel further in water than in air, this distance could be even greater. Acoustic frequencies from the power plant were not detected across a mangrove barrier located approximately 1.0 kilometers from the power plant. This implies that mangroves may have an unreported noise reduction function which, in this case, mitigates and completely blocks off acoustic frequencies from the power plant.**

With the exponential expansion of industrial and recreational activity, anthropogenic stress on marine environments is becoming ever more present. Recreational boating, industrial shipping freighters, seismic exploration, sonar, and drilling are some examples of excess noise produced in aquatic environments (Kunc et al. 2016). Sound plays an indispensable role in the life of many marine organisms. It is used for the detection of prey by predators and vice versa, it is important for intraspecific and interspecific communication, and for migration of many aquatic mammals such as whales (Peng et al. 2015).

The problem arises when sounds turn into noise, which depends on each species (sensitivity threshold) and the type of impact generated (Sordello et al. 2020). Noise may cause stress in animals, increase the risk of mortality by unbalancing predator-prey interaction, and interference with sound-based orientation communication, especially in reproductive contexts (Peng et al. 2015).

Anthropogenic noise can affect an individual's anatomy, physiology, and/or behavior in several ways. Observed effects of noise on marine mammals include changes in vocalizations, respiration, swim speed, diving and foraging behavior, displacement avoidance, shifts in migration paths, stress, hearing damage, and strandings (Erbe et al. 2018). By overlapping with the bandwidth of acoustic information, many species may change behavioral patterns (Kunc et al. 2016). Based on this knowledge, it can be said that noise pollution can make a habitat unfavorable for some species. It is important to note that constant noise pollution will affect a wide variety of biodiversity both in diurnal and nocturnal hours (Girard et al. 2020). These nocturnal hours are very important since most of the vocalization activities that comes from fish, which are usually associated with reproductive behavior, takes place at night (Rice et al. 2017).

While anthropogenic noise pollution is known to affect the presence of wildlife biodiversity, there is a considerable gap of knowledge on the subject for Puerto Rico's coastal ecosystems. This research was focused on Jobos Bay National Estuarine Research Reserve (JBNERR), and the impact of anthropogenic noise originated from Aguirre Power Plant Complex in the reserve's natural soundscape. Jobos Bay possesses a mangrove barrier that separates the bay area of the reserve from an intricate mangrove system. This "barrier" is located approximately two kilometers from Aguirre Power Plant. The mangrove vegetation refers to a taxonomically diverse group of trees and shrubs that dominate plant communities in tidal and salty marshes

FIG. 1. Google Maps Satellite image of the Caribbean, red square shows Puerto Rico and yellow square shows Jobos Bay National Estuarine Research Reserve and nine data collection points labeled A–I. Point A was the first recording. It took place outside of the mangrove system around 450 m away from the power plant. Point B was recorded outside of the mangrove system around 1.10 km away from the power plant. Point C was recorded outside of the mangrove system around 1.5 km away from the power plant. Point D was recorded around 2.5 km away from the power plant. This is the furthest recording point outside of the mangrove system. Point E was recorded around 2.30 km away from the power plant. This point is located at the entrance of the mangrove system. Point F was recorded inside the mangrove system around 2.0 km away from the power plant. Point G was recorded inside the mangrove system around 2.30 km away from the power plant. Point H was recorded inside the mangrove system around 1.58 km away from the power plant. This is the closest recording point to the power plant inside the mangrove system. Point I was recorded around 2.50 km away from the power plant and was recorded over a 10-meter-deep "hole" in the seabed. Generated in BioRender.com.

along sheltered tropical and subtropical coastlines (Kalasuba et al. 2023). In Jobos Bay four species can be found: Red Mangrove (*Rhizophora mangle* L.), Black Mangrove (*Avicennia germinans* L.), White Mangrove (*Laguncularia racemosa* Gaertn), and Buttonwood Mangrove (*Conocarpus erectus* L.) (Departamento de Recursos Naturales y Ambientales 2023). These plants are halophytes, they thrive in saline environments with daily inundations (Kalasuba et al. 2023). Mangrove ecosystems are one of the major types of natural wetlands along the tropical shores and are vital to estuarine ecosystems. They provide protection against floods and hurricanes, reduction of shoreline and riverbank erosion, and maintenance of biodiversity. Their roots serve as nursery habitats for juvenile fish protecting them from large fish and birds in shallow water environments (Srikanth et al. 2016). No data to date suggest that mangroves may play a role of sound mitigation in their habitat, protecting an enclosed ecosystem from external noise.

