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Hydro-acoustic survey of shallow water seagrass beds using a line array of hydrophones, a case study in Xincun Lagoon, Hainan Island

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Key Points:

- A line array of hydrophones was deployed in a seagrass bed to record the ambient noise.
- The noise is divided into three distinct categories: biophony, anthrophony, and geophony.
- The wide-band, high energy and long duration ship noise raises concern regarding the impairment of seagrass.

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Abstract: Sound is considered an important aspect of an ecosystem and acoustic methods have emerged as effective tools for ecosystems research. Xincun Lagoon, Hainan Island, is an important ecosystem characterized by dense seagrass, which has been declining due to increased human activities, raising great concerns. Previous studies have identified various threats to seagrass, including heavy metal pollution, poor quality water, and so on. In this study, we investigate sources and levels of noise in seagrass beds and attempt to point out potential threats from noise pollution. A line array of six hydrophones was deployed over a period of seven days, from January 15 to January 21, 2024. The recordings captured various sounds from marine life, human activities, and natural processes. Biological sounds, such as fish sounds and whale calls, were the most prevalent. Low-frequency noise from wind and tide were often recorded. Xincun Bay hosts more than 1500 fishing vessels; however, due to bad weather conditions that kept most vessels docked during the recording period, only one segment of boat noise was recorded; it lasted for 7 minutes, exhibiting strong energy over a broad frequency band. This event underscores the necessity of long-term monitoring of noise to identify and evaluate not only boat noise but other noise sources, especially ones that are intermittent but strong, that were not encountered during the limited period of observation on which this report is based.

Keywords: seagrass; ambient noise; hydrophone; impulsive noise; boat noise; whale call

1. Introduction

Seagrasses represent the sole group of flowering plants that thrive underwater. Characterized by their green, grass-like leaves, these plants provide energy and oxygen through photosynthesis. Seagrasses are found in shallow coastal waters, spanning both temperate and tropical zones (Short et al., 2007). They can cover the seafloor densely, creating ecosystems referred to as seagrass *beds* or *meadows*. These meadows play an important role in global marine ecosystems by providing habitat and food for various marine creatures (Orth et al., 2006), facilitating nutrient cycling (Berlinghof et al., 2024), stabilizing sediments (Potouroglou et al., 2017), and sequestering carbon (Macreadie et al., 2014; Serrano et al., 2021; Fu CC et al., 2023). It is estimated that seagrass meadows sequester approximately 27.4 Tg of carbon annually, accounting for roughly 10% of estimated yearly organic carbon burial in the Earth's oceans (Fourqurean et al., 2012). However, both natural and anthropogenic factors have caused significant losses of seagrass, placing many seagrass species at risk of extinction (Orth et al., 2006; Waycott et al., 2009; Du JG et al., 2023).

Xinchun Lagoon, located in the southeast of Hainan Island, serves as a representative example of seagrass resources. This area encompasses a national seagrass nature reserve and is designated as a pilot site for the first-round implementation of the Blue Bay Remediation Action Plan (Fang X et al., 2021). Nonetheless, the seagrass populations in this lagoon have exhibited signs of decline, primarily due to increased pollution caused by human activity (Liu SL et al., 2017). Satellite images from 2016 to 2020 indicate a reduction of 79.224 hectares in the total seagrass area, a loss of 16.5% in those four years (Li YQ et al., 2022).

To safeguard seagrass beds, it is imperative to conduct regular, continuous monitoring. Traditional methods for surveying seagrass beds include field sampling, underwater photography, and satellite observations (Yang DT and Yang C, 2009; Li YQ et al., 2022); however, these approaches can be time-consuming and are often constrained by weather conditions.

In recent years, the significance of sound within ecosystems has

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received increasing attention (Krause, 2008; Pijanowski et al., 2011; Minello et al., 2021; Lin TH et al., 2021; La Manna et al., 2024). Soundscapes are recognized as a critical component of ecosystems, with the concept of noise pollution extending beyond the human world to encompass broader natural noises. The effects of noise on both fauna and plants are widely investigated (McCauley et al., 2017; Solé et al., 2021). Utilization of sound as a tool for ecosystems study, including evaluations of healthy status and monitoring of temporal changes, has gained popularity (Gumusay et al., 2019; Manik and Apdillah, 2020; Williams et al., 2022). In the domain of seagrass research, preliminary studies attempted to evaluate seagrass productivity through sound (Hermand et al., 2000; Felisberto et al., 2015). Several researchers have conducted numerical and laboratory experiments to establish a theoretical foundation for acoustic monitoring of seagrass (Jerome et al., 2023; Torres et al., 2023).

This study presents results from a hydro-acoustic survey conducted in the seagrass beds of Xincun Lagoon, located on Hainan island. This is the first attempt to measure ambient noise in this seagrass reserve. The objectives were to (1) identify sources of noise, (2) gain a preliminary understanding of the characteristics of each type of noise, and (3) provide some basis for further development of acoustic monitoring of seagrass in this area.

