Identifying acoustic indices of oyster reef health

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ABSTRACT

Oyster reefs provide habitat, breeding grounds, and food for a number of organisms, many of which are sound producing. Currently, oyster reefs are declining, and traditional monitoring methods are time consuming, labor intensive, and invasive. Passive acoustic monitoring (PAM) is less invasive, takes less time, and requires less labor than traditional monitoring methods, such as benthic habitat tray sampling. Additionally, PAM has great potential for detecting sound-producing organisms, and acoustic indices could provide essential information on the health and biodiversity of an oyster reef and its surrounding area. However, acoustic monitoring in marine environments is relatively new and knowledge is lacking compared to terrestrial systems where passive acoustic monitoring is widely used. Here, we determine if acoustic indices are an accurate representation of oyster reef health and biodiversity across two basins in Louisiana. We compared sound pressure levels in several frequency bands (20-2000 Hz,1-10 kHz, and 20 Hz – 48 kHz) and several acoustic complexity indices to biodiversity estimates generated through a traditional sampling technique, benthic habitat trays. Some acoustic indices are promising, but relationships across basins are different. These results provide the first set of evidence that will allow us to determine if acoustic monitoring and acoustic indices can be used as an indicator of biodiversity and health of oyster reefs.

INTRODUCTION

Oyster reefs provide habitat, breeding grounds, and food for a number of sound producing organisms (Breder 1968, Fish and Mowbray 1970, Lillis et al. 2017). Not only are they an essential habitat for the organisms they house, but they provide a number of services for mankind (La Peyre et al. 2014). Healthy oyster reefs are essential for the economy and culture of Louisiana; they stabilize shorelines, improve water quality, and provide support for many economically important species and other reef-associated biodiversity. Oyster reefs are declining due to anthropogenic activities, subsidence, climate change, and increased frequency of extreme weather events; this decline in oyster reefs is changing the shape and stabilization of the Gulf Coast recreational and commercial fish harvests. Our current monitoring methods for oyster reefs are time consuming, labor intensive, and invasive and can often lead to damage and further stress on already unstable reefs. An alternative monitoring method, passive acoustic monitoring (PAM) is used most commonly in terrestrial systems and it has yet to be studied in depth and more commonly utilized in marine environments (Marques et al. 2013, Ladich and Winkler 2017, Staaterman et al. 2017, Bradfer-Lawrence et al. 2019, Francomano et al. 2020). Passive acoustic monitoring is less invasive, takes less time, and requires less labor than traditional monitoring methods, such as benthic habitat tray sampling. PAM can be used to measure biodiversity through many calculated indices (Dimoff et al. 2021). For this study, we focused on the following indices: Acoustic Complexity Index (ACI), Sound Pressure Level (SPL), Events, Entropy, and Normalized Difference Soundscape Index (NDSI). We define the following indices as:

Acoustic Complexity Index: An index that measures variability in sound intensity: high ACI values are produced by large variations in sound intensity (Pieretti et al. 2011).

Sound Pressure Level: How loud the sound is in decibels (Merchant et al. 2015).

Events: Acoustic events (distinct short-duration increases in sound intensity) per minute in each noise-reduced frequency bin (Towsey 2017).

Entropy: A normalized index of sound energy across frequency bands within a time step (Towsey 2017).

Normalized Difference Soundscape Index: A ratio of sound pressure level in two frequency bands: one associated with biophony (animal-produced sound) and the other associated with anthrophony (man-made noise) to determine which is dominant (Rajan et al.2019).

METHODS

Hydrophones and benthic trays were deployed across two bays in Louisiana (Figure 1): Calcasieu Lake and Terrebonne Bay. Calcasieu Lake had hydrophones deployed in the Summer (June 21-23, 2022), and Terrebonne Bay had hydrophone deployed in both the Spring (April 5-7, 2022) and the Summer (July 8-11, 2022). There were three sites within each bay, two reef sites and one control (mud) site. Hydrophones were set to the high gain setting with a sampling frequency of 48 kHz and recorded continuously for a period of 48 hours, and benthic trays soaked for a period of two weeks. The hydrophones were placed in the middle of the set of benthic trays at each site and recorded for the 48 hours preceding the collection of the benthic trays to best match the acoustic and benthic tray samples. After retrieval, benthic trays were processed and species richness from benthic trays was compared to SPL and the acoustic indices described above from the recordings collected by each hydrophone. We manually reviewed hydrophone data for the acoustic signatures of the sound producing organisms that were found in the benthic trays: snapping shrimp and eastern gulf toadfish. The manual review also included noting incidences of rain, wave, and boat noises. From our recordings, we calculated the acoustic indices and created false colored spectrograms through R and R-Studio (version 4.1.0, R Core Team 2021).