MATERIALS AND METHODS

Jobos Bay National Estuarine Research Reserve, situated between Guayama and Salinas, Puerto Rico, encompasses a sprawling 2,883 acres (Fig. 1). Administered by the Puerto Rico Department of Natural and Environmental Resources, this reserve plays a pivotal role in advancing research and safeguarding the delicate ecosystems of mangroves, reefs, and marine species. It was specifically selected for its exceptional biodiversity and its proximity to the Aguirre Power Plant Complex, boasting a substantial 900 MW capac-

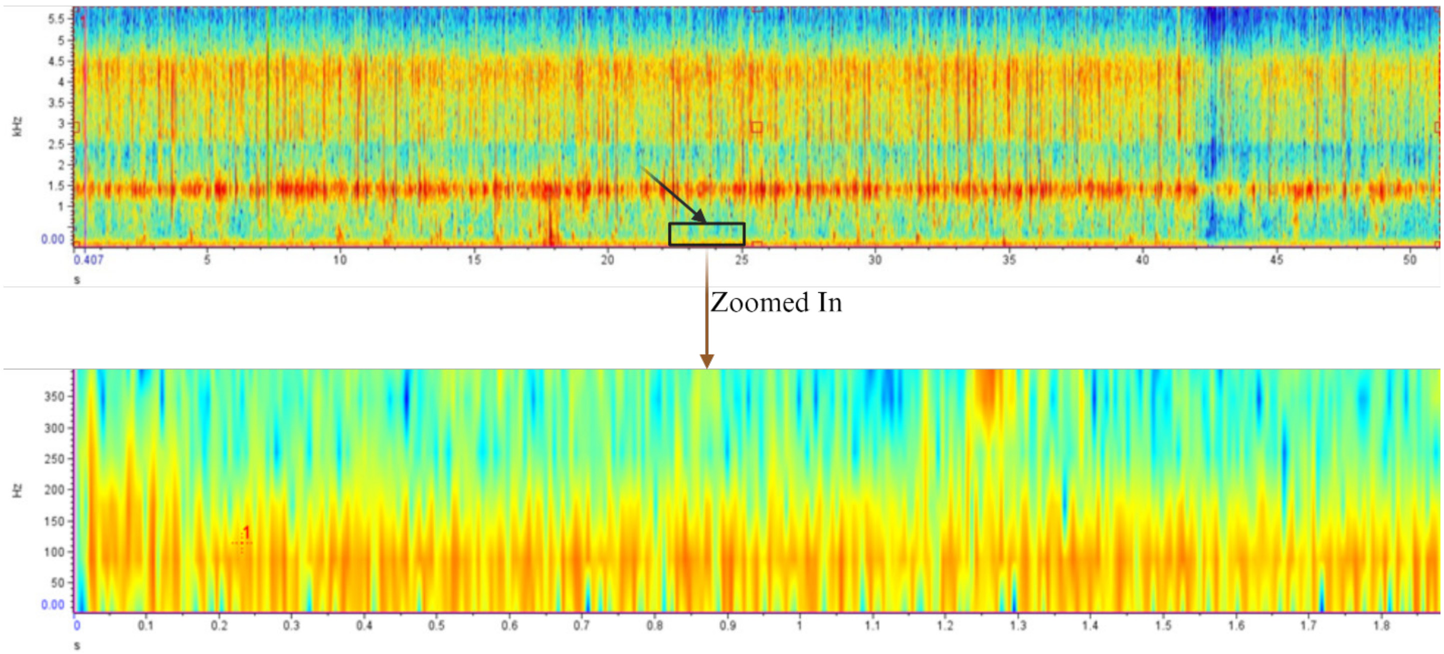

FIG. 2. Spectrogram of Point A. Black arrow shows the Aguirre Power Plant Complex acoustic footprint with frequencies in the 0.01–200 Hz range with a loud rumbling sound. See Fig. 3 for zoomed acoustic footprint. Lower part is a zoomed spectrogram of the Aguirre Power Plant Complex acoustic footprint. Generated in BioRender.com.

ity. This strategic choice renders JBNERR an ideal and relevant locale for our research. Nine data collection points were strategically chosen based on their proximity to the power plant. These selections were made to ensure a comprehensive representation of various environmental scenarios, such as open water, proximity to mangrove barriers, and locations within the mangrove reserve.

Data regarding acoustic frequencies were gathered using a hydrophone (model: Dolphin Ear Pro Series) and a recorder (model: zoomH6). Each recording was analyzed through a specialized program (Raven Pro-Cornell labs) to compare the frequencies in the locations marked.

Our initial recordings were conducted exclusively during daylight hours, specifically between 8:00 and 11:00 am. Regrettably, we were unable to collect any data during the nocturnal hours due to logistical constraints. At each designated point of interest, we captured a two-minute recording of environmental sounds. To ensure precision in our data collection, we employed boat sonar technology to accurately position the hydrophone one meter above the marine floor at each location. Subsequently, in the laboratory, we subjected the sound data to analysis using Raven Pro®, an interactive sound analysis software developed by Cornell University.

