OCS Study
BOEM 2015-026

Baseline Bioacoustic Characterization for Offshore Renewable Energy Development in the North Carolina and Georgia Wind Planning Areas

U.S. Department of the Interior
Bureau of Ocean Energy Management
Gulf of Mexico OCS Region

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ABBREVIATIONS AND ACRONYMS

dB	Decibels, referenced to 1 µPa
BOEM	Department of the Interior's Bureau of Ocean Energy Management
BRP	The Bioacoustics Research program at Cornell University's Laboratory of Ornithology
BSEE	Department of the Interior's Bureau of Safety and Environmental Enforcement
EFH	Essential fish habitat
GDEM	General Digital Environment Model
HAPC	Habitat Areas of Particular Concern
Hz	Hertz (frequency measurement)
µPa	mircoPascal (pressure measurement)
MARU	Marine autonomous recording unit that records acoustic data; developed by BRP
ORE	Offshore renewable energy
RAM	Range-Dependent Acoustic Model
RMS	Root mean square
SAB	South Atlantic Bight
SEAMAP-SA	Southeast Area Monitoring and Assessment Program - South Atlantic
SEL	Sound exposure level
SMA	Seasonal Management Area, protected area for North Atlantic right whales
SPL	Sound pressure level
USWTR	Under sea warfare training range
XBAT	eXtensible BioAcoustic Tool, a MATLAB-based interactive sound visualization software (Figueroa and Robbins 2008)

1. BACKGROUND AND OBJECTIVES

The concern with human-driven climate change motivated technological developments for harnessing energy from the ocean environment, which is a promising energy resource to offset carbon emissions from fossil fuel use (e.g., Pelc and Fujita 2002). However, while technological improvements in offshore renewable energy (ORE), specifically wind and hydrokinetic energy capture, have made these energy sources a practical reality in the immediate future, there are concerns over what the impact of large offshore energy-capture installations may be on the marine environment (Cada et al. 2007; Gill 2005; Inger et al. 2009; Petersen and Malm 2006; Punt et al. 2009). Locating offshore energy installations requires a balance between areas with sufficient wind or tidal energy with shallow seafloor depths which are close enough to shore (Punt et al. 2009) and the habitat impact on these coastal ecosystems (Gill 2005).

The installation of offshore energy facilities is a multi-phased process that produces varying degrees of noise, including ship traffic, sonar use, and construction noise from pile-driving and trenching. These steps involve both long- and short-term disturbances with different frequencies and intensities of sound, potentially impacting a wide variety of marine vertebrates. The operation and servicing of the installation also produces noise, though the range over which these sounds propagate is site-specific and has previously not been well documented in the U.S. east coast (Clark et al. 2009; Madsen et al. 2006).

Marine vertebrates (i.e., mammals and fishes) may be affected by anthropogenic noise (e.g., Clark et al. 2009; National Research Council 2003; National Research Council 2005; Nowacek et al. 2007; Popper 2003; Radford et al. 2014; Slabbekoorn et al. 2010; Slabbekoorn 2012), but there is a limited understanding of how ORE construction and operation would specifically affect them (marine mammals: Madsen et al. 2006; fishes: Wahlberg and Westerberg 2005). Understanding the quality of the noise and how far it is transmitted is critical to determining how the area over which the noise might influence the acoustic habitat (Clark et al. 2009; Madsen et al. 2006). Fishes may be able to detect operating wind farms as far as 25 km away (Wahlberg and Westerberg 2005). Harbor porpoises and harbor seals respond to the sounds from wind turbines (Koschinski et al. 2003; Madsen et al. 2006), and may be able to detect construction-related noise as far as 20–200 km away (Bailey et al. 2010; Madsen et al. 2006; Tougaard et al. 2009b). Construction and operation of European OAE installations may result in a significant percentage of harbor porpoises abandoning the habitat altogether (Gilles et al. 2009). However, the degree and breadth of the acoustic impact of ORE development on communication masking and habitat abandonment of both sonic and non-sonic animals is still unclear (Madsen et al. 2006; Wahlberg and Westerberg 2005).

Marine mammals are of principal concern in the context of anthropogenic ocean noise (Hildebrand 2009; Nowacek et al. 2007; Tyack 2009); construction and shipping activity potentially mask communicatory signals (Clark et al. 2009), increased stress (Nowacek et al. 2007; Rolland et al. 2012), or habitat abandonment (Gilles et al. 2009; Rako et al. 2013). Though the reactions of toothed whales (i.e., dolphins and porpoises) to ORE development have been explored (Carstensen et al. 2006; Gilles et al. 2009; Koschinski et al. 2003; Tougaard et al. 2009a; Tougaard et al. 2009b), there are no data on the reactions of baleen whales to ORE development (Madsen et al. 2006).

Like cetaceans, the behavior of individuals and populations of many fish species can be assessed with passive acoustics (Fine and Thorson 2008; Luczkovich et al. 2008a; Luczkovich et al. 2008b; Rountree et al. 2006). The U.S. Atlantic coast is home to over 100 species of sonic fishes (Fish and Mowbray 1970; Rountree et al. 2006), and many of these species' biology (and changes in their ecology) can be understood using acoustics in a similar manner as used to study to marine mammals (e.g., Hernandez et al. 2013; Rountree et al. 2006; Van Parijs et al. 2009).

1.1. PROJECT OBJECTIVES AND APPROACH

The goal of this effort is to conduct a baseline ecological assessment of two wind planning areas (shown below in Figure 2.2) along the U.S. Atlantic coast (Table 1.1) to identify the potential environmental impact of offshore wind energy construction. Our goal was to establish a baseline of seasonal activity of focal species using passive acoustic monitoring to understand their acoustic presence and calling patterns, and establish the baseline noise conditions of the areas. These baseline data would be used to evaluate potential changes that may result from future wind energy construction and operation.

We sought to investigate two suites of organisms as part of this project. The first are three species of baleen whales (North Atlantic right whales, fin whales, and humpback whales) that are thought to potentially migrate through or near the wind planning area. These species are protected by both the Endangered Species Act and the Marine Mammal Protection Act, and as federally protected species, any human activities must seek to minimize any possible impact (either direct or indirect) to members of the population. The second group of organisms is comprised of two species of acoustically active fishes (black drum [*Pogonias cromis*] and oyster toadfish [*Opsanus tau*]) that produce sounds as part of their life history. Both black drum and toadfish are distributed along the entirety of the U.S. Atlantic coast, and produce well-characterized sounds in agonistic and reproductive contexts (Mok and Gilmore 1983); these fish choruses are some of the most prominent sounds of the biological sound spectrum (Tavolga 1965; Urick 1983). Because toadfish are benthic and poor swimmers, though black drum are demersal and much better swimmers, differences in the calling patterns between these two species following construction may indicate different degrees of impact on the marine benthic compared to the pelagic community.

This project had two complementary components to the biological species monitoring. ESS Group, Inc. conducted a literature-based habitat assessment of both wind planning areas to investigate the benthic habitat and evaluate the natural resources occurring in these areas. Marine Acoustics, Inc. created a sound propagation model to estimate the spatial extent and magnitude of noise produced by wind turbine construction activities.

1.2. PROJECT HISTORY AND EVOLUTION

This project was originally designed to implement a broadly applicable approach at four candidate wind planning areas (Rhode Island, North Carolina, Georgia, Florida) at the time of the opportunity announcement. The characterization of noise activities and impacts was also intended as a before-during-after monitoring paradigm, with surveys within the wind-planning area and at suitable control sites. After the project began, the project sites were narrowed down to the North Carolina and Georgia wind planning areas (Table 1.1). As year one of the project came to a close, it became clear that it was unlikely that any offshore wind construction would occur at either of the wind planning areas during the course of the project, so in consultation and agreement with the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE), the scope of the project was changed to be a baseline study to characterize habitat sites, evaluate focal species occurrence, and model wind turbine construction activities.

Table 1.1. BOEM Outer Continental Shelf (OCS) blocks within the Beaufort and Brunswick regions, designated as wind planning areas.

Region (Lease Block)	OCS Lease Sub-Block Number
Beaufort (NI18-04)	6727 6782, 6781, 6780, 6779, 6778, 6777, 6776, 6775 6833, 6832, 6831, 6830, 6829, 6828, 6827, 6826, 6825 6884, 6883, 6882, 6881, 6880. 6879, 6878, 6877, 6876 6933, 6932, 6931, 6930, 6929, 6928, 6927, 6926 6982, 6981, 6980, 6979, 6978, 6977 7031, 7030, 7029, 7028, 7027 7079, 7078
Brunswick (NH17-02)	6126

2. SOUND RECORDING METHODS

Acoustic data were collected using marine autonomous recording units (MARUs). A MARU is a digital audio recording system contained in a positively buoyant 17” glass sphere that is deployed on the bottom of the ocean for periods of weeks to months (Figure 2.1, Calupca et al. 2000). A hydrophone mounted outside the sphere is the mechanism for acquiring sounds that are recorded and stored in a binary digital audio format on internal electronic storage media. The MARU can be programmed to record on a daily schedule and deployed in a remote environment, where it is held in place by an anchor. At the conclusion of a deployment, the MARU is sent an acoustic command to release itself from its anchor and float to the surface for recovery. After the recovery, the MARU data are extracted, converted into audio files and stored on a server for analysis. The unit is then refurbished (batteries and hard drive replaced, etc.) in preparation for a subsequent deployment. Data recorded by a MARU are thus accessible only after the device is retrieved.

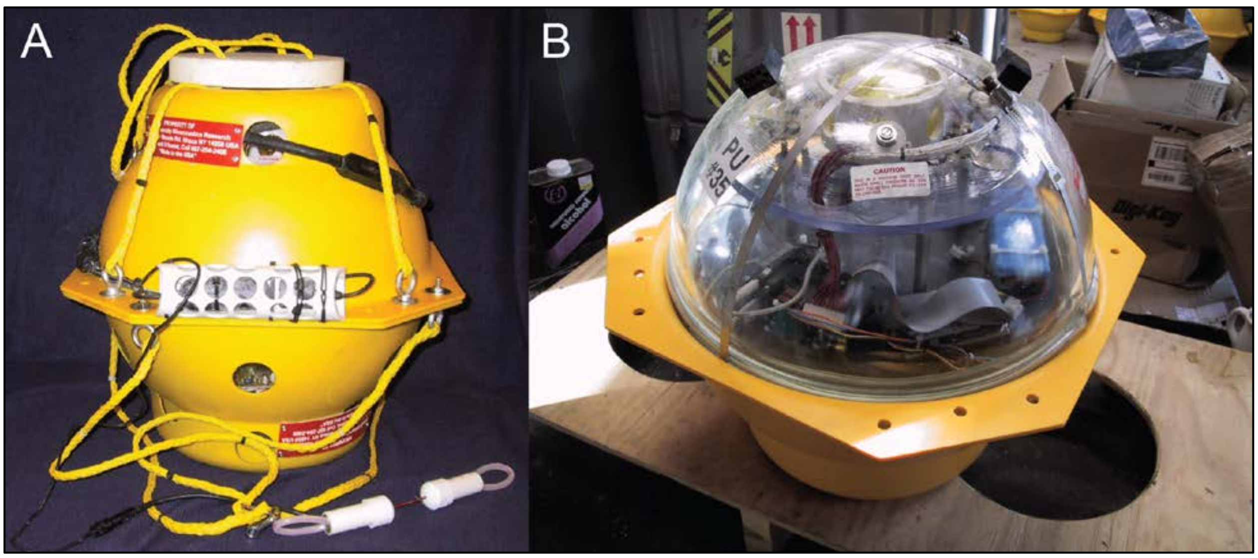

Figure 2.1. Views of the MARU.
A) External and B) internal views of the Marine Autonomous Recording Unit (MARU) used for sound data recordings in this project.

The MARUs were deployed at two wind energy planning areas off the coasts of North Carolina and Georgia (Figure 2.2). At each site, three MARUs were deployed in a linear formation across the wind energy planning area and designated from north to south as NC-North, NC-Central, NC-South, GA-North, GA-Central, GA-South (Figure 2.2, Table 2.1). Distance between MARUs was approximately 35 km in the North Carolina site and 18 km in the Georgia site, and seafloor depths at the deployment locations ranged from 14 m to 38 m (Table 2.1).

Acoustic data were recorded in two consecutive deployments of the MARUs at each site, from 12 June–10 November 2012 and 12 November 2012–15 April 2013 at the North Carolina site and 9 June–8 November 2012 and 10 November 2012–12 April 2013 at the Georgia site. A total of 307 consecutive days were recorded at each site, with the exception of 11 November 2012 in North Carolina and 9 November 2012 in Georgia, when MARUs were replaced for the following deployment. Sound data were sampled at 2 kHz with high-pass and low-pass filters set at 10 Hz and 800 Hz, respectively. The high-pass filter was implemented to reduce electrical interference produced by the MARU, while the low-pass filter reduced aliasing. The effective recording bandwidth of 10 Hz to 800 Hz had a flat frequency response (± 2.0 dB).

Sound data from the MARUs at each site were synchronized in time and concatenated into three-channel sound files for analysis.

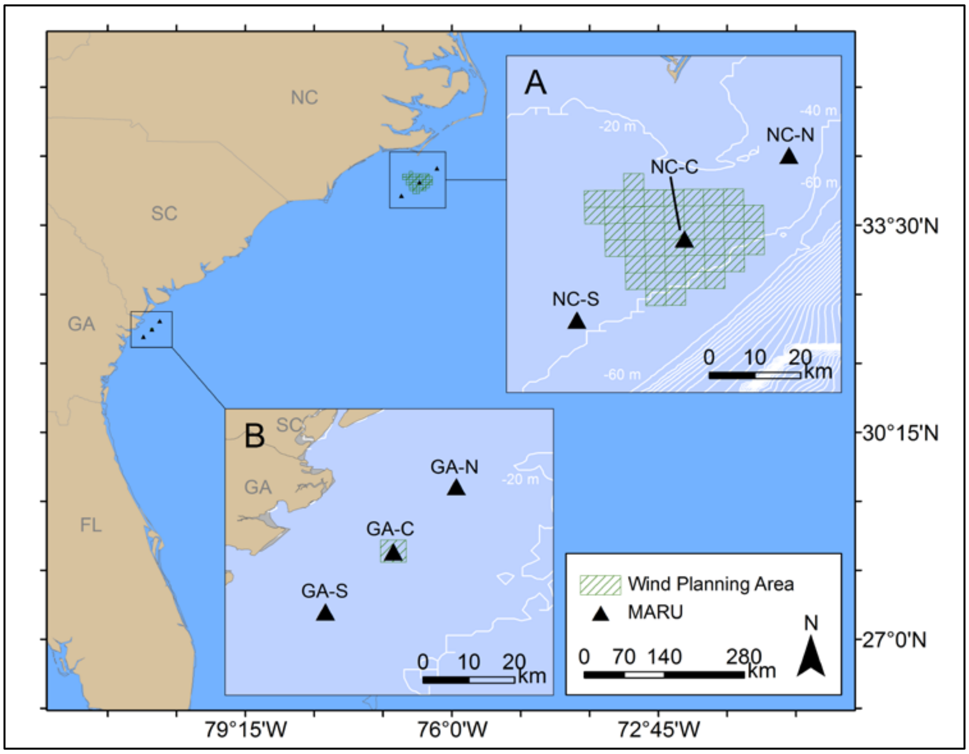

Figure 2.2. Deployment locations of MARUs.
Deployment locations of three Marine Autonomous Recording Units (MARUs) (North (N), Central (C), South (S)) at the (a) North Carolina site and (b) Georgia site, with respect to the wind planning areas.

Table 2.1. Coordinates and depths of marine autonomous recording units (MARUs) deployed at the North Carolina site and the Georgia site.

	MARU	Latitude°	Longitude°	Depth (m)
North Carolina Site	NC-North	34.3927	-76.2356	31
	NC-Central	34.1741	-76.5098	34
	NC-South	33.9613	-76.7925	38
Georgia Site	GA-North	31.9922	-80.5970	14
	GA-Central	31.8640	-80.7207	14
	GA-South	31.7463	-80.8544	14

3. BALEEN WHALE PRESENCE

3.1 INTRODUCTION

The North Atlantic right whale (*Eubalaena glacialis*) is one of the most endangered whale species in the world; it is protected by the Endangered Species Act and the Marine Mammal Protection Act (Clapham et al. 1999; Waring et al. 2013a). Currently, the western North Atlantic population consists of approximately 400–500 individuals (Pettis 2013; Waring et al. 2013a). Despite a recent growth in stock assessment estimation, right whales continue to have a slow and difficult recovery due to low population size, low reproductive rates, and exposure to anthropogenic threats (Fujiwara and Caswell 2001; Fujiwara and Caswell 2001; Kraus et al. 2007; Kraus et al. 2005; Kraus et al. 2005; Kraus and Rolland 2007; Waring et al. 2013a). Ship strikes and entanglement with fishing gear are the leading causes of human-induced mortality for this population, and sub-lethal threats, such as noise pollution, may potentially disrupt biologically relevant behaviors (Clark et al. 2009; Knowlton and Kraus 2001; Kraus 1990; Parks and Clark 2007).

The National Oceanic and Atmospheric Administration (NOAA)'s National Marine Fisheries Service (NMFS) implemented protective measures to mitigate anthropogenic threats to right whales (NMFS 2005), including designating seasonal management areas (SMAs) along the southeast, mid-Atlantic, and northeast nearshore waters of the western North Atlantic that require vessels 65 ft. (19.8 m) or greater to reduce speeds during seasons when right whales are likely to be present (NOAA 2008). Although reducing vessel speed decreases the risk of ship strike mortality (Conn and Silber 2013; Vanderlaan and Taggart 2007; Wiley et al. 2011), current mitigation efforts may not provide adequate protection due to incomplete spatial and temporal coverage of right whale habitat and occurrence (Schick et al. 2009; van der Hoop et al. 2013). Because the efficacy of current management protocols is uncertain, it has been recommended that managers re-evaluate and modify management regulations as necessary (Pace 2011; van der Hoop et al. 2013).

NOAA designated right whale critical habitats to protect and manage geographic areas important for right whale conservation (FWS 2011; NOAA 1994). The U.S. Endangered Species Act defines critical habitat as geographic areas that contain physical and biological features important for life processes and reproduction, which may include breeding and calving grounds, feeding sites, and representative habitats of the historical distribution of a species (FWS 2011; NOAA 1994). Currently, protected right whale habitats include calving areas along the coasts of Florida and Georgia and feeding areas in the Great South Channel (southeast of Cape Cod) and both Massachusetts Bay and Cape Cod Bay (Figure 3.1) (NOAA 1994). Other known right whale habitats, however, are not included, and thus not afforded the same protections as critical habitats. Because calving and feeding events have been documented outside of critical habitat boundaries (Patrician et al. 2009; Whitt et al. 2013), other areas may also be essential right whale habitats. Moreover, efforts to conserve right whales may be diminished if right whales are not protected within the migratory corridor between critical habitat areas (NMFS 2005). Therefore, regulations have been proposed to expand critical habitat boundaries (NOAA 2010).

Understanding right whale distribution and seasonal migratory patterns is essential to inform current management practices. Visual surveys indicate that right whale movements are characterized by an annual, round-trip migration in nearshore waters along the western north Atlantic (Winn et al. 1986). During this migration, right whales congregate in Florida and Georgia calving grounds during winter, migrate in nearshore waters during late winter and early spring to Cape Cod and Massachusetts Bays, then travel to the northern feeding grounds in the Great South Channel during spring, and peak during summer and autumn either in the Bay of Fundy feeding and nursery grounds or the Scotian Shelf feeding grounds (Kenney et al. 2001; Kenney et al. 1995; Kraus et al. 1986; Winn et al. 1986). Although the migration explains the distribution of many right whales, recent studies have detected right whales at times of the year when their occurrence in a region was not previously expected. For instance, Morano et al. (2012) and Whitt et al. (2013) detected right whale occurrence year-round in Massachusetts Bay and the New Jersey coast, respectively, and Mellinger et al. (2007) detected right whales on the Scotian Shelf in late December, when much of the population would be predicted to have left for more southerly areas. These observations suggest seasonal migratory movements are not characteristic of the entire population, because only a subset of the population (predominately reproductive females, calves, and juveniles) are observed traveling along the migratory corridor between calving and feeding grounds (Kraus et al. 1986; Winn et al. 1986), and it is not known where the remaining members of the population spend the winter (Kraus et al. 1986; Winn et al. 1986). Given these findings, investigating right whale spatial and temporal patterns along the right whale's migratory route, particularly in regions where movement patterns are not well understood, could help inform management decisions.

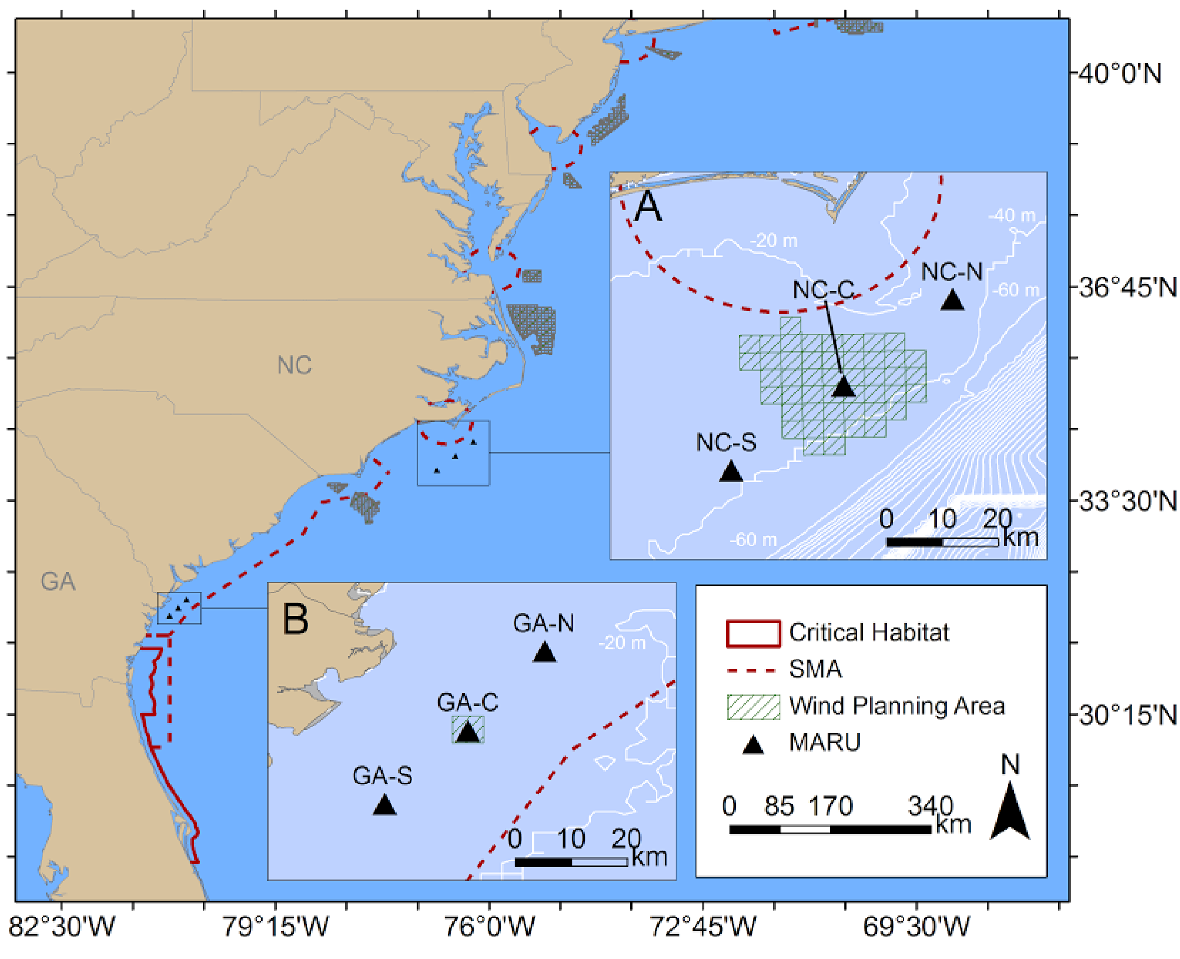

Figure 3.1. Deployment location of MARUs with respect to protected areas for right whales. Deployment locations of marine autonomous recording units (MARUs) at the A) North Carolina site and B) Georgia site, with respect to critical habitats, seasonal management areas (SMAs), and wind planning areas.

The coastal waters of Georgia and North Carolina are part of the mid-Atlantic migratory habitat for right whales traveling between the southeast calving grounds and the northeast feeding grounds (Waring et al. 2013a). However, little is understood about right whale spatial and temporal occurrence in the migratory corridor, due to limited systematic visual survey effort in the mid-Atlantic U.S. (Firestone et al. 2008; Knowlton et al. 2002). Other endangered whales, including fin and humpback whales, also inhabit the mid-Atlantic U.S., yet this region has some of the heaviest vessel traffic along the eastern seaboard and is considered the region of highest risk for vessel-strike mortality (Knowlton et al. 2002; Silber and Bettridge 2010; van der Hoop et al. 2013). Currently, coastal Georgia and North Carolina are being considered for offshore wind energy development (BOEM 2012a; BOEM 2012b), which would increase vessel traffic and the risk of injury or mortality to cetaceans due to ship strikes (van der Hoop et al. 2012). Development activities, including construction and site surveys, would also introduce disturbances that could cause acoustic masking, hearing impairment, or stress (Clark et al. 2007; Madsen et al. 2006; Rolland et al. 2012; Weilgart 2007). Given that baleen whales are susceptible to these threats, information regarding right, fin, and humpback whale occurrence is needed to minimize potential impacts of offshore energy development activities.

We performed an eleven-month ecological baseline study to characterize right, fin, and humpback whale occurrence in two proposed offshore wind energy sites in the mid-Atlantic U.S. In this paper, we summarize passive acoustic survey data to elucidate spatial and temporal patterns of right whale occurrence along the migratory corridor in two survey areas along the Georgia and North Carolina coasts. We discuss the management implications of our findings for right whale occurrence along the migratory corridor with respect to mitigating threats introduced by offshore energy development.

3.2 METHODS

Analysis of acoustic recordings (see Chapter 2) focused on the presence of three baleen species: North Atlantic right whales, fin whales (*Balaenoptera physalus*), and humpback whales (*Megaptera novaeangliae*). We determined the acoustic presence of right whales by identifying contact calls (up-calls), the predominant call type of the species (McDonald and Moore 2002; Mellinger et al. 2007; Parks and Tyack 2005; Parks and Clark 2007; Parks et al. 2007), with an automated detection algorithm (Urazghildiiev et al. 2009). Performance evaluations of the algorithm by Urazghildiiev et al. (2009) and Dugan et al. (2010) reported true detection rates of 80% and 75%, respectively. To verify the validity of detections in this dataset, we reviewed 10–450 Hz spectrograms of the detection output in the MATLAB©-based software program XBAT© (BRP 2012), with a 512-point (256 ms) Hann window and 75% overlap (frequency resolution of 3.91 Hz, time resolution of 64 ms). We applied the following set of criteria to distinguish up-calls from other biological and anthropogenic sounds: (i) starting frequency occurred between 65–170 Hz; (ii) minimum and maximum frequencies differed by 75–200 Hz; (iii) duration ranged from 0.3–1.3 s; (iv) energy was concentrated in the lower portion of the signal; and (v) signal contour sloped upward (Figure 3.2).

The daily presence of right whales at each site was determined as the occurrence of at least one up-call per day on at least one MARU at the site. Percent daily presence during each month was normalized for recording effort by dividing the number of days containing up-calls by the number of recorded days within the month. To represent presence seasonally, months were grouped into seasons, and the number of days containing up-calls within a season was divided by the number of recorded days in the season. Seasons were defined as follows: summer (July 2012–September 2012), autumn (October 2012–December 2012), winter (January 2013–March 2013), and spring (June 2012 and April 2013). To determine the proportion of daily presence that occurred while the mid-Atlantic SMA was in effect, we divided the number of days containing up-calls during November 1–April 30 by the total number of days in the study that contained up-calls.

