Comparing the Diversity of the Soundscapes at Two Fish Spawning Aggregation Sites in Western Puerto Rico

Comparando la Diversidad de los Paisajes Sonoros en Dos Sitios de Agregación de Desove de Peces en el Oeste de Puerto Rico

Comparaison de la Diversité des Paysages Sonores sur Deux Sites de Concentration de Poissons en Phase de Frai dans l'Ouest de Porto Rico

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EXTENDED ABSTRACT

Introduction

Soundscapes are composed of three basic components: biophony (sounds produced by organisms), geophony (geophysical sounds), and anthrophony (human-generated sounds) (Pijanowski et al. 2011). In marine environments, the study of these components can provide important dynamic and sensory information about marine organisms (Coquereau et al. 2017), and could potentially reflect many ecological processes and responses to anthropogenic impacts or interactions (Piercy et al. 2014, Popper and Hawkins 2019). Soundscape studies of coral reef habitats have mainly focused on describing the general temporal and spatial variability of sound production and on understanding the link between acoustic diversity and fish assemblages and habitat complexity using acoustic parameters or acoustic diversity indices. Yet, few studies have looked at the soundscapes of critical habitats, such as fish spawning aggregation (FSA) sites where multiple species of groupers spawn, by classifying sounds into the three basic components of the soundscape and studying their interactions.

Besides being of high ecological importance, FSA sites are particularly vulnerable to fishing, due to their predictability in space and time. Thus, aggregation sites have long been heavily exploited by commercial and recreational fishers, and are considered a valuable fishery resource of reef ecosystems (Sadovy et al. 2012). Passive acoustic monitoring has proven to be an efficient mechanism to monitor aggregations, since most groupers are soniferous (Rountree et al., 2006). Long-term passive acoustic monitoring at grouper FSA sites has mainly been used for studies at the species level, such as describing courtship-associated sounds in the wild (Mann et al. 2010), determining the relative density of an aggregation (Rowell et al. 2012), acoustically mapping an aggregation site (Rowell et al. 2010) and to assess correlations of calling activity with lunar cycles and oceanographic conditions (Mann et al. 2010, Nemeth et al. 2012). However, no studies have described the acoustical components that make up the soundscape of a FSA site. Recent studies have suggested that soundscapes, and especially anthropogenic sounds, may reflect environmental conditions, biodiversity and human use of critical habitats (Kaplan and Mooney 2015). Therefore, quantifying the occurrence and intensity of anthropogenic sounds may be used to estimate the potential impact of human activity in the FSA.

Passive acoustic monitoring has been ongoing at two FSA sites off the west coast of Puerto Rico, in order to document the presence of soniferous species such as red hind (*Epinephelus guttatus*). The aim of our study was to characterize and determine the frequency of occurrence of sounds classified into the different sources of biophony, geophony and anthrophony at these sites, determine if there is a relationship among the three and measure their variability between and across sites and time periods.

Methods

Passive acoustic recordings were collected at two FSA sites, Abrir la Sierra (ALS) and Buoy 4 (B4), located off western Puerto Rico. These sites differ in their fishing regulations: ALS is closed to all fishing from December 1-February 28 (CFMC 1996) in order to protect the red hind FSA, while B4 (located 9 miles southward of ALS) is open to fishing year-round, with exception of seasonal bans for certain species, including red hind (December 1 - February 28). While red hind is the only grouper known to aggregate at these locations, other grouper species have been observed but are infrequent. Recordings were made with a single underwater passive acoustic recorder (LS-1 DSG, Loggerhead Instruments) at each site. Each unit contained a hydrophone (ALS: sensitivity = -179 dBV μPa^{-1}, 20dB gain; B4: sensitivity = -179.8 $dBV\mu P^{-1}$, 20dB gain), a processing board, 128GB micro-SD card and 24 alkaline D-cell batteries. Recordings were scheduled for 20s every 5 minutes and converted to .wav format at a sample rate of 44.1kHz. All units were deployed in early December and recorded throughout the red hind spawning season. To maximize the probability of anthrophony detection, sound files were analyzed for the morning time period (06:00 AST to 11:00 AST) in both the 2016 and 2017 red hind spawning seasons to determine fine scale temporal patterns. Analysis of the selected recordings were performed individually for each file using the visual spectrogram (Hanning window, 1024 window size) from Audacity (ver. 2.2.2). Red hind and Humpback whale sounds were classified as biophony, sounds reflecting surface and internal waves were classified as geophony, while diver and vessel sounds were classified as anthrophony. Daily frequency of the classes of sounds within the three levels were plotted across the red hind spawning season to reveal detailed temporal patterns of use of the acoustic environment.

