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Assessing marine ecosystem acoustic diversity across ocean basins

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ABSTRACT

Concurrent with the elevation of the concern over the state of sound in the ocean, advances in terrestrial acoustic monitoring techniques have produced concepts and tools that may be applicable to the underwater world. Several index values that convey information related to acoustic diversity with a single numeric measurement made from acoustic recordings have been proposed for rapidly assessing community biodiversity. Here we apply the acoustic biodiversity index method to low frequency recordings made from three different ocean basins to assess its appropriateness for characterizing species richness in the marine environment. Initial results indicated that raw acoustic entropy (H) values did not correspond to biological patterns identified from individual signal detections and classification. Noise from seismic airgun activity masked the weaker biological signals and confounded the entropy calculation. A simple background removal technique that subtracted an average complex spectrum characteristic of seismic exploration signals from the average spectra of each analysis period that contained seismic signals was applied to compensate for salient seismic airgun signals present in all locations. The noise compensated (H_N) entropy index was more reflective of biological patterns and holds promise for the use of rapid acoustic biodiversity in the marine environment as an indicator of habitat biodiversity and health.

1. Introduction

Acoustic recordings provide a relatively low-cost method of collecting data on sound sources in the environment. Passive acoustic monitoring can provide a continuous record of acoustic signals of interest, and the scope of these monitoring systems ranges from short duration, single point recordings to vast sensory networks that span the globe (Blumstein et al., 2011; Fox et al., 2001). Historically, long-term continuous acoustic monitoring was limited to low-frequency/bandwidth sensors due to constraints in power consumption, data storage, or installation costs. In recent years, costs related to power consumption and data storage space have been drastically reduced. This has resulted in a dramatic increase in the number of long-term continuous acoustic recordings being collected at higher sample rates. Acoustic monitoring has been utilized in a wide range of applications, ranging from long-term low frequency units that have been used to measure seismic activity (Fox et al., 2001) to higher frequency regional data collected using both autonomous and cabled systems (Wiggins and Hildebrand, 2007; Zaugg et al., 2010).

A major challenge that comes with these long-term datasets is the management of the vast quantities of data that are collected. Data can come from continuous long-term recordings (months or years in duration) from multiple sensors, resulting in a veritable flood of information (Fox et al., 2001; Lammers et al., 2008). Manual inspection, based on visual or aural inspection, of these large acoustic datasets quickly becomes impractical (Swiston and Mennill, 2009; Urazghildiiev and Clark, 2007). Over the past two decades, multiple approaches toward automated and semi-automated processing of terrestrial and aquatic recordings have been developed and range from assessment of ambient background noise to specific detailed analysis of acoustic behavior of individual species (Blumstein et al., 2011; Mellinger and Clark, 1997; Mellinger et al., 2007; Urazghildiiev and Clark, 2007).

Quantifying biological diversity is a vital aspect of conservation biology to allow for ecosystem monitoring to inform conservation and management efforts (Gotelli and Colwell, 2001; Pimm and Lawton, 1998). An emerging area of research is the use of statistical analyses of data collected with remote sensors to rapidly assess biodiversity or ecosystem health (Sueur et al., 2008; Turner et al., 2003). Acoustic remote sensing data is well suited for detection and as an indirect measure of the biodiversity of sound producing organisms (Riede, 1993; Sueur et al., 2008) and of human disturbance associated with anthropogenic noise (Barber et al., 2010).

Automated acoustic indices have been used to indirectly assess acoustic biodiversity including the quantification of temporal and spectral acoustic entropy (H_t and H_f) (Sueur et al., 2008), temporal and spectral dissimilarity indices (D_t, D_f) (Gasc et al., 2013; Sueur et al., 2008), and metrics to capture diversity, evenness, richness, and dominance (Villanueva-Rivera et al., 2011). These approaches have been utilized to investigate acoustic diversity in two terrestrial habitats, including woodlands and tropical forests (Depraetere et al., 2012; Sueur et al., 2008). Studies using realistic field data indicate that background noise can unduly influence entropy measurements, leading to necessary

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refinement in the analysis procedures including pre-filtering for background noise and calculating the median values of overall signal amplitude (M) (Depraetere et al., 2012).

These statistical acoustic indices have not yet been applied to marine acoustic recordings. Previous underwater studies have used a variety of methods to characterize annual variation in long-term marine acoustic recordings (Hatch et al., 2008; Lammers et al., 2008; Miksis-Olds et al., 2012; Nieukirk et al., 2012). In general, marine systems are often dominated by abiotic sound sources (weather, seismic events) (Wenz, 1962) and increasing levels of human generated noise (Slabbekoorn et al., 2010). Reduced levels of transmission loss of acoustic energy in the marine environment when compared to air, result in greater ranges of acoustic propagation. This results in the ability to detect acoustic signals at greater distances, increasing the effective range of distant abiotic and anthropogenic sources of acoustic energy competing with the acoustic energy contribution from local biotic species. This exploratory study applies the acoustic entropy indices developed for terrestrial recordings (Sueur et al., 2008) to low frequency marine recordings from three oceans to assess the effectiveness of this method in quantifying differences in acoustic biodiversity between sites, between seasons, and in differing background noise conditions in the marine environment.