Our analysis focused primarily on quantifying the soundscape, which included identifying bandwidth utilization at each location. Of particular importance was our effort to isolate and distinguish the Aguirre Power Plant Complex noise, while carefully examining its presence within the frequency composition of each recording.

RESULTS

The study site is situated within a bay, encircled by discrete land masses (cays) extending approximately 9.43 km. This geographical setup channels vibrational waves emitted by the power plant, thereby enhancing their concentration within the bay and, consequently, the marine reserve. Notably, the Aguirre Power Plant Complex is spatially distinct from the natural reserve, demarcated by a 1.53 km-long expanse of mangroves. This gradient serves as an acoustic boundary between the open bay and the mangrove barrier, presenting an intriguing soundscape interface worthy of further investigation.

Our initial recordings near the Aguirre Power Plant Complex were established to ensure that the noise produced by the power plant was isolated. Each data point was selected to measure sounds in diverse surroundings such as: concrete dock, dead coral barrier, inside a bay, inside/outside mangrove system, and floating sargassum raft (Fig. 1). The closest location to the power

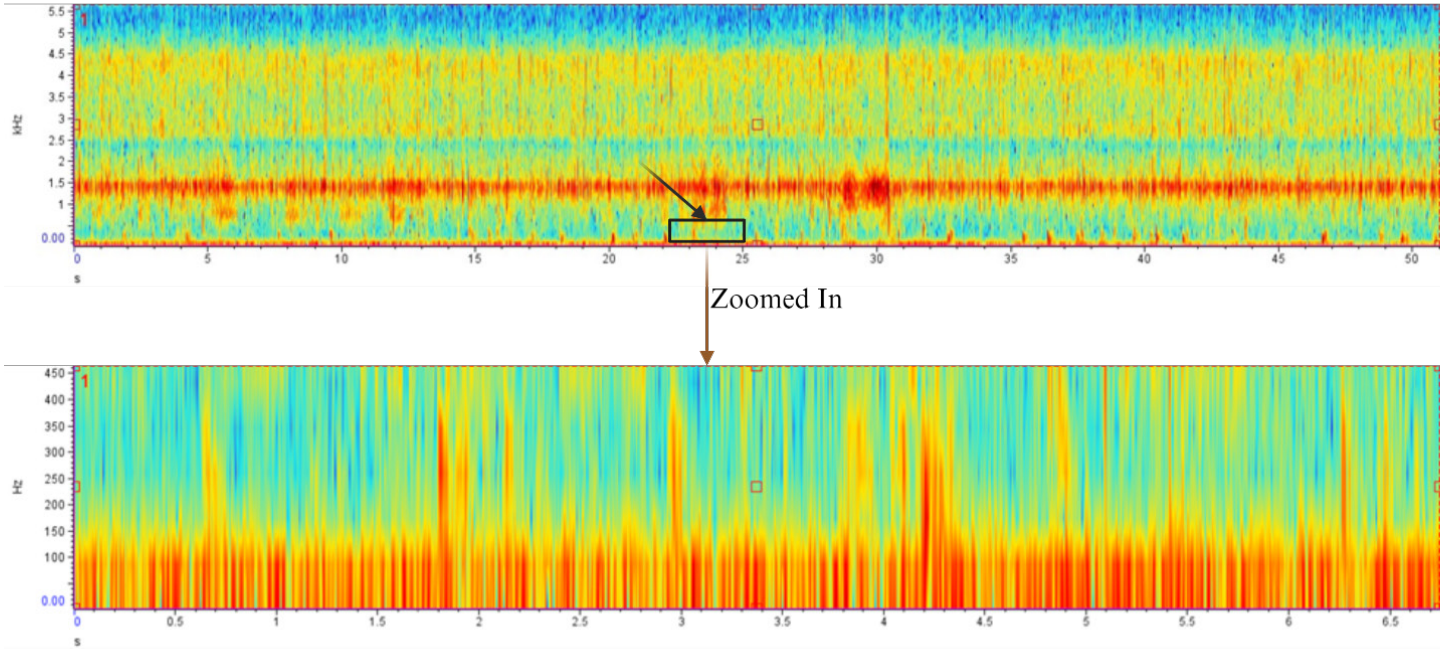

FIG. 3. Spectrogram of Point B. The black arrow shows the noise produced by the power plant is detected in the 0.01–150 Hz frequency range. Lower part is a zoomed spectrogram of the Aguirre Power Plant Complex in the 0.01–150 Hz range. Generated in BioRender.com.

plant complex, point A, provided compelling evidence of a dominant, low-frequency (0.01–200 Hz) noise near the concrete dock of the complex (Fig. 2). Inside the bay, (Point B: 1.1 km from the Aguirre Power Plant Complex) the acoustic footprint was detected in the 0.01–150 Hz frequency range in a benthic zone mainly comprised of sand (Fig. 3). Point C was recorded over a dead coral reef next to the mangrove system (1.5 km from the power plant). In this recording, we noted noise extending up to 1.5 kHz, attributed to a hot water discharge pipe. (Fig. 4). Points B and C also captured anthropogenic noises related to local boating activity, constituting the primary sources of anthropogenic acoustic emissions in this context. Audio data in point D, approximately 2.5 km from the Aguirre Power Plant Complex, could not be included due to feedback from the hydrophone.