Results

Passive acoustic recordings at both FSA sites revealed a diversity of biophonic sounds as well as frequent anthropogenic and geophonic sounds during certain periods throughout each season. Red hind were the most frequent source of biological sound during their reproductive period. While not as frequent, dolphins and fish species besides red hind including squirrelfish, lionfish, Nassau grouper (*Epinephelus striatus*) and black grouper (*Mycteroperca bonaci*) were also recorded. Humpback whale sounds were common during late February through March over a wide frequency range, which on occasion could reach the same frequencies as those of red hind sounds (50-400Hz).

Vessels were the most frequent anthropogenic sound at both sites, and were greater at B4. Vessels in movement and at distance produced engine and cavitation noise with a narrow bandwidth (approx. 100Hz) within the range of 50-100Hz. When vessels neared the recording unit, intense noise interference masked all other sounds and spanned a wide frequency range. While infrequent, bubbles generated by SCUBA divers and conch shell hammering by fishers were also heard at both sites. Recordings of red hind sounds per day were more frequent at ALS than B4 during both seasons (Figure 1). In general, vessel sound activity followed the daily temporal patterns of increased red hind calling activity at both sites. This relationship was seen more clearly at B4 than at ALS, as certain periods of increased red hind sounds did not always correspond with increases in vessels sounds at ALS. Sounds produced by internal waves, surface waves or currents at ALS were common only in certain periods possibly being caused by winter swells or strong winds. Periods of increased wave activity correlated with lower periods of vessel activity.

Discussion

As FSA sites have traditionally been commercially important fishing sites, it was not surprising to detect abundant vessel activity even in areas where regulations prohibit fishing during those days. The higher number of recordings with vessels at B4 than ALS could be due to difference in regulations, as fishing for other species is allowed at B4 during the selected time period. Positive relationships between increased periods of vessel activity and red hind calling activity at B4 and at ALS (2016) suggest that poaching of red hind may be occurring during their seasonal ban as there is limited at sea enforcement in the area. However, the presence of diver and conch hammering sounds, indicates that red hind is not the only target being poached, as conch fishing is illegal at both locations year-round in federal jurisdiction waters.

The presence of red hind or other targeted species, however, is not the only factor that may determine vessel activity in these sites. The negative relationship between wave activity and vessel activity suggests that sea state influences vessel activity and can limit fishing. However, wave and current sounds do not always reflect sea surface conditions (e.g., wave height, wind speed, rain), and internal waves can likely be a source of geophonic sounds not necessarily generated by local conditions. Also, we did not analyze the intensity of the geophonic sounds, only their presence. Therefore, a threshold of sea conditions to the presence of vessels could not be determined. Other factors such as, the presence of law enforcement vessels, fuel prices, or even the day of the week may have influenced daily patterns of vessel activity. A study by Rodriguez-Ferrer (in press) found that the vast majority of vessels over 4m in southwestern Puerto Rico are of recreational use. While this suggests that most boating would likely occur during weekends, Appeldoorn and Valdes-Pizzini (1996) found that only 13.8% of boats surveyed at boat ramps during weekends were engaged in fishing.

Vessel noise often masked red hind calls, which may hinder communication between individuals during aggregations. However, further studies are necessary to determine if vessel noise affects the calling behavior of red hind. As vessels could easily be detected using passive acoustics, this may be an efficient and effective way to measure compliance by monitoring vessel activity, especially in remote areas. This information could then be used to asses enforcement agencies to focus their efforts during periods of increased vessel activity or peak days of fish activity, revealed by previous temporal patterns.

