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ACOUSTIC MULTI-COMPONENT MONITORING OF ECOSYSTEMS: TRAINING FOR MANGROVES' CONSERVATION IN AFRICA

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ABSTRACT

Mangrove ecosystems are critical habitats that provide a diversity of ecological services. Societal and economic sustainability of populations living with mangroves rely on health of those ecosystems, through fishing activities and extraction of firewood, material to build houses, furniture and fishing gear. A knowledge-based support to policy decisions and identification of appropriate interventions for conservation and restoration of ecosystems is needed, including education and training of young generations. We describe the experience of a training course for the installation and management of an observing station for the monitoring of the soundscape. For the first time, a system for monitoring the acoustic field in air, soil, and water has been installed in Inhaca (Mozambique) to provide clues on the mangroves' ecosystems. The potential of operational acoustic measurements, as well as protocols for training and managing observing stations for conservation and protection of the environment, are provided. By integrating acoustic measurements into conservation efforts, the station not only advances ecological monitoring but also acts as a key resource for local communities and schools, fostering environmental education and empowering stakeholders in the protection and sustainable management of mangroves. The experience highlights both the potential and challenges of leveraging soundscape data for environmental stewardship.

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1. INTRODUCTION

Mangroves are intertidal habitats, occurring in the sub-tropics along sheltered and shallow-water coastlines [1]. There are important ecosystems that provide goods and services for coastal environments, communities and society as a whole [2-4]. Above the water, the mangrove trees and canopy provide an important habitat for a wide range of species, including birds, insects, mammals and reptiles. Below the water, the mangrove roots are overgrown by epibionts such as tunicates, sponges, algae, and bivalves [1]. Despite being among the most productive ecosystems, mangrove forests have historically been undervalued, and their area has been reduced due to poor management and increasing demand for coastal lands for development [3; 5]. Thus, it has been a high priority for the global community to arrest mangrove loss and restore degraded mangrove ecosystems, and the Knowledge-based approach has been an important support to policy decisions and the identification of appropriate interventions for the conservation and restoration of these ecosystems.

Education and training programs of mangrove ecosystems are held worldwide, to understand all the aspects of the structure and function of mangroves, as well as their biogeographical affinities and their conservation and management, which is important to have a considerable knowledge of the species composition and ecology [1-2]. These educational programs are to guide and equip the local communities with the basic technical know-how and skills for conserving, managing and rehabilitating mangroves in their areas.

In Mozambique, the Sapienza - University of Rome, in collaboration with Eduardo Mondlane University, launches an annual Intensive Summer School Course "ManGrowth - Preservation of Ecosystems for Sustainable Development." The course is promoted and funded by the Italian Agency for Development Cooperation, as part of the ManGrowth Project (Preservation of Ecosystems for Sustainable Development – AID 012432/01/2), which focused on the importance of mangrove forests as an essential ecosystem to promote the sustainable development of coastal areas, the mitigation of the effects of climate change and the conservation of animal and plant species that are linked to them by their life cycle.
In this context, as part of the technical training and capacity building for young researchers, two low-cost bioacoustics stations were installed. Sounds from the air, soil, and water were recorded to monitor the soundscape made by the living organisms that occur in the mangrove ecosystems and their behavior due to the floatation of tides and day season into the mangrove. The use of bioacoustics as a biomonitoring tool allows us to understand what the ecosystem's dynamics can tell about the habitat's health, which may aid in monitoring the success or progress of ecosystems restoration and conservation [6-8].

2. THE TRAINING APPROACH

The training course was focused on soundscape ecology. Soundscape ecology is the integration of geophysical, biological and anthropogenic sounds that fill an ecosystem and which vary over space and time [9]. It has recently emerged as an interdisciplinary scientific field that investigates the acoustic field in relation to ecological processes. In this context, the training course tested in mangrove ecosystems an innovative instrumental set-up aimed to use multi-component observing stations of the biosphere for the identification of emergent properties of the status of the ecosystems.
The design and development of the training course was mainly guided by a "learning by doing" approach. Frontal teaching on fundamentals of acoustics, signal treatment, specifications and calibration of instrumentation, concepts of measure, sensitivity and bits were provided. Students were involved from the beginning in a co-decision process for the identification of locations for the observing stations and the adjustment of the parameters of the instrumentation. Students were also divided into sub-groups for the responsibilities of recharging the batteries, inspection of the functioning of the instrumentation, data analysis.

Figure 1. Training session on the field: first concepts of bioacoustics and instrumentation used (Photo by Enrico Nicosia).

Every day, an early morning briefing and a post-dinner reflection meeting were implemented to plan activities and further developments. The duration of the course was a whole week and was included in a one-month summer school (see the acknowledgements for further details), with a final report to be delivered [10], and an extension of 4 more days for the collection of additional data.