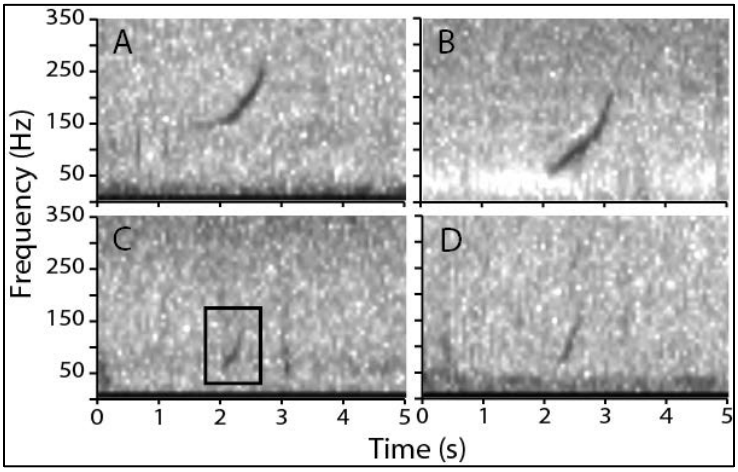

Figure 3.2. Examples of right whale contact calls.
Examples of right whale contact calls (up-calls) recorded at the Georgia site on A) 3 January 2013, B) 14 October 2012, C) 13 July 2012, and D) 28 June 2012. The selection box in example C) distinguishes the contact call from adjacent noise.

The daily presence of fin whales was based on the occurrence of the 20 Hz note, a subunit of fin whale song and a prominent call type of the species (Thompson et al. 1992; Watkins et al. 1987; Watkins 1981). Notes were detected using the data template detector function in XBAT, which performs spectrogram cross correlations between a user-defined exemplar signal and the recording (Mellinger and Clark 2000). We verified the detection output using 60-second spectrograms spanning 10–100 Hz, with a 1024-point (512 ms) Hann window and 75% overlap (frequency resolution of 1.95 Hz, time resolution of 128 ms). We applied the following set of criteria to distinguish 20 Hz notes from other biological and anthropogenic sounds: (i) minimum frequency occurred between 17–20 Hz; (ii) maximum frequency occurred between 20–30 Hz; (iii) note duration was approximately 1 s; (iv) three or more consecutive notes were visible with a consistent internote interval; and (v) internote intervals were no less than 6 s and no greater than 21 s (Figure 3.3).

To evaluate the performance of the fin 20 Hz note detector, we manually browsed the days containing valid fin whale detections and determined the detector's accuracy in reporting hourly presence of 20 Hz notes. We measured hourly presence of 20 Hz notes instead of daily presence because of the rare occurrence of fin 20 Hz notes in the data. Days were manually browsed using 15 min spectrograms spanning 10–60 Hz, with a 4,096-point (2,048 ms) Hann window and 75% overlap (frequency resolution of .49 Hz, time resolution of 512 ms). The detector had a true positive detection rate of 0.39 (29 of the 75 hr containing 20 Hz notes). Although these hourly results may be difficult to extrapolate to daily presence, this performance provides an estimate of the degree that fin whale presence is unaccounted.

Humpback whales, which produce highly variable, frequency modulated signals in the form of calls (social sounds) (Dunlop et al. 2007; Dunlop et al. 2008) and structured song (Payne and McVay 1971; Stimpert et al. 2011), were noted opportunistically when their signals were observed during the verification of right whale up-call detections (Figure 3.4) and during fish presence analyses (see Chapter 4.2.2). Because humpback whales were noted opportunistically rather than systematically, we did not determine spatiotemporal trends in presence.

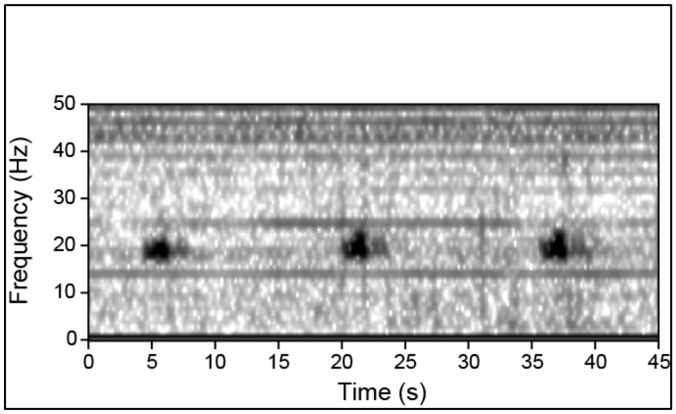

Figure 3.3. Example of fin whale 20 Hz note.
Example of fin whale 20 Hz note recorded at the North Carolina site on 15 March 2013.

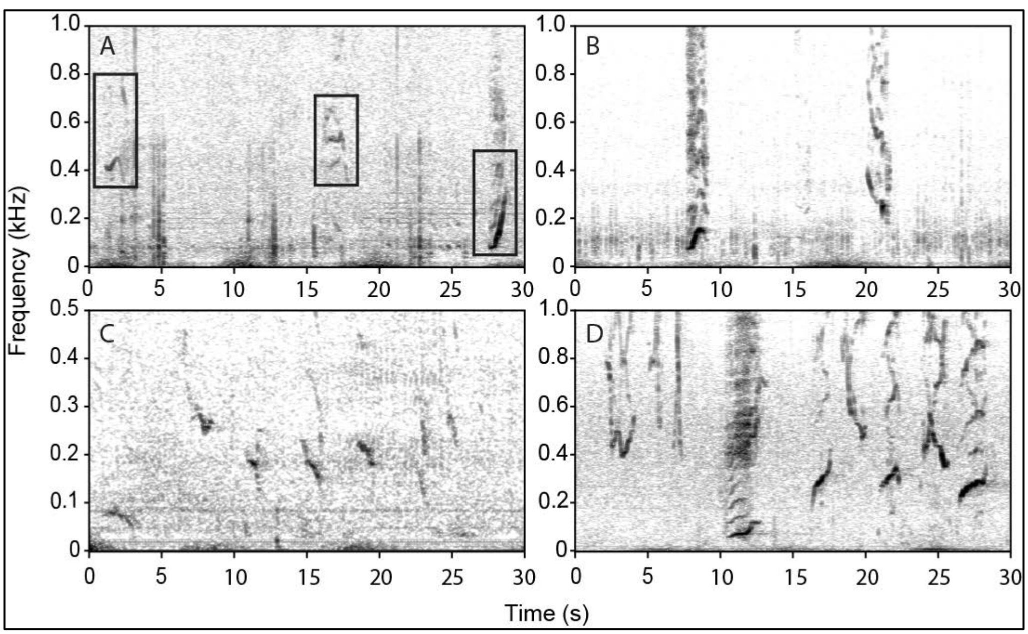

Figure 3.4. Examples of Humpback Whale Social Sounds
Examples of humpback whale social sounds recorded at the Georgia site on A) 15 November 2012, and B) 2 December 2012, and at the North Carolina site on C) 3 December 2012, and D) 4 December 2012. The selection boxes in example A) distinguish social sounds from adjacent noise. Note the frequency scale in example C) differs from the others.

3.3 RESULTS

Right and humpback whales were acoustically detected in both the Georgia and North Carolina survey areas, and fin whale was acoustically detected in the North Carolina survey area. Right whale up-calls were acoustically detected on 80 days (26.1%) in the Georgia site and 22 days (7.2%) in the North Carolina site out of the 307 total days surveyed. Fin whale 20 Hz notes were detected on six days in the North Carolina site, resulting in 2% daily vocal presence (Table 3.1). Humpback whale vocalizations were opportunistically found on eight days in the Georgia site and twelve days in the North Carolina site (Table 3.1).

Table 3.1. Dates fin and humpback whales were detected at the North Carolina site and the Georgia site.

North Carolina Site		Georgia Site	
Fin	**Humpback**	**Fin**	**Humpback**
11/21/2012	06/25/2012		08/31/2012
11/23/2012	08/01/2012		11/15/2012
11/24/2012	12/02/2012		12/02/2012
11/26/2012	12/03/2012		12/08/2012
12/16/2012	12/04/2012		12/15/2012
03/15/2013	12/05/2012		12/20/2012
	12/06/2012		01/22/2013
	12/25/2012		02/06/2013
	02/08/2013		
	03/06/2013		
	03/07/2013		
	03/08/2013		
	03/10/2013		

Right whale up-calls were detected acoustically in every season in the North Carolina survey area (Figure 3.5A). Right whales were not acoustically detected during August 2012, October through November 2012, and April 2013. February 2013 had the greatest number of detection days, with a total of seven days (25%) vocal presence (Figure 3.6A). The peak seasonal daily presence was 14.4% in the winter, followed by 6.6% seasonal daily presence in autumn (Figure 3.5A). Summer and spring had 2.2% and 2.9% peak seasonal daily presence, respectively. Approximately 13.6% of right whale daily presence occurred outside of the mid-Atlantic SMA time window.

Right whale up-calls were acoustically detected in the Georgia survey area every season (Figure 3.5B), present in every month from June 2012 through March 2013 (Figure 3.6B). No detections were found during April 2013. Over the sampled months, December 2012 had the greatest number of detection days, with a total of 29 days vocal presence out of 31 days recorded. Daily percent presence per month had a bimodal trend; an initial peak occurred in June and July 2012, with right whales detected on 18.2% of days in June, and 22.6% of days in July. Peak detections dropped at or below 10% in August through October 2012. A larger, secondary peak occurred in November and December 2012, with right whales detected on 44.8% of days in November and 93.6% days in December (Figure 3.6B). Peak daily presence dropped below 30% in January through March 2013. Subsequently, peak seasonal daily presence occurred in the autumn and winter, with seasonal daily presence of 49.5% and 21.1%, respectively (Figure 3.5B). Summer had 13% seasonal daily presence, and spring had the lowest seasonal daily presence of 10.8%. Nearly a third (28.8%) of right whale daily presence occurred outside the mid-Atlantic SMA time window.

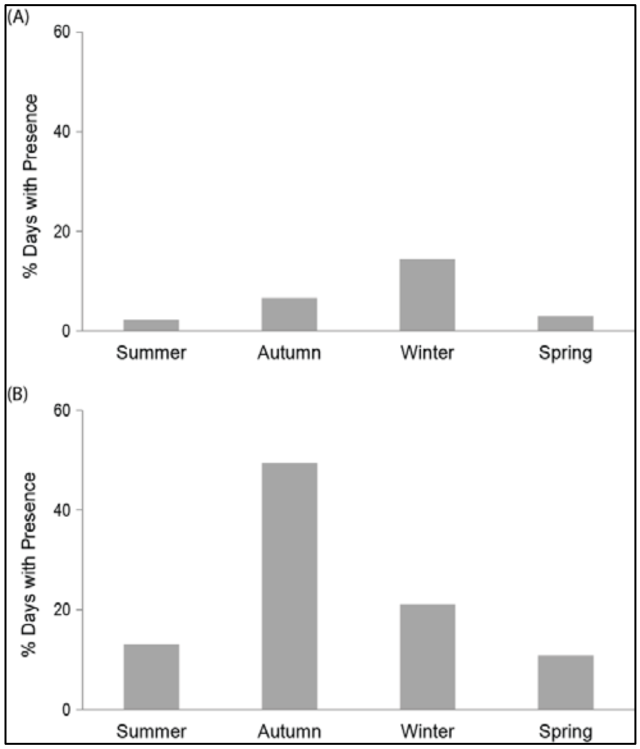

Figure 3.5. Seasonal presence of right whales.
Seasonal presence, percent of recorded days during each season with acoustic presence, of right whales at the (A) North Carolina site and (B) Georgia site.

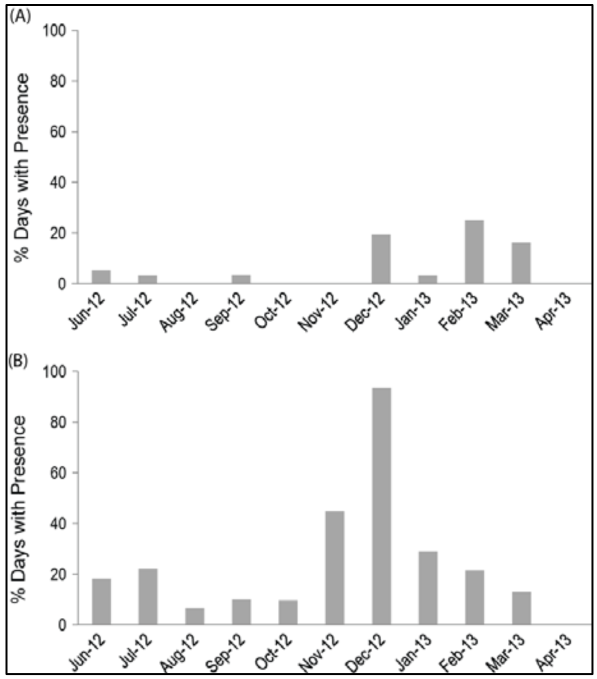

Figure 3.6. Percent vocal presence of right whales.
Percent vocal presence, percent of recorded days during each month with acoustic presence, of right whales at the (A) North Carolina site and (B) Georgia site. No recordings were made during May.

3.4 CONCLUSIONS

In our acoustic survey, fin whales were detected only in the North Carolina survey site, for a total of six days during the autumn and winter months. Our findings are consistent with previous acoustic studies and stranding records from similar latitudes (Nieukirk et al. 2004; Webster et al. 1995). The North Atlantic fin whale stock is commonly found north of Cape Hatteras within the U.S. Exclusive Economic Zone (Waring et al. 2013b). Given that both the Georgia and North Carolina survey sites occur just south of Cape Hatteras, it is expected that fin whale presence in lower latitudes would be infrequent. However, fin whales are a highly distributed species, and little is still known regarding fin whale migratory movements, breeding sites, and calving areas (Nieukirk et al. 2004; Waring et al. 2013b). Fin whale presence and absence in the North Carolina and Georgia study sites provides additional baseline information for future studies.

Humpback whales were detected opportunistically in both the Georgia and North Carolina survey sites, predominately during the autumn and winter months. Our findings are consistent with previous acoustic surveys, stranding records, and visual sightings along the mid-Atlantic U.S. (Barco et al. 2002; Hodge 2011; Nieukirk et al. 2004; Webster et al. 1995). Although the majority of humpback whales migrate from northern feeding areas to the southern breeding grounds near the West Indies at this time, many individuals stay in the mid-Atlantic U.S., possibly as a supplemental feeding ground (Barco et al. 2002; Waring et al. 2013a). A systematic acoustic survey would reveal more information regarding seasonal occurrence of humpback whales in the mid-Atlantic U.S.

In our acoustic survey along the coastal waters of Georgia and North Carolina, right whales were detected during all seasons. Right whale sounds were also found in a majority of the months sampled during this study, suggesting that right whales may be present in the surveyed sites year-round. Given how little is known about right whale movements and distribution in the mid-Atlantic U.S., our data provide a baseline understanding of right whale occurrence in the nearshore waters of Georgia and North Carolina.

The traditional migratory paradigm describes a seasonal presence of right whales along the mid-Atlantic U.S. between November and April, likely for travel between calving and feeding grounds (Winn et al. 1986). Although right whales were detected between November and April, our results show right whales occurred in the Georgia and North Carolina sites outside of the previously documented migratory period. The nearly year-round presence of right whales at the survey sites indicates a pattern of presence inconsistent with what has been described as the “typical” seasonal migratory model. Our results suggest that these regions along the mid-Atlantic U.S. could also be important non-migratory habitat for right whales. The North Carolina site had a fairly consistent low level of presence throughout the survey period when compared to the Georgia site, which may have been due to fewer whales in the area, or possibly due to the presence of non-vocalizing whales. Peak presence in the Georgia site occurred during the late autumn and early winter months, which overlaps with the occurrence of right whales in the designated critical calving habitat (Kenney et al. 2001; Kraus et al. 1986). Given our demonstration of right whale presence in the Georgia study site during calving periods, and given the proximity of the study site to the designated critical calving habitat, it is possible that this region of the mid-Atlantic U.S. could be important for calving activities (Waring et al. 2013a). The North Carolina site may also be important for calving activities, because rare calving events have occurred outside of the critical calving habitat along the mid-Atlantic and northeast U.S. (Patrician et al. 2009; Waring et al. 2013a).

Peak acoustic presence in the Georgia and North Carolina survey areas occurred between November and April, when whales are described to migrate through the mid-Atlantic U.S. (Winn et al. 1986). Peak presence may have been due to a greater number of right whales in the area, increased vocal activity, or both. Our data shows a decreased percent presence at the Georgia site and an increased percent presence at the North Carolina site between January and March. The temporal differences in peak presence between survey areas may reflect the previously described northerly migration in the late winter and early spring, when right whales depart the southern winter calving grounds along the Florida and Georgia coasts and travel to spring feeding areas in the northeast U.S. (Kenney et al. 2001). However, because we do not have observational data to confirm right whale behavior, it is unclear in what direction the right whales may be traveling, or if our data detected the same individuals between survey sites.

A second, smaller increase in presence occurred in June and July in the Georgia study site, when right whales typically aggregate in the Great South Channel, and the Gulf of Maine, and on the Scotian Shelf (Winn et al. 1986). Although visual surveys have detected occasional right whales in mid-Atlantic U.S. coastal areas during summer months, right whales have not been observed in the southeast at that time (Winn et al. 1986). It is unclear if our data indicate a rare occurrence or an unknown but more consistent presence of right whales at this time of year. Nevertheless, movement patterns that are not characteristic of the entire right whale population have been documented before, including presence in historical ranges and unexpected habitats (Jacobsen et al. 2004; Mate et al. 1997; Mellinger et al. 2011; Moore and Clark 1963). Because right whales are not typically observed so far south outside of the calving season, further investigation is needed to understand what is influencing right whale summer distribution along the nearshore waters of Georgia.

Our data demonstrate that right whales are within the Georgia and North Carolina survey areas nearly year-round, and this information can be used to evaluate management decisions with respect to offshore energy development activities. Currently, mitigation protocols are informed by the known right whale seasonal distribution, limiting regional management actions to times when right whales are most likely to be present (BOEM 2012b). These protocols include: restricted energy development activities during time-area closures, based on the mid-Atlantic SMA time window (November 1 through April 30); constrained development activities in designated critical habitat during time-area closures; compliance with vessel speed restrictions in the mid-Atlantic SMA; and marine mammal monitoring on survey vessels (BOEM 2012b). Because right whales are present in the Georgia and North Carolina survey areas outside of the designated mid-Atlantic SMA time period, right whales in these areas would be at risk of exposure to lethal and sub-lethal threats when restrictions are not in effect. When right whales are not in SMAs or DMAs, BOEM Standard Operation Conditions still provide protection for this endangered species to restrict or prevent, or both, risk of exposure to lethal and sub-lethal threats. Additionally, the mid-Atlantic SMA zone has discontinuous coverage of speed zone areas concentrated around major ports, which offer protection within a 20 nmi (37 km) radius (NOAA 2008). Right whales may occupy habitat beyond the 20 nmi radius, as evidenced by the data collected from the North Carolina survey site, which is located approximately 30 nmi (55.6 km) offshore. Therefore, right whales further offshore than the mid-Atlantic SMA region would also be at risk of exposure to all threats associated with energy development activities. Also, right whales in both the Georgia and North Carolina survey sites will not be afforded the same protections as whales within the critical calving habitat. Thus, enacting management decisions based solely on the “typical” right whale seasonal migration may not provide adequate protection for right whales in the surveyed mid-Atlantic regions.

The loss of even one individual right whale, particularly a reproductive female, can have severe consequences to the recovery of this population from the threat of extinction (Caswell et al. 1999; Kraus et al. 2005). Preventing right whale mortality is of utmost importance for the conservation of this species, and given the risk of exposure to threats associated with anthropogenic activities, we suggest our data warrants a re-evaluation of many previously established management protocols. The current SMA geographic coverage in the mid-Atlantic U.S. may need to be amended to include other areas of suitable right whale habitat. Our results demonstrate right whale presence nearly year-round outside the 20 nmi radius of SMA protection in North Carolina. Extending the protective coverage to a minimum of 30 nmi, as suggested in Schick et al. (2009), would potentially mitigate vessel strikes, since reduced vessel speeds decrease the risk of ship-strike mortality (Conn and Silber 2013; Vanderlaan and Taggart 2007). The SMA time period may also need to be extended to include other seasons when right whales may occur in the area (Pace 2011). Last, our data could be used to consider the extension of critical habitat boundaries into areas along the mid-Atlantic migratory corridor (NOAA 2010). Nearly year-round presence of right whales in mid-Atlantic U.S. coastal waters may indicate that this region contains features important for right whale survival and reproduction.

Although our data show right whale vocal presence in all seasons, our survey period is not long enough to elucidate long-term seasonal patterns of distribution and inter-annual variability. Other processes, such as prey distribution, are known to affect the movement patterns of right whales, and these patterns may vary over time (Baumgartner et al. 2003; Pendleton et al. 2009; Wishner et al. 1995). A longitudinal monitoring effort would not only reveal further information about right whale spatial and temporal patterns, but could also address questions regarding demography, abundance, and habitat use. Currently, visual survey monitoring efforts are not conducted in the North Carolina survey area, and aerial monitoring is being discontinued in the Georgia survey area (Hain et al. 2013). Given how little is known about right whales in the mid-Atlantic migratory corridor, we recommend long term monitoring efforts be conducted along the Georgia and North Carolina coasts in the mid-Atlantic U.S. We recommend managers consider the use of passive acoustic monitoring in conjunction with visual survey efforts. Visual surveys provide observational data that inform questions regarding demography and behavior of right whales, which cannot be addressed with passive acoustic data. However, passive acoustic monitoring is an effective and economical tool for monitoring right whales over extended periods, particularly when right whale occurrence is infrequent, and when aerial surveys cannot be performed due to the time of day or inclement weather (Clark et al. 2010; Mellinger et al. 2007). Passive acoustic monitoring, in conjunction with visual survey efforts, would provide the most comprehensive understanding of right whale distribution and habitat characterization to better inform management decisions.

4. FISH PRESENCE

4.1 INTRODUCTION

Coastal marine ecosystems provide a range of ecosystem services, yet are under threat from many anthropogenic pressures (Foley et al. 2010; White et al. 2012). These ecosystems contain most of the world's fisheries, provide the potential for energy exploration and extraction, facilitate global trade through commercial shipping, and provide sources of tourism and recreation (Foley et al. 2010; White et al. 2012). The increased awareness of acute and chronic environmental impacts resulting from human activities has necessitated a desire to balance the need for such activities with environmental protection and preservation, and is central to the concept of environmental sustainability (Clark and Dickson 2003; Foley et al. 2010). Emphasis on marine sustainability has coincided with the approach referred to as Coastal and Marine Spatial Planning, which seeks to balance human environmental use with sustainable development in ocean environments (Foley et al. 2010; Lester et al. 2013; White et al. 2012).

Evaluating how ecosystems are impacted by human use requires measuring environmental parameters that are indicative of an ecological response. Initial environmental impact assessments typically focus on acute and/or lethal impacts to organisms, but longer-term study of habitats has revealed the potential severity of sub-lethal, chronic impacts. Many human activities in natural habitats create multiple complex stressors on the habitat (Crain et al. 2008; Ellison et al. 2012), and it can be challenging to evaluate differential effects from different sources, or the cumulative impact from multiple stressors (Crain et al. 2008). To evaluate impact on an ecosystem, monitoring approaches are needed that include surveys for organisms and their behavior or physiology in response to human activities. Such monitoring approaches need to account for the fact that ecological change may occur gradually, and unfold over long periods of time and at broad spatial scales. Ecological change may manifest itself as the change in habitat quality, habitat structure, species composition, or species behavior.

Passive acoustic monitoring has emerged as a non-invasive, data-intensive, low-cost methodology to survey the occurrence, abundance and behavior of acoustically active organisms (Bridges and Dorcas 2000; Van Parijs et al. 2009; Zimmer 2011). Passive acoustic surveys have been used to examine the response of specific taxonomic groups to environmental correlates or pressures (Busby and Brecheisen 1997; Gibbs et al. 2005; Luczkovich et al. 2008a; Rountree et al. 2006), as well as to identify those taxonomic groups whose occurrence or behavior could reflect habitat fidelity (Arroyo-Solis et al. 2013; Hansen et al. 2005). Acoustic recorders can collect data over long time periods and broad spatial scales to provide large-landscape evaluations of environmental change. Additionally, the ability to store and archive acoustic files allows for long term accessibility of acoustic survey data to allow datasets to be re-examined to evaluate changes in bioacoustic activity many years after they were first collected. Passive acoustic surveys can be conducted in remote locations that are not easily accessible by more traditional survey techniques.

Along the U.S. Atlantic coast, a great number of fish species produce sounds for intraspecific communication. Atlantic coast fishes are probably the best acoustically characterized assemblage of fishes, with research on these species spanning over a century (Fish and Mowbray 1970; Tavolga 1965; Tower 1908). Fishes, like many other vertebrates, produce sounds as a fundamental component of their life history, primarily in reproductive or agonistic contexts (Bass and McKibben 2003). During spawning season, many fishes form large assemblages and produce advertisement calls that are sustained over hours or days, and are regularly the most dominant biological acoustic signal in the environment (e.g., Aalbers and Drawbridge 2008; Gannon 2008; Locascio and Mann 2011a; Locascio and Mann 2011b; Rowe and Hutchings 2006). The acoustic behavior of fishes is advantageous for passive acoustic monitoring approaches that can document species occurrence, distribution, behavior, and potential habitat quality

(Van Parijs et al. 2009), as has similarly been done with frogs (Bridges and Dorcas 2000), birds (Blumstein et al. 2011; Hansen et al. 2005), and marine mammals (Mellinger et al. 2007; Zimmer 2011).

Documented knowledge of sound production among a variety of fish species can be used to identify occurrence, population level changes, and important habitat areas (Lowerre-Barbieri et al. 2013; Luczkovich et al. 2008b; Luczkovich et al. 1999; Walters et al. 2009), or in an applied context to understand population responses to environmental perturbations (Walters et al. 2013). By using passive acoustic monitoring to understand and document baseline spawning periodicity of populations, observations of changes from these established baselines can be used as an indicator of potential changes in population ecology.

Different fish species can be potential ecological indicators for different habitats. Many of the acoustically active fish species often have relatively limited migration distances, and are regularly resident in certain areas. Different fish species occupying the same habitat have a diversity of ecological roles and requirements, and simultaneous observations of multiple species can reveal differential impacts across the ecosystem. Reproductive activity is one of the first measurable behaviors to change in response to environmental disturbance; this has been demonstrated in a wide variety of acoustically active taxa (Arroyo-Solis et al. 2013; Gibbs et al. 2005; Rako et al. 2013; van Buggenum and Vergoossen 2012). Whereas much of coastal marine spatial planning examines the potential impact to protected marine species such as marine mammals and sea turtles (White et al. 2012), these protected species are not intended to serve as ecological indicators of an ecosystem, and the ability to infer habitat or ecosystem changes from monitoring these species is limited. Marine mammal monitoring is targeted for species conservation under the U.S. Endangered Species Act, and not targeted or necessarily effective for ecosystem assessment. Surveying the behavior of different focal fish species provides a way to evaluate their ecology and habitat changes more effectively than low abundance or seasonally migrating species, such as whales. Several of the soniferous Atlantic fish species have served as model organisms for understanding fish and vertebrate communication (Amorim 2006; Bass and McKibben 2003), and there is a detailed understanding of the production, perception, behavioral function, and ecological role and importance of their acoustic behavior (Bass and Ladich 2008). We suggest that the knowledge of the function, behavior and ecology of fish sounds makes fish a potentially valuable indicator of ecosystem status.