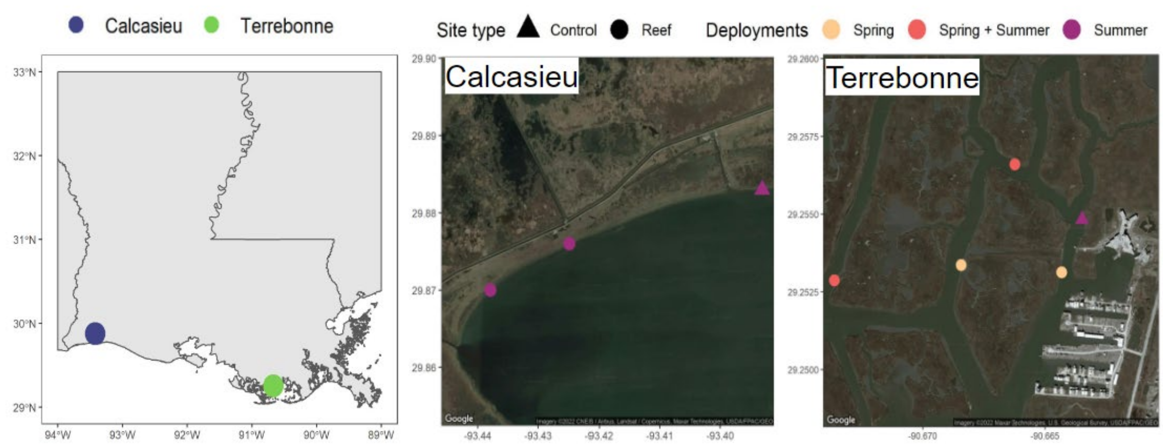

Figure 1. Hydrophone and benthic tray deployment across Calcasieu Lake and Terrebonne Bay at reef and mud (control) sites.

RESULTS

Terrebonne Bay had higher species richness than Calcasieu Lake whether it was a reef site or control. Across basins we found a correlation (Pearson's Correlation Coefficient, ρ) between species richness and both Broadband SPL and NDSI (Figure 2). Higher SPL is correlated with a higher species richness ($\rho = 0.60$), and a higher NDSI (i.e., more biophony) is correlated with a higher species richness ($\rho = 0.49$). For false color spectrograms, we assigned each a color to three different indices; red was ACI, blue was entropy, and green is events. The saturation of the color corresponds to the scaled value of the index with higher values being more saturated. False color spectrograms can be useful tools for visualizing components of the soundscape and we found this to be true. At Calcasieu Lake the false color spectrograms highlighted wind events (Figure 3), and diurnal patterns in burrowing behavior of a reef resident (Figure 3B). In Terrebonne Bay the false color spectrograms highlighted diurnal tidal patterns and snapping shrimp choruses (distinct dark vertical banding in Figure 4). The false color spectrograms strongly depict diurnal patterns across both bays at both reef and mud sites.

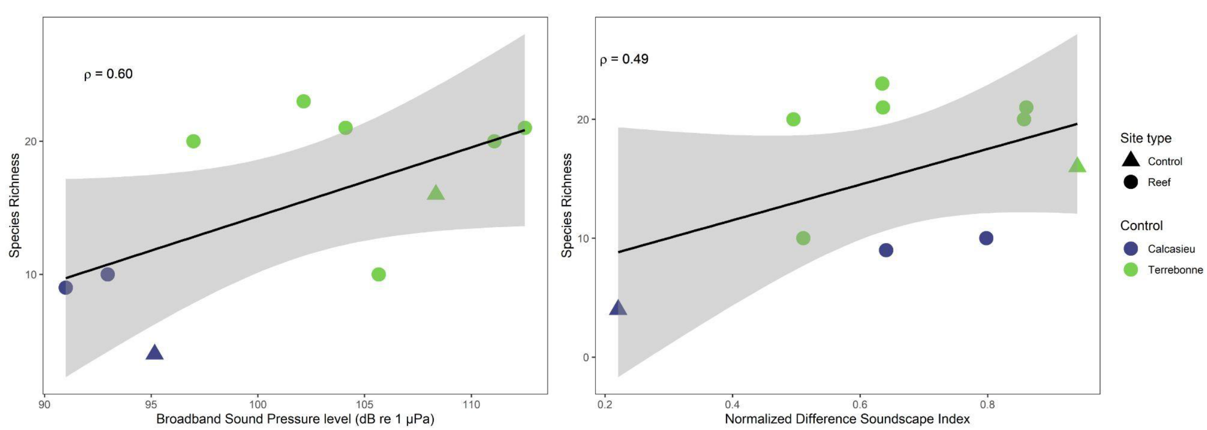

Figure 2. Species richness of reef and mud sites compared to SPL and NDSI.