However, within the confines of the Jobos Reserve, particularly within the protective mangrove barrier situated less than 2.0 kilometers from the power plant, a stark contrast in the acoustic landscape was observed. Anthropogenic sources, including boating activity and power plant noise emissions, were notably reduced. Remarkably, 2.3 km from the Aguirre Power Plant Complex, recordings from Point E taken at the entrance of the mangrove system (Fig. 5) displayed a reduction on the noise of the power plant mainly because of the mangrove barrier to the west of the reserve. The acoustic footprint was reduced from 0.01–200 Hz to approximately 0.01–100 Hz.

This characteristic was also observed inside the mangrove system, around two kilometers away from the power plant, in Point F (Fig. 6), where the frequency range from the Aguirre Power Plant Complex was also reduced to 0.1–100 Hz.

In the subsequent phase of our investigation, comprising five consecutive recordings, we turned our attention to sounds of uncertain origin, postulated to be of biological nature. In Point G (Fig. 7), 2.3 km away from the power plant, recordings were taken within a sargassum patch and some of the detected noises were identified in around the 1.5 kHz frequency range. However, the Aguirre Power Plant acoustic footprint was not detected in this recording. The same was observed in the sound recording in point H (Fig. 8). This point was inside the mangrove system, 1.58 km from the Aguirre Power Plant, and lacked its acoustic footprint.

Lastly, 2.5 km from the power plant, the sound recording in Point I (Fig. 9) detected a loud "clicking" like noise that started at 15 seconds, paused, and resumed at 32 seconds. This recording was done over a 10-meter-deep "hole" that manatees use for shelter inside the mangrove system. Consistent with the previous recordings inside the mangrove system, the Aguirre Power Plant acoustic footprint was not detected in this recording.

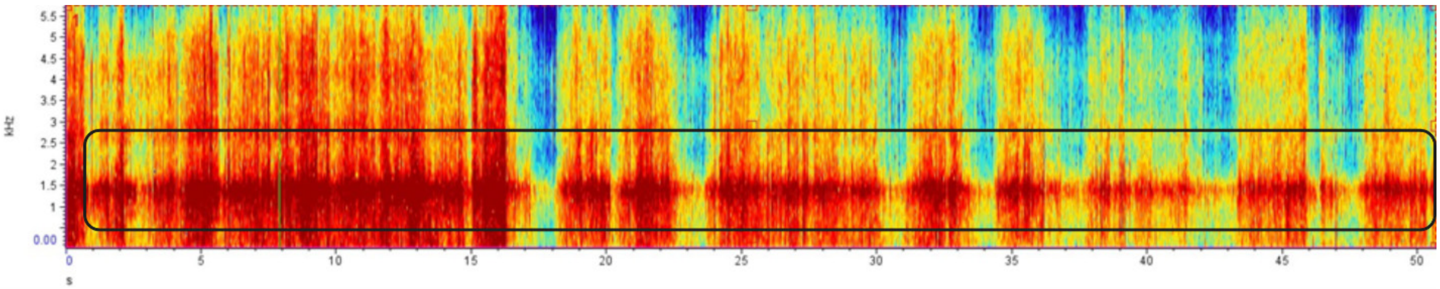

FIG. 4. Spectrogram of Point C. The black rectangle points out the noise produced by a hot water discharge tube connected to the power plant. Aguirre Power Plant Complex noise could not be detected because of spectral overshadowing. Generated in BioRender.com.