Several offshore locations along the U.S. Atlantic coast have been identified as potential sites for wind energy development. The development of offshore wind as a renewable energy resource offers tremendous potential for sustainable energy in the U.S., but there are concerns about the possible ecological impacts from wind turbine construction and operation. Ecological monitoring in the North Sea has been conducted to evaluate possible impacts of wind farm development and operation on different marine species, with mixed results (Andersson and Öhman 2010; Bailey et al. 2010; Gilles et al. 2009; Kikuchi 2010). However, these previous studies are primarily evaluating potential impacts to fish populations with acute or lethal criteria, and not examining the role of sub-lethal chronic impacts leading to behavioral or ecological changes in fish populations resulting from offshore wind development and operation. The passive acoustic monitoring methods used in this study allow for the continuous monitoring of the behavior of fish populations through different stages of development and operation, and have the potential to reveal subtle changes in fish behavior.

4.2 METHODS

4.2.1 Focal Species

Black drum (*Pogonias cromis*) and oyster toadfish (*Opsanus tau*) are coastal fishes, distributed along the Atlantic coast of the U.S., from New England to Argentina and New England to Florida, respectively (e.g., Silverman 1979). Both species associate closely with the benthic habitat. Black drum are demersal and feed on mollusks in mud and sand (Pearson 1929). Oyster toadfish are omnivorous, preferring crabs (Gray and Winn 1961). Black drum reside in bays, estuaries, and shallow, euryhaline areas and can tolerate hypersaline estuaries (Frisbie 1961; Silverman 1979). Larvae and juveniles may remain within these smaller bodies of water, but adults may move offshore (Frisbie 1961) or travel hundreds of kilometers up the U.S. coast during spawning season (Murphy et al. 1998). Adult toadfish move into shallow water for spawning, but then move offshore in the winter. Juvenile oyster toadfish remain inshore (Fine 1978; Isaacson 1964; Schwartz 1974).

Black drum are group-synchronous, broadcast spawners, aggregating in the spring near mouths of bays and rivers to fertilize pelagic eggs (Fitzhugh et al. 1993; Nieland and Wilson 1993; Silverman 1979). Using muscles attached to the swimbladder (Tower 1908), males produce a distinct call for reproductive advertisement (Fish and Mowbray 1970; Mok and Gilmore 1983) that can be loud, exceeding 160 dB (Locascio and Mann 2011a). Male toadfish also produce a call to attract females (Gray and Winn 1961; Gudger 1912) using dedicated muscles on the swimbladder (Burkenroad 1931). Males defend benthic nests in late spring through summer and remain with the nests until the larvae are free swimming (Gray and Winn 1961). During the peak of the reproductive season, when multiple male black drum and toadfish are calling simultaneously, the high rate of calls is termed a chorus. Although these calls are associated with courtship and spawning, toadfish can continue to call beyond the mating season (Fine 1978).

4.2.2 Acoustic Analysis

From the acoustic data collected at three MARUs at each of the North Carolina and Georgia sites (see Chapter 2), we determined the daily presence of both black drum and oyster toadfish by identifying the loud drum calls of black drum (Mok and Gilmore 1983) (Figure 4.1.A–D) and the boat whistle calls of oyster toadfish (Tavolga 1958) (Figure 4.1.E–H). Calls were initially identified opportunistically during right whale analysis (see Chapter 2), but on those days without identified calls, we reviewed 60-s spectrograms spanning 10–450 Hz with a 512-point (256 ms) Hann window and 75% overlap (frequency resolution of 1.95 Hz, time resolution of 26 ms) using the Matlab-based software program XBAT (Bioacoustics Research Program 2012). Because oyster toadfish call throughout the day (Fine et al. 1977) and black drum typically call from dusk to midnight (Mok and Gilmore 1983; Saucier and Baltz 1993), we analyzed 12 hours of each day from 0:00–6:00 and 18:00–24:00. Black drum calls were distinguished from other biological and anthropogenic sounds using the following criteria (sensu Fish and Mowbray 1970; Mok and Gilmore 1983): (i) fundamental frequency occurred between 70–120 Hz, (ii) 0–4 harmonics were visible, (iii) duration ranged from 0.2–0.5 s, (iv) signal was preceded by a broadband pulse when the signal to noise ratio was optimal, and (v) signal contour sloped downward. Oyster toadfish calls were identified by the following criteria (Fine and Thorson 2008; Tavolga 1958): (i) fundamental frequency occurred between 100–300 Hz, (ii) 0-2 harmonics were visible, (iii) duration ranged from 0.2–0.4 s, and (iv) signal contour was flat or sloped downward. Daily presence of each fish species was determined as the occurrence of at least one call per day on each MARU.

Black drum and toadfish choruses were determined by examining 60-min spectrograms spanning 0–1000 Hz with a 512-point (256 ms) Hann window and 25% overlap (frequency resolution of 1.95 Hz, time resolution of 26 ms) and identifying sustained calling by black drum or toadfish, which is visible as a continuous band of signals corresponding to the fundamental frequencies and harmonics of each species' call (approximately 80 Hz, 160 Hz, and 240 Hz for black drum; approximately 120 Hz and 240 Hz or 230-250 Hz for toadfish) (Figure 4.2). This results in a calling rate of approximately one or more calls per second, and calls may overlap. Chorusing is distinctly different from individual, isolated calls that cannot be seen in 60-min spectrograms. Daily presence of the chorus for each species and the approximate start and end times (rounded to the closest hour) was determined for each day on each MARU.

If signals from humpback whales were visible during these analyses for black drum and toadfish, they were noted and contributed to humpback whale opportunistic presence analyses (see Chapter 3).

Water temperature was recorded every 15 minutes with a Hobo® Pro v2 (Onset Computer Corporation, Bourne, MA) in each MARU. Daily average temperature was calculated at each recoding site and compared to daily presence of black drum and oyster toadfish with a logistic regression in JMP® Pro 10 (SAS Institute Inc., Cary, NC) to examine the relationship between water temperature and occurrence of these fish.

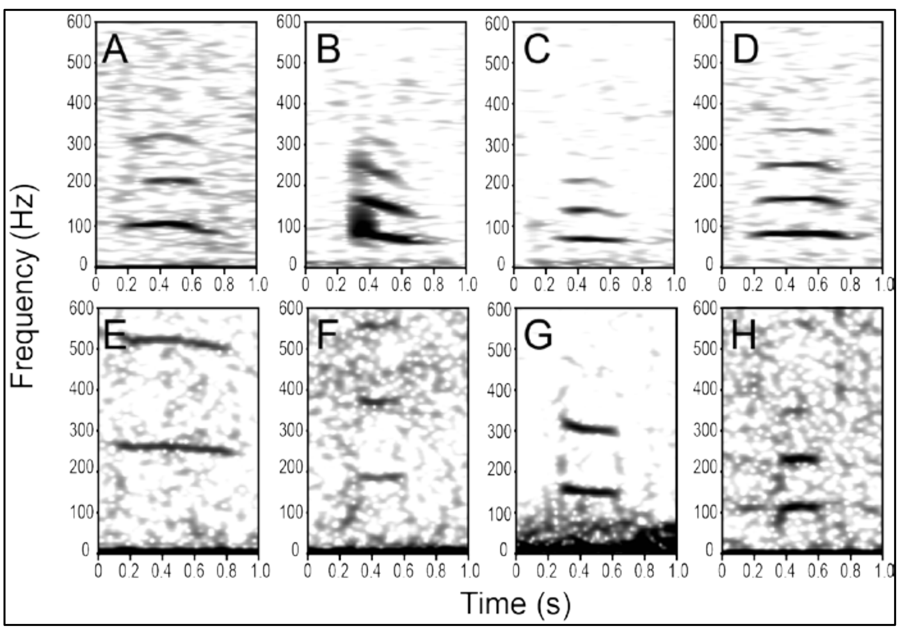

Figure 4.1. Variation in black drum loud drum and oyster toadfish boat whistle calls identified in North Carolina and Georgia.
Fundamental frequency (F_o) of black drum calls varied between 70-100 Hz. For example, black drum **A**) F_o = 100 Hz recorded at NC-North on 16 December 2012, **B**) F_o = 80 Hz recorded at GA-Central on 8 January 2013, **C**) F_o = 75 Hz recorded at GA-Central on 8 January 2013, and **D**) F_o = 85 Hz recorded at GA-Central on 8 January 2013. The F_o of oyster toadfish calls varied between 100-170 Hz. For example, toadfish **E**) F_o = 250 Hz recorded at GA-North on 15 July 2012, **F**) F_o = 180 Hz recorded at GA-North on 19 October 2012, **G**) F_o = 150 Hz recorded at GA-North on 12 November 2012, and **H**) F_o = 100 Hz recorded at GA-South on 31 March 2013. Spectrograms were created in Raven 1.5 (Bioacoustics Research Program 2014), for A–D, with a 512-point Hann window and 90% overlap (frequency resolution of 3.91 Hz, time resolution of 25.5 ms), and for E–H, with a 256-point Hann window and 89.8% overlap (frequency resolution of 7.81 Hz, time resolution of 13 ms).

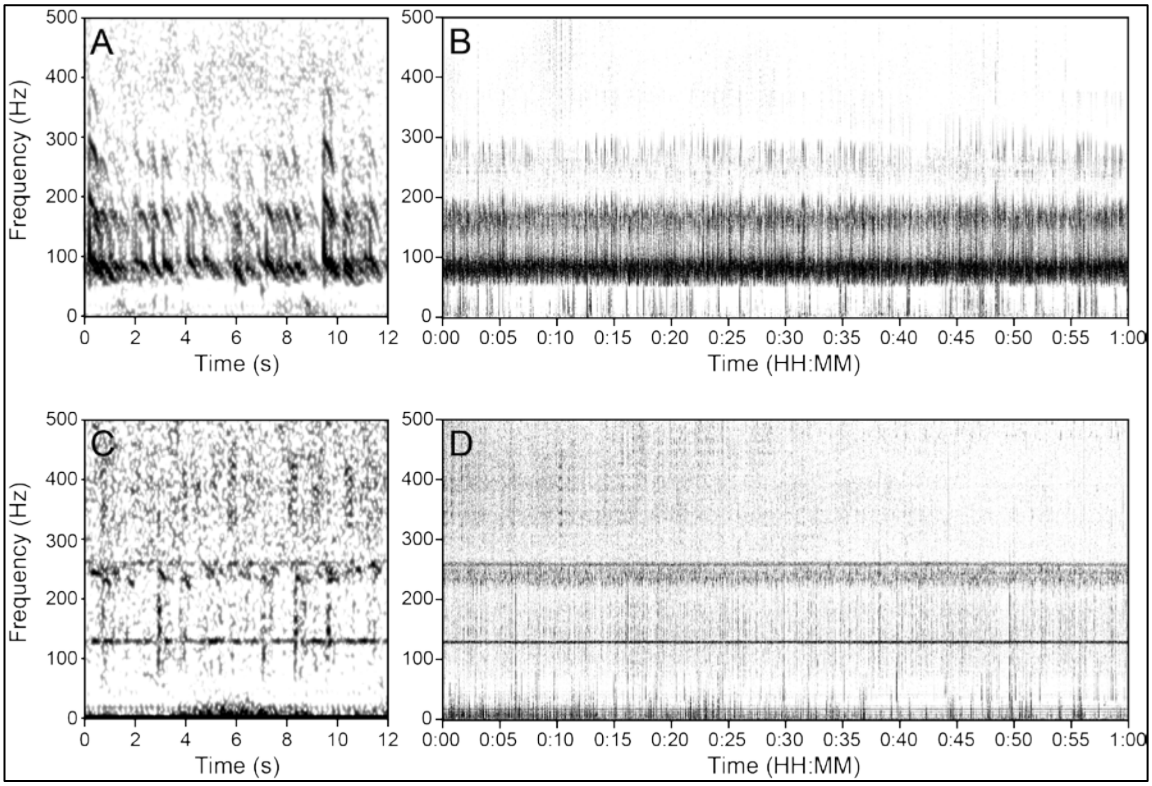

Figure 4.2. Black drum and toadfish chorusing.
A) 12-s spectrogram of black drum chorus and **B**) a 1-hr spectrogram view of the black drum chorus, where the sustained, high rate of calls produces a continuous band of energy with the fundamental frequency (F_o) at ~80 Hz and harmonics at ~160 Hz and ~240 Hz at GA-Central on 6 April 2013. **C**) 12-s spectrogram of toadfish chorus and **D**) a 1-hr spectrogram view of the toadfish chorus, where the sustained, high rate of calls produces a continuous band of energy with the F_o at ~250 Hz at GA-North on 11 June 2012. Spectrograms were created in Raven 1.5 (Bioacoustics Research Program 2014), for A and C, with a 512-point Hann window and 90% overlap (frequency resolution of 3.91 Hz, time resolution of 25.5 ms), and for B and D, with a 2048-point Hann window and 90% overlap (frequency resolution of 0.977 Hz, time resolution of 103 ms).

4.3 RESULTS

Black drum and oyster toadfish were present over differing time periods at the North Carolina and Georgia sites. Black drum are predominantly present from the autumn through spring (November–April 2013). Oyster toadfish are predominantly present in the early spring and summer (March–April 2013 and June–August 2012) (Figure 4.3). Both species were detected on more days in Georgia than in North Carolina (Figure 4.3). Black drum were present on 463 days of 614 days analyzed across three MARUs in Georgia, but on only 31 of 614 across three MARUs in North Carolina, Toadfish were present on 257 days of 614 days analyzed across three MARUs in Georgia, but on only 13 in North Carolina.

There was greater variation in species presence among MARUs in North Carolina than in Georgia where black drum and oyster toadfish were present at all MARUs. In North Carolina, oyster toadfish were detected at NC-North and NC-Central for only a total of 13 days and were not detected at NC-South (Figure 4.3A). Black drum were present on days at NC-Central in November–December 2012 and February–April 2013, and present only one day each at NC-North and NC-South (Figure 4.3A). In

Georgia, black drum were more frequently present on the same day across all MARUs than were toadfish (Figure 4.3B). Toadfish were present in fewer days at GA-Central (38 days), overall, than GA-North (128 days) and GA-South (91 days) (Figure 4.3B).

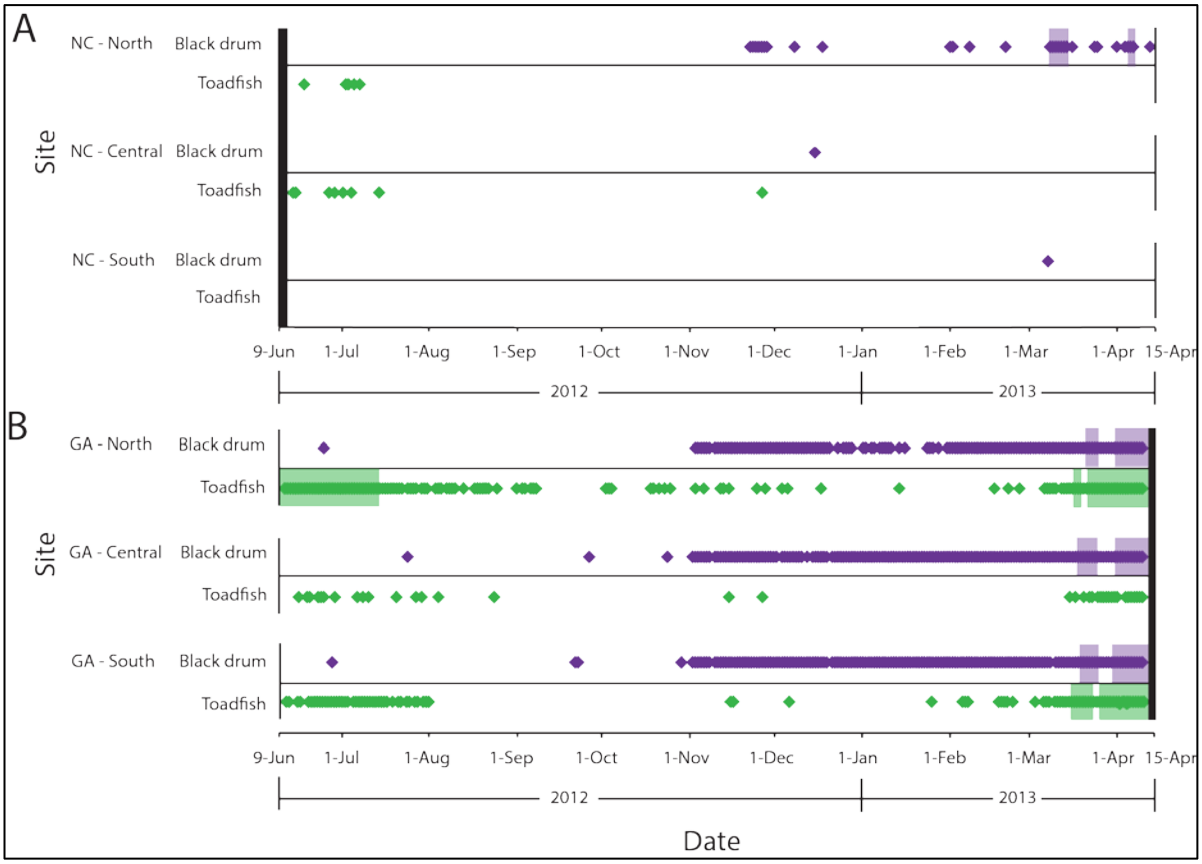

Figure 4.3. Black drum and oyster toadfish occurrence and chorusing periods in North Carolina and Georgia.
A) Black drum (black triangles) and toadfish (gray triangles) presence at each MARU in North Carolina, 12 June 2012–15 April 2013. B) Black drum and toadfish presence at each MARU in Georgia, 9 June 2012–12 April 2013. Shaded boxes correspond to chorusing periods. Black vertical lines indicate days not analyzed in each site.

Black drum chorused 21–25 March and 1–12 April 2013 at GA-North, 18–25 March and 1–12 April 2013 at GA-Central, and 19—25 March and 31 March–12 April 2013 at GA-South (Figure 4.3). Black drum also chorused 9–15 March and 6–9 April 2013 at NC-North; no chorusing was detected at NC-Central and NC-South (Figure 4.3). Start and end times of chorusing were variable between days and among MARUs, but chorusing occurs between approximately 15:00 and 06:00. Chorusing started as early as 10:00 on 12 April 2013 in North Carolina. Chorusing occurred most frequently between 18:00 and 5:00, and exceeded amplitudes of 100 dB at frequencies corresponding to the fundamental frequency and harmonics of the call, at approximately 80 Hz, 160 Hz, and 240 Hz (Figure 4.4). Oyster toadfish chorused 9 June–12 July 2012 at GA-North, 18–20 March 2013 and 22 March–12 April 2013 at GA-Central, and 16–24 March 2013 and 26 March–12 April 2013 at GA-South. Oyster toadfish chorusing was not detected in North Carolina. Chorusing occurred continuously throughout the day, creating visible energy frequency bands that correspond to the fundamental frequency and harmonics of the calls. Although we did not systematically measure the fundamental frequency of oyster toadfish calls, based on our identification of boat whistle calls, the fundamental frequency varied throughout the year. During the first deployment, June–November 2012, the fundamental frequency varied greatly between approximately 180 and 270 Hz (Figure 4.1). In the second deployment, November 2012–April 2013, the fundamental frequency gradually increased from approximately 120 Hz to 125 Hz (Figure 4.1).

The average annual water temperature between North Carolina (21.7 ^{o}C ± 0.2 [SE], range = 13.4-29.0 ^{o}C) and Georgia (21.0 ^{o}C ± 0.1, range = 12.8-29.9 ^{o}C) were similar, but daily water temperature was more variable between sites and days in North Carolina than in Georgia (Figure 4.5). Excluding the low fish presence data from NC-Central and NC-South, the occurrence of both species was associated with water temperature at the sites. Oyster toadfish occurrence was significantly associated with water temperatures below 20 ^{o}C and above 24 ^{o}C (logistic regression, df = 1, χ^2 = 5.90, p = 0.0152) (Figure 4.6). Black drum occurrence was strongly associated with temperatures below 20 ^{o}C (df = 1, χ^2 = 976.36, p < 0.0001).

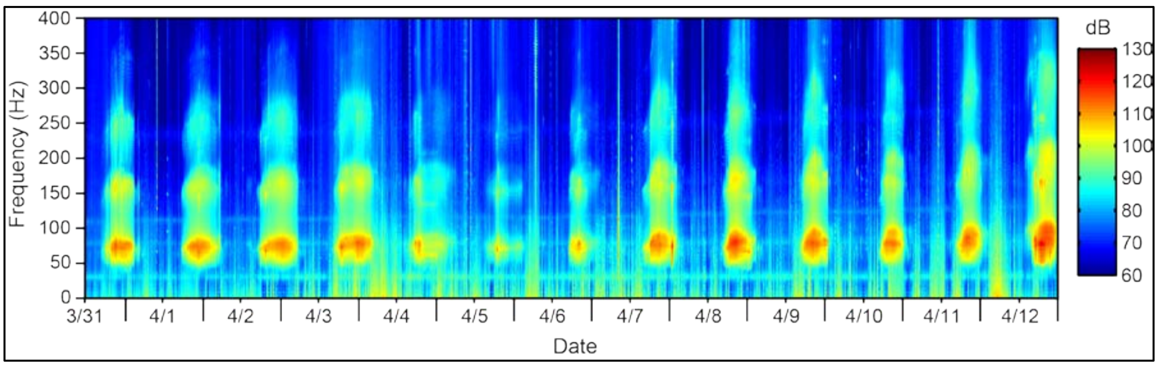

Figure 4.4. Diel pattern of black drum chorus.
Black drum chorusing overnight from approximately 15:00-5:00, 31 March–12 April 2013 at GA-South. Chorusing produces sound levels >120 dB at the fundamental frequency of the call (~80 Hz) and sound levels >100 dB at the first and second harmonics (~160 Hz and 240 Hz). Major tick marks identify 0:00, the start and end of each day; minor tick marks identify 12:00.

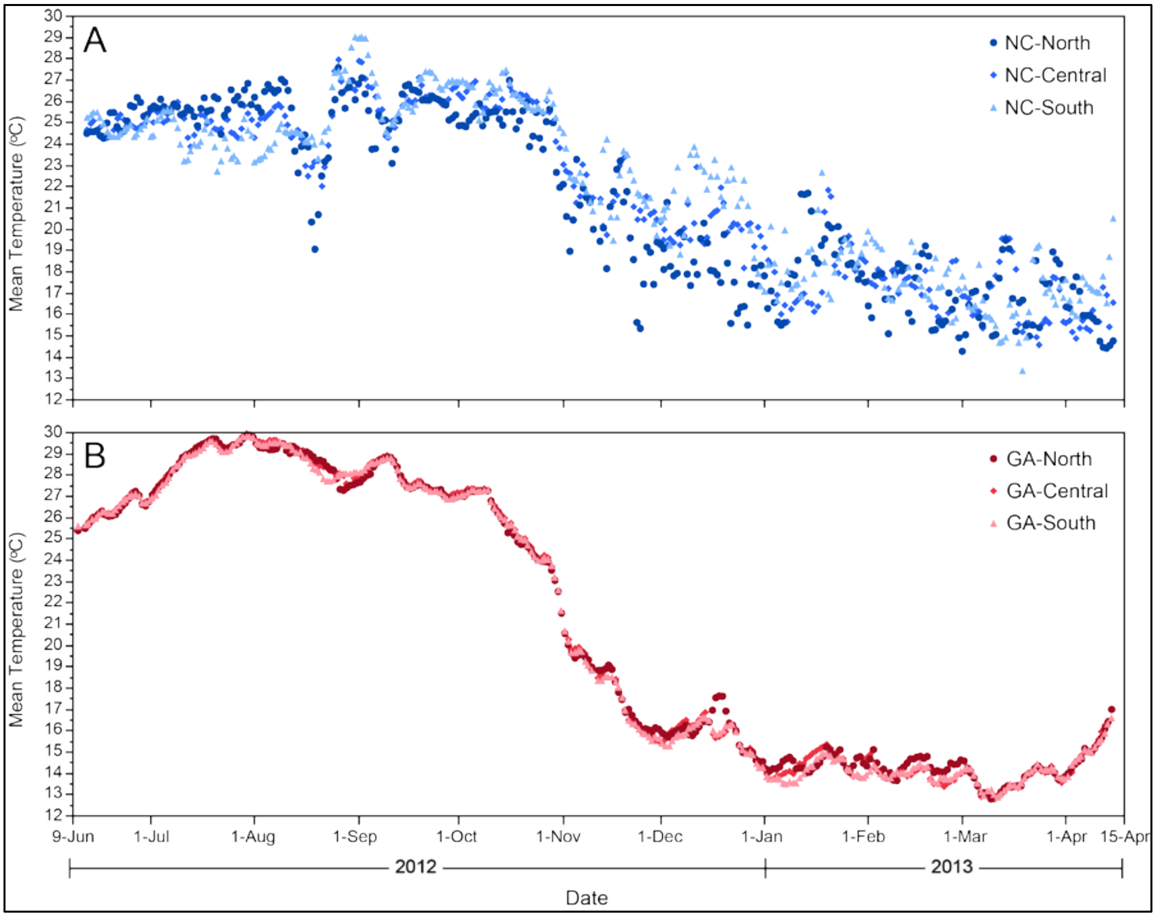

Figure 4.5. Mean daily temperature in North Carolina and Georgia.
Mean daily temperature at each MARU in A) North Carolina, 12 June 2012–15 April 2013, and B) Georgia, 9 June 2013–12 April 2013.

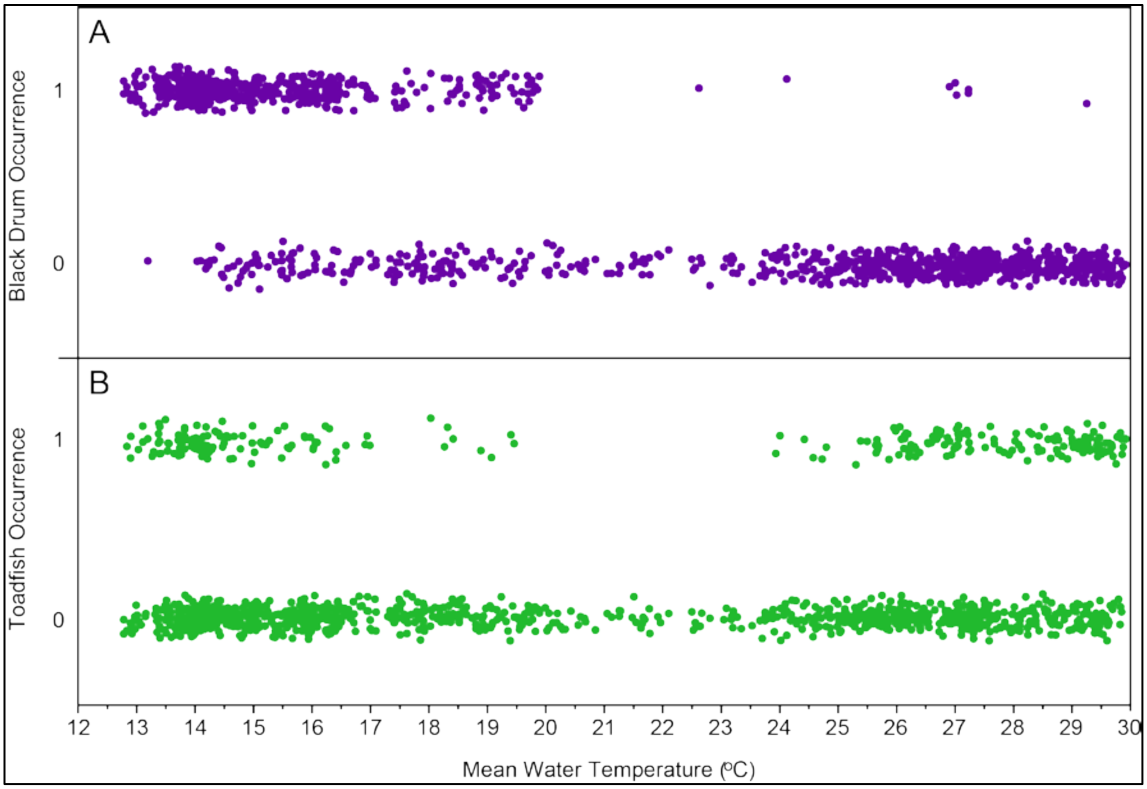

Figure 4.6. Relationship between acoustic occurrence and water temperature. A) Relationship between black drum occurrence and water temperature. B) Relationship between toadfish occurrence and water temperature. Acoustic presence = 1, lack of acoustic presence = 0.

