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Variation of ocean acoustic environments along the western North Atlantic coast: A case study in context of the right whale migration route

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ABSTRACT

Differing physical characteristics and levels of biological, environmental, and anthropogenic sounds contribute in varying levels of noise in different ocean environments. As a result, animals migrating over large ranges or widely distributed species are now exposed to a myriad of different acoustic environments, within which they must navigate, forage and reproduce. Given current increases in low-frequency (<1000 Hz) anthropogenic noise, there is concern that resultant masking of communication and naturally occurring sounds may stress cetaceans already facing other forms of habitat degradation. As a critical first step to understanding the acoustic environments of coastal marine ecosystems, we examined month-long acoustic data from ten sites along the U.S. east coast that are either designated critical habitats or located along the migratory corridor of the North Atlantic right whale (*Eubalaena glacialis*): Gulf of Maine, Jeffreys Ledge, Massachusetts Bay, Cape Cod Bay, New York, New Jersey, North Carolina, South Carolina, Georgia (North), and Georgia (South). Data were collected using hydrophones positioned at depth to evaluate differences in the acoustic environment at these sites. High noise levels were observed at both major (New York, Boston) and non-major (Georgia) shipping ports located in or near the areas of study. Of the ten study sites, New Jersey and New York experienced the highest equivalent sound levels, while South Carolina and the Gulf of Maine presented the lowest. The majority of noise variability was found in low-frequency bands below 500 Hz, including the 71–224 Hz communication range utilized by long distance, contact-calling right whales and many other whale and fish species. The spatio-temporal variability of anthropogenic noise can be viewed as a form of habitat fragmentation, where inundations of noise may mask key sounds, resulting in a loss of "acoustic space" (overlapping frequency band and time of a whale's vocalization), which could otherwise be occupied by vocalizations and other acoustic cues utilized by cetaceans. This loss of acoustic space could potentially degrade habitat suitability by reducing the geographic distance across which individuals acoustically communicate, and ultimately, over long timescales, disrupt aspects related to their natural behavior and ecology. Because communication plays a vital role in the life history of cetacean species, understanding temporal and geographical differences in ambient noise as part of cetacean ecology and habitat may elucidate future conservation strategies related to the assessment of noise impacts.

1. Introduction

Ocean ambient noise is comprised of a variety of biological, environmental, and anthropogenic sources (Hildebrand, 2009; Knudsen et al., 1948; Urick, 1986). The combination of these sources defines the ocean's acoustic environment, which can vary both spatially and temporally. Local geophysical properties, biological communities and environmental conditions, combined with varying degrees of anthropogenic input, create site-specific acoustic characteristics, changing sound propagation conditions and thus, generate diverse ambient noise levels throughout the ocean (e.g., Hildebrand, 2009; Urick, 1986; Wenz, 1962); the same is true of terrestrial habitats (Pijanowski et al., 2011a, 2011b). Because of the multitude of factors at play, broad spatial-scale quantitative comparisons of noise levels among different ocean environments are still rare (but for examples, see Andrew et al., 2011; Bardyshev, 2010; Gaul et al., 2007; Knudsen et al., 1948; McDonald et al., 2008; McWilliam and Hawkins, 2013; Parks et al., 2009; Radford et al., 2010). Thus, while it is intuitive that geographically separated ocean environments may differ in their acoustic characteristics, the lack of direct comSparisons makes it difficult to evaluate the degree to which these acoustic environments are different. For migrating oceanic animals, location-specific acoustic characteristics result in the exposure of those animals to a wide variety of ambient sounds, within which they must forage, navigate, and reproduce. Given increases in anthropogenic noise throughout Northern Hemisphere oceans (Andrew et al., 2002, 2011; Curtis et al., 1999), these species are now exposed not only to diverse, but also altered acoustic environments.

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Aside from the potential for acute or direct physical impact from exposure (Kight and Swaddle, 2011; Nowacek et al., 2007), other possible adverse effects of chronic exposure to increased ambient noise over ecologically relevant spatial and temporal scales remain poorly understood (Ellison et al., 2012). Increases in anthropogenic noise levels lead to a reduction in the area over which an animal can successfully communicate, referred to by Clark et al. (2009) as “lost communication space”. Loss of communication space, or communication masking, may further pressure individuals that are already facing other forms of stress, by adding an obstacle to behaviors that rely on effective communication or acoustic perception of the environment (Ellison et al., 2012). Thus, examining spatial and temporal variation in ambient noise is critical for a thorough understanding of when, where, and to what degree cetacean signals might be vulnerable to communication masking. To quantify trends of this nature, analysis must occur over spatial and temporal scales large enough and long enough to be ecologically significant to entire populations. In that context, ambient noise is a fundamental element to understanding the spatial extent of an animal's communication range and thus its overall acoustic ecology (Clark et al., 2009).

This study provides a broad-spatial scale comparison of marine acoustic environments collected along the eastern coast of the United States, with the goal of understanding how the acoustic characteristics of these widely spaced locations differ. In order to better understand the potential implications of acoustic differences in different habitats to the ecology of marine organisms, these ambient noise data are analyzed in the context of the home range of the North Atlantic right whale (*Eubalaena glacialis*), an endangered marine mammal for which acoustic communication and surrounding sounds are critical to understanding their basic behavioral ecology (Morano et al., 2012a; Parks et al., 2011b).