2. Study Area

Xincun Lagoon, a representative tropical coastal lagoon, is located in the southeastern part of Hainan Island (Figure 1a). The water area is about 22 km^2, with dimensions of about 6 km in width (east–west direction) and 4 km in length (north–south direction) (Figure 1b; Yang Y et al., 2017). The average water depth is around 4 m, with deeper areas located in the southwest, where the maximum depth is over 12 m (Gong WP et al., 2008). The lagoon supports highly productive ecosystems, including mangrove forests and seagrass beds, the latter predominantly found in the southern part, covering an area of 3.28 km^2 (Fang X et al., 2020). The seagrass species identified in Xincun Lagoon include *Enhalus acoroides*, *Thalassia hemprichii,* and *Cymodocea rotundata* (Shen J et al., 2023). Human activities in the lagoon are diverse, including net cage mariculture in shallow waters, urban sewage discharge, and tourism (Fang X et al., 2021). As a significant fishing port in Hainan, Xincun bay accommodates over 1500 fishing vessels (Shen J et al., 2023). Increasing human activity has led to environmental degradation, posing a threat to the seagrass ecosystem (Liu SL et al., 2017; Zheng J et al., 2018; Zhang L et al., 2021; Chen SY et al., 2022).

3. Sound Recording

To investigate the ambient noise of the seagrass bed, six SH-I mode hydrophones were deployed in the seagrass zone. These hydrophones have sensitivity of −160 dB (referenced to 1 V/μPa), frequency bandwidth ranging from 1 Hz to 20 kHz, and dynamic range of 120 dB. The depth of the study site is about 1.2 m. The configuration of the hydrophones during data collection is illustrated in Figure 1c; six hydrophones numbered 5 to 10, spaced approximately 3.125 m apart, were inter-connected through a single cable that was supported by three buoyant spheres hung in the front, middle and back parts of the cable. This hydrophone

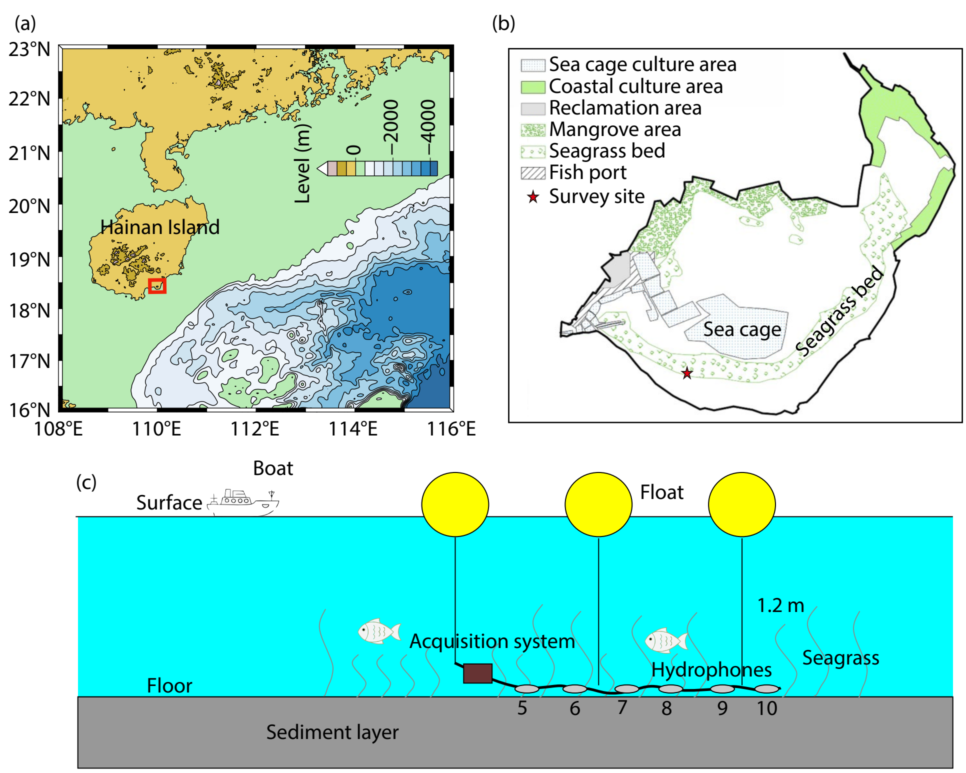

Figure 1. Overall information regarding the monitoring experiment. (a) Background setting of the monitored site. (b) Human activities and shallow water ecosystems around the monitored site; modified from Fang X et al. (2020). (c) Configuration of the hydrophone array.

array was anchored on the water bottom. Continuous data recording with a sampling frequency of 2000 Hz commenced on January 15, 2024, at 18:00 and concluded on January 22, 2024. Raw amplitudes were measured in μV. A gain of 20 dB was applied; however, upon data retrieval this was found to be excessive. Raw data retrieved from the hydrophones were converted into the Seismic Analysis Code (SAC) format prior to analysis.

4. Hydro-acoustic Data Analysis

The raw amplitudes without instrument correction were analyzed primarily using Matlab software. We first scanned all data to gain a preliminary sense of the recorded events and to evaluate data quality. The raw recordings revealed a very noisy environment throughout the recording period. Significant amplitude clipping was observed in many instances (Figure 2a). The clipped waveforms were not further analyzed by spectral methods. Although some variations were observed (Figure 2b), the recordings from different hydrophones exhibited considerable similarity (Figure 2c), which was anticipated given that the maximum distance between hydrophones was less than 20 m; consistency of events across the hydrophones confirms the reliability of the recordings.