4.4. Conclusions

4.4.1. Geographic Variation in Fish Calling

Our passive acoustic surveys in offshore North Carolina and Georgia reveal vocally active black drum and toadfish at both locations over the course of the year. Both black drum and toadfish occurred with greater regularity in the Georgia location than in North Carolina; this may be related to the habitat differences between locations. The Georgia locations were closer to shore (mean distance to shore ± SE: GA=18.7 ± 1.3 km, NC=51.2±11.7 km), and shallower in depth (14 m in Georgia compared with an average of 34.3 m in North Carolina. Because much of the calling behavior of both species is associated with reproductive advertisement displays (Burkenroad 1931; Fine et al. 1977; Gray and Winn 1961; Locascio and Mann 2011b; Locascio et al. 2012; Mok and Gilmore 1983), and both species spawn in shallower coastal waters (Gray and Winn 1961; Gudger 1910; Mok and Gilmore 1983), it is possible that the Georgia locations provide more suitable habitats for reproductive or social behaviors. Given the comparatively low degree of acoustic presence of both black drum and toadfish at the North Carolina sites, it is difficult to explore ecological patterns from these data.

Among the three MARUs at the Georgia site, there were differences in the temporal pattern of toadfish acoustic presence. There was a longer duration of toadfish calling at GA-North compared to the GA-Central and GA-South sites. Because water temperature was similar among the three locations, other water quality characteristics (e.g., salinity, dissolved oxygen) or physical habitat differences may account for the difference in behavior of toadfish at these three locations. Because toadfish males establish nests and guard eggs (Gray and Winn 1961; Gudger 1910), it is likely that the GA-North site had a greater number of available nesting habitats compared to the GA-Central and GA-South locations, and may account for the prolonged calling activity at GA-North.

Black drum, in contrast to toadfish, do not seem to indicate the same degree of preference or limitation of habitat. As such, the black drum calling data shows a similar temporal pattern across the MARUs in Georgia, and a sudden seasonal start of acoustic occurrence that is seen at all three MARUs. This nearly simultaneous onset of chorusing activity over a 25 km distance suggests an environmental cue triggering the initiation of reproductive behavior (e.g., Mann and Grothues 2009).

Available nesting habitats in this area may be patchy in distribution across the broader geographical area. The bottom structure of the Georgia Bight, the region containing the Georgia study site, is a mixture of hard bottom and sand, with intermittent live bottom cover (see Chapter 6, Kendall et al. 2005; Kendall et al. 2007). In the context of the present study, the heterogeneous bottom cover, and resulting patchy distribution of focal species, warrants caution for identifying and characterizing appropriate control sites to compare with the wind planning area (Landres et al. 1988; Noss 1990). If there is a heterogeneous distribution of available habitat for toadfishes, differences in calling between locations (particularly after the onset of wind farm construction) may reflect physical habitat differences between sites, rather than population-level changes in behavior.

Much of Onslow Bay contains a combination of gravel and sand bottom cover with less than 10% of the bottom structure comprised of hard- and live-bottom habitats, and less than 6% serving as essential fish habitat (Chapter 7, also Department of the Navy 2009). Despite the lower proportion of fish habitat, there were numerous sounds being produced by fishes from many unidentified species (see Appendix), which suggests that this habitat is outside of the typical range of the two focal species, and not necessarily the result of a decrease in biodiversity. Onslow Bay is just south of the dividing lines between the northern and southern biogeographic provinces in the Western North Atlantic (Mahon et al. 1998), and this area may represent a transitional species composition between the subtropical species assemblages seen to the south, and the mid-Atlantic temperate fish assemblages which inhabit northern waters.

4.4.2. Temporal Patterns in Fish Calling

The acoustic survey showed the two focal species calling throughout the survey period. Both focal species were acoustically present in a higher proportion of the study period in Georgia than in North Carolina. At the Georgia site, toadfish called nearly every day throughout the summer, and then tapered off (except at GA-North), and then black drum started calling at all MARUs around November. Sustained chorusing for both focal species started in mid-March, with initiation of the choruses starting within a short period of time of each other. During these sustained choruses toadfish show little to no diel pattern, whereas black drum primarily chorused at night (also see Locascio and Mann 2011b). Given that signals overlap in their frequency range (F_0 of toadfish and $2F_0$ of black drum), there may be acoustic competition during these chorusing periods, as there are many identified instances during these time periods with overlap of black drum and toadfish calls.

Because the calling behavior of both species shows no decline towards the end of the project, and continues until the end of the recording period, it is likely that the chorusing period continues through April into May. Because there was only less than a single year of acoustic data collected from these locations, year-to-year variability in chorusing duration in offshore populations of these species has not been examined, and it would be interesting to evaluate the synchrony of elevated acoustic activity and the consistency across years. Accounting for temporal variability in calling behavior would be another critical component to assess from a monitoring perspective (Bridges and Dorcas 2000).

Studying the calling behavior of these species across years would be interesting to evaluate how consistent occurrence and seasonality is at these locations. Because both species migrate (Gudger 1910; Isaacson 1964; Murphy et al. 1998; Schwartz 1974; Silverman 1979), it would be useful to understand whether black drum or toadfish display site fidelity and return to the same locations across multiple years for spawning. If the same individuals, or members of the same population, are returning to these locations across years, then it further supports the approach that these species could be used as ecological indicators, and differences in acoustic activity between years could reflect some degree of ecological change within the habitat. However, if the presence of fish and their acoustic activity is variable across years, differences in calling of these species across years would not necessarily be indicative of change within the ecosystem.

One of the limitations in the approach used for data analysis here was that the patterns of calling for both species was only evaluated at a daily-occurrence level of resolution. Daily presence/absence is often used as a metric in the course of ecological monitoring (e.g., Morano et al. 2012), when it is not necessarily feasible, cost-effective, or required to analyze all calls per unit time. Thus, these daily occurrence data combined with a high-level perspective on chorusing behavior can only provide a rough idea of the behavior of these populations. Determining the number of calls produced by each species at a smaller time interval would provide a greater degree of detail of the acoustic behavior of each species, and possibly provide insight into changes in calling rates (Fine et al. 1977; Fine 1978; Grava et al. 2012), as well as the relative (or modeled) abundance of each population present at each site (Fine et al. 1977; Marques et al. 2013; Royle and Nichols 2003; Royle 2004). With the large amount of data collected, analysis of all calls produced by each species is not realistic, but sub-sampling approaches of calling rate over the course of the project period could capture potential changes in behavior. Automated detection algorithms have been developed to identify calls in the passive acoustic study of marine mammals, (e.g., Mellinger and Clark 1997), but, the overlap of black drum calls or the lack of temporal separation between black drum or toadfish calls in a chorus would make the automated recognition of these calls extremely difficult and would favor an alternative methodology.

4.4.3. Use of Fish Calls as Ecological Indicators

In addition to conducting a seasonal survey to understand calling and chorusing patterns for these two focal fish species, one of the motivations for this approach was to further develop the approach of using these two fish species as complementary ecological indicators to evaluate possible habitat disturbance during wind farm construction.

In order for a particular species to serve as an effective indicator, a number of criteria must be met (Cairns et al. 1993; Goodsell et al. 2009). In particular, a measurable change in behavior or ecology should be exhibited in response to a specific stressor (either a correlative, or preferably, a causal relationship - Goodsell et al. 2009), but be biologically and socially relevant, broadly applicable, anticipatory, cost-effective and non-invasive to measure (Cairns et al. 1993). Passive acoustic monitoring of fish calls satisfies many of these criteria. With further understanding in how patterns of fish calling are influenced by habitat changes, passive acoustic monitoring of fish calls offers the potential for evaluating ecological changes (Van Parijs et al. 2009).

In the case of wind farm construction, likely stressors would include increases in noise level and physical habitat disturbance associated with pile-driving, trenching, or operation of service boats during the construction phase (Kikuchi 2010; Madsen et al. 2006; Wahlberg and Westerberg 2005). From a noise perspective, impacts to fishes would likely be chronic and sub-lethal, and include increased stress levels associated with increased noise levels or acoustic masking. Many of these effects have been suggested in fishes (Popper 2003; Slabbekoorn et al. 2010; Slabbekoorn 2012), but have been demonstrated in a wide range of vertebrate taxa (Arroyo-Solis et al. 2013; Grava et al. 2012; Hansen et al. 2005; Price et al. 2005; van Buggenum and Vergoossen 2012). Recent work has also demonstrated a decrease in fish foraging success related to increase in noise levels (Voellmy et al. 2014). Primary or secondary effects from these stressors may either inhibit acoustic/reproductive activity or drive the animals from the site (Rako et al. 2013). Physical habitat modification may also displace animals. Both physical habitat perturbation and increases in anthropogenic noise could potentially result in a cessation in advertisement calling, and this change in behavior would be measurable during the course of passive acoustic surveys. However, a critical step in evaluating the reliability of black drum or toadfish calling as potential indicator species would be to demonstrate a causal relationship between increased noise levels and decreased calling activity. Many empirical studies in different vertebrate groups have suggested that changes in vocal behavior is a measurable ecological indicator of disturbance (Arroyo-Solis et al. 2013; Grava et al. 2012; Hansen et al. 2005; Price et al. 2005; van Buggenum and Vergoossen 2012), and this is likely the case in fishes. However, future studies would be useful to either demonstrate the use or limitations of using fish sounds as ecological indicators.

Given both species' regularity of calling, both toadfish and black drum would be significantly more effective ecological indicators in the Georgia wind planning area, compared to the North Carolina planning area. However, given the wide diversity and abundance of unidentified fish calls (see Appendix), it is likely that different acoustically active fish species could be developed to serve as ecological indicators in Onslow Bay.

4.4.4. Recommendations for Future Study

This initial baseline survey of fish calling activity at these two locations shows interesting results, and a great deal of promise. To better understand the context and ecological drivers of fish acoustic activity, a number of recommendations have emerged from this study that should be applied to future efforts.

There was a wide range of spatial and temporal variability in the amount and seasonality of calling behavior of black drum and toadfish. Designing a survey that includes spatial replication would help demonstrate the degree of micro-scale variability occurring of the focal species behavior and occurrence (e.g., Dawson and Efford 2009; Underwood 1994). Because demersal and benthic species have a heterogeneous distribution in different recording areas, single recording locations will not provide sufficient spatial representation to characterize focal species occurrence. The behavior of the fishes analyzed here show a strong seasonal signal in their acoustic behavior, which warrants a complete year-round survey (only 11 months of data were collected here), and preferably a multi-year baseline survey to capture intra- and inter-annual variability in focal species' behavior. The acoustic detection range of these two species has not been established in these locations, so it is unclear the spatial distance that is being sampled with the recorders.

Because these two species showed a degree of seasonal separation in their calling activity over the course of the study period, it is possible that toadfish calling patterns could be used as an ecological indicator through the summer, and black drum calling could serve as an ecological indicator through the winter and spring. The abundance of calls and the appearance of a seasonal pattern suggest that the passive acoustic monitoring of fish vocalizations could be useful to evaluate population-level or habitat changes. The differences calling behavior of fishes across the years and among locations further reveal the value (and difficulty) of appropriate baseline studies.

Study requirements and selection of focal species should be selected after the project sites are decided upon. As mentioned earlier, these fish species were selected before wind planning area selection, and were chosen on the basis of their readily identifiable, species-specific sounds, their extensive previous study, and wide distribution along the U.S. Atlantic coast. Though black drum and toadfish were recorded at nearly all of the locations, they were more commonly recorded at the Georgia sites, and only sporadically detected in North Carolina. An evaluation of site-specific acoustic data could reveal which fish species are most suitable to serve as focal species at particular locations.

Though neither black drum nor toadfish were particularly vocally active at the North Carolina sites, there were many unidentified biological sounds likely produced by other fish species in the area. This abundance of unidentified fish sounds highlights the major acoustic role that fish species have within their ecosystems, and demonstrates the value in future efforts to conduct baseline research identifying the sources of these sounds. When the sources are identified, these signals may be used in future long-term monitoring efforts.

5. AMBIENT NOISE

5.1 INTRODUCTION

Sound is a critical component of the marine environment, and many, if not most, marine animals use sound in different aspects of their life history. Measurements of ocean ambient noise have long been used to characterize different geographic areas from an oceanographic or physical perspective (for example, see reviews by Urick 1986; Wenz 1962; Wenz 1972); these measurements are now being calculated in different ecosystems to evaluate how marine animals may be influenced by sound from environmental and anthropogenic processes (Clark et al. 2011; e.g., Samuel et al. 2005; Simard et al. 2010). Analysis of the ambient noise environment over large spatial and temporal scales provides a broad, quantitative perspective on ecosystem function.

The term “ocean ambient noise” includes the combination of biological, environmental, and anthropogenic sounds occurring within a particular region (Hildebrand 2009; Urick 1986; Wenz 1962). In the marine environment, major contributors to the overall acoustic ambient noise environment include the combination of surface wave action (generated by wind), marine organisms, and anthropogenic sound sources such as ships, geophysical seismic surveys, and construction (Hildebrand 2009). These different sound sources are detectable over different orders of magnitude in both temporal and spatial scales. In the case of sounds from commercial shipping vessels, this acoustic signature is detectable in the low frequency bandwidth thousands of kilometers from the actual ship (Hildebrand 2009). Anthropogenic noise between the 20–150 Hz frequency range is usually due to shipping and mining operations (Jobst and Adams 1977), and environmental noise above 150 Hz in the deep ocean is surface-generated (Jobst and Adams 1977; Urick 1986; i.e., wind and waves, Wenz 1972). Ambient noise analysis characterizes the acoustic environment and is a mechanism to evaluate acoustic activity and other stimuli of both focal and non-focal species.

One of the fundamental characteristics of the ambient noise environment is its variability (Wenz 1962); thus, long term studies are needed to statistically characterize the ambient noise variability (Wenz 1972). In these long-term data collection efforts, analysis of ambient noise allows the chance to broadly evaluate the periodicity of physical environmental processes, vocally active biological constituents of an acoustic environment, and the contribution of anthropogenic sounds to the ambient noise environment. The combined analysis of biological acoustic activity in relation to different anthropogenic or environmental sound levels offers the chance to examine how increases in noise levels may impact behavior of vocal and non-vocal species. Specific to the waters off the coast of Georgia and North Carolina, we provide opportunities to assess the possible future impacts of pile driving and other associated construction and wind farm operation noise by characterizing the baseline ambient noise environment, and highlight potential species that are susceptible to increased risk or impact from anthropogenic noise.

5.2 METHODS

Acoustic data from each MARU (see Chapter 2) were processed using the Noise Analysis tools within the SEDNA toolbox for MATLAB© (Dugan et al. 2011), using a Hann window, FFT size of 2000 samples, time resolution at 1 s, and frequency resolution at 1 Hz. To evaluate the ambient noise conditions, two different representations of sound were used: frequency compared to time (spectrogram) and power compared to frequency (power spectra).

Spectrograms of acoustic data were created using 1-hr integration time slices for each MARU, and a FFT of 2000 samples. Two different frequency scales were used to represent the data, a linear scale with frequencies between 0–1 kHz, and a scale based on 1/3rd octave frequency bands between 10–630 Hz (see below). We visually and acoustically analyzed noise events present in the spectrogram and were able to categorize them according to the type of source such as weather events, anthropogenic sources or biological sources (Figure 5.1).

Traditional signal processing methods divide the acoustic signal into smaller frequency bands (based on octaves), to reduce the amount of data being analyzed for greater ease in processing and interpretation (Peterson and Gross 1978). These bands effectively filter the data into smaller subsets. For sound analysis in a biological context, 1/3 octave bands are commonly used for two principal reasons: use of these bands cover a 10-to-1 frequency range (Peterson and Gross 1978) and the function of the mammalian ear can be approximated as a set of bandpass filters with a sensitivity of approximately 1/3 of an octave (Madsen et al. 2006; Richardson et al. 1995). With these 1/3 octave bands, the bandwidth is approximately 23% of the center frequency (Peterson and Gross 1978). This spectrographic representation also provides a good illustration of energy in lower frequency ranges, which are difficult to see with a full-bandwidth linear scale spectrogram.

The power spectral density represents the amount of power in the signal as a function of frequency. We calculated power spectral densities and represented them as statistical percentiles of total data (Roth et al. 2012; similar to Samuel et al. 2005). Data were represented using the lower 5th, 25th, 50th (= median), 75th, and upper 95th percentiles. In order to understand the variation in sound levels and frequency distribution and how they differ depending on type of noise, we calculated and compared power spectral densities for time periods where the dominant source of noise was from biological, anthropogenic and weather related activities.

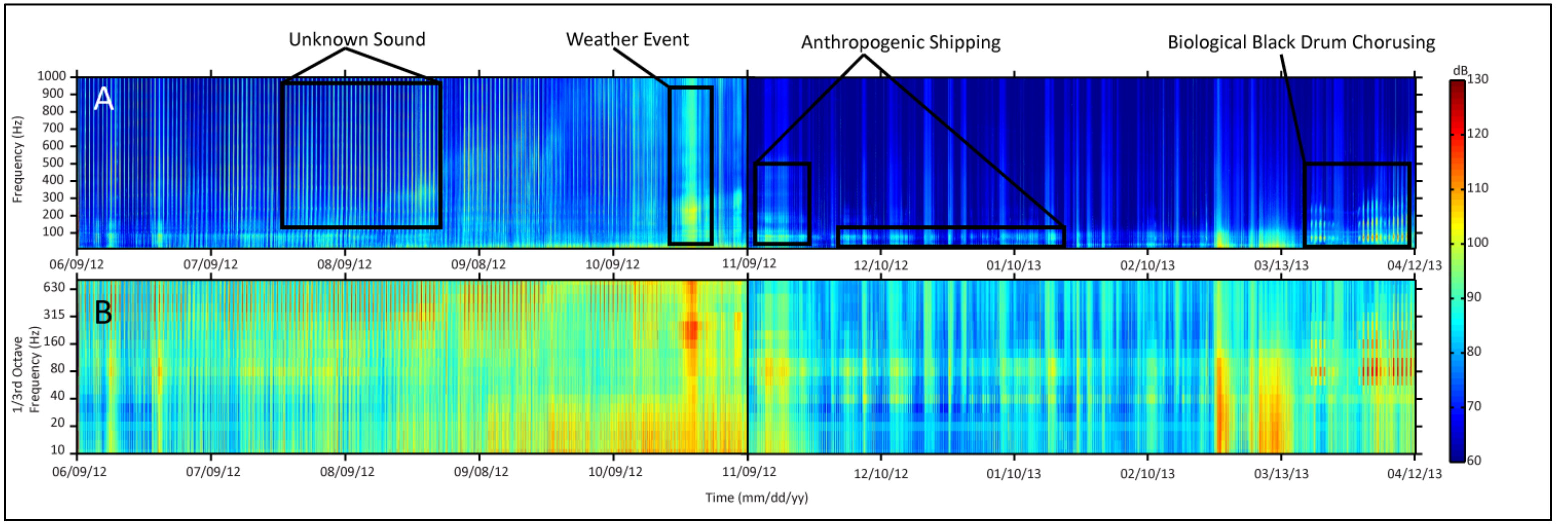

Figure 5.1. Example long term spectrogram.
Spectrogram of acoustic data from GA-South (09 June 2012–12 April 2013) represented as A) linear frequency axis from 10-1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). Example noise events are boxed and labeled.

5.3 RESULTS

5.3.1 General Trends

Looking at long-term plots of spectrogram noise, we found seasonal and geographical trends in ambient noise patterns. Overall, summer and fall months (June–November) had higher levels of noise in comparison to winter and spring months (December–April). Geographically, the three sites in Georgia qualitatively showed higher levels of noise than the three sites in North Carolina. Within each geographic location, there was not a significant, qualitative variation in noise between individual sites. See Figures 5.2–5.13 for spectrogram noise plots for the entire MARU recording period from each site. In the subsequent chapters, we take a look at specific patterns and noise events and categorize the different types of noise found in both arrays throughout the year.

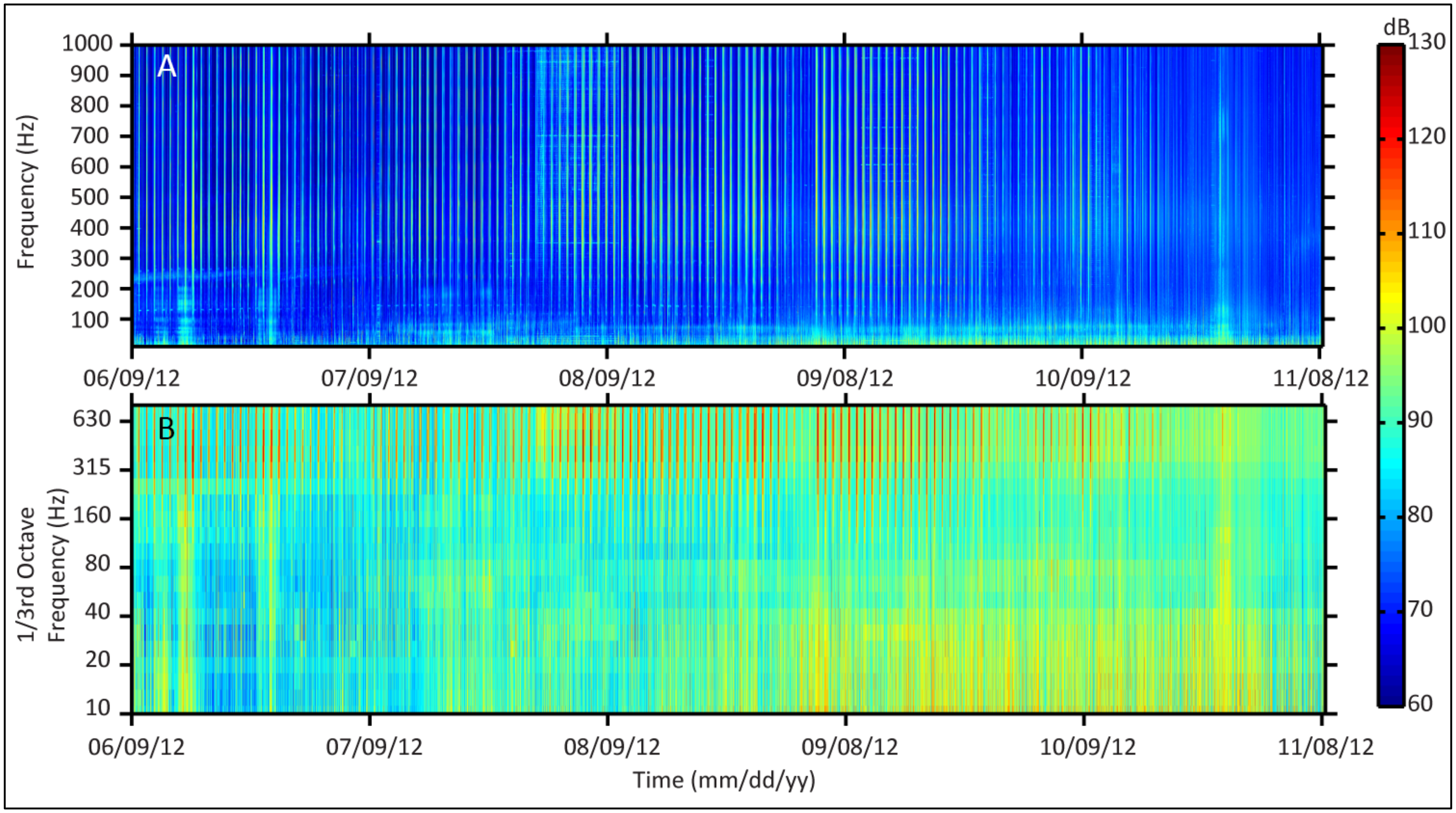

Figure 5.2. Spectrogram of acoustic data from GA-North (9 June–9 November 2012).
Spectrogram of acoustic data from GA-North (9 June–9 November 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

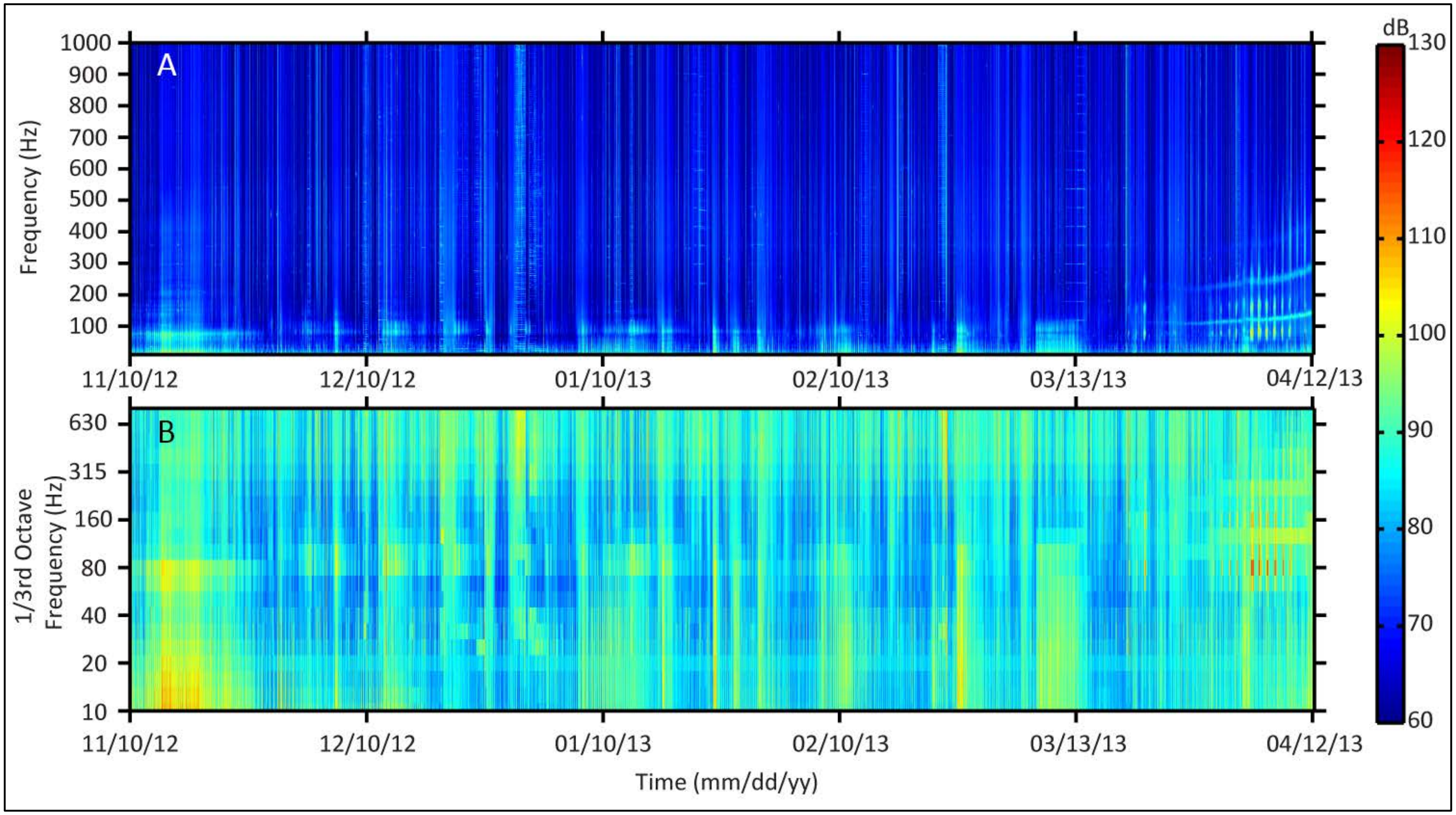

Figure 5.3. Spectrogram of acoustic data from GA-North (10 November 2012–12 April 2013).
Spectrogram of acoustic data from GA-North (10 November 2012–12 April 2013) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10-650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