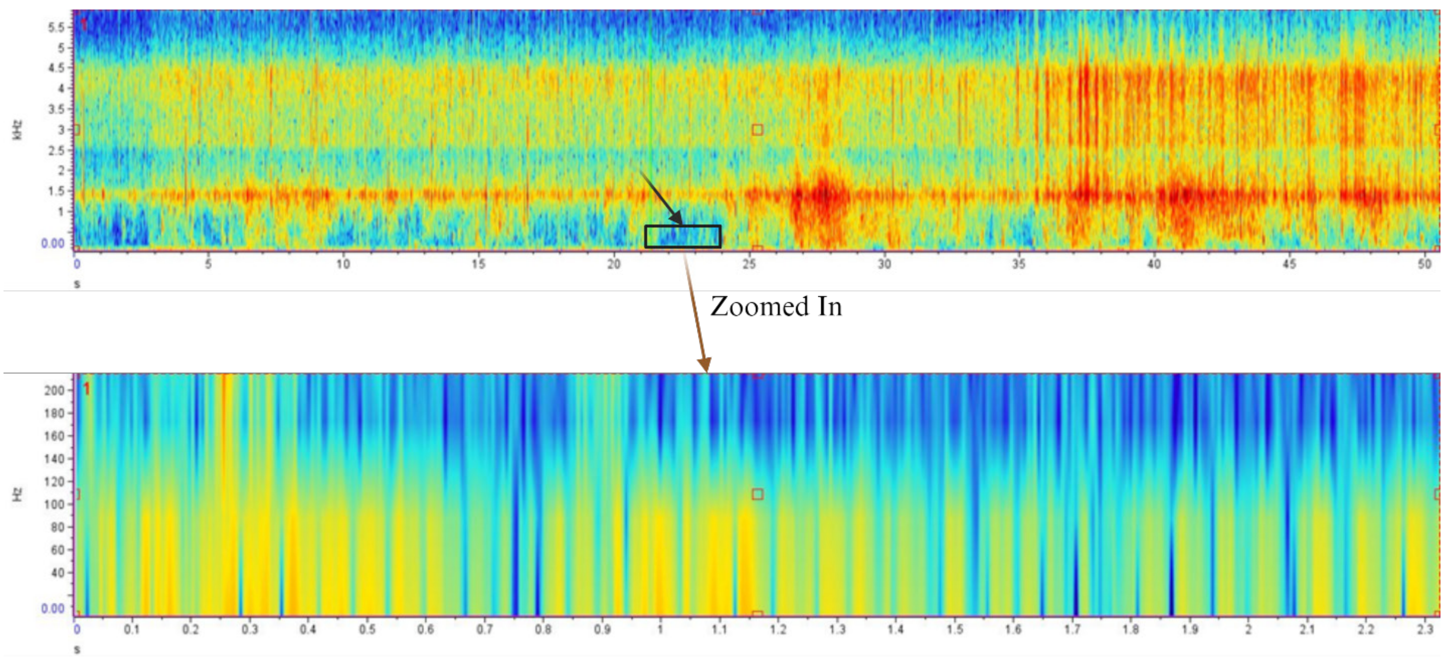

FIG. 5. Spectrogram of Point E: The black arrow points out that frequencies from the Aguirre Power Plant Complex was greatly reduced from 0.1–200 Hz to 0.01–100 Hz range at the entrance to the mangrove system. Lower part is a zoomed spectrogram of the 0.01–200 Hz frequency range in Point E which reveals reduced noise (dB of the acoustic footprint). Generated in BioRender.com.

DISCUSSION AND CONCLUSION

The results from our research into the acoustic environment around the Aguirre Power Plant Complex in Jobos Bay National Estuarine Research Reserve provide valuable insights into the impact of anthropogenic noise on the marine ecosystem, as well as the role of natural barriers like mangroves in mitigating this noise. The initial recordings near the power plant clearly demonstrate the dominance of a low-frequency noise in the 0.01–200 Hz range. This noise is attributed to the operations of the power plant, with occasional vibrations extending up to 1.5 kHz, likely stemming from hot water discharge near the recording site. Additionally, local boating activity contributes to the anthropogenic acoustic emissions in the area. These findings align with previous research highlighting the impact of industrial and recreational activities on marine environments (Kunc et al. 2016).

However, the most intriguing aspect of our study emerges within the protective area of the mangrove barrier, about two kilometers from the power plant. Here, a notable contrast in the acoustic landscape becomes evident. Anthropogenic noise sources, including both boating activity and power plant sound emissions, are significantly reduced within this zone. Instead, a rich diversity of biological and environmental sounds emerges, reflecting the diverse aquatic life within the mangrove ecosystem. These sounds encompass arthropods and fish-like sounds, which add to the natural acoustic phenomena of the area. Importantly, recordings from specific points within the mangrove barrier