The raw data were segmented and transformed into one-hour-long mat-format files. First, we manually identified and picked events of interest by visual inspection of the data. Next, we calculated Fast Fourier Transform (FFT) spectrum and spectrograms to extract frequency content. The FFT spectrum was calculated from 1024 samples, while the spectrograms were produced using 2048 sample FFTs with a 512 sample overlap, yielding a spectral resolution of approximately 1 Hz. By integrating the waveform characteristics, frequency contents, and spectrograms, we identified manually the varying natures of the recorded events and then performed more precise classifications.

5. Results

Marine sounds are divided into three distinct categories (Krause, 2008; Erbe et al., 2015; Duarte et al., 2021; Vieira et al., 2021): biophony (the sounds produced by living organisms, such as whales, dolphins, fish and crustaceans), anthrophony (human-generated sounds, including those from ships, offshore drilling and seismic survey), and geophony (sounds resulting from physical events, such as wind, waves, and ice-break). We use these categories to present the results of our analysis.

5.1 Biophony

Visual inspection of the time series data reveals a predominance of impulsive noise within the sound field, as demonstrated by both the 24-hour recording (Figure 2a) and the one-hour-long recording (Figure 3a). *Impulsive noise* here refers to the sounds of short duration (approximately 1 to 2 seconds) and sudden high amplitudes, manifested as isolated pulses. This type of noise is characterized by a weak precursor signal, then a pronounced peak, followed by a series of amplitude decays (Figure 3c). The impulsive noises in our data concentrate the energy mostly in the 0–100 Hz range (Figure 3b) and exhibit two narrow peak frequencies, approximately 25 Hz and 50 Hz (Figure 3d). Such impulsive noise is interpreted as fish sound (Tricas and Boyle, 2014; Mouy et al., 2023; NOAA, 2023). The widespread fish sound recorded by our hydrophones could be attributed to the proximity of mesh-cage mariculture. However, impulsive noise from other events, such as small crustaceans, sensor hits, or substrate movement,

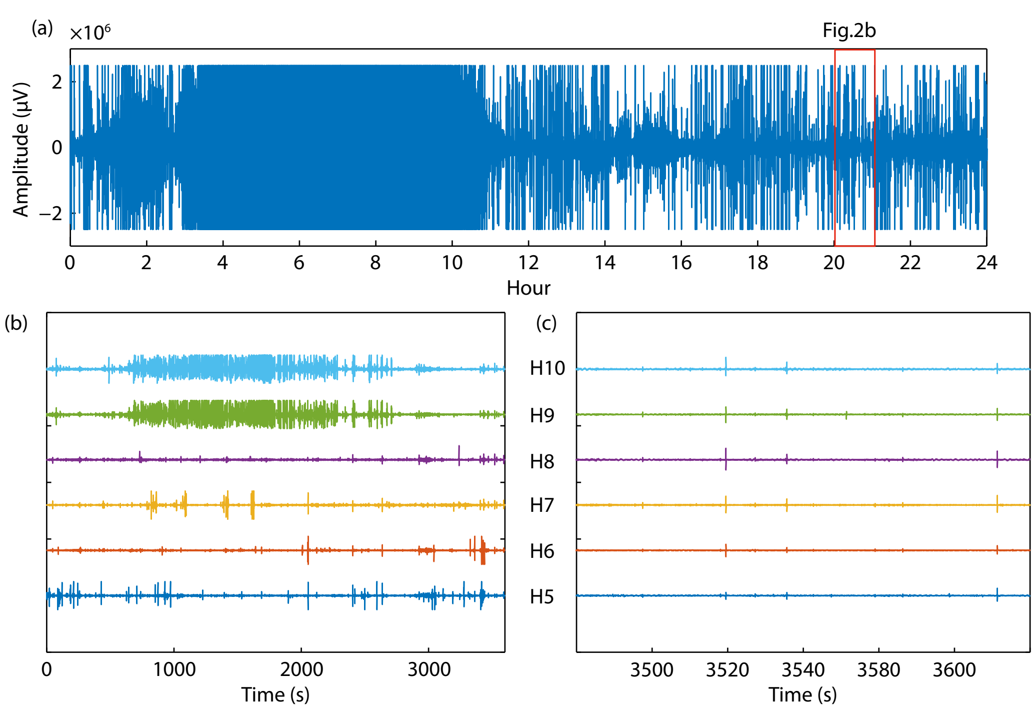

Figure 2. Raw recordings. (a) A 24-hour recording with instances of amplitude clipping. (b) One-hour-long recordings from six different hydrophones. (c) One-minute recording from six different hydrophones, highlighting the impulsive nature of the recordings.