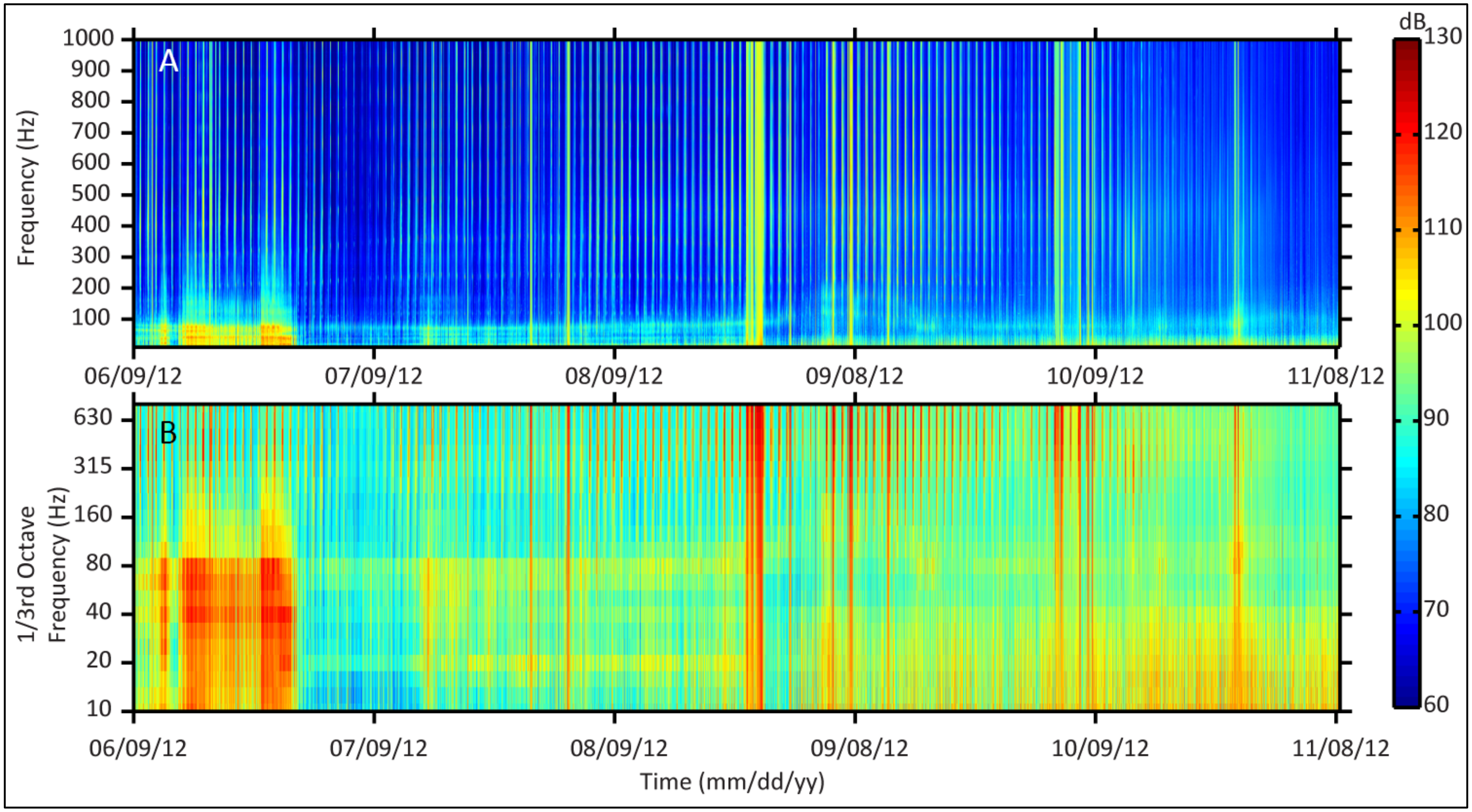

Figure 5.4. Spectrogram of acoustic data from GA-Central (9 June–9 November 2012).
Spectrogram of acoustic data from GA-Central (9 June–9 November 2012) represented as A) linear frequency axis from 0 Hz-1 kHz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 μPa).

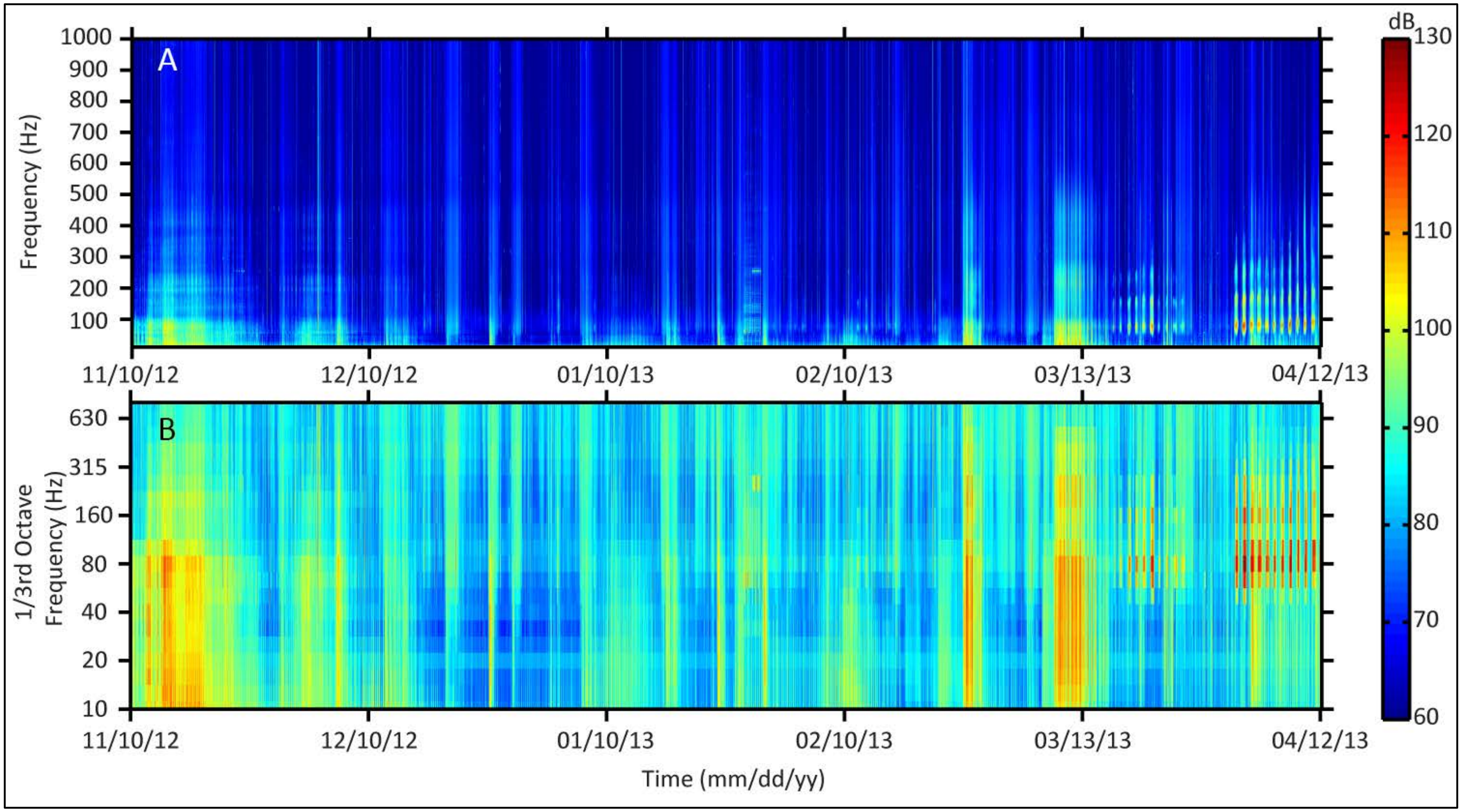

Figure 5.5. Spectrogram of acoustic data from GA-Central (10 November 2012–12 April 2013).
Spectrogram of acoustic data from GA-Central (10 November 2012–12 April 2013) represented as A) linear frequency axis from 10-1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

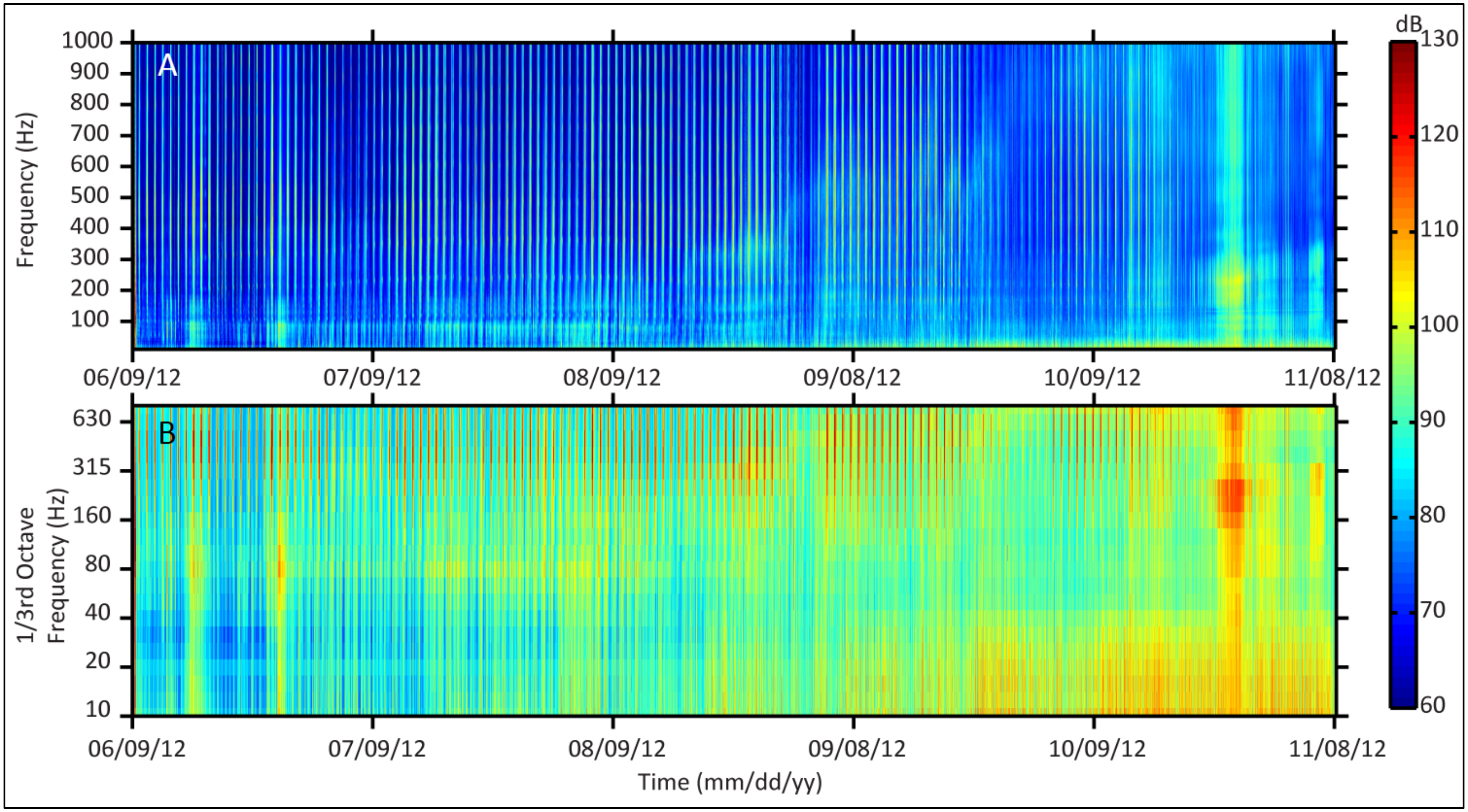

Figure 5.6. Spectrogram of acoustic data from GA-South (9 June–9 November 2012).
Spectrogram of acoustic data from GA-South (9 June–9 November 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

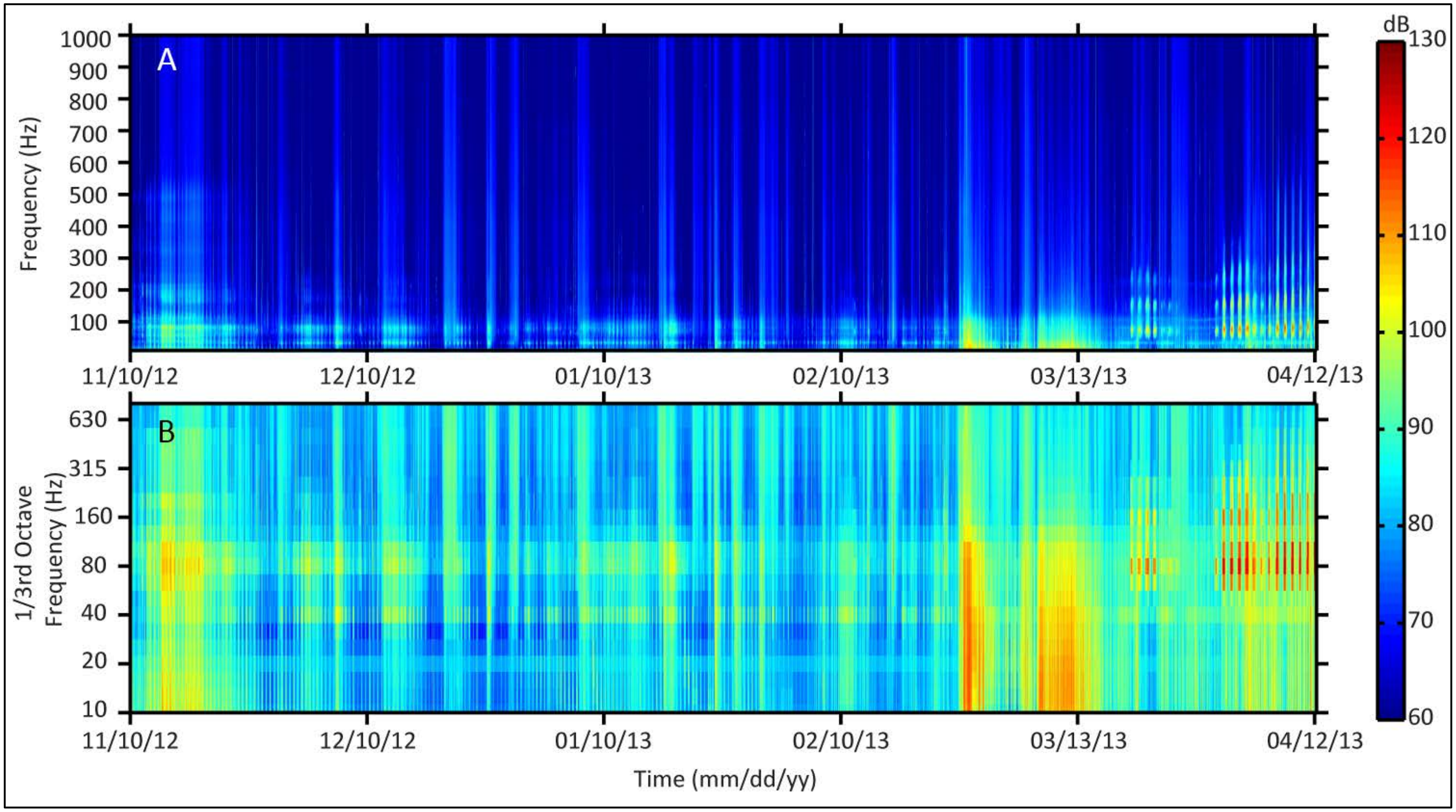

Figure 5.7. Spectrogram of acoustic data from GA-South (10 November 2012–12 April 2013).
Spectrogram of acoustic data from GA-South (10 November 2012–12 April 2013) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

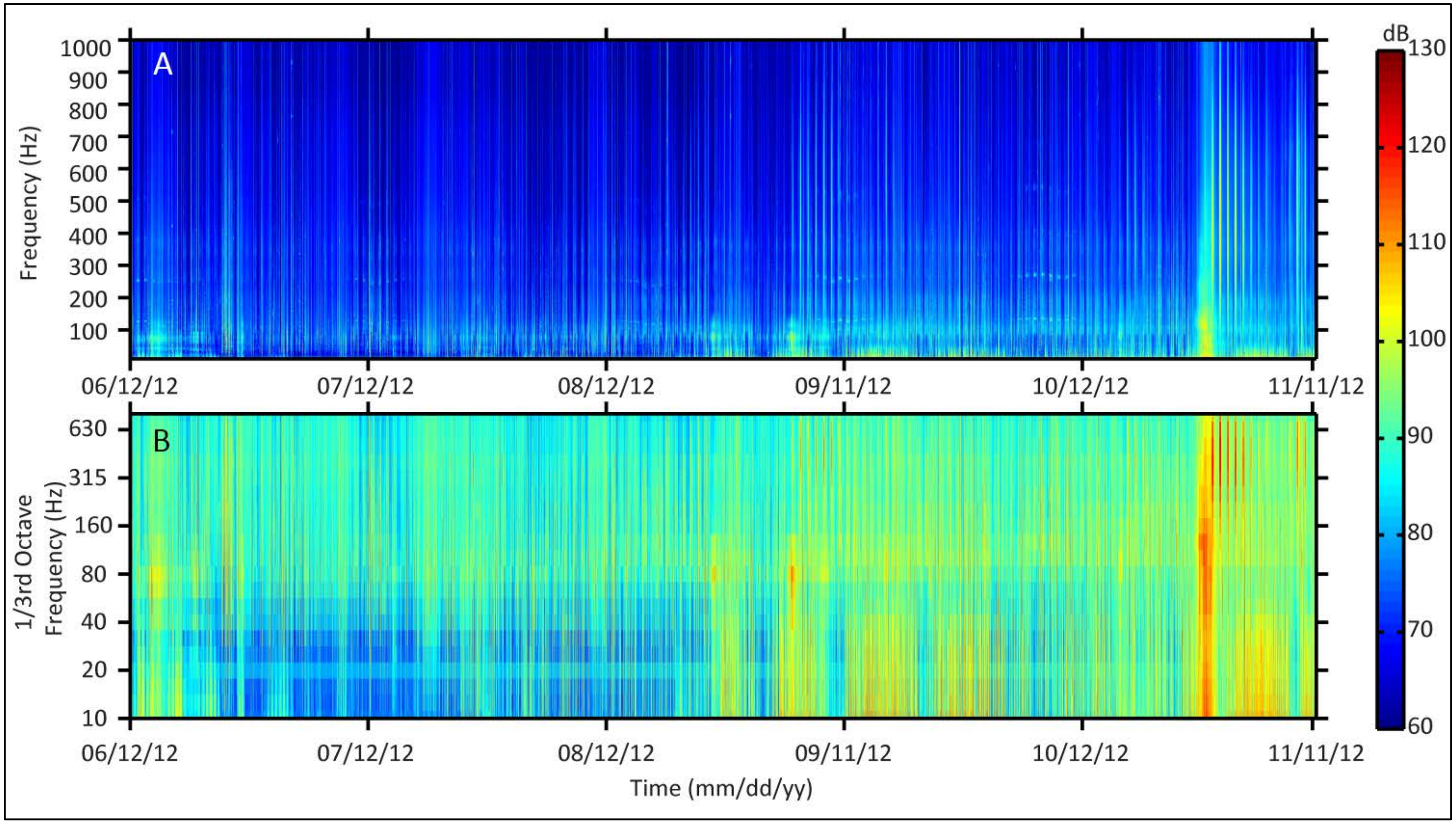

Figure 5.8. Spectrogram of acoustic data from NC-North (12 June–11 November 2012).
Spectrogram of acoustic data from NC-North (12 June–11 November 2012) represented as A) linear frequency axis from 10_1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

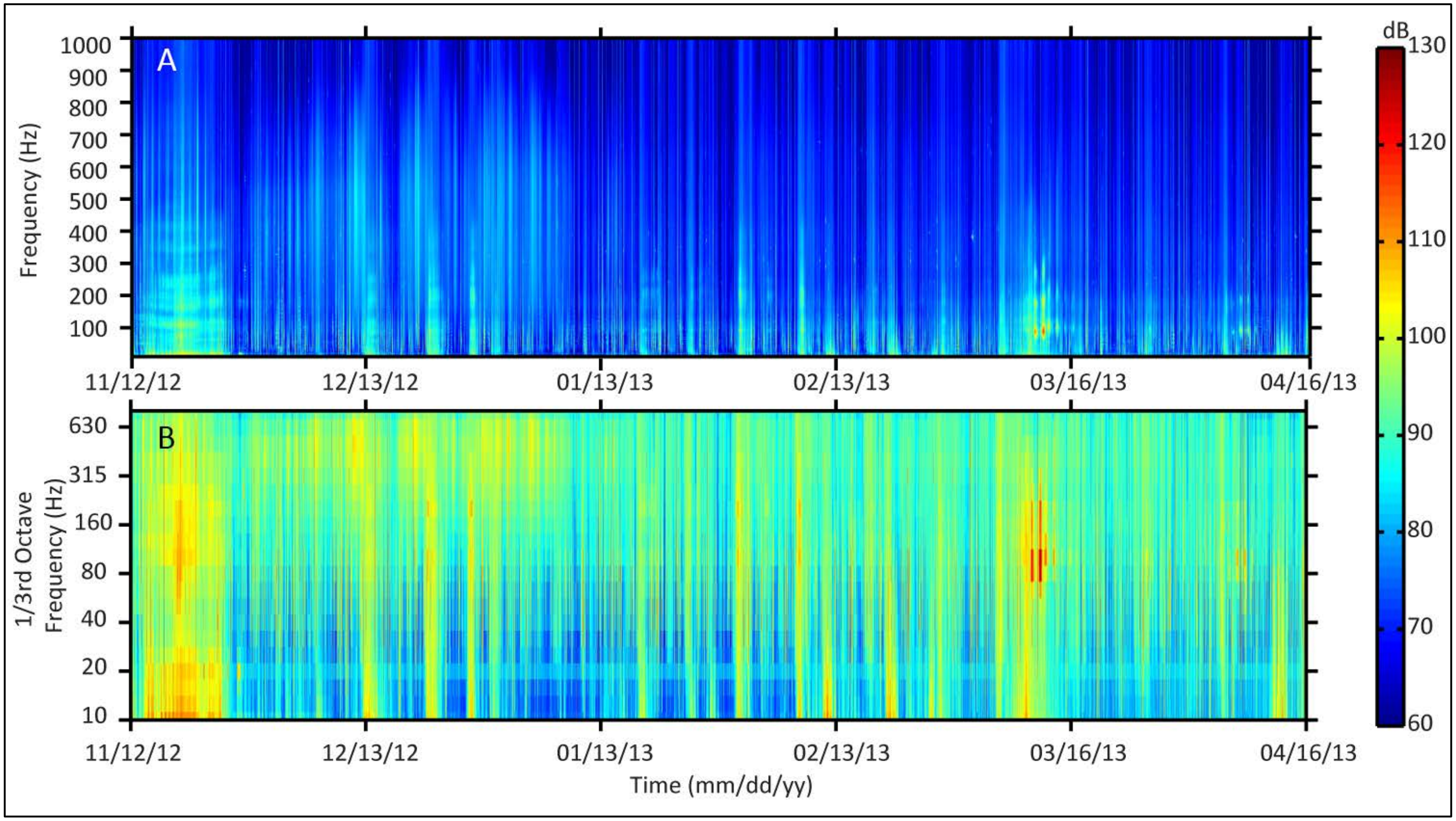

Figure 5.9. Spectrogram of acoustic data from NC-North (12 November 2012–16 April 2013).
Spectrogram of acoustic data from NC-North (12 November 2012–16 April 2013) represented as A) linear frequency axis from 10–000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

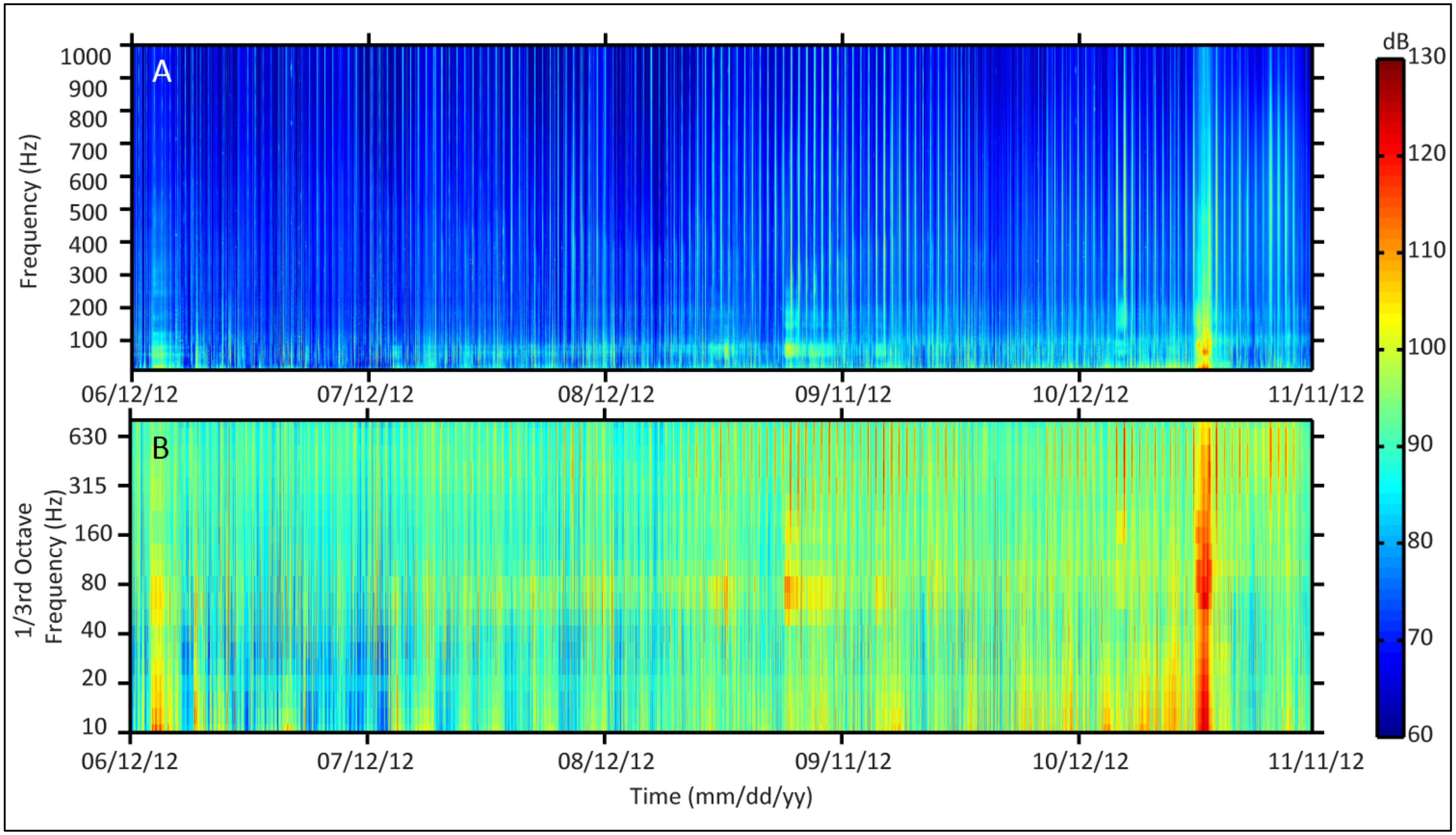

Figure 5.10. Spectrogram of acoustic data from NC-Central (12 June–11 November 2012).
Spectrogram of acoustic data from NC-Central (12 June–11 November 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