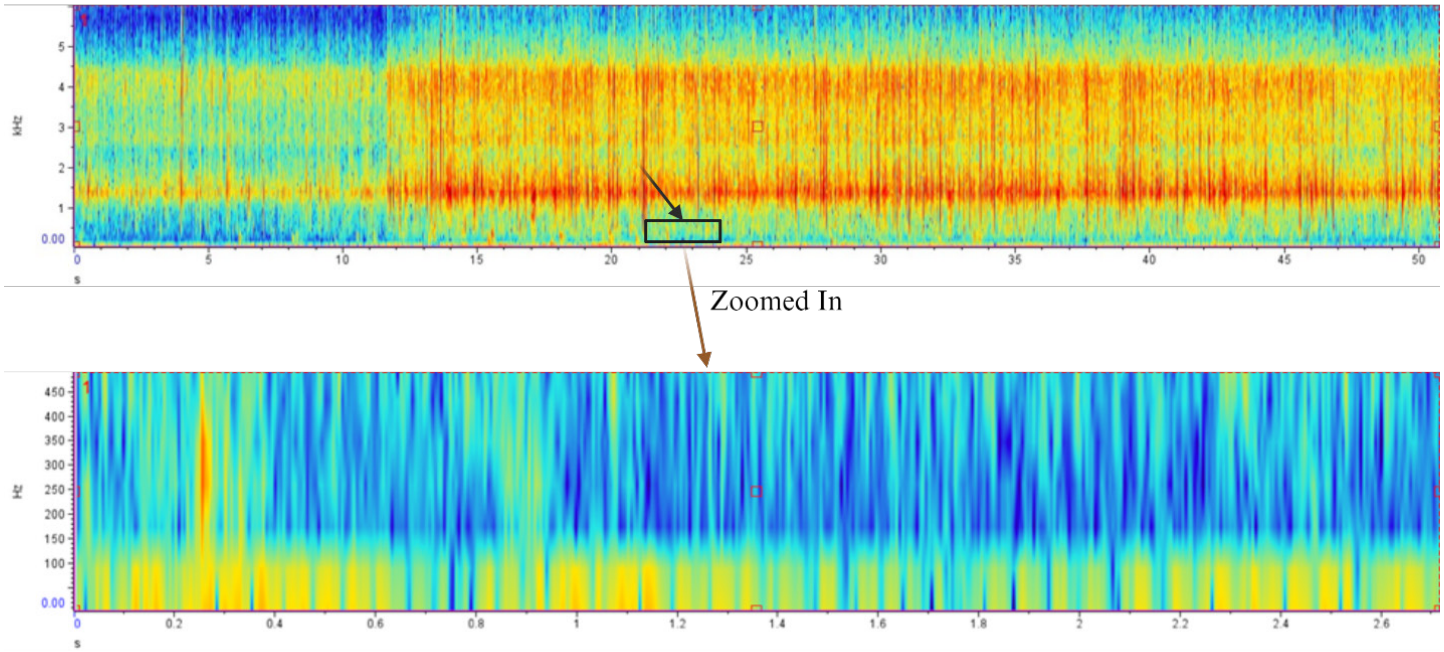

FIG. 6. Spectrogram of Point F. Black arrow shows spectral range for the Aguirre Power Plant Complex. The noise was greatly reduced in the 0.01–200 Hz frequency range. Lower part is a zoomed spectrogram that reveals the absence of the Aguirre Power Plant Complex acoustic footprint above the 100 Hz frequency range. Generated in BioRender.com.