3. THE EXPERIENCE IN INHACA

3.1 Study Area

Inhaca Island (Mozambique) is a 40 km² island with diverse ecosystems, including coastal forests, mangroves, and seagrass meadows. Two bioacoustics monitoring stations were set up: one near the Inhaca Marine Biology Station and another at Ponta Rasa. The island experiences a tropical climate with distinct wet and dry seasons. Inhaca has semidiurnal tides, crucial for both ecosystem dynamics and study design. Stations were installed during low tide to ensure accessibility and reduce equipment damage.

3.2 Equipment and Setup

To ensure effective acoustic monitoring that captured the full range of environmental sounds, the recording system was designed with a combination of hydrophones and microphones, strategically positioned in air, water, soil, and intertidal zones. At the core of the setup was the Zoom P4 PodTrak recorder, powered by reliable power banks to maintain continuous operation in the field [10].

Figure 2. Study area: this is an overview of the second station at Ponta Rasa, which was very close to a channel with continuous water flow from the sea to the internal areas (Photo by Augusto Nhampossa).

Special attention was given to installation to minimize environmental interference. Microphones were shielded to reduce wind noise, while hydrophones were carefully anchored to ensure constant submersion. Additionally, all equipment was securely mounted to prevent accidental disturbances that could affect data quality.

Figure 3. Setup of the acoustic stations: cables needed to be accurately positioned in order to avoid contact with water or movements that could give biased sounds in the recordings (Photo by Enrico Nicosia).

3.3 Data Collection

Recordings were conducted from October 1–8, 2024. Data were collected in segments of 3h22min53sec, and a further selection or shorter time intervals allowed a smooth processing for later analysis [10].

Figure 4. Hydrophone hung on the roots in order to be outside of the water with the low tide and submerged with the high tide (Photo by Enrico Nicosia).

Figure 5. Recorder: as inputs, we used one microphone for air and three hydrophones for water and soil (Photo by Aura Rapino).

3.4 Challenges and Solutions

Several environmental factors posed challenges during the study. The muddy terrain made installation difficult, requiring careful planning and teamwork to position the equipment properly. Ensuring a stable power supply was also crucial, and the use of power banks provided a reliable solution for uninterrupted monitoring and silent generators [10].

Wind interference was another challenge, necessitating adjustments to microphone shielding to reduce background noise. The placement of hydrophones required particular attention as well, as maintaining continuous submersion was essential for accurate data collection. Additionally, managing the large volume of data was a key consideration, with daily recordings reaching approximately 30 GB, making efficient segmentation necessary to facilitate analysis [10].

Figure 6. Microphone hung on a higher branch in order to record air sounds, covered to avoid disturbance from wind and rain (Photo by Enrico Nicosia).

3.5 Recommendations

For future monitoring efforts, conducting a preliminary site assessment can help identify potential challenges and optimize equipment placement. Ensuring secure installations is also essential to minimize environmental and human disturbances. Combining acoustic monitoring with additional sensors, such as anemometers, thermometers and camera traps, can provide a more comprehensive understanding of environmental dynamics. Ultimately, bioacoustics monitoring proves to be a cost-effective and valuable tool for mangrove conservation, offering critical data for assessing ecosystem changes and informing management strategies.

4. CONCLUSIONS

This study highlights the feasibility of monitoring mangrove ecosystems using accessible and cost-effective acoustic techniques. By capturing variations in soundscapes, passive acoustic monitoring provides valuable insights into biodiversity, habitat health, and ecosystem dynamics. However, to fully harness its potential, future research should focus on refining methodologies, expanding monitoring efforts, and establishing standardized protocols for long-term ecosystem assessments.

One key avenue for development is the identification of reliable acoustic indicators that reflect the state of the ecosystem. Distinctive sounds produced by organisms such as crabs, shrimps, fish, and insects, as well as abiotic elements like bubbles and water flow, could serve as bioacoustics markers for assessing habitat quality and ecological changes. Creating archives of reference signals would be instrumental in building a comparative framework, enabling researchers to detect shifts in species composition, human-induced disturbances, or natural seasonal variations.

Mozambique, with its vast coastal and wetland habitats, presents a significant territorial opportunity for expanding acoustic monitoring beyond the initial study site. Establishing a network of monitoring stations across key mangrove regions could provide large-scale, long-term datasets, supporting conservation strategies at both national and regional levels. Scaling these efforts across other African coastal ecosystems could contribute to a continent-wide initiative aimed at protecting critical biodiversity hotspots using non-invasive, technology-driven approaches.

Beyond scientific applications, fostering community engagement is essential for the success and sustainability of bioacoustics monitoring. Training a new generation of “guardians” and citizen scientists—including local fishers, students, and conservationists—can promote widespread participation in data collection and habitat protection. Educational programs, field workshops, and accessible training materials could empower local communities to take an active role in conservation, bridging the gap between research and real-world impact.