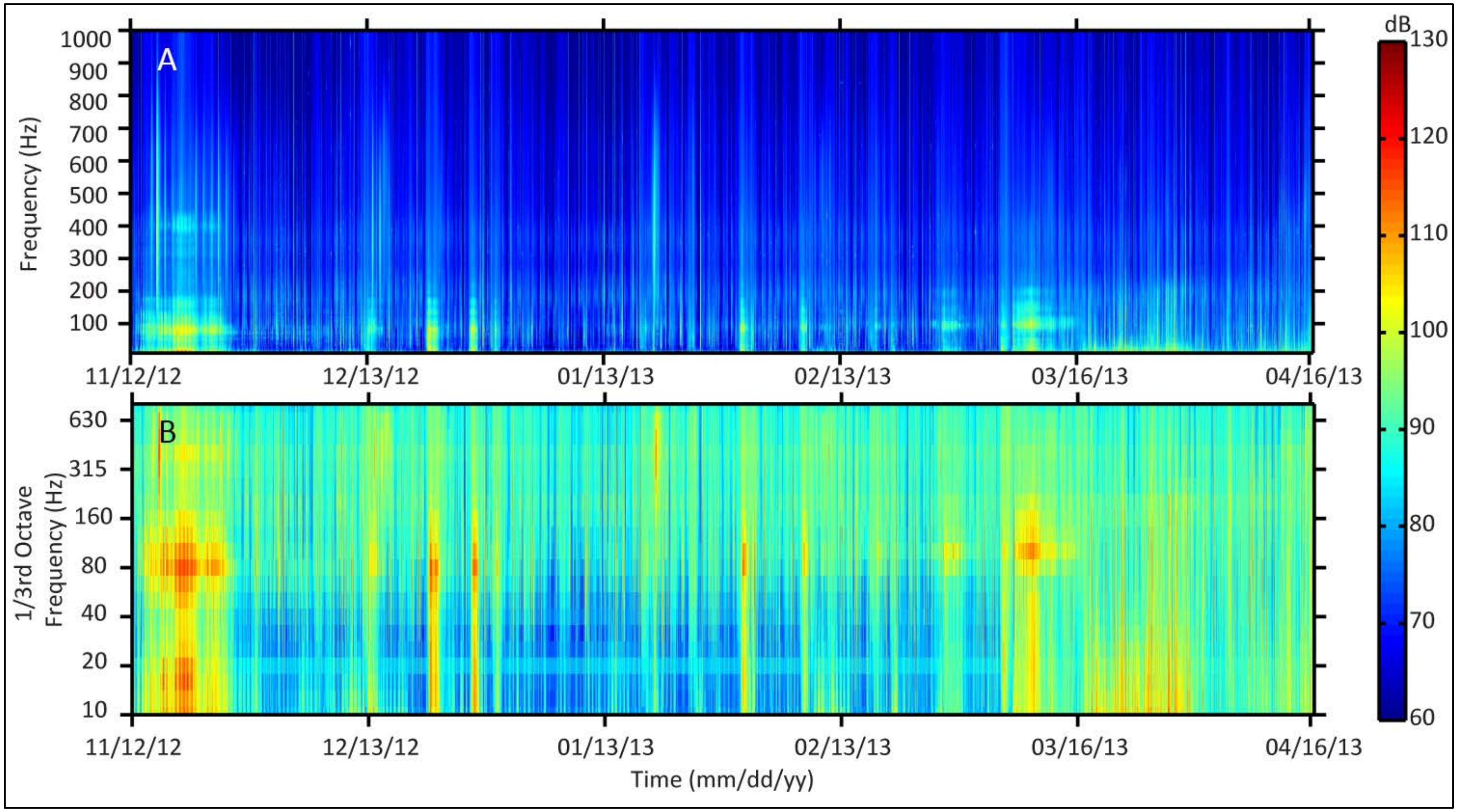

Figure 5.11. Spectrogram of acoustic data from NC-Central (12 November 2012 –16 April 2013).
Spectrogram of acoustic data from NC-Central (12 November 2012–16 April 2013) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 μPa).

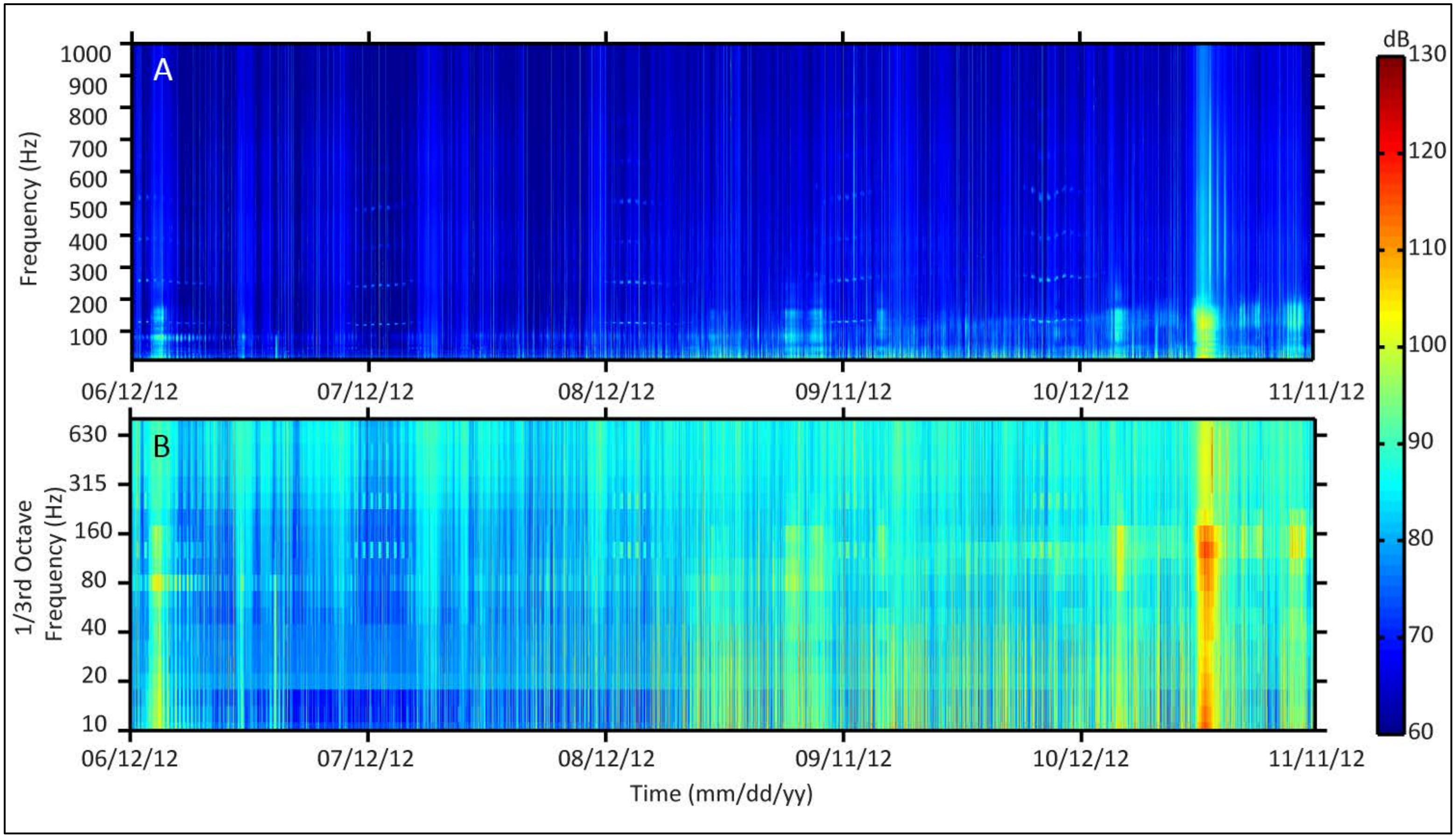

Figure 5.12. Spectrogram of acoustic data from NC-South (12 June–11 November 2012).
Spectrogram of acoustic data from NC-South (12 June–11 November 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

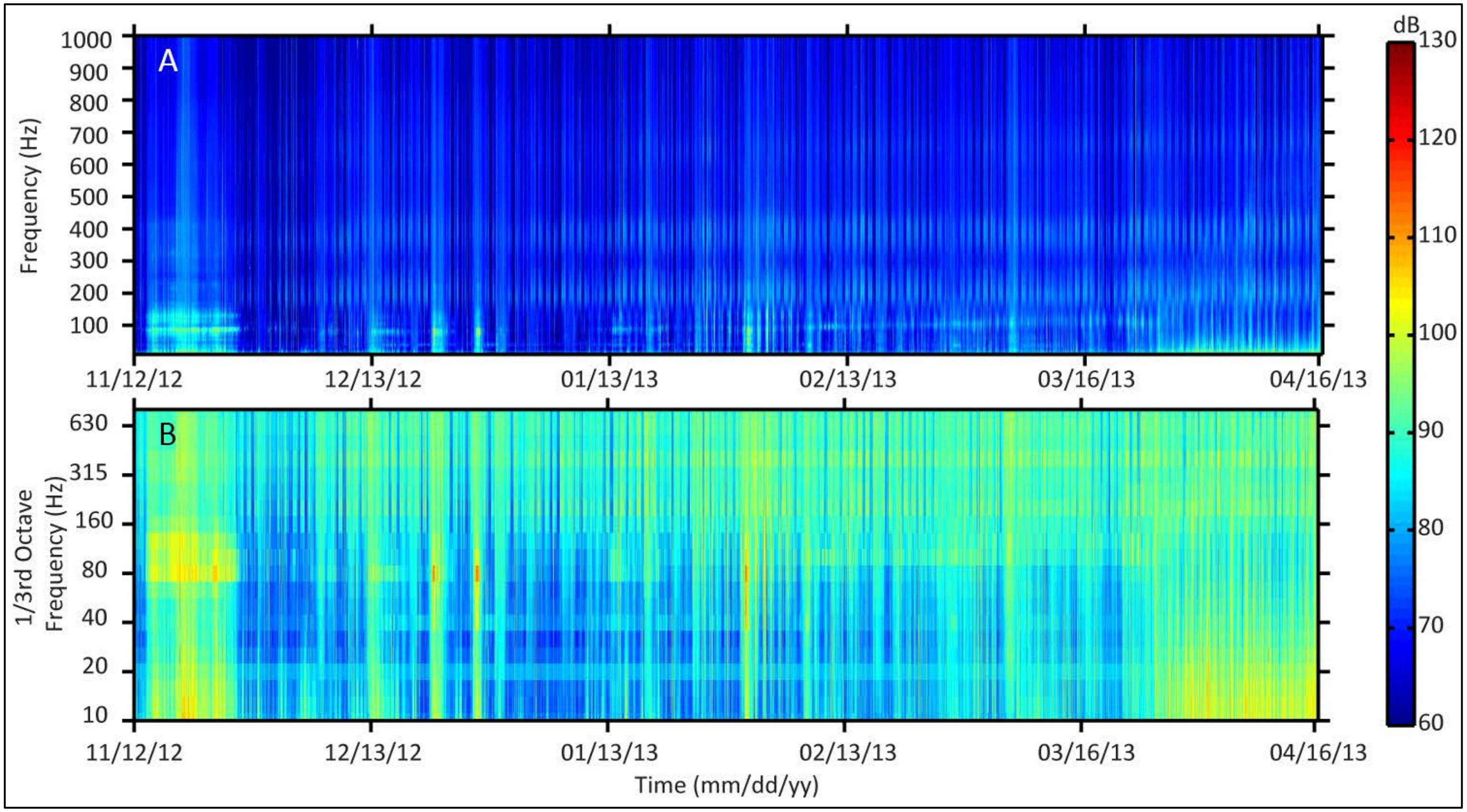

Figure 5.13. Spectrogram of acoustic data from NC-South (12 November 2012–16 April 2013).
Spectrogram of acoustic data from NC-South (12 November 2012–16 April 2013) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa).

5.3.2 Noise Patterns

Noise events in the North Carolina and Georgia environments, as seen in the long-term spectrograms, can be grouped into several categories: biological, weather, anthropogenic, and unknown sounds.

5.3.2.1 Biological Sources

The sporadic vocal activity of marine mammals such as the right whale and humpback whale was not visible on the multi-month long spectrograms, but black drum and toadfish chorusing were visible from mid-March–April at all three Georgia sites (Figures 5.3, 5.5, 5.7). Black drum chorusing is a high rate of calls that continue for over an hour (see Chapter 4) and is visible as a band of energy around 70 Hz (the fundamental frequency), often with up to two harmonics at 140 Hz and 210 Hz (Figures 5.14, 5.15) . Many of these choruses were recorded in excess of 100 dB. Toadfish chorusing, in contrast, can be seen in the spectrograms as two solid horizontal, parallel lines, with a fundamental around 100 Hz, with one harmonic associated with it (Figures 5.3, 5.15). In toadfish, the fundamental frequency of the call is related to water temperature (Fine 1978), so a slight increase (up to 50 Hz) can be seen as the water increases in temperature from winter to spring. Compared to black drum, toadfish chorusing had a lower sound level, with an average power less than 90 dB.

5.3.2.2 Weather

Severe weather was found to be a significant contributor to ocean noise in both Georgia and North Carolina. Due to the relatively shallow depth of the MARUs, any significant increase in wave action introduced anchor-related self-noise into the MARU recordings, which was recorded by the hydrophone. In some cases, this self-noise was site specific, such as with the GA-Central during June 2012 (Figure 5.4). Noise was concentrated below 100 Hz, up to 120 dB at times (Figure 5.16). However, during extreme weather, such as Hurricane Sandy, which developed in the fall of 2012 (late October–early November), significant broadband noise was recorded on all MARUs at all sites in Georgia and North Carolina (Figures 5.2, 5.4, 5.6, 5.8, 5.10, 5.12, 5.17). The higher frequency noise associated with the wave-driven motion of the MARU is most likely attributed to the waves themselves.

5.3.2.3 Anthropogenic Sources

Another source of ocean ambient noise is from human related activities such as military, construction, shipping and other commercial and recreational activities. Boat vessel noise was recorded throughout the year at both sites and appears in the long term spectrograms as low frequency noise, often between 80 and 120 dB (Figure 5.18). Vessel noise usually appears to increase and then decrease in power as the ship gets closer and farther away from the MARU.

5.3.2.4 Internal Electronic Noise

In a few rare instances, internal electrical interference or temporary problems with the MARU's recording hydrophone caused the unit to malfunction and introduce static or self-generated noise to the recordings. This occurred briefly in the GA-Central during late August and early October 2012 (Figure 5.18). In the long term spectrograms, this is characterized as a loud (~100 dB) broadband noise event ranging from 10–1000 Hz (Figure 5.19). Every effort is put forth to eliminate this source of noise, but it is necessary to be aware of how internal self-generated noise manifests itself in the recordings so that it can be properly accounted for during any analysis.

5.3.2.5 Unknown Sounds

The source of some recorded sounds cannot be definitively identified, but suggest either anthropogenic or biological sources, depending on the characteristics of the sound. Some unknown sounds apparent in the long duration spectrograms have characteristics that are consistent with the types of signals that fish produce; the sounds are short in duration and are repeated in irregular patterns. One sound that is potentially from an unidentified fish species is visible as two bands of energy, each with a bandwidth of approximately 100 Hz, and centered at 200 Hz and 400 Hz, as a daily pattern on December 2012–April 2013 spectrogram in North Carolina (Figure 5.13). A closer examination on 15 February–17 March 2013, showed that this signal occurred overnight between approximately 1700–0600 hrs (Figure 5.20). These signals are short duration (~0.2 s) upsweep-like signals that occurred in bouts lasting approximately 5 s or more (see Appendix, Figure A-4). Overlapping signals and bouts suggest that there were multiple sources for these signals.

Sound recorded in both Georgia and North Carolina from June through October 2012 illustrated two unknown sounds (Figure 5.21). The first sound consisted of broadband noise from 200 to 1000 Hz, with the noise tapering off in the lower frequencies and averaging six hours in duration. The noise began in the evening and ceased in the morning, and this pattern continued for weeks at a time. Signal characteristics suggest that this is anthropogenic. The second sound is a band of energy that occurred within a few hours after this first unknown sound, but the signal consists of peaks of energy every 100 Hz beginning at approximately 250 Hz (Figure 5.21). These signals were stacks of downsweeps, approximately 0.6 s in duration, and repeated in an irregular pattern (see Appendix, Figure A-3). These signals also overlapped, indicating there were multiple sources. Signal characteristics suggest that this signal may be biological.

5.3.3 Potential for Noise Masking

To investigate whether anthropogenic noise sources can mask fish chorusing events, power spectral density measurements were calculated to compare the relative loudness of different types of ocean noise. Using data from GA-North, we selected a period of time where the prominent source of noise was from anthropogenic shipping (13 December 2012–01 January 2013) and then compared that to a period of time (21 March–13 April 2013) when the prominent source of noise was from biological fish chorusing. The power spectral density showed that for most of the frequency range between 20–1000 Hz, the noise levels from shipping were higher than the noise levels from the black drum and toadfish chorusing activity (50^{th} percentile, 80 dB vs ~72 dB). That is, if the shipping noise were to occur at the same time as the fish chorusing, the fish signals would be masked at those frequencies (Figure 5.22). This masking can be seen at a much smaller time frame (1–2 hr in duration) than the long term spectrograms. On 14 March 2013 at NC-Central, black drum choruses are masked by vessel noise from 15:50–16:20 (Figure 5.23).

Marine mammal vocalizations were recorded throughout the study, but they were not frequent enough to be visible on long term spectrogram plots. However, the power spectral density plot for two weeks of time where anthropogenic shipping and vessel noise was the dominant source of ocean noise, the 50^{th} percentile in the right whale communications frequency (~70-300 Hz) was about 80 dB. Depending on the proximity of the whale to the ship, the potential for masking is still present.

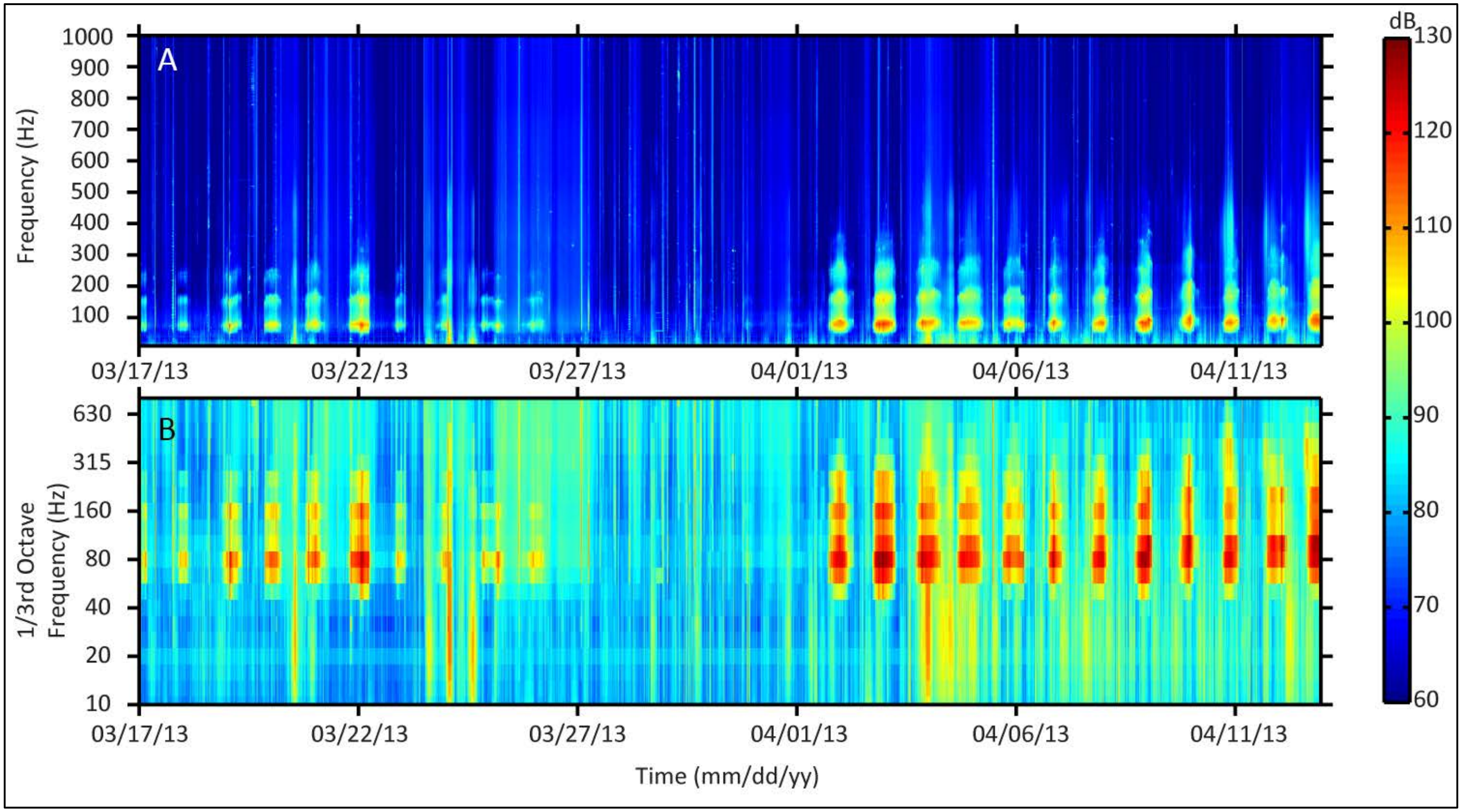

Figure 5.14. Biological example of black drum chorusing.

Spectrogram of acoustic data from GA-Central (17 March–13 April 2013) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). Black drum chorusing can be seen as pulsed events with stacked harmonics of 10–13 hr in duration, many of which are >110 dB in power.

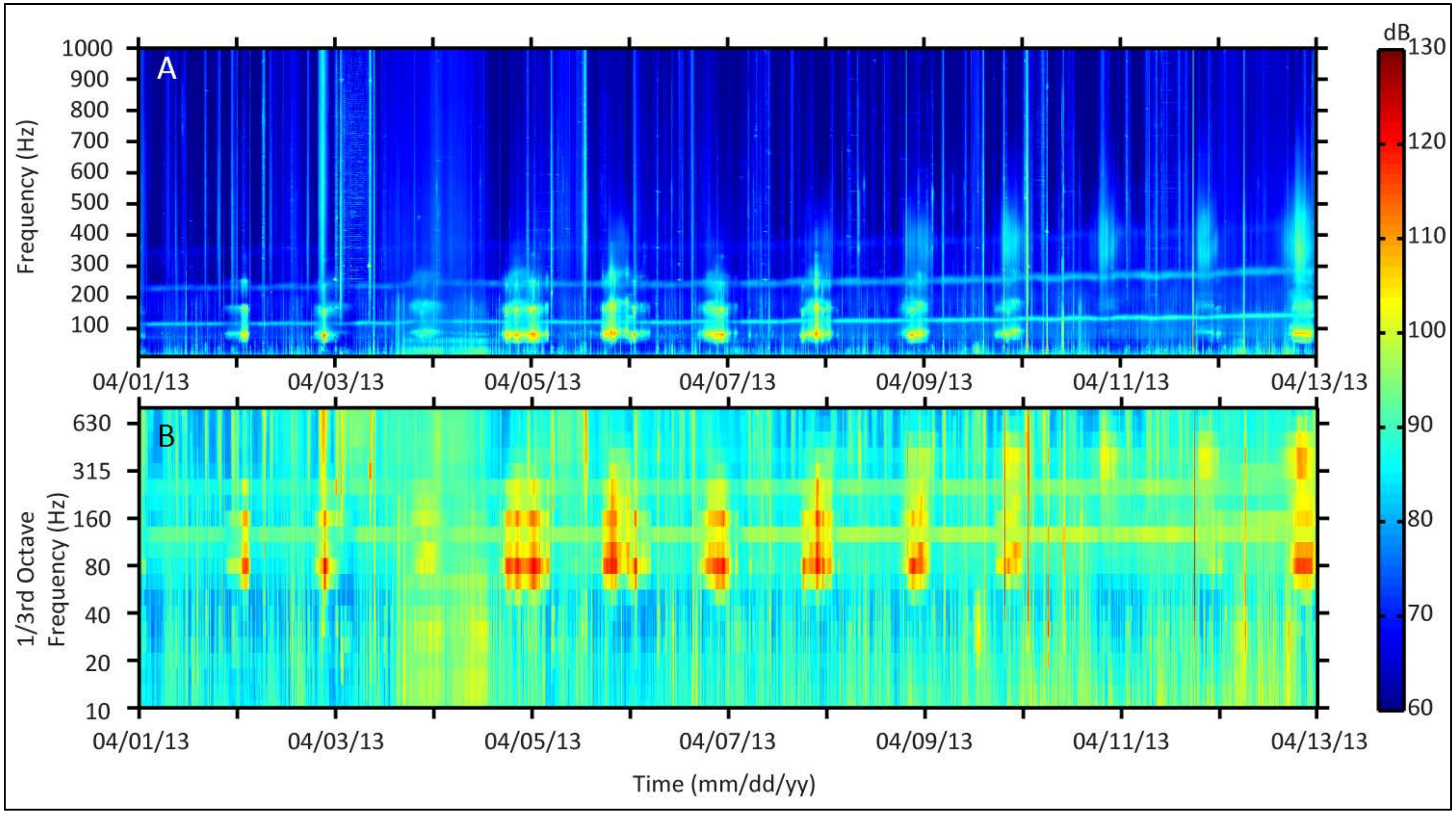

Figure 5.15. Biological example of black drum and toadfish chorusing.
Spectrogram of acoustic data from GA-North (01 April–13 April 2013) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). Black drum chorusing can be seen as pulsed events with stacked harmonics of 10–13 hr in duration. Toadfish chorusing can be seen as two narrow frequency bands at ~100 and 200 Hz, increasing in frequency over time.

