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Underwater soundscapes in near-shore tropical habitats and the effects of environmental degradation and habitat restoration

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ABSTRACT

Most marine habitats have unique soundscapes and, among other potential ecological consequences, the larvae of many fish and invertebrates use habitat-specific sounds to locate appropriate settlement habitat. Anthropogenic stressors have degraded coastal ecosystems worldwide, but the effects of this degradation on the sounds emanating from deteriorated habitats are largely undocumented, as is the effectiveness of habitat restoration in reestablishing natural soundscapes. In this study, we investigated how ambient sound emanating from three near-shore, tropical habitats (subtidal mangrove prop-root habitat, seagrass, and sponge-dominated hard-bottom) in the Florida Keys, Florida (USA) varied with time-of-day and lunar phase. We also examined whether the destruction of sponge communities in hard-bottom habitats struck by cyanobacteria blooms alters the soundscape of that habitat, and if restoration of sponge communities can reestablish natural underwater soundscapes. Soundscapes of each habitat were examined using several acoustic metrics, including spectral analysis and counts of fish calls and snapping shrimp snaps. Mangrove, healthy hard-bottom, and restored hard-bottom habitats had higher soundscape spectra levels than seagrass and degraded hard-bottom whether at noon or dusk during new or full moons. Low-frequency sounds, most likely fish calls in the ~300 Hz frequency range, were most prevalent in mangroves during dusk full moons. There were also higher numbers of snapping shrimp snaps in mangrove, healthy hard-bottom, and restored hard-bottom habitats than in degraded hard-bottom and seagrass beds, especially during the prominent dusk snapping shrimp chorus. Our results demonstrate that near-shore tropical habitats have unique soundscapes that are diminished by habitat degradation, but can be reestablished by habitat restoration, at least in the case of sponge-dominated hard-bottom.

1. Introduction

Soundscape ecology – the study of sounds that emanate from a landscape – is a growing field whose roots lie in terrestrial ecology (Pijanowski et al., 2011), but now include many studies in marine ecosystems (Harris and Radford, 2014). This field of science merges aspects of psychology, behavior, humanities, and ecology to examine how soundscapes (i.e., all sounds emanating from a specific landscape) vary over space and through time, how anthropogenically generated and naturally generated sounds interact, and how best to monitor and conserve soundscapes for their intrinsic and ecological value (Pijanowski et al., 2011).

Underwater sound and seascape ecology has been studied for decades (Harris and Radford, 2014), with some of the earliest works by Tait (1962) and Cato (1976, 1978) who described biological choruses that peak at dawn and dusk. More recent studies have described the biotic and abiotic components of underwater sounds (Radford et al., 2008a,b; Schärer et al., 2014; Staaterman et al., 2014), how sounds vary over diel and lunar periods (Radford et al., 2008a,b) and among marine habitats (Radford et al., 2010; Kennedy et al., 2010; McWilliam and Hawkins, 2013), how anthropogenic factors distort natural soundscapes (Watanabe et al., 2002), and how marine animals use underwater sound to navigate to specific habitats (Tolimieri et al., 2000; Montgomery et al., 2006; Stanley et al., 2012; Lillis et al., 2013 and others). Because soundscapes vary temporally and spatially, they carry with them information about the habitat from which they originated, and can do so over long distances exceeding those possible with visual, chemical, or tactile cues (Rogers and Cox, 1988; McCauley and Cato, 2000; Montgomery et al., 2006; Radford et al., 2007).

Many taxa of marine fishes and invertebrates produce sounds (Myrberg, 1981; Ladich, 2004; Versluis et al., 2000; Bouwma and Herrnkind, 2009; Schärer et al., 2014; Staaterman et al., 2014) and possess a wide range of auditory sensory abilities (Rogers and Cox, 1988; Popper and Fay, 2011). Some fish larvae avoid reef noise to avoid the gauntlet of predators stationed near reefs (Simpson et al., 2011), but a number of studies have shown that reef sounds increase the settlement of larval fishes and invertebrates (Tolimieri et al., 2000, 2004; Jeffs et al., 2003; Radford et al., 2007). For example, settlement-stage crab larvae detect and interpret habitat-associated differences in underwater

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sound (Stanley et al., 2012), as do oyster larvae that are attracted to the sound of oyster beds in which they prefer to settle (Lillis et al., 2014).

As more studies link the ecological processes of larval recruitment and soundscape production, it will become increasingly important to monitor and conserve coastal soundscapes. Unfortunately, habitat degradation, whether by anthropogenic influences or natural disturbance, disproportionately affects near-shore environments (Vitousek et al., 1997; Limburg, 1999; Watanabe et al., 2002; Lotze and Milewski, 2004), where the nursery habitats of many marine organisms occur. Marine habitat restoration and restoration ecology are becoming indispensable tools not only to repair damaged environments, but also to test ecological theories (Peterson and Lipcius, 2003; Halpern et al., 2007). Yet, how habitat degradation diminishes underwater soundscapes, and whether habitat restoration aids in soundscape recovery remains largely untested.

The goals of the present study were threefold. First, we sought to compare soundscapes among three shallow, near-shore benthic habitats of the Florida Keys (mangrove, seagrass, hard-bottom) during new and full moons in the summer through the use of several acoustical metrics. We also examined how degradation affects the soundscapes of a specific habitat: sponge-dominated, shallow hard-bottom. Finally, we determined whether the restoration of hard-bottom sponge communities, previously destroyed by harmful algal blooms, also results in the return of natural soundscapes.