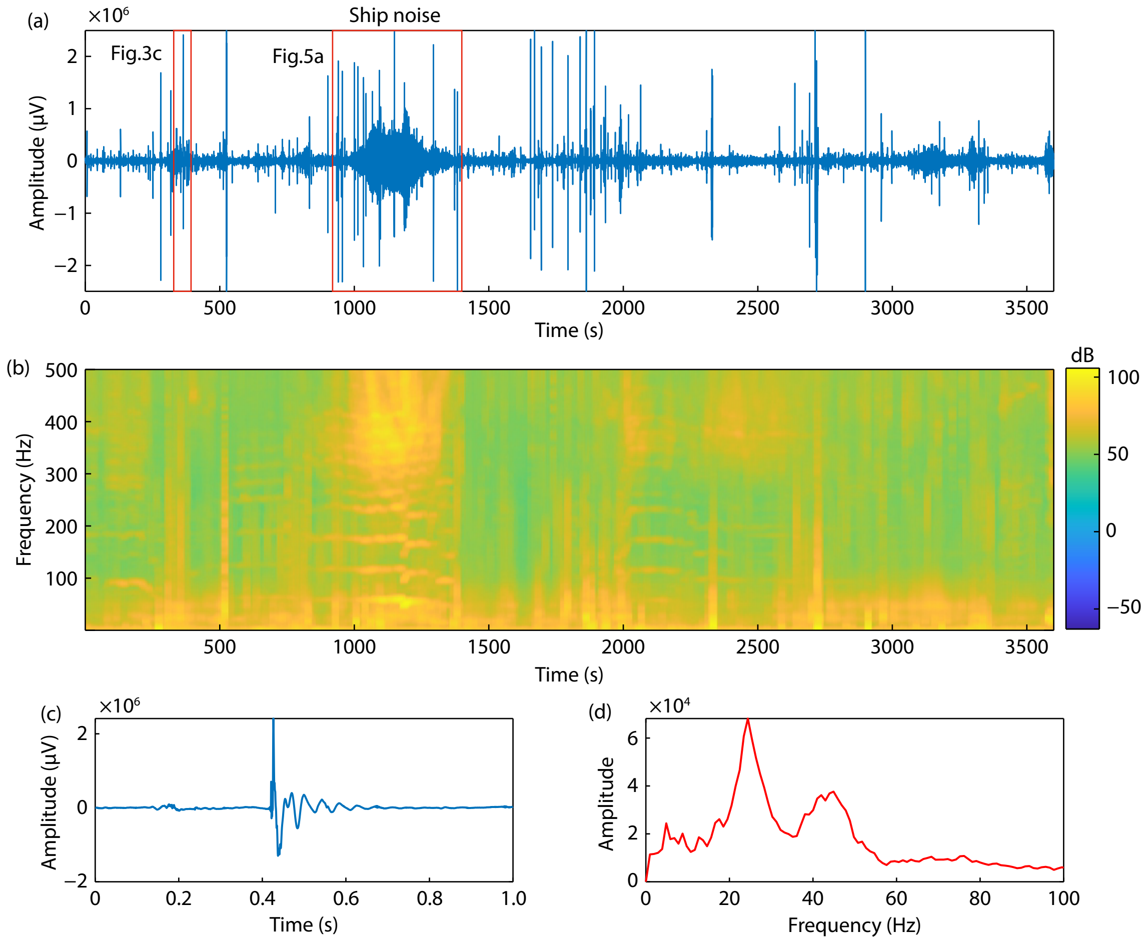

Figure 3. Fish sounds. (a) One hour long recording that contains wide-spread impulsive noise; (b) spectrogram of (a). (c) One segment of fish sound; (d) its corresponding spectrum.

cannot be completely ruled out.

Additionally, potential whale calls are prevalent in the recordings of January 18 (Figure 4a). The intervals between calls appear to be relatively regular (Figure 4c). The pattern of the spectrogram (Figure 4b) is similar to that of whale calls observed in other areas (Tran et al., 2014). A single call lasts approximately 40 ms (Figure 4e), and is characterized by a narrow frequency band with dominant frequency around 800 Hz (Figure 4g); this frequency content differs from whale sounds previously documented in the South China Sea (Dong LJ et al., 2023). For comparative purposes, a recording of a Pacific blue whale's call is used, sourced from the library of animal vocalizations maintained by the Cornell University Bioacoustics Research Program. (This recording is accessible within the Matlab database and can be directly imported into the Matlab environment.) The audio data is sampled at 4 kHz. The Pacific blue whale call is similar to our recordings: it lasts about 40 ms (Figure 4d) and exhibits a noticeable peak at around 900 Hz (Figure 4f). Given these similarities, it is plausible to assert the presence of whale calls in our recordings. Nevertheless, dolphin vocalizations cannot be ruled out. For example, some low frequency vocalizations with peak frequencies near 990 Hz have been documented in recordings of bottle-nose dolphins (Simard et al., 2011).

5.2 Anthrophony

Noise radiated from ships is very common; it contributes sgnificantly to ambient noise in the ocean. As the number of ships increases, noise produced by ships, particularly in the low frequency band (<1000 Hz), becomes the predominant source of ocean noise in many locations. In shallow waters, where the presence of large vessels is unlikely, small boats are prevalent. Small boat noise is reliably identified in our recordings through the shapes of waveforms and the spectrograms. The waveform of boat noise typically appears in hydrophone recording (Figure 5a) as an oval shape, caused by variations in the distance between the boat and the hydrophone. These spectrograms feature numerous narrow band components alongside a broadband background (Figure 5c). The narrow band components are attributed to the boat's engine and drive train; the broadband energy is speculated to be dominated by propeller cavitation. The broadband background appears as a bathtub-like shape (McKenna et al., 2012); also evident is a Lloyd's mirror pattern, indicative of multi-path interference. The power spectral density (PSD) of the boat noise in our data is concentrated primarily below 800 Hz (Figure 5b). The rareness of boat noise in our data could be attributed to the poor weather conditions during our recording period, which kept most boats anchored in the harbor.