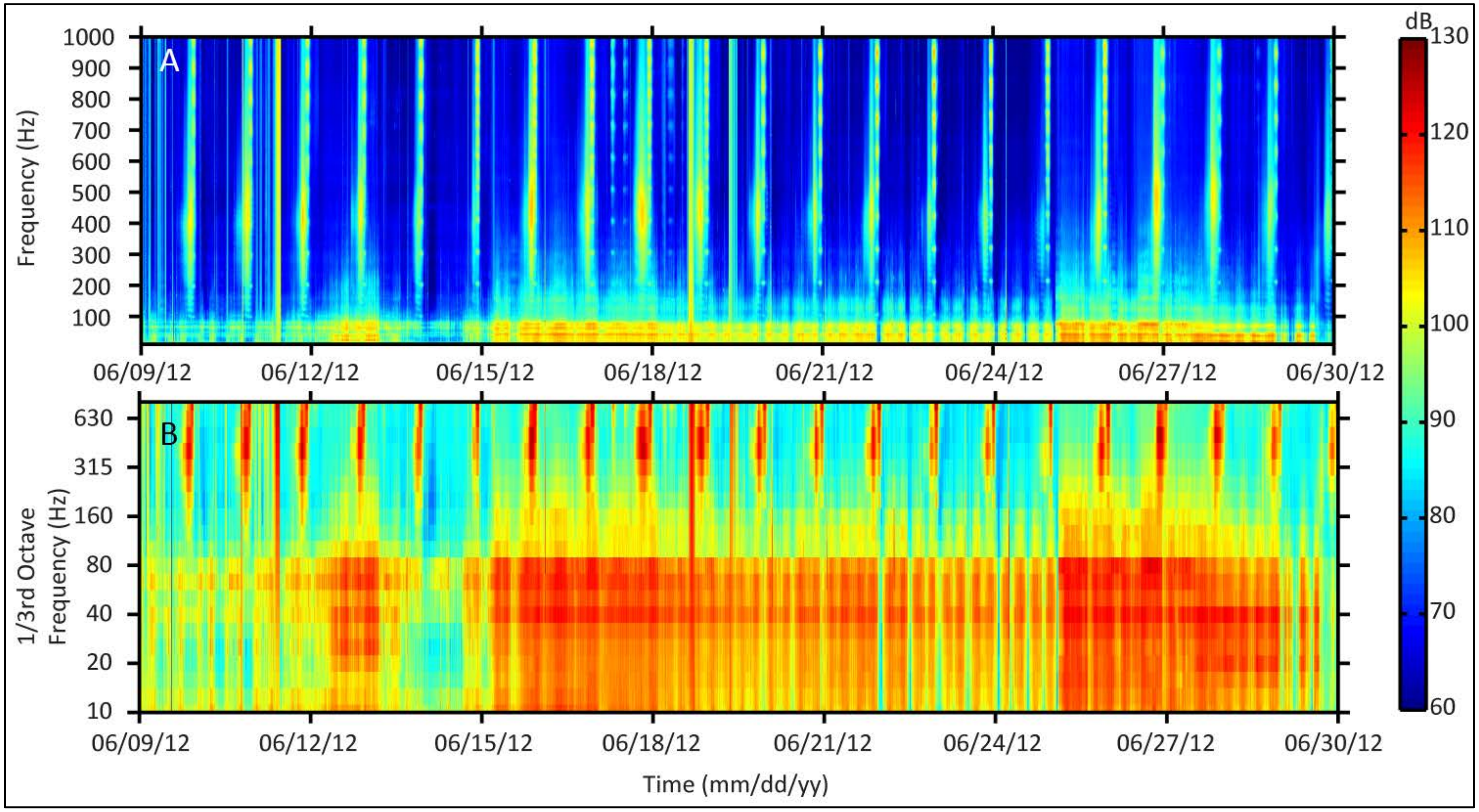

Figure 5.16. Example of weather-related noise.

Spectrogram of acoustic data from GA-Central (9 June–30 June 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). MARU banging and jostling due to weather can be seen as the noise below 100 Hz. The broadband pulses are examples of the unidentified noise described in Figure 5.21.

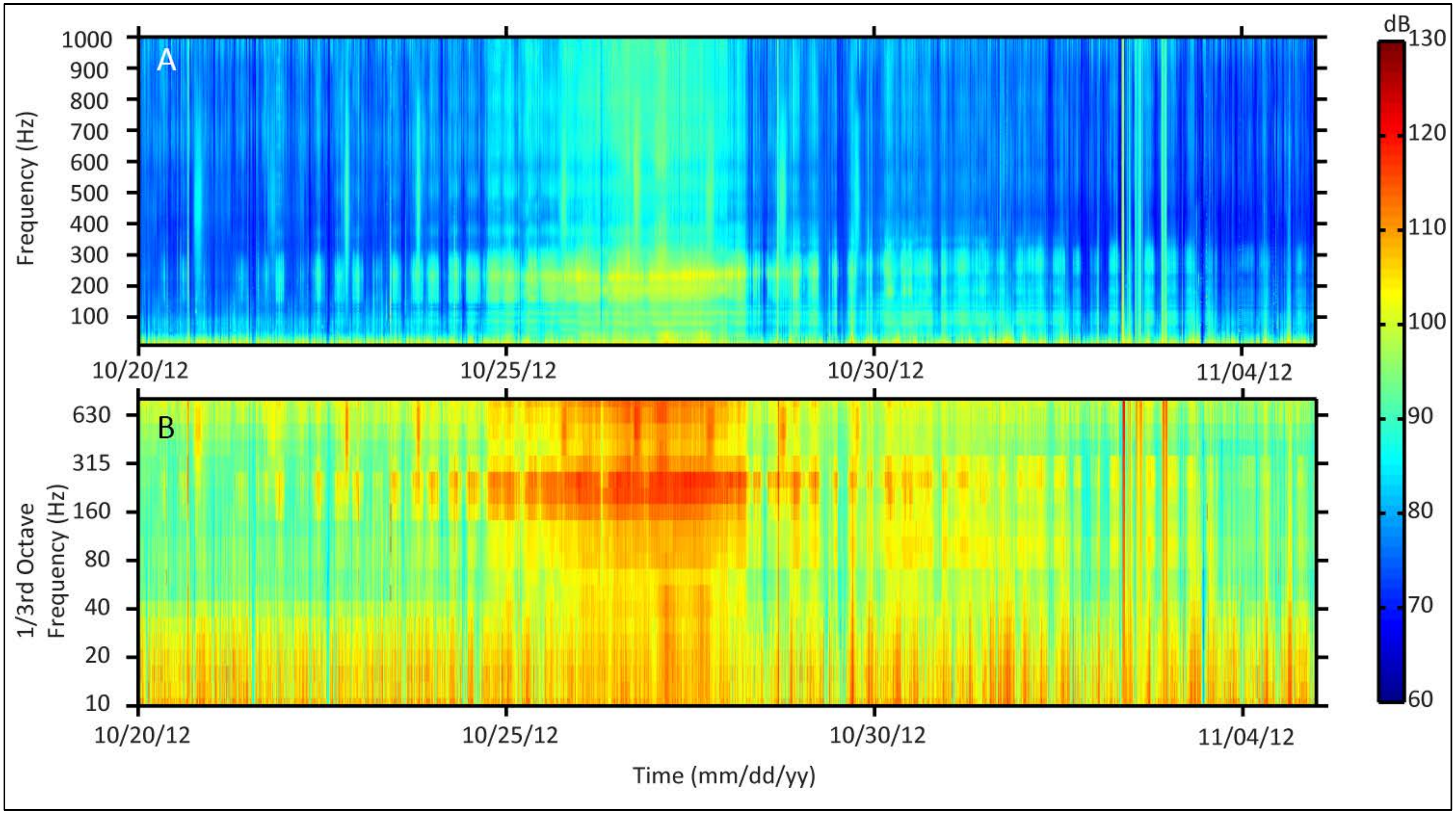

Figure 5.17. Example of extreme weather noise from Hurricane Sandy.
Spectrogram of acoustic data from GA-South (20 October–6 November 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). Weather related to Hurricane Sandy is present as broadband noise, especially from 25 October –28 October 2012.

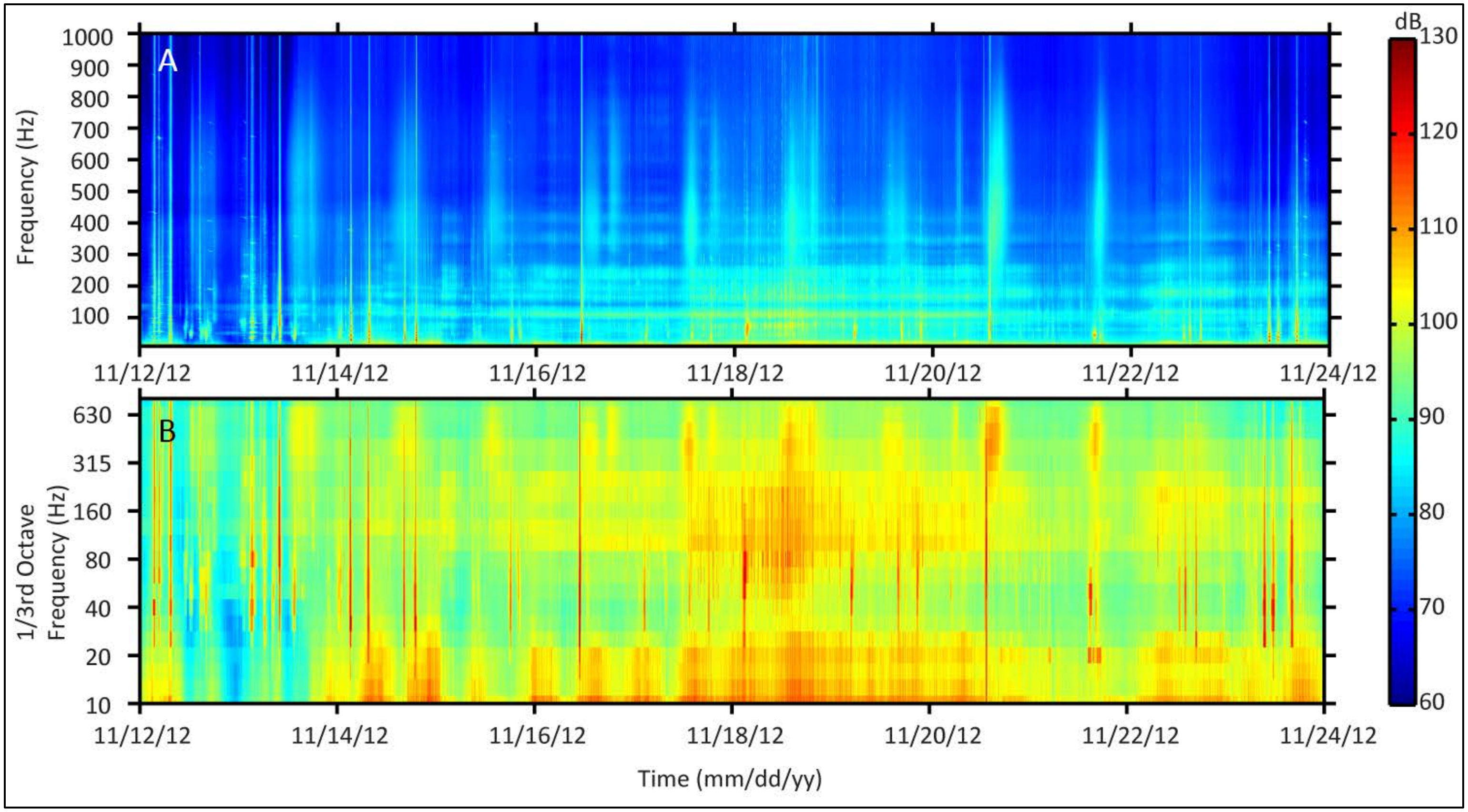

Figure 5.18. Anthropogenic example of shipping noise.
Spectrogram of acoustic data from NC-North (12 November–24 November 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). Noise due to human shipping, commercial fishing, or other boat traffic is seen as low frequency noise events concentrated around 160 Hz.

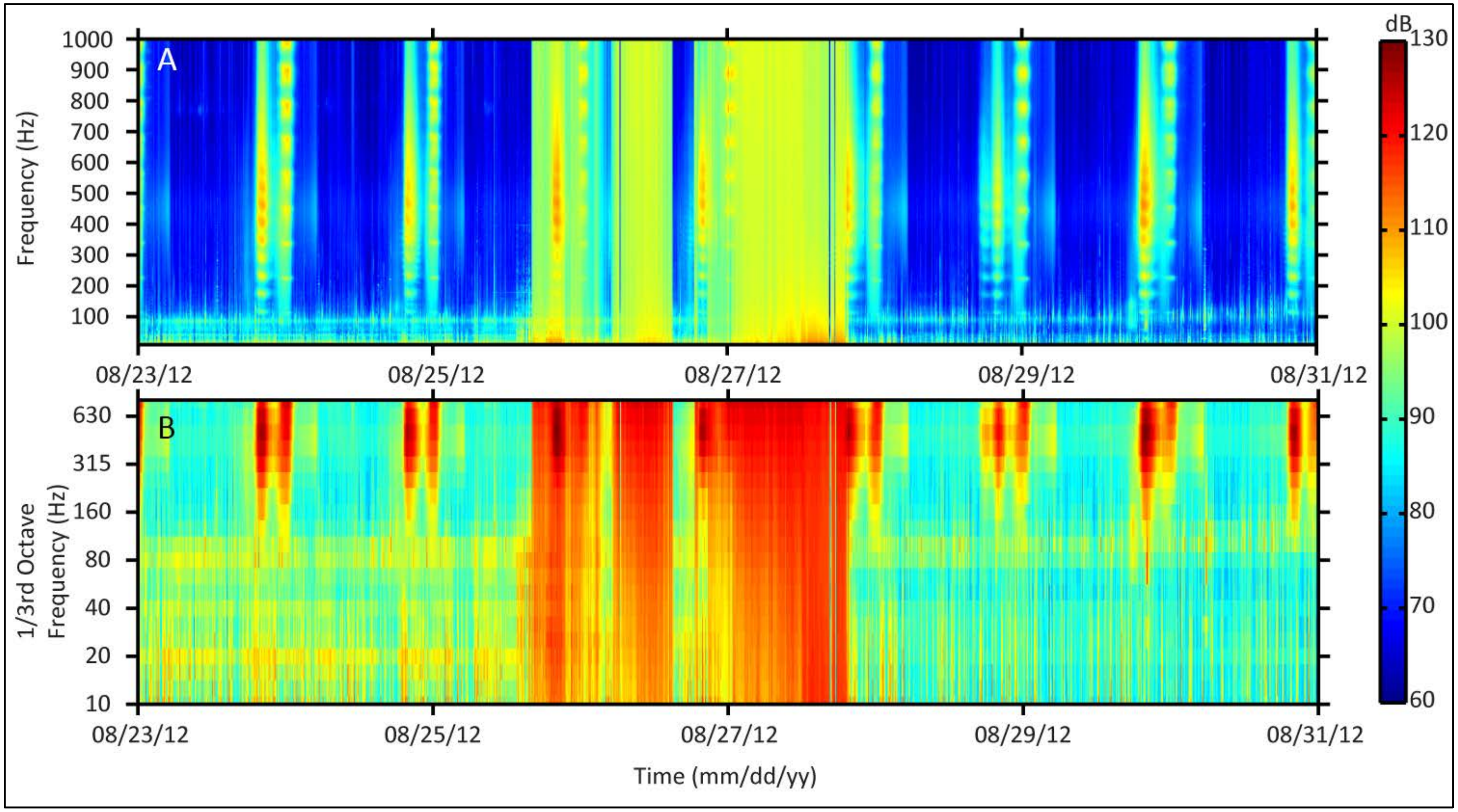

Figure 5.19. Internal hydrophone noise.

Spectrogram of acoustic data from GA-Central (23 August–31 August 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). Internal self-generated noise can be seen as broadband noise blocks (10–1000 Hz) of about 105 dB, occurring before and after 27 August 2012. The bands of noise occurring before and after the internal-generated noise are an example of two unknown sources of noise described in Figure 5.21.

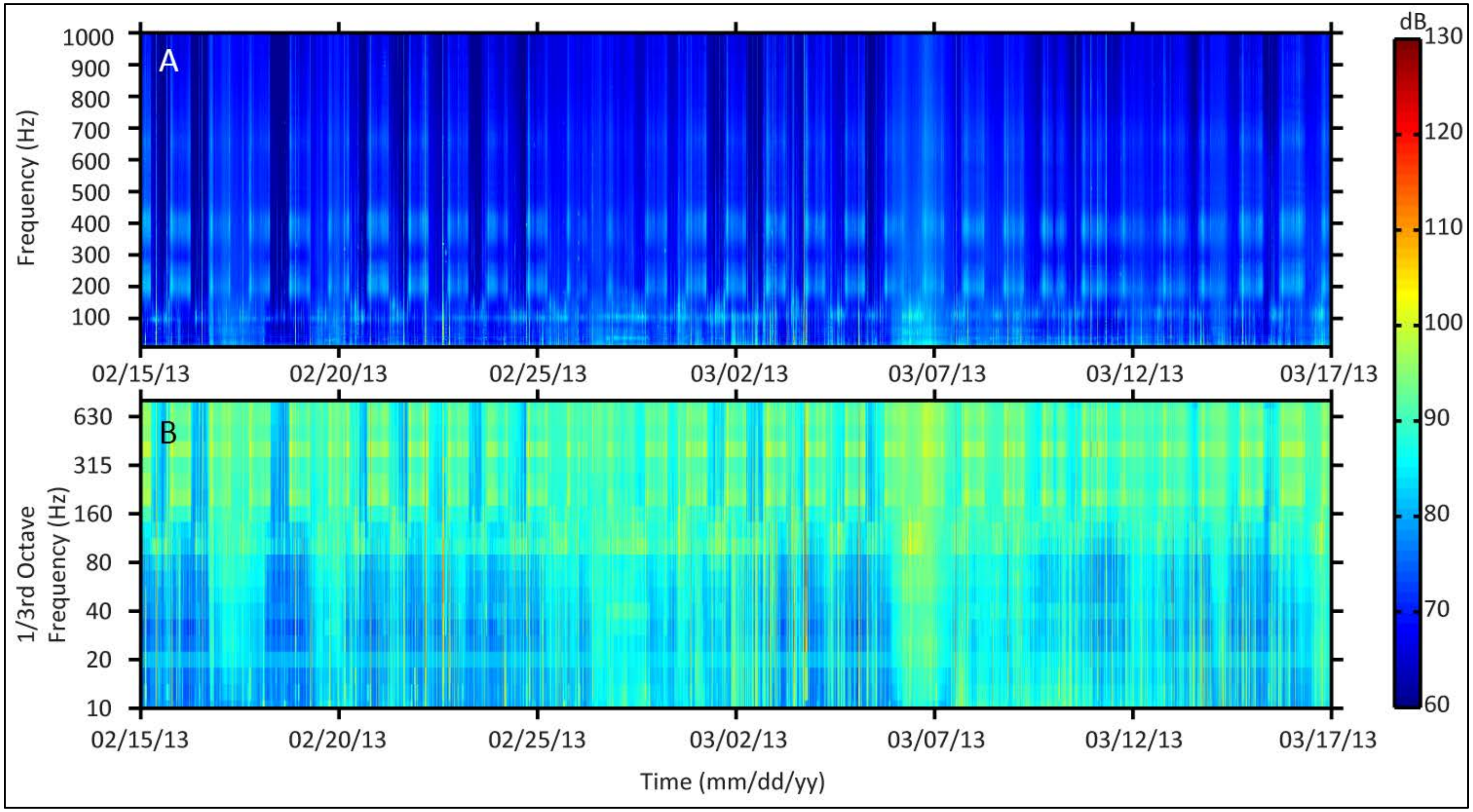

Figure 5.20. Unknown sound source, potentially biological.
Spectrogram of acoustic data from NC-South (15 February–17 March 2013) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). An unidentified sound source, potentially biological (see Appendix, Figure A-6), can be seen as signals with a bandwidth of approximately 100 Hz at approximately 200 Hz and 400 Hz. With closer examination of these signals, these are short duration (~0.2 s) upsweep-like signals that occur in bouts lasting approximately 5 s or more. Overlapping signals and bouts suggests that there are multiple sources.

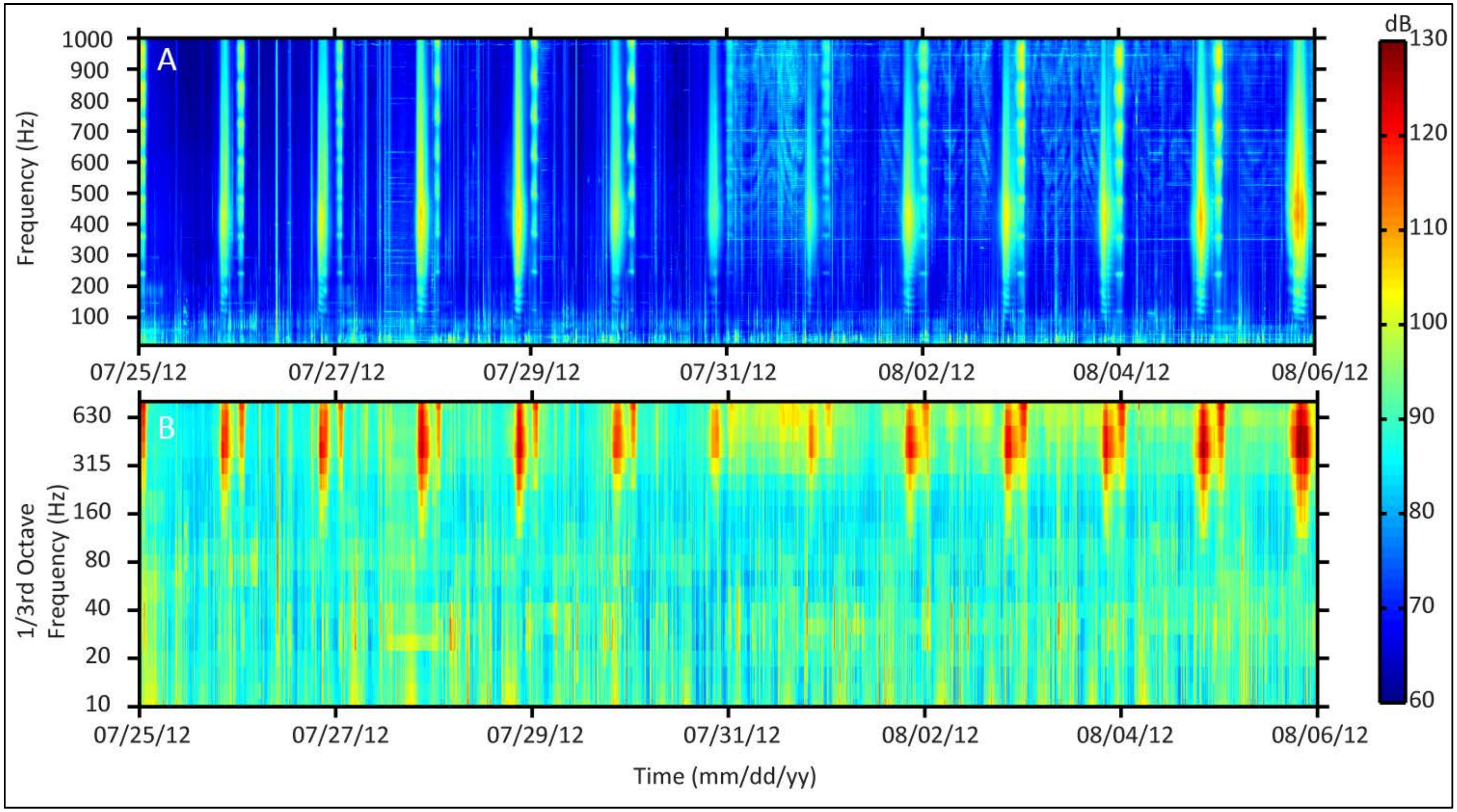

Figure 5.21. Unknown sound sources, potentially anthropogenic and biological.
Spectrogram of acoustic data from GA-North (25 July–6 August 2012) represented as A) linear frequency axis from 10–1000 Hz and B) 1/3 octave band frequencies between 10–650 Hz. The color bar to the right of both panels indicates the power scale, in dB (re: 1 µPa). Broadband noise, with peak energy at approximately 300–500 Hz, occurs in the evening of each day and continues until morning of the next day. This unknown sound may be anthropogenic. A second band of energy occurs after this unknown sound, but the signal consists of peaks of energy every 100 Hz beginning at approximately 250 Hz. This signal may be biological.

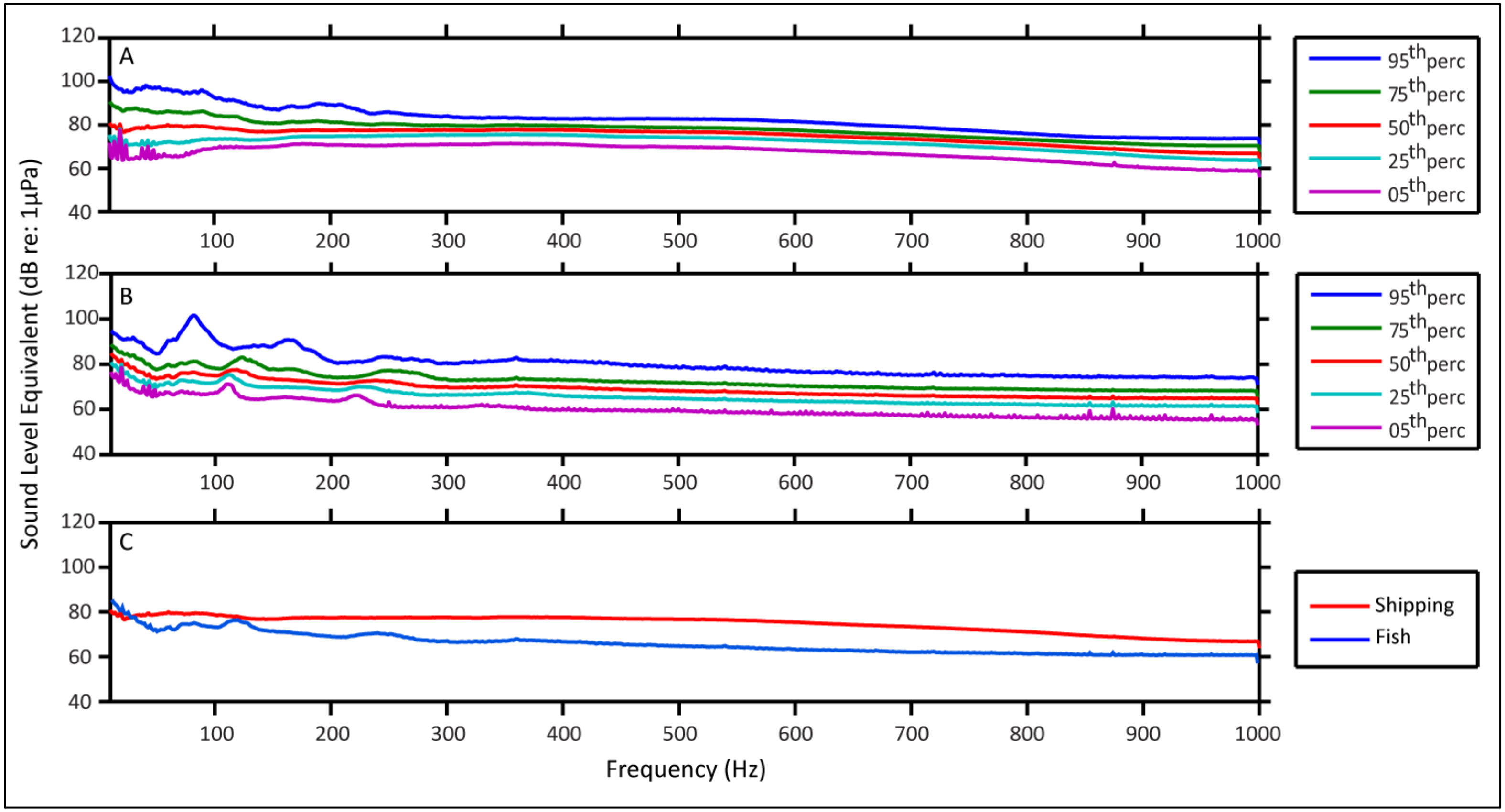

Figure 5.22. Power spectral density of anthropogenic and biological sounds.
Power Spectral Density where the sound power level (dB) is plotted versus the frequency (Hz). A) The percent of noise with 95th (loudest) and 05th (quietest) percentiles for GA-North (13 December 2012–01 January 2013) where anthropogenic shipping noise was the dominant source of noise. B) The percent of noise with 95th (loudest) and 05th (quietest) percentiles for GA-North (21 March–13 April 2013) where biological fish chorusing was the dominant source of noise. C) Overlays of the 50th percentile noise from plots A and B. At any given frequency, the line that is at a higher power level will mask any sound at the lower level.