2. Materials and methods

2.1. Site selection

Our study was carried out in Florida Bay, and the near-shore waters of the Florida Keys, Florida (USA) where the coastal environment is a patchwork of seagrass beds, mangrove islands, and hard-bottom habitat that provide shelter and foraging grounds for a variety of juvenile fish and crustaceans. Turtlegrass (*Thalassia testudinum*) dominates the seagrass beds and banks (Hall et al., 1999), and Red Mangrove trees (*Rhizophora mangle*) line the seaward edge of mangrove islands (Ley et al., 1999), their submerged prop roots providing substrate and shelter for sessile and motile animals. Sponges, octocorals, ahermatypic stony corals, and macroalgae characterize hard-bottom, but large sponges, like the loggerhead sponge *Spheciospongia vesparium* and vase sponge *Ircinia campana*, are the dominant vertical structural features of these communities (Chiappone and Sullivan, 1994; Butler et al., 1995; Bertelsen et al., 2009).

Unfortunately, hard-bottom communities within the central and lower portions of Florida Bay have suffered massive sponge die-offs (Butler et al., 1995, Stevely et al., 2011), leaving barrens denuded of sponges. This habitat destruction has inspired hard-bottom sponge community restoration efforts, wherein sponges have been transplanted from unaffected hard-bottom areas onto 25 m × 25 m experimental restoration sites (n = 24 sites; ~700 sponge transplants of up to seven species per site) within the degraded area (M. Butler, unpubl. data). Thus, the degradation of sponge communities and their subsequent restoration on experimental sites afforded us the opportunity to compare soundscapes in unaffected "healthy", degraded, and restored hard-bottom.

Sites for sound recordings were selected haphazardly within four habitat types (seagrass, mangrove edge, hard-bottom affected by sponge die-offs, and hard-bottom unaffected by sponge die-off), using the South Florida Benthic Habitats ArcGIS shapefile (FWC-FWRI); habitat designations were visually confirmed by divers. Recordings were also made at existing hard-bottom restoration sites, thus constituting a fifth habitat type at which we recorded sound. We sought to maintain a balanced sampling design with equal replication of each habitat type, however, due to equipment failure and inclement weather conditions, the actual number of replicates within each habitat type, moon phase, and time of day combinations was unequal: healthy hard-bottom and mangrove, N = 8; degraded hard-bottom, N = 7; seagrass, N = 4; and restored hard-bottom, N = 3. Fig. 1 shows a map of the study area and acoustic recording sites.

2.2. Acoustic recordings

From mid-May to mid-August in 2012 and 2013, habitat recordings were made using submersible hydrophone systems. Each system included a manufacturer-calibrated Aquarian Audio H2a omnidirectional hydrophone (Aquarian Audio Products: sensitivity −180 dB re: 1 V/μPa [±4 dB 20 Hz–4 kHz]; flat frequency response 10 Hz–100 kHz), connected to a Roland Edirol R-05 solid-state WAV recorder (Roland Corporation, Japan; 48 kHz; 16 bit) housed within a waterproof housing. The system (hydrophone and recorder) was calibrated using pure sine wave signals from a signal generator, measured in line with an oscilloscope. Recordings were analyzed using MATLAB software (MathWorks Inc.) with code specifically written for the calibration of hydrophone systems. The set-up was weighted to be negatively buoyant and placed at the site with the hydrophone elevated ~0.5 m off the substrate.

Recording systems were deployed for 24-hour periods up to two days prior to or two days following a new or full moon. Continuous recordings were made at each site, and a fifteen-minute clip was pulled from the recording at solar noon and sunset time periods (http://www.timeanddate.com/astronomy/usa/key-west). Habitats were only recorded during calm conditions (i.e., no breaking surface waves with wind speed <15 kts [http://www.ndbc.noaa.gov]) to reduce the influence of weather-driven sound generation; only recording clips without obvious anthropogenic noise (e.g., from boats) were analyzed. All habitat types were represented within each recording period (i.e., each five-day period around a moon phase) to allow for direct comparison of soundscapes among habitat types.

2.3. Acoustic and statistical analyses

Digital recordings were analyzed using MATLAB 2014b software (MathWorks, Inc.) and R (R Foundation for Statistical Computing). Sound clips were analyzed in the manner of Radford et al. (2010), wherein five 10-second subsamples were extracted from each 15-minute sound clip. For each 10-second subsample, a threshold level was set on the raw data and any transient (<0.2 s) spike above this threshold was counted as a snapping shrimp (Alphaeidae) snap. Mean number of snaps for each sound clip was compared using a split-split plot ANOVA (whole plot = habitat type, sub-plot = moon phase, sub-sub-plot = time of day, block = site), and the data were rank transformed because they did not meet the ANOVA assumptions of normality and homoscedasticity. Tukey's HSD test was used to determine homogenous subsets within significant factors, and interaction plots were used to examine significant interaction terms.

For each 15-minute sound clip, the acoustic complexity index was also calculated (Pieretti et al., 2011), which uses power spectra to calculate the variability in acoustic energy within a soundscape. Overall acoustic complexity was calculated for each recording (Window type: Blackman, FFT size: 1024), and the ACI scores were analyzed using a split-split plot ANOVA (whole plot = habitat type, sub-plot = moon phase, sub-sub-plot = time of day, block = site). The data were inverse-transformed to meet ANOVA assumptions, and interaction plots were used to examine significant interaction terms. In addition, sound clips were low-pass filtered below 1000 Hz to remove snapping shrimp influence, and ACI scores were recalculated for the sound clips. However, the results from this analysis were the same as the results using the overall ACI scores, so only those results are presented below. Because the ANOVAs for both snapping shrimp snaps and sound spectra used data from the same sound clips and are thus not truly independent, we maintained experiment-wise error by adjusting our critical p-values for determining significance to the 0.025 level or lower.