KEYWORDS: Fish spawning aggregations, passive acoustics, soundscape, vessels

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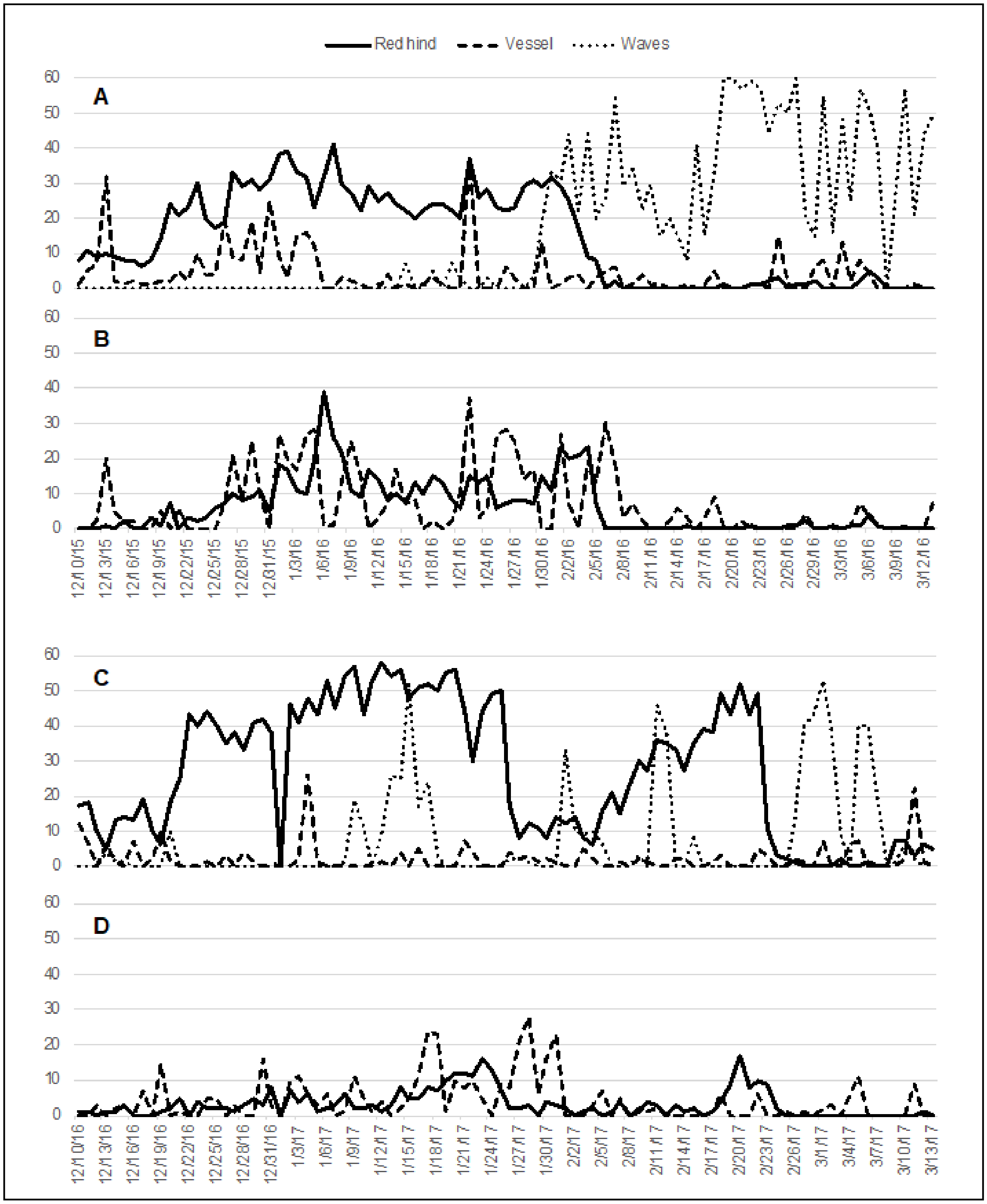

Figure 1. Recordings per day (max. 60) for the morning time period (06:00AST to 11:00AST) with vessel, waves or red hind courtship sounds at ALS (A: 2016, C: 2017) and B4 (B: 2016, D: 2017) during the 2016 and 2017 red hind spawning seasons.