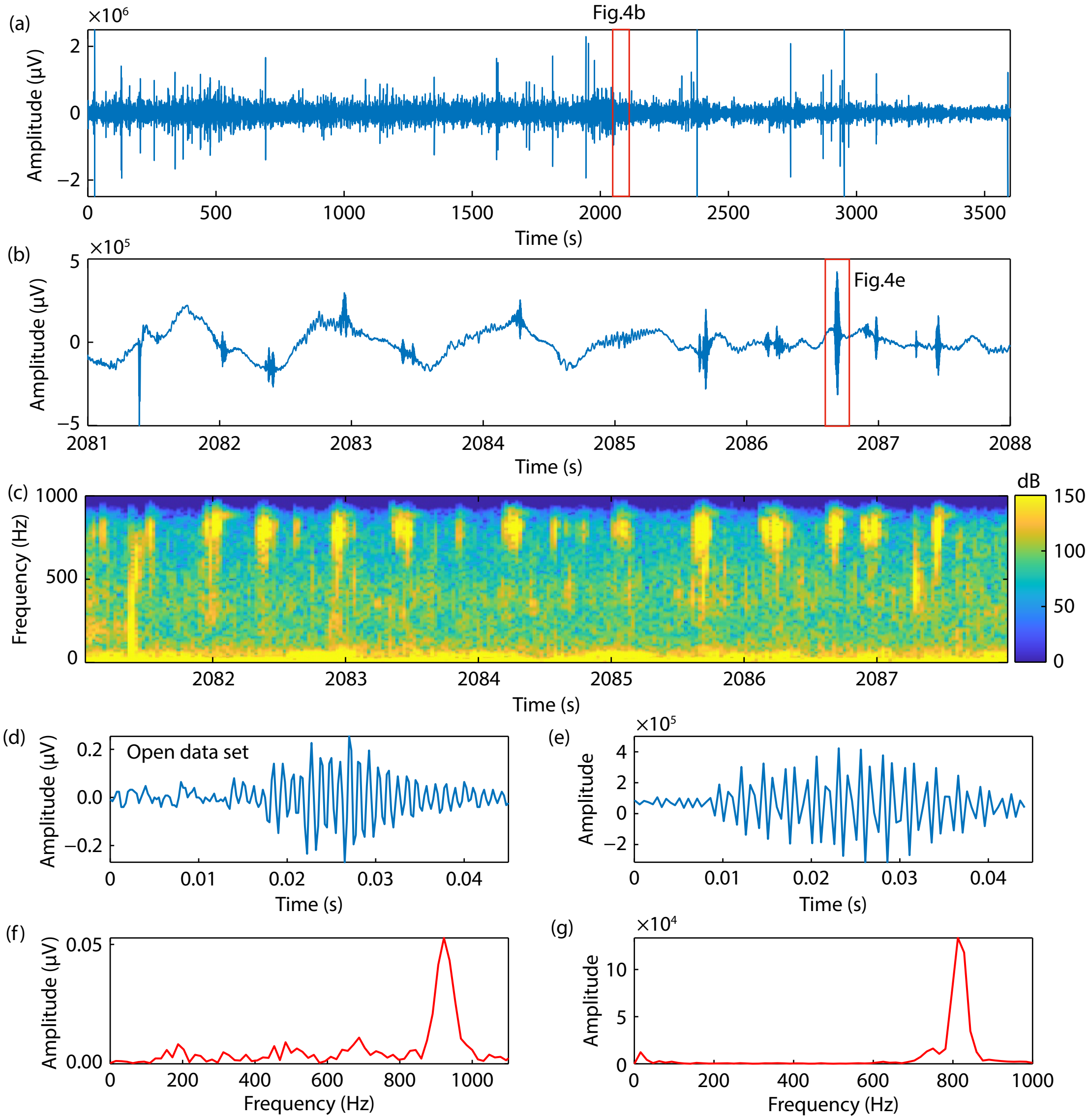

Figure 4. Whale calls. (a) One-hour long waveform. (b) Zoomed views of segments of the recording and (c) spectrogam of (b). (d) Whale song from a Pacific blue whale (from data stored in the Matlab database under the filename "bluewhale.su") and (f) spectrum of the Pacific blue whale song (d). (e) Whale song from our recording and (g) spectrum of the whale song (e).

5.3 Geophony

Geophony has a significant influence on soundscapes. Within the low frequency range, water current noise is the predominant contributor. Both wind and tide can alter currents around the hydrophones and buoys. Current-induced noise is characterized by a long-lasting harmonic waveform with a dominant frequency of around 1 Hz (Zali et al., 2023). Xincun Bay, which is connected to the open sea via a narrow channel in the southwest, experiences significant tidal effect. The tides in this area are classified as mixed semi-diurnal, with an annual tidal range of 1.34 m (Chen SY et al., 2022). Additionally, weather conditions during the experiment period were bad, with strong winds that persisted over the waters. Both tidal and wind forces contributed much current-induced noise that is observed frequently throughout the recordings (Figure 6a, b). This current-induced noise is represented by a harmonic waveform (Figure 6c) with a dominant frequency of 0.8 Hz (Figure 6d). Another type of low frequency noise is also frequently observed throughout the recordings (Figure 7a, b). It lasts approximately 2 seconds and is characterized by a broad trough (Figure 7c), with a dominant frequency around 2 Hz (Figure 7d). This noise is of shorter duration and features higher frequencies than the current-induced noise; we interpret it as hydrophone self-mooring sounds increased by tidal flow (Vieira et al., 2021).