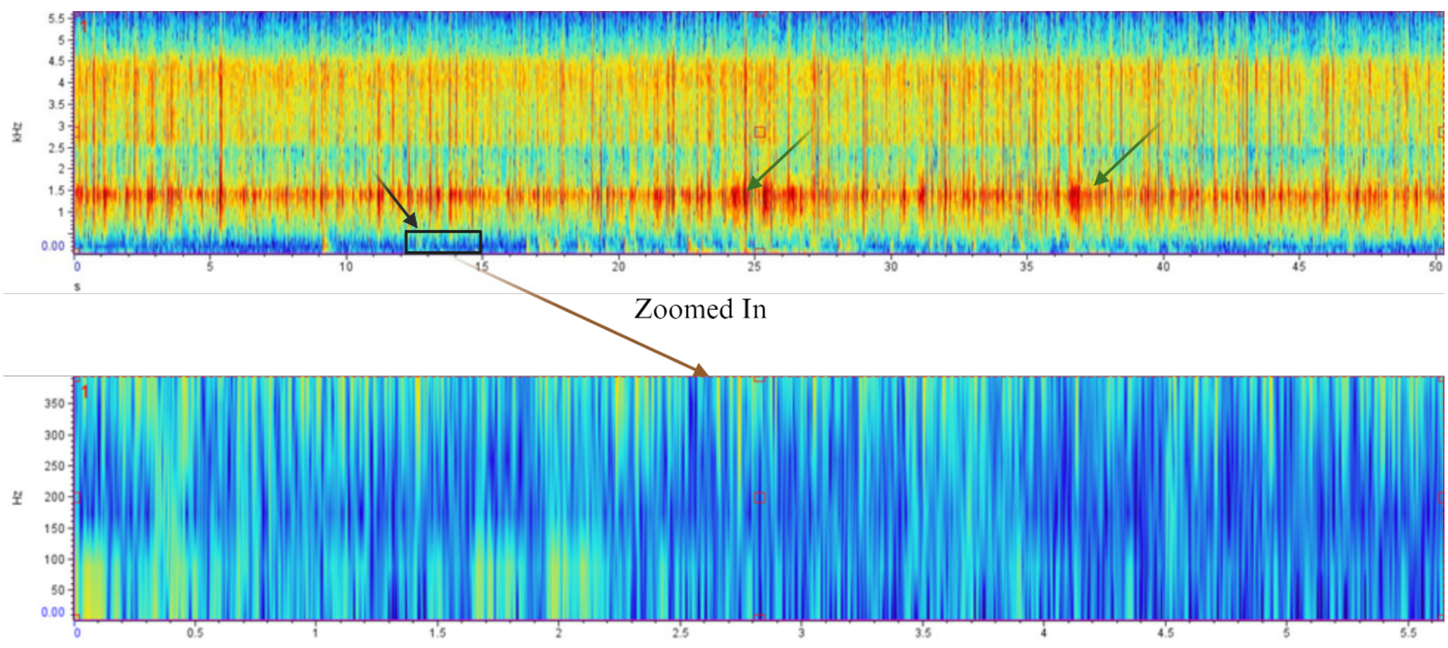

FIG. 7. Spectrogram of Point G. This point was taken within *Sargassum* patch floating 2.3 km away from the power plant. The sound spectrogram shows a variety sounds; green arrows represent sounds that might have originated from the invertebrate life within the *Sargassum*. The black arrow shows noise from the power plant could not be detected within the 0.01–200 Hz frequency range. Lower part is a zoomed spectrogram of the 0.01–200 Hz frequency range in Point G reveals the absence of the Aguirre Power Plant Complex acoustic footprint. Generated in BioRender.com.

show an absence of the characteristic Aguirre humming sound, underscoring the protective role of mangroves in mitigating anthropogenic noise.

This observation raises several important questions and avenues for further discussion. For example, mangroves as natural noise barriers. The clear reduction in anthropogenic noise within the mangrove barrier suggests that these natural habitats may serve as effective