The North Atlantic right whale is a nearshore cetacean species for which a significant portion of the population spends the November–March period in southern U.S. waters, and the March–November period in northern U.S. waters such that it migrates south in the late summer/fall to give birth off the southeast coast and north in the late winter/early spring to feed in waters in the Gulf of Maine region (Kraus and Rolland, 2007; Kraus et al., 1986; Winn et al., 1986). Because these migrations take the population through the full range of the U.S. east coast, these animals are exposed to a variety of elevated ambient noise environments, including those near busy shipping ports such as New York, Boston or Savannah. Since right whales rely on effective acoustic communication and interaction with conspecifics, the population is vulnerable to the behavioral and physiological effects of elevated ambient noise (Hatch et al., 2012; Parks et al., 2011a; Rolland et al., 2012).

This paper evaluates the potential diversity of low-frequency acoustic environments along the U.S. east coast. We use the context of the right whale as a relevant case study to examine the combination of ambient sounds that contribute to the different acoustic environments at ten sites through which they migrate. Right whales may serve as an appropriate indicator-species for a wide range of broadly distributed or migratory taxa along the North Atlantic coast that utilize low-frequency sounds and may also be exposed to this diversity of acoustic environments. A basic spatial, temporal, and spectral understanding of the constituents of different acoustic environments is a critical first step toward understanding and possibly mitigating the effects of anthropogenic activities on the coastal acoustic environment (Clark et al., 2009; Ellison et al., 2012; Hatch et al., 2012; Moore et al., 2012).

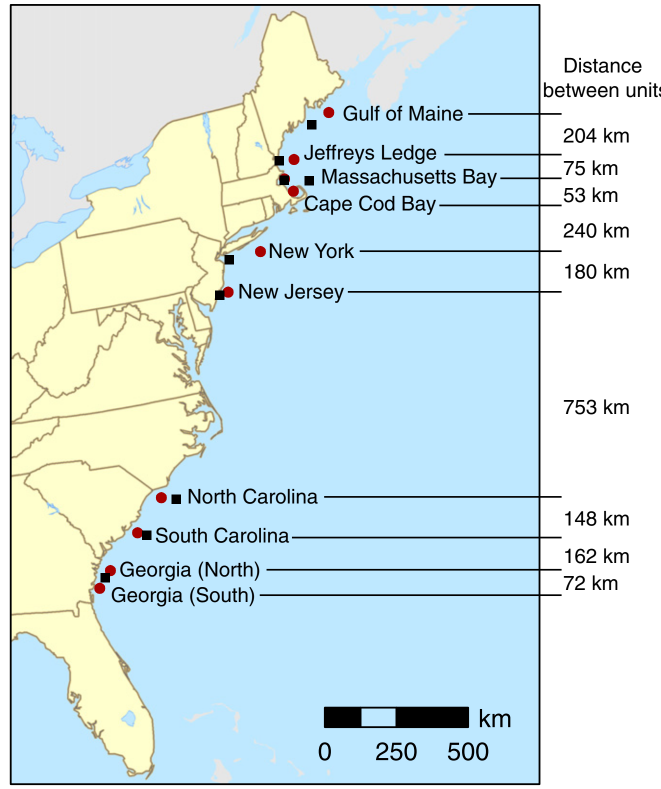

Fig. 1. Map of ten western North Atlantic study sites, indicated by red circles. Exact coordinate location, sensor depth, time period and duration of data analyzed are listed on Table 1. Black squares indicate the location on NOAA weather buoys used for correlation of acoustic data with wind.

2. Materials and methods

2.1. Acoustic data collection

We examined long-term acoustic data from ten geographic locations along the U.S. east Coast (Fig. 1) that are either known seasonal resident areas or located on the migratory corridor of the right whale (see summaries in Kraus and Rolland, 2007; Morano et al., 2012a). Data were collected using bottom-mounted Marine Autonomous Recording Units (MARUs; Calupca et al., 2000), each equipped with a single hydrophone (HTI-94-SSQ, High Tech, Inc., Gulfport, MS) set to record continuously at a 2 kHz sampling rate. A high-pass filter of 10 Hz and a low-pass filter of 840 Hz were used to reduce self-noise and aliasing effects, and the system had a flat frequency response (± 1 dB) between 15–585 Hz.

For many of these recording locations, multiple MARUs were deployed and configured as a network or time-synchronized array; in these cases, acoustic data from all units in the array were processed, and the sensor with the highest noise level was selected for further analysis. For more detailed description of the MARU system, see Clark and Clapham (2004); Morano et al. (2012a) and Au and Hastings (2008, pg. 653–655).

Table 1 details the exact MARU coordinates, arranged from the northernmost to the southernmost locations. We selected a continuous month-long period (30–31 days) from each of these datasets (Table 1), during months when right whales are predicted to be in the area, based on seasonal patterns of their occurrences throughout their entire home range (Table 2; Kraus and Rolland, 2007; Winn et al., 1986). Because this study is a meta-analysis of previous acoustic surveys, not all acoustic data were recorded within the same year.

2.2. Data analysis

We used a series of quantitative methods to characterize the spatial, temporal and spectral patterns of the acoustic environment, for each of the ten locations where sound recordings were made along