6. Discussion

6.1 Ambient Noise Field of Xincun Seagrass Bed

Numerous studies have shown that sounds can indicate the presence and strength of particular ecosystems (Lin TH et al., 2021; Minello et al., 2021; Williams et al., 2022; La Manna et al., 2024). In the context of marine ecosystems, such as seagrass beds and coral reefs, acoustic monitoring may be useful in achieving three

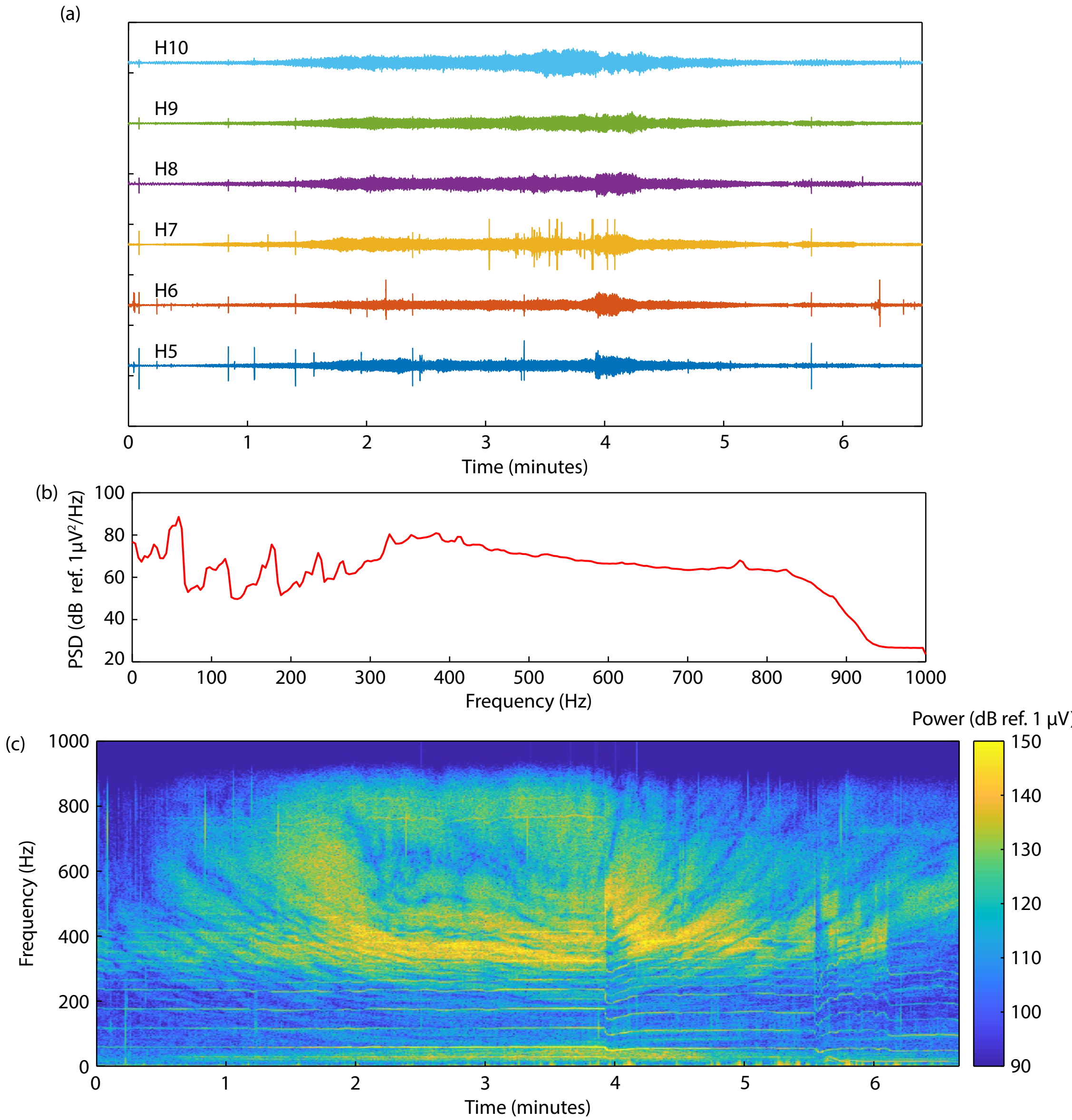

Figure 5. Small boat noise. (a) Time series of boat noise recorded by different hydrophones. (b) Power spectral density from the Welch method. (c) Time frequency spectrum computed with the short time Fourier transform. The spectrogram was computed with the Matlab function spectrogram.

primary objectives: (1) to evaluate overall health, (2) to estimate quantitatively some critical parameters, and (3) to assess effects of noise on a particular marine ecosystem. The underlying hypothesis of this acoustical methodology is that noticeable differences exist between soundscapes of healthy and degraded ecosystems. For example, a thriving coral reef system is likely to support a diverse array of marine life, resulting in a rich acoustic environment (Ferrier-Pagès et al., 2021), whereas a deteriorating coral reef system may exhibit notable absences of some sound patterns. In addition to these qualitative assessments, soundscape ecologists have proposed a number of quantitative indicators, including the Acoustic Complexity Index (ACI), Acoustic Diversity Index (ADI), Normalized Difference Snow Index (NDSI), and Acoustic Entropy Index (Bradfer-Lawrence et al., 2019; Alcocer et al., 2022). These qualitative indicators are calculated from sound recordings and are widely used in ecosystem studies.