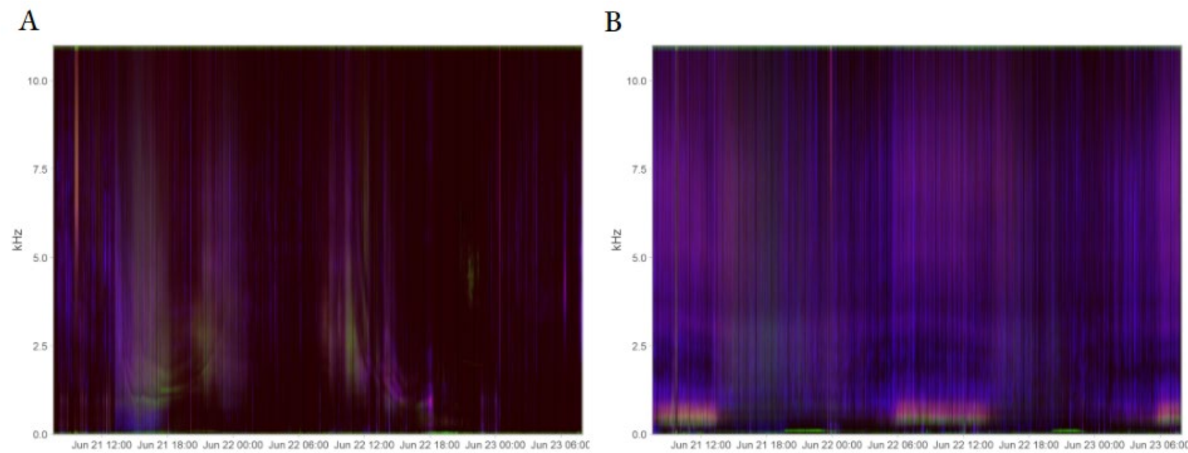

Figure 3. False color spectrogram of Calcasieu Lake control (A) and reef (B) sites. Red is ACI, blue is entropy, and green is events.

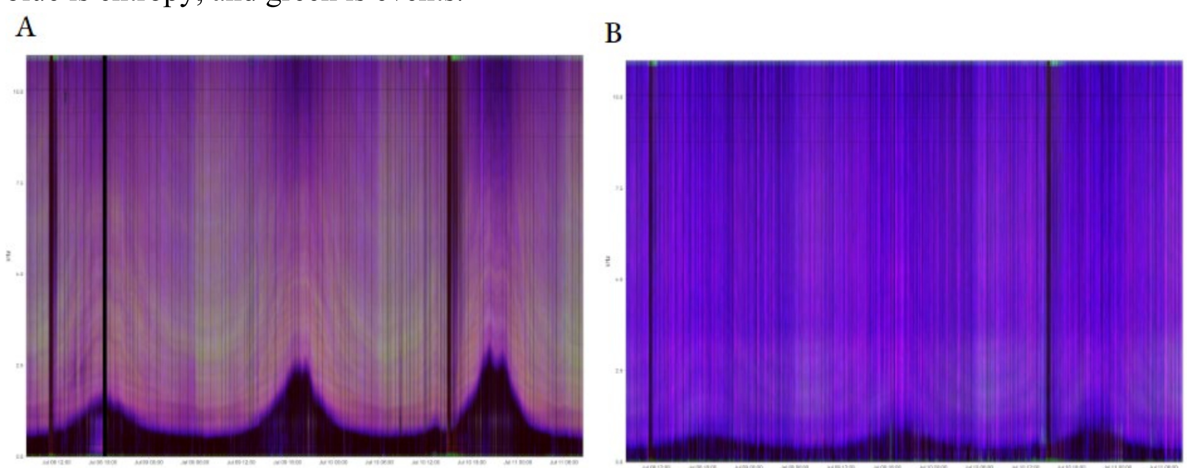

Figure 4. False color spectrogram of Terrebonne Bay control (A) and reef (B) site. Red is ACI, blue is entropy, and green is events.

CONCLUSION & DISCUSSION

PAM has provided some promising results for its future in oyster reef monitoring in Louisiana estuaries. We found a clear correlation between species richness and both SPL and NDSI across both bays, although the slope of these relationships may be different across basins. Terrebonne Bay had higher SPL, regardless of season, than Calcasieu Lake; this may be due to higher boat traffic in the immediate area adjacent to the deployment sites. Despite higher boat traffic at Terrebonne, the bay still had higher levels of biophony, as shown through the higher levels of NDSI. Some of our results in Calcasieu Lake may have been skewed because all but one benthic tray at the control site was lost, suggesting that we do not have an accurate value of species richness at this site. The differences across the bays could also be a result of oyster reef structure; Terrebonne Bay has loose, naturally structured oyster reefs while Calcasieu Lake oyster reefs are artificially created reefs, where reef material is confined to cages placed by The Nature Conservancy in 2017. Future work should also focus on how manual biodiversity sampling methods (e.g., cores, suction sampling, or seining vs benthic trays) impact the estimate of biodiversity at these sites and how that changes the relationship to acoustic measures examined here. Passive acoustic monitoring indices have potential to be an indicator of oyster reef biodiversity and health; however, it is not yet ready to be used as a standalone.

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