2. Material and methods

2.1. Acoustic dataset

Acoustic data from the Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty International Monitoring System (CTBT IMS) in the South Atlantic (Ascension Island, H10, 8.0°S, 14.4°W), Indian (Diego Garcia, H08, 7.3°S, 72.4°E) and North Pacific (Wake Island, H11, 19.3°N, 166.6°E) ocean basins were obtained from the AFTAC/US NDC (Air Force Tactical Applications Center/ US National Data Center) (Fig. 1). Each CTBT IMS location consists of a cabled 3-hydrophone array with a frequency response from <1 to 125 Hz deployed on the north and south sides of each island with sensors positioned in the deep sound channel, ranging in depth from 600 to 1400 m, depending on location. This study analyzed data from a single hydrophone (Hydrophone 1 from the North site) at each ocean location. The Ascension Island hydrophone, H10, was deployed at 847 m. The Diego Garcia hydrophone, H08, was deployed at 1248 m. The Wake Island hydrophone, H11, was deployed at 731 m.

Data were sampled continuously at a 250 Hz sampling rate and 24 bit A/D resolution. The hydrophones were calibrated individually prior to initial deployment in January 2002 and re-calibrated while at-sea in 2011 by the CTBT IMS organization. All hydrophones had a flat (3 dB) frequency response from 5 to 110 Hz. Information from individual hydrophone response curves was applied to the data to obtain absolute values over the full frequency spectrum (1–125 Hz). Data for this study were obtained from four weeks of simultaneous recordings from each of these locations. One week of data in each of four seasons was examined at each location in 2008: 01–07 Jan, 02–08 Apr, 30 Jun-06 Jul, and 01–07 Oct. These dates were selected to systematically reflect the year to detect potential seasonal differences between locations. To prevent confusion in communicating and interpreting results, text and figures accurately reflect hemispheric seasons with appropriate notation referring to the month of the year. Sites H08 and H10 were in the Southern hemisphere, with January representing austral summer, April representing autumn, June–July representing the austral winter and October representing the spring. Site H11 was in the Northern hemisphere, with January representing winter, April representing spring, June–July representing summer and October representing autumn. An example of one hour of data from each site on the same date is shown in Fig. 2.

2.2. Signal detection and classification

Each of the four weeks of data from each site were visually and aurally assessed by an experienced analyst (S.E.P.) using the program Xbat (www.xbat.org) written in Matlab (Mathworks Inc.) to determine the presence of low frequency abiotic (natural seismic signals from earth quakes and volcanic activity), anthropogenic (ship noise and seismic exploration signals) and biotic (low frequency tonal baleen whale) sound sources in the recordings (Fig. 3). Baleen whale calls were identified to species based on values published in the literature (McDonald et al., 2006; Širović et al., 2004; Stafford et al., 2004) and a combination of matched template detectors and visual browsing were used to

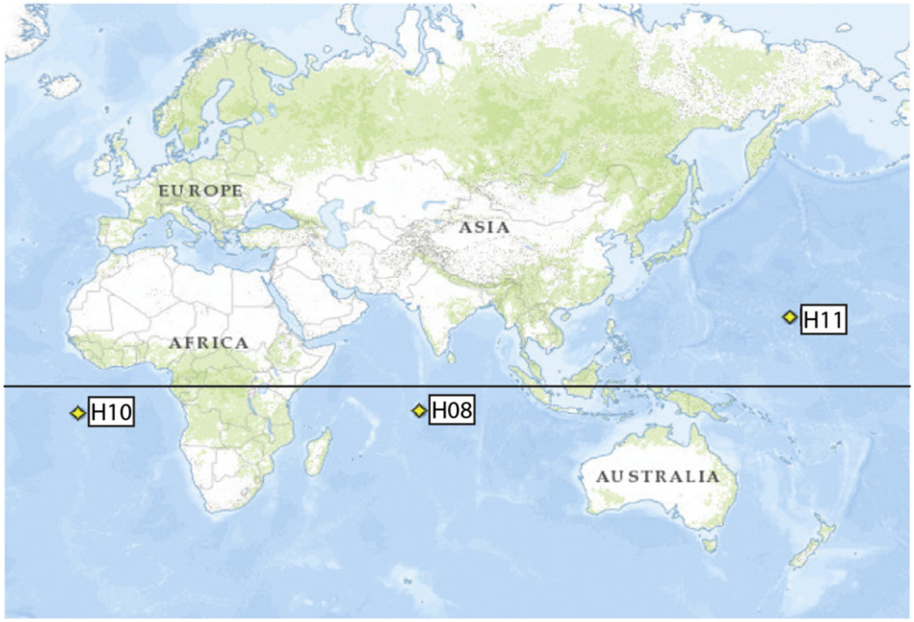

Fig. 1. Map showing the locations of the three cabled arrays in the South Atlantic (H10N), Indian (H08N) and North Pacific ocean (H11N). Map created with GPSVisualizer.com, maps data from ArcGIS.