Regardless of the specific purposes or methodologies employed, their success hinges on a good understanding of the *noise* present, and on careful separation of ecosystem sounds from sounds unrelated to the ecosystem. Thus, identification of *types* of noise found in any study location is of great importance. Despite publication of several case studies addressing the noise field in the seagrass zone (Felisberto et al., 2014, 2016), knowledge remains limited due to the scarcity of field recordings. The complexity and variability of shallow water sound make this issue more complicated, as shallow water environments are characterized by a multitude of sound sources, including surface waves, wind, rain, marine fauna, and human activities. For instance, in the Cassivo study, the ambient noise was initially attributed to the

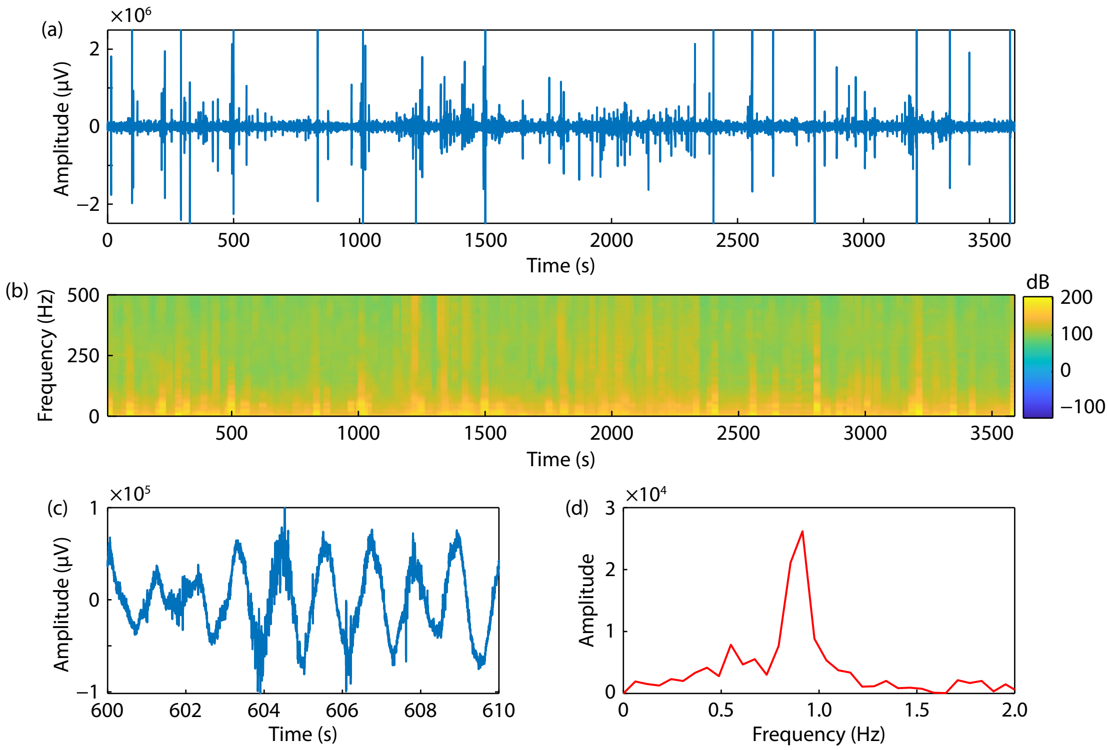

Figure 6. A one-hour long recording that contains current-induced wave noise. (a) Amplitudes. (b) Time frequency spectra. (c) A zoomed segment of current-induced wave noise amplitudes. (d) Frequency spectrum of the current-induced wave noise amplitudes in (c).