The integration of social media and web platforms could further enhance outreach and collaboration. By sharing acoustic recordings and findings through digital platforms, or common devices such as mobile phones, researchers can engage a wider audience, increase public awareness, and facilitate knowledge exchange between scientists, conservationists, and the general public.

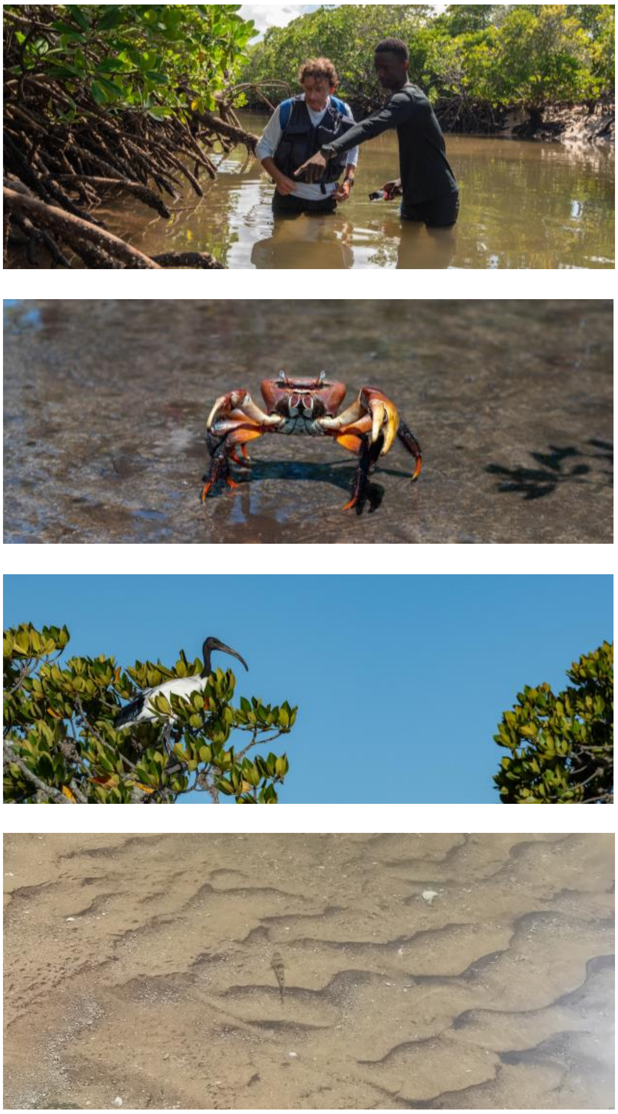

Figure 7. During the field stations, different species where observed in the ecosystem. From top to bottom: crabs, birds, fish (Pictures by Enrico Nicosia and Pier Francesco Moretti).

Open-access databases for bioacoustics data sharing could also help create global repositories of environmental sounds, supporting comparative studies and collaborative research initiatives. Furthermore, the user-friendly, low-cost nature of this system makes it easy to handle and accessible for widespread implementation, ensuring that local communities and researchers can adopt it with minimal technical barriers. Strengthening methodologies, expanding research networks, and engaging local communities will ensure that these efforts contribute to the long-term sustainability of coastal environments. This study serves as a foundation for future bioacoustics monitoring initiatives, demonstrating the potential of soundscape analysis in environmental conservation.

In conclusion, bioacoustics has the potential to become a powerful tool for mangrove conservation, blending science, technology, and community participation. Strengthening methodologies, expanding monitoring networks, and integrating digital tools can significantly enhance our ability to assess and protect these critical ecosystems for future generations.

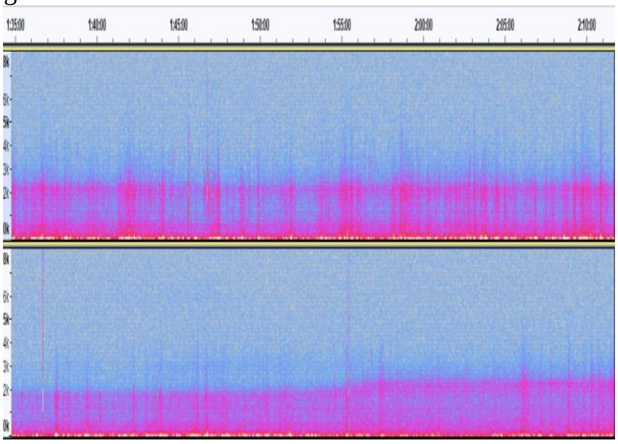

Figure 8. Spectrograms of two selections of approximately 35 minutes of data from the hydrophone hanging on the roots (partially in air and partially in water). Low and high tide cycles are clearly visible, as well as differences in the intensity and variety of sounds, that needs further analysis. Spectrograms are obtained through Audacity® ver. 3.6.4 [11], white and reddish colors refer to more powerful signals.

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