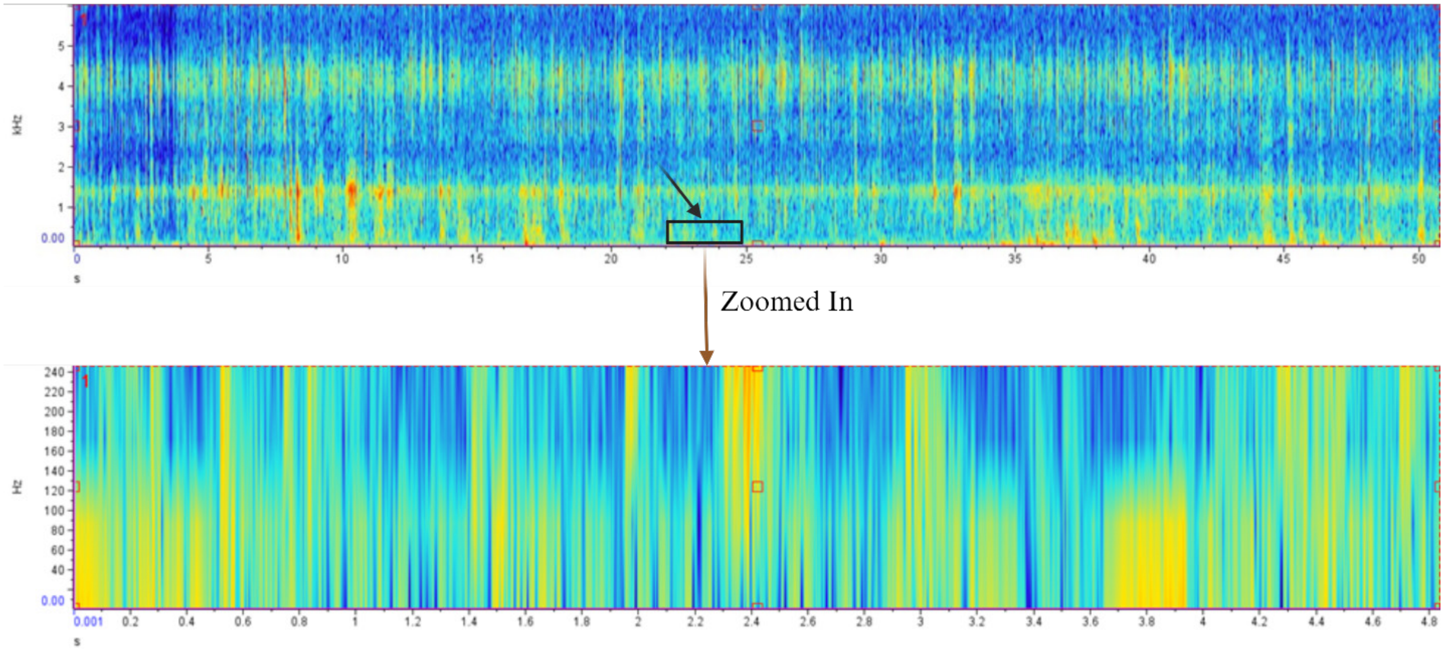

FIG. 8. Spectrogram of point H. Black arrow shows the Aguirre Power Pant Complex acoustic footprint could not be detected within the 0.01–200 Hz frequency range. Lower part is a zoomed spectrogram of the 0.01–200 Hz frequency range reveals the absence of the Aguirre Power Plant Complex acoustic footprint in Point H. Generated in BioRender.com.

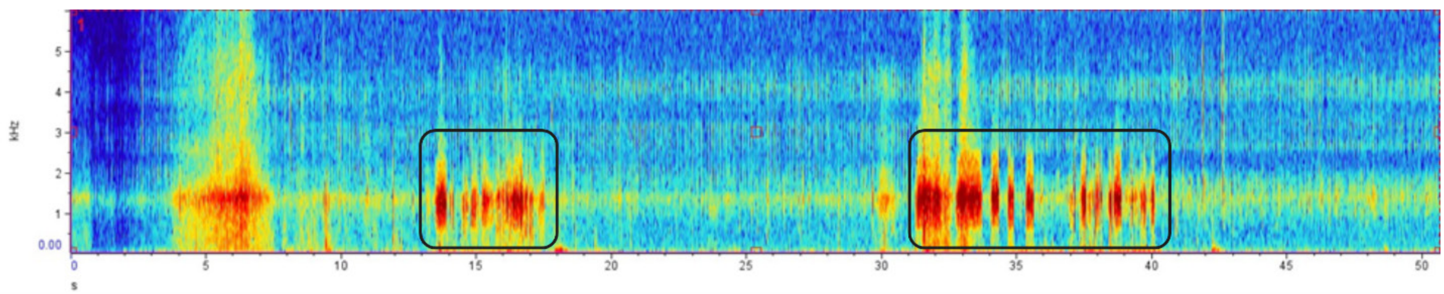

FIG. 9. Spectrogram of Point I. This recording occurred over a 10-meter-deep "hole" in the seabed within the mangrove system that detected a loud "clicking" sound of unknown origin, pointed out by the black rectangles. Noise from the Aguirre Power Plant Complex could not be detected within the 0.01–200 Hz frequency range. Generated in BioRender.com.

noise barriers. This finding prompts further investigation into the mechanisms through which mangroves absorb or reflect sound, and whether this phenomenon is consistent across different types of mangrove species. Furthermore, this function could have biodiversity implications. The presence of a diverse array of biological and environmental sounds within the mangrove barrier is promising. However, it also highlights the potential impact of anthropogenic noise on marine biodiversity outside of such protected zones. Further research is needed to understand how the absence of these protective barriers affects the behavior and communication of marine organisms. For example, Johnston et al. (2006) reported the fourth largest population of Red Hind (*Epinephelus guttatus* Linnaeus, 1758), in which spawning aggregations are protected. The site they reported was in proximity with our study site in Arroyo vicinity. This is one example of many species in which anthropogenic noise can interrupt and even change their reproductive behavior reducing reproduction rate and species recruitment (Duarte et al. 2019; Popper and Hawkins 2019). More importantly, this area is known to have one of the highest manatee densities on the island.

Also, the discovery of sounds with uncertain origins, such as the distinct clicking noise attributed to snapping shrimps as described in sound spectrograms by Castro (2017), underscores the complexity of underwater acoustics and the need for continued research into the communication and behavior of marine species. Understanding the significance of these sounds in the context of the ecosystem is essential. In addition, these findings have direct implications for the management and conservation of marine ecosystems. We suggest that preserving or restoring natural barriers like mangroves could be a viable strategy to mitigate the negative effects of anthropogenic noise on marine life. Furthermore, reforestation projects along coastal industries can mitigate the damage to the marine soundscape and protect these natural environments and its inhabitants. This concept warrants consideration in coastal development and conservation planning. Lastly, long-term bioacoustics monitoring to develop soundscape models will be essential to monitor ecosystem health.

In conclusion, our research provides valuable evidence of the influence of anthropogenic noise on marine soundscapes and highlights the potential for natural barriers like mangroves to protect and preserve the acoustic environments vital for marine organisms. This work underscores the importance of further research in this field to inform conservation efforts and sustainable practices in coastal areas.

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