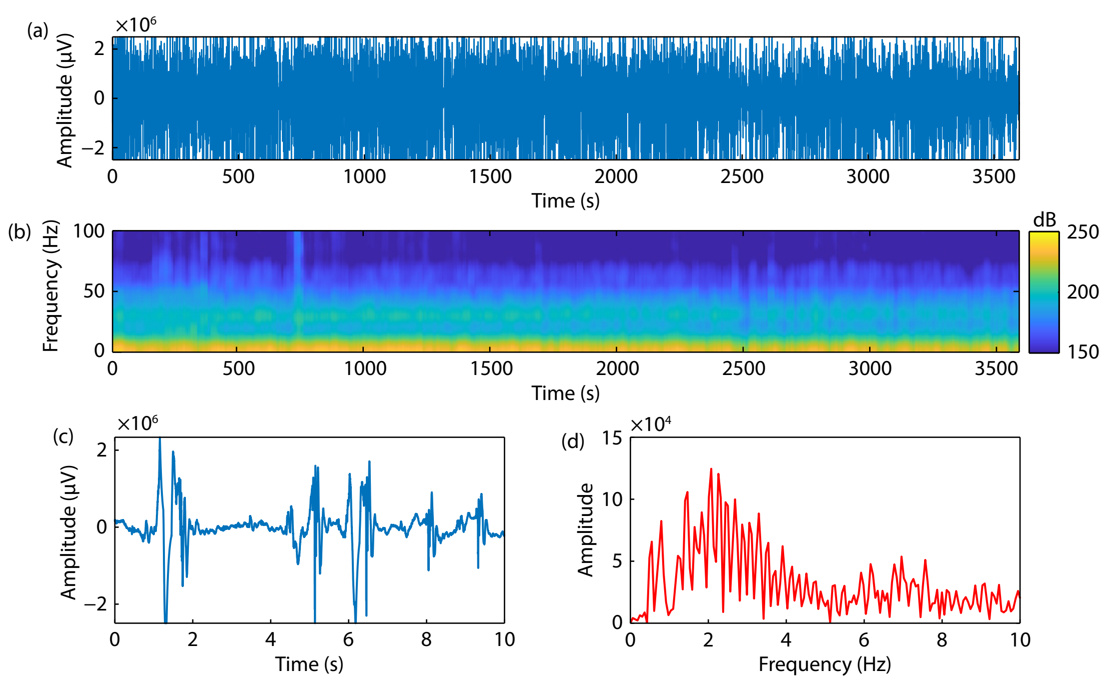

Figure 7. A one-hour long recording that contains tide-induced hydrophone self mooring noise. (a) Noise amplitudes. (b) Time frequency spectrum. (c) A zoomed segment of hydrophone self mooring noise amplitudes. (d) Frequency spectrum of the hydrophone self mooring noise amplitudes in (c).

seagrass bubble process, and the average PSD was related to the oxygen concentration (Felisberto et al., 2015). However, in subsequent work, researchers concluded that the ambient noise field is dominated by impulsive noise, which resembles the sound produced by snapping shrimp or shellfish (Felisberto et al., 2016). Our study area, too, exhibits a complex and diverse soundscape, including contributions from biophony, geophony, and anthrophony. Noise of different origins differ significantly in amplitude, frequency, and duration time. Impulsive noise generated by fish or other events has the largest amplitudes and the shortest duration times (Figure 3a). This type of noise occurs frequently. Considering that the possible seagrass-related noise has similar impulsive nature, we anticipated that the most difficult part of this study would be to identify seagrass-related noise in the recordings. Ship (boat) noise has relatively smaller amplitudes than impulsive noise (Figure 3a and Figure 4a). It is characterized by distinct oval shapes in the time domain and stripe patterns in the time-frequency domain (Figure 4b), which makes it unlikely to disrupt the identification of target noise. However, ship noise may pose severe threats to the seagrass ecosystem, as will be discussed below.

When we consider the types of noise, one limitation of this work pertains to the low frequency nature of the hydrophone employed. Besides low frequency noise, in shallow waters there is also much high frequency noise. For example, snapping shrimp produce noise by rapidly closing their snapper claws at an extremely high speed (Versluis et al., 2000); this noise ranges from tens of Hz to over 200 kHz (Au and Banks, 1998). To fully record the shallow waters noise field, broad band hydrophones are needed.

6.2 Potential Impact of Small Boat Noise on Seagrass

The potential of noise to have negative effects on marine animals, particularly marine mammals, has garnered increased attention. It is now widely acknowledged that underwater noise can impede communication, harm hearing, and alter vocal behaviors (Hatch et al., 2012). The impact of noise on marine flora, however, has received less attention, largely due to the assumption that plants lack auditory sensory mechanisms. However, some studies that elucidate negative effects of noise on plants have emerged in recent years. For instance, research indicates that seismic surveys can cause significant mortality to zooplankton populations, with effects extending up to 1.2 km (McCauley et al., 2017). Additionally, a controlled experiment has demonstrated that seagrass experienced morphological and ultra-structural changes after exposure to sound, and its nutritional processes were also affected (Solé et al., 2021). These pilot experiments have been one of the drivers of recent interest in surveying the ambient noise in the Xincun seagrass nature reserve.

As in our study case, the underwater world is very noisy. Among the various noises that may be harmful to marine life, boat-generated noise is of particular concern. Four key factors contribute to the potential detrimental impact of boat noise: (1) the pervasive nature of boat noise, which predominates in the ambient noise field, particularly in the low frequency band (<1000 Hz); (2) the long duration of boat noise; (3) the strong energy associated with boat noise; (4) the broad frequency range of boat noise. During our survey, we recorded a single segment of boat noise, which was notably loud and lasted for 7 minutes. As mentioned, this rarity of boat noise in our recordings can be attributed to bad weather conditions that kept boats in the harbor. Given that Xincun Lagoon accommodates over 1500 fishing vessels and numerous tourist boats, it is clear that the study we present here collected inadequate data to give any meaningful measure of the impact of ship noise on marine flora in the study location.

While controlled laboratory experiments indicate potential harm, specific effects of noise on seagrass in natural and wild environments remain uncertain. It is unclear how long it may take to collect sufficient observations to estimate with acceptable accuracy the impact of ship noise on seagrass growth. Future research is necessary to address these questions, not only long term monitoring of ship noise but also integration of acoustic observations with underwater photography and field sampling.

7. Conclusion

Several hydrophones were deployed to survey the ambient noise in a shallow water seagrass bed located in Xincun Lagoon, Hainan Island. This survey represents the first attempt to investigate potential threats posed by noise pollution to seagrass beds in this region. The data presented here indicate that the shallow water environment is characterized by high levels of noise from various sources, including biophony, geophony, and anthrophony. Among these, ship noise is identified as wide-band noise with high energy and long duration, raising significant concern regarding the impairment of seagrass due to this loud noise.

This preliminary survey of ambient noise within this particular shallow water seagrass region provides a valuable demonstration dataset that reveals the complex and diverse nature of its soundscape. We suggest that the dataset and analysis presented here will be useful to the design of a practical acoustic approach to future monitoring and evaluation of seagrass ecosystems.

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Data Availability Statement

Datasets associated with this research can be obtained by contacting the corresponding author upon reasonable request.

Conflict of Interest: Authors declare no conflict of interest.

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