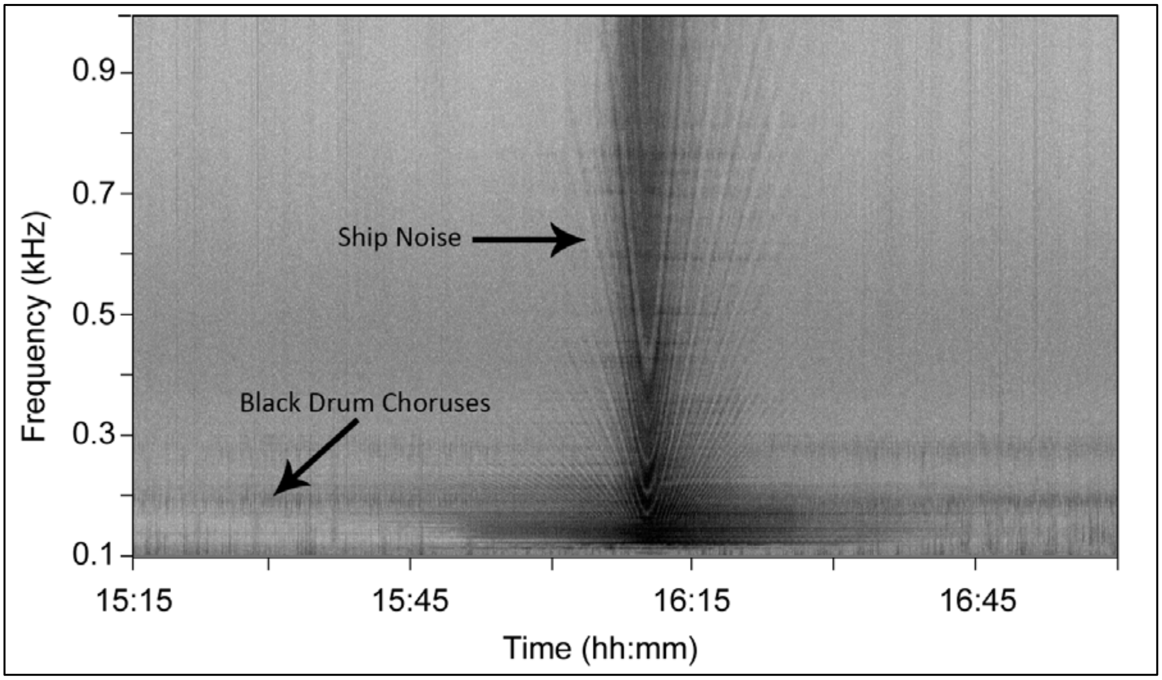

Figure 5.23. Acoustic masking of black drum chorusing.
Spectrogram from NC-Central on 14 March 2013 from 15:15–17:00. Frequency range is from 10–1000 Hz. Black drum chorusing can be seen at 15:15 and becomes masked by the incoming vessel around 15:50. By 16:40, black drum signals are clearly visible again as the ship noise dissipates.

5.4 CONCLUSIONS

Long term ambient noise spectrograms visualize the noise characteristics of the Georgia and North Carolina ecosystems, which can be extremely variable depending on weather, marine animals, human shipping, fishing, and construction activities. Within both the Georgia and North Carolina recording areas, each site had different noise characteristics. Though some noise events such as extreme weather (Hurricane Sandy) were registered on all MARUs, the signals differed in strength depending on specific sites. The same could be observed for anthropogenic and biological sounds. Some sites showed higher levels of shipping noise than others, and other sites showed black drum and toadfish chorusing at higher power intensities. These differences underscore how the ocean acoustic environment at any given location is highly variable and dependent on not only the physical noise characteristics (ocean temperature, salinity, bathymetry), but the source levels of the target sounds (fish, whales, ships, construction) and their proximity to the recording area. However, despite this variability, the baseline data gathered here give many opportunities to measure effects of future increases in noise associated with wind farm construction, pile driving, and operation. Being able to distinguish different sources of ocean noise is critical in comparing changes over time and correlating increases or decreases in certain types of noise in relation to each other.

Combining visual analysis of ocean acoustic noise from long term spectrograms and quantitative analysis using power spectral density plots, we have an opportunity to determine how much noise is introduced into the environment from shipping, biological fish choruses, and weather events, and whether certain types of noise have the potential to acoustically mask one another. With black drum and fish chorusing events, the baseline data showed examples of how shipping noise has the potential to mask the fish signals, but further monitoring can be done to quantify this impact on the fish and track changes at each site. The same concept applies to monitoring impacts from chronic and acute ocean noise on marine mammals. Though marine mammal vocalizations were not visible on the long term spectrogram plots, noise levels during periods of time where peak marine mammal vocal activity was detected could be compared to noise periods where high levels of human construction, pile driving or shipping noise occurred. Measuring increases and decreases in levels of construction and ship vessel noise and correlating these with levels of biological noise can provide data on ecosystem health in response to anthropogenic activities.

Overall, collecting baseline long term spectrograms of ocean noise is critical to understanding how much and what kinds of noise are already present in the ecosystem so that the effects of increased vessel traffic, construction, and wind farm operation can be objectively assessed for impacts to marine organisms living in these areas.

6. NOISE MODELING

6.1 INTRODUCTION

The goal of this project is to predict the levels of sound that would be produced during the installation of an offshore wind farm at one or two specific locations. A table of potential construction activities and the acoustic characteristics associated with those activities was created. After the characteristics of these activities were defined, then the acoustic propagation from those sound sources was predicted using acoustic propagation models. The model output was used to predict the spatial extent affected by wind farm construction noise at the two sites.

Water depth is one the dominant factors affecting acoustic propagation. The actual depth variation at the Georgia modeling site was quite small and therefore a single location was selected for acoustic propagation modeling. The range in actual depth was greater at the North Carolina location. There two acoustic modeling sites were selected, representing the shallowest and deepest locations. The model outputs from these two North Carolina sites will therefore account for any effect of variation in water depth.

6.1.1 Technical Background

6.1.1.1 Amplitude Measurements

Typically, underwater sound is reported in units of decibels (dB). The decibel is defined as a ratio of measured acoustic intensity (I) and a reference intensity level (I_{ref}).

$$\mathrm{dB} = 10 \log_{10}\left(\frac{I}{I_{ref}}\right)$$

More than one reference intensity level can be used to create a decibel value. Care must be taken when reporting and reading sound levels in decibels to ensure that measurements are properly described. Sound levels are often measured as pressure levels (P) rather than directly as intensity. These two measures can be related with the following equation:

$$I = \frac{P^2}{\rho c}$$

Where ρ is the density of the medium (e.g. water) and c is the speed of sound in that medium. The equations can be combined to produce the following:

$$\mathrm{dB} = 10 \log_{10}\left(\frac{P^2}{P^2{}_{ref}}\right)$$

or

$$\mathrm{dB} = 20 \log_{10}\left(\frac{P}{P_{ref}}\right)$$

In underwater acoustics, the traditional reference pressure is 1 microPascal (μPa), leading to the common use of the unit of 'dB re 1 μPa', which means a decibel referenced to a pressure of 1 microPascal. However, there are more factors that must be considered, specifically measurement type and measurement bandwidth.

Measurement type refers to how the pressure was measured. Changing the type" of measurement can change the reported sound level of a given sound by up to 9 dB. The most common types are root-mean-square (RMS), peak (also reported as 0-peak), and peak-to-peak. RMS measures are essentially an average intensity over a given amount of time. These measures are most appropriate for longer (i.e., non-impulsive) signals. Impulsive signals, such as airguns and boomers, are best measured with a peak or peak-to-peak measurement. These signals are of such limited duration, that it is difficult to appropriately calculate a RMS value. These peak measurements simply measure the maximum amplitude of the signal, without consideration of time.

Another preferred metric when considering impulsive signals and their effect upon animals is Sound Exposure Level (SEL). This metric, appropriate for all signal types, is the integration of all sound energy produced from a source, which is then normalized to the level necessary to produce that amount of energy in a single second. These values are reported with units of dB re 1 μPa^2-sec.

The bandwidth of the signal and the measurement must also be properly considered. In general, most of the sounds addressed in this study can be classified as tonal (or narrow-band) or broadband (incorporating many frequencies). The difference is relevant when considering the sound level of the signal. For a given sound pressure level (SPL), the acoustic energy can be concentrated in a single, or a very small number of frequencies. Broadband signals have their energy distributed over a large range of frequencies. Thus it is important to report the bandwidth over which the measurements were made. Spectral Levels are measurements made at a single frequency, and have units of dB re 1μPa^2/Hz. Broadband measurements encompass all of the frequencies in a signal, and are reported in units of dB re 1μPa.

6.2 METHODS

The acoustic propagation models used to predict the regions of sound influence require multiple input datasets. First, the acoustic parameters of the sources must properly characterized. This includes their loudness, or source level. Spectral and temporal characteristics of the acoustic sources also need to be included in the model. The specific sources and values for this project are summarized in Table 6.1.

Acoustic propagation models also require information on the physical characteristics of the underwater environment. These include the sound velocity profile of the water column, the roughness of the water surface which influences acoustic reflection from the surface, and the reflective properties or geologic composition of the seafloor. All of these factors affect how sound propagates through the underwater environment.

Acoustic propagation models produced predicted sound fields for each source and location combination. These were used to estimate the distance from the source to various regulatory sound threshold levels. These begin to estimate the area that would be ensonified by activities that would likely occur during the construction of alternative energy installations at modeling sites off Georgia and North Carolina.

Table 6.1. Summary of source level information for sources to be considered for modeling.

Source	Frequency Range	Signal Duration	Modeled SL (dB re 1μPa)	Source Level Range (dB re 1μPa)	Type	Reference
Boomer	200 H–16 kHz	~500 μs	See Fig 6.8	190–220	Peak	(Department of the Interior 2012)
Chirp	3.5, 12, 200 kHz	4–64 ms	217	215–222 218–225	SPL Peak	(based on Au et al. 1988)
Geotechnical Drilling	2–2050 Hz	Continuous	145	141–148	RMS	(Mann et al. 2009)
Impact Pile Driving	Broadband (10 Hz–10 kHz)	400–500 ms	See Fig 6.2	222–235 239–244	SPL Peak	(Blackwell 2005)
Vibratory Pile Driving	Broadband (10 Hz–10 kHz), with LF tonals	Continuous	See Fig 6.2	199–212	SPL	(Blackwell 2005)
Vessel Noise	Broadband	Continuous	178	175–195	RMS	(Hatch et al. 2008a; Kipple and Gabriele 2004)
DPS Vessel Noise	Broadband (e.g., 10 Hz–10 kHz)	Continuous	193	190–193	RMS	(McCauley 1998; Roth et al. 2013)

6.2.1 Acoustic Propagation Models

Low frequency sources were modeled using the range-dependent acoustic model (RAM). RAM is a PE-based model that incorporates a geoacoustic ocean bottom model (Collins 1993). Low-frequency propagation modeling in shallow water is commonly regarded as difficult. However, a comparison of measured sound propagation and model prediction found that RAM was able to predict the sound field from a shallow water pile driver with good accuracy (Malme et al. 1998). The mid- and high- frequency sources were modeled with the Bellhop ray-trace model (Porter 1992).

6.2.2 Acoustic Propagation Modeling Environmental Inputs

6.2.2.1 Sound Velocity Profile

Sound velocity profiles were extracted from the National Coastal Data Development Center's General Digital Environmental Model (GDEM-V) (version 3.0) database for the month of September.

6.2.2.2 Bathymetry

The NOAA National Geophysical Data Center's ETOPO 1 database (Amante and Eakins 2009) was used to extract the bathymetry for the two modeling areas. This database has a 1° resolution in latitude and longitude. It was the finest resolution database available that covered all of the area to be modeled. For the higher frequency sources with lower source levels that required modeling over a smaller area, the higher resolution (three arc-seconds) Coastal Relief Model (NOAA National Geophysical 2013) was used to supply bathymetry.

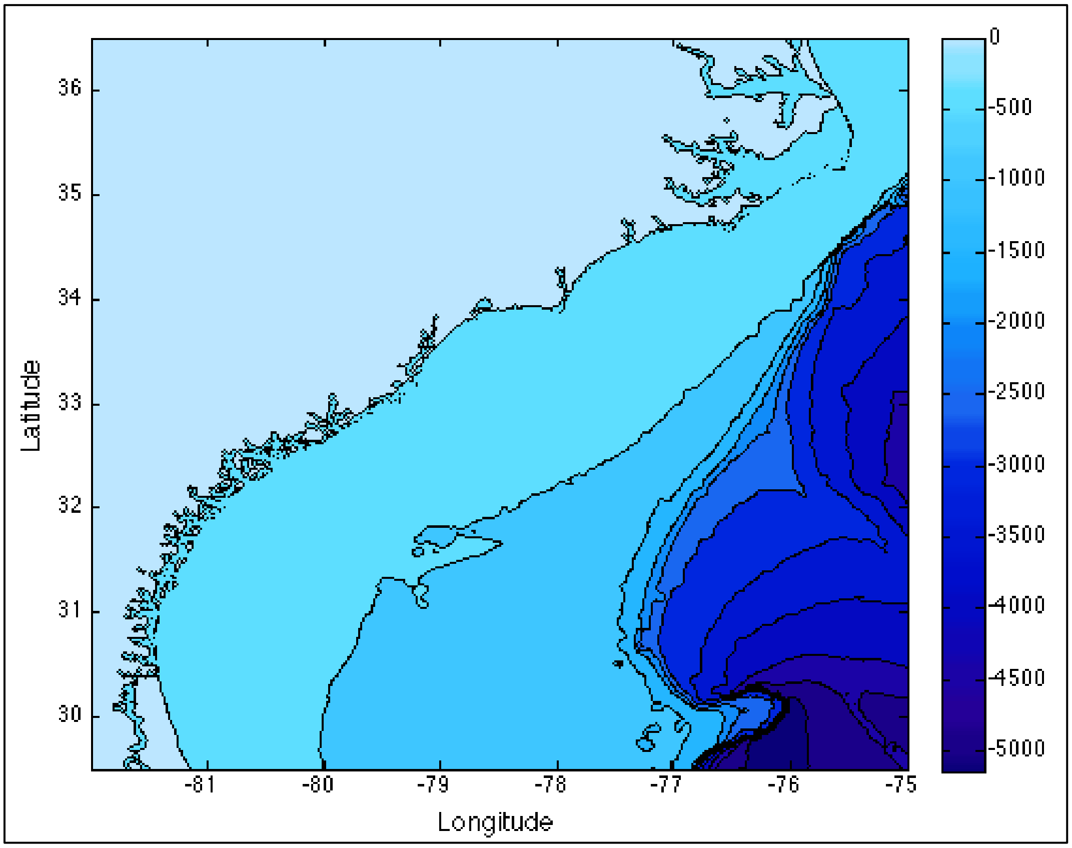

Figure 6.1. ETOPO1 bathymetry for the modeling areas.

6.2.2.3 Bottom Characterization

The bottom characteristics of the area from Cape Hatteras to Cape Canaveral was summarized in Volume III (page 13) of the Fishery Ecosystem Plan of the South Atlantic Region (South Atlantic Fishery Management Council 2009b): "Most of the bight substrate is covered by a vast plain of sand and mud (Newton et al. 1971) underlain at depths of less than a meter by carbonate sandstone (Riggs et al. 1996; Riggs et al. 1998)." This description was used for both the North Carolina and Georgia sites. The USGS sediment thickness database reported that the depth to the acoustic basement was 34.5 meters in the North Carolina site and 35 meters for the Georgia site (Divins 2003).

6.2.2.4 Bottom Loss Model: Geoacoustic Model Construction

The propagation of low frequency sources was modeled with RAM using the geoacoustic model presented in DOI (2012, Table D-18) for sandy bottoms (Table D-18). his model is shown in Table 6.2. The mid and high frequency sources were modeled with the Bellhop model, which incorporates a loss v. angle bottom loss function. This was calculated using the Rayleigh bottom loss scattering model (Officer 1958).

Table 6.2. Bottom parameters for the modeling area.

Depth (m)	Density (g/cm^3)	Compressional wave velocity (m/s)	Compressional Wave attenuation (dB/λ)	Shear Wave Velocity (m/s)	Shear Wave Attenuation (dB/λ)
0–10	1.87	1,648–1,785	0.45–0.92	158	0.07
10–50	1.87	1,785–1,987	0.92–1.45		
50–150	1.87–2.04	1,987–2,276	1.45–1.79		
150–300	2.04	2,276–2,482	1.79–2.08		
300–600	2.04	2,482	2.08		

6.2.2.5 Surface Loss Model

Surface loss is the loss of acoustic energy resulting from interaction with the water's surface. The Bellhop model runs used the Beckman-Spizzichino Model (Leibiger 1978) to estimate surface loss. The RAM PE model used its integral surface loss model. The data input to both of these models is windspeed. Windspeed data was extracted from the National Data Buoy Center database (NOAA NDBC 2015). The two weather buoys nearest to the modeling locations were buoy number 41008 (31.4°N, 80.86°W) for the Georgia location and buoy number 41036 (34.207°N, 76.949°W) for the North Carolina location. The 2012 data for windspeed was downloaded for both of these buoys and the monthly average for September was calculated. The mean windspeed was 5.45 knots for the North Carolina location and 5.69 knots for the Georgia location.

6.2.3 Scenario Construction

This acoustic modeling study was conducted as part of a larger project to predict and assess the environmental impact of noise that may be produced during the construction of offshore wind farms. Prospective locations were identified and ambient noise measurements were made at those sites. These locations were used as the basis for selecting locations for acoustic noise field predictions. This study has focused on pre-construction and construction activities. However, some of these results, specifically the vessel noise results, would also be applicable for operational assessment.

A subset of the six ambient noise recorders sites was selected for modeling locations (see Table 6.3). Because the range of depths between the three Georgia locations was small, only a single modeling location was chosen for Georgia. For the North Carolina site, the shallowest and the deepest water locations were chosen for modeling efforts.

For each construction activity the associated noise characteristics were established through a literature review. These characteristics include source level, frequency bandwidth, beam pattern and duty cycle. A separate acoustic modeling run was constructed for each sound type at each modeling location. A virtual sound source was placed in the environment at each of the three modeling locations. The depth selected for each source is dependent on the activity. For example, vessels were modeled with a source depth of four meters, the approximate depth of the propellers while pile-driving sources were placed on the ocean floor. The horizontal range of each model was selected based on loudness of the source being modeled. For example, pile drivers were modeled with a distance of 50 km, whereas chirp sonars were modeled to a range of only 1 km.

Table 6.3: Locations of modeling sites.

Site	Longitude	Latitude	Depth (m)	Modeled
GA-North	-80.20946382	31.95322182	20	
GA-Central	-80.65711959	31.91721722	15	Y
GA-South	-80.72975008	31.82680252	15	
NC-North	-76.41164212	34.23590549	29	
NC-Central	-76.40920941	34.23585906	28	Y
NC-South	-76.82990523	34.00456306	37	Y

6.2.4 Acoustic Characteristics of Modeled Sources

6.2.4.1 Pile Driving Acoustic Parameters

Piles that are being driven are actually line sources, with sound being emitted from the total length of the pile, which couples to both the water column and the sediment and rock of the bottom. However, propagation models that can handle line sources are not readily available. Nevertheless, a comparison of measured data and propagation predictions made with the RAM PE model showed good agreement when the pile was modeled as a point source on the ocean floor (Malme et al. 1998).

Impact and vibratory pile drivers were measured in Knik Arm, AK (Blackwell 2005) with shallow and deep hydrophones. The piles were 150 feet long (~46m), 36 inches (91cm) in diameter and had 1-inch thick steel walls. The measured acoustic characteristics of these pile driving activities were used as inputs for the current modeling study.

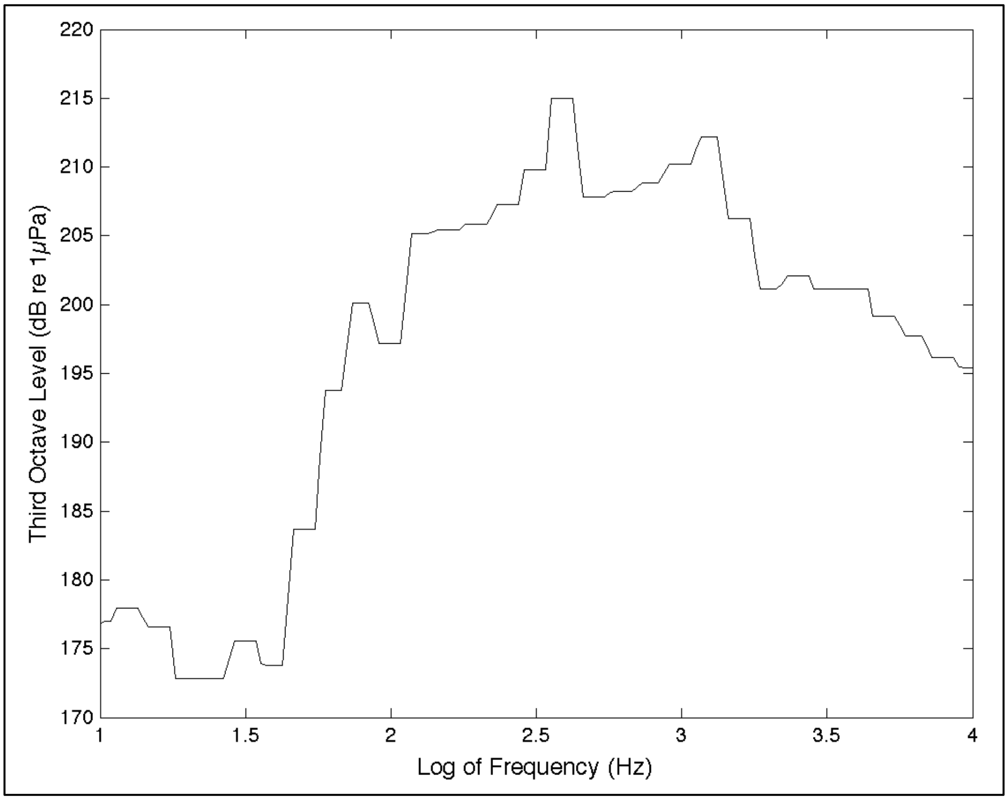

Figure 6.2. Source 1/3-octave levels measured from a pile being driven with a diesel impact hammer.

The impact-driven pile was recorded at a distance of 62 meters from the pile. The transmission loss was measured in situ, and those data were used to estimate the source levels shown in Figure 6.2. The pile driven with the vibratory driver was recorded at a distance of 56 meters, and the in situ measured transmission loss function for that pile was used to estimate the source levels shown in Figure 6.3.

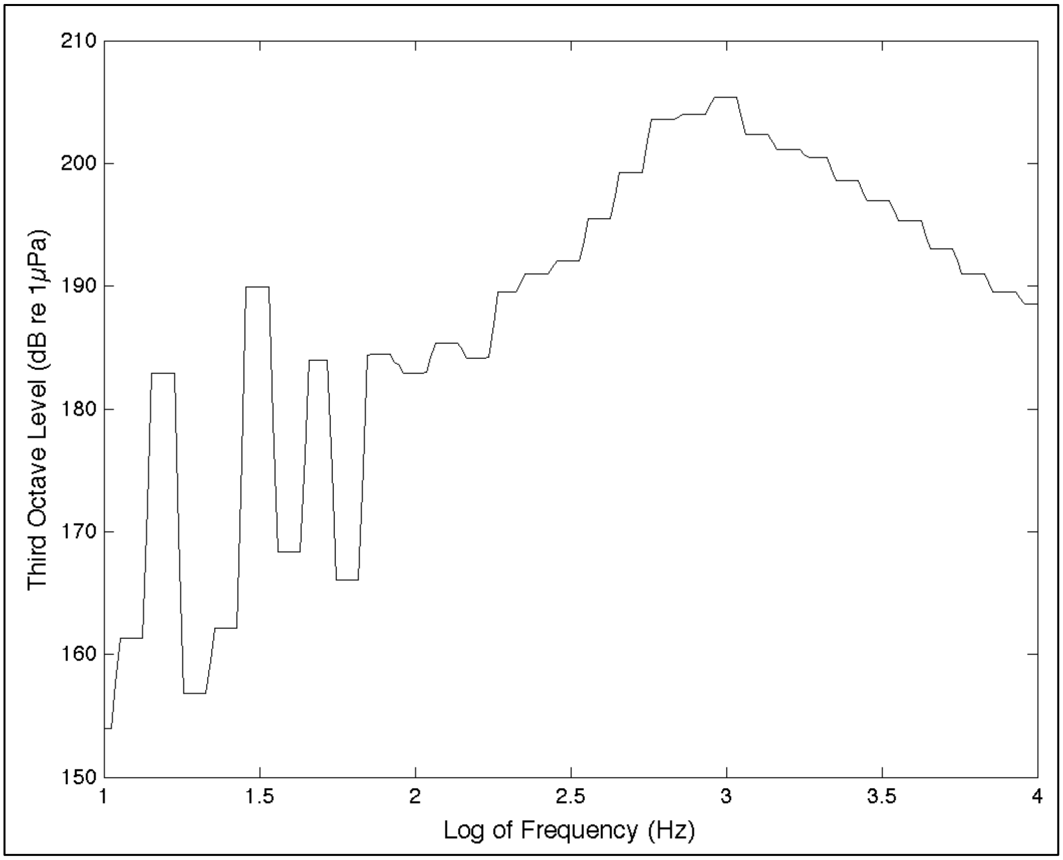

Figure 6.3. Source 1/3-octave levels (solid line) measured from a pile being driven with a vibratory hammer.

6.2.4.2 Boomers

A Huntec ED10 boomer has been characterized as being capable of producing zero-to-peak levels of 190 to 220 dB re 1μPa at 1m, depending upon the power setting (Simpkin 2005). In a recent EIS, this source was modeled with a broadband source level of 212 dB re 1 μPa at 1m (Department of the Interior 2012). This source level was used in this analysis.

The transmission loss for each 1/3-octave band from 200 Hz to 16 kHz was predicted separately with the Bellhop transmission loss model. The source was placed at a depth of five meters. The model was run with 1600 rays and used coherent addition of the rays. The lower frequencies had an omnidirectional radiation pattern, and the rays modeled for these ranged from -90 to 90 degrees (i.e., all possible angles). At mid and higher frequencies, the beam pattern of the source became more focused downward. For these frequencies the angular range of outgoing rays was limited to the beam angle specified in Table 6.4. Thus at high frequencies, only rays representing straight down and angles up to 8° from straight down were modeled. This accounted for the beam pattern at each of the frequencies.

These transmission loss values were then subtracted from the appropriate 1/3-octave source level (Table 6.4) to produce a set of sound pressure level predictions for the boomer source as a function of bearing, range and depth.

Table 6.4. Estimated source levels (RMS SPL) and beam width from the representative boomer distributed into twenty 1/3rd-octave bands.

Third-Octave Band Center Frequency (Hz)	RMS SPL (dB re 1 μPa at 1 m)	SEL (dB re 1 $\mu Pa^2 \cdot s$ at 1 m)	Beam Width
200	196.0	158.6	omnidirectional
250	196.4	159.0	omnidirectional
315	197.1	159.7	omnidirectional
400	197.7	160.3	omnidirectional
500	198.5	161.1	omnidirectional
630	199.4	162.0	omnidirectional
800	200.0	162.6	omnidirectional
1,000	200.8	163.4	omnidirectional
1,250	201.5	164.1	105°
1,600	201.6	164.2	78°
2,000	201.9	164.5	60°
2,500	201.4	164.0	47°
3,150	200.8	163.4	37°
4,000	200.1	162.7	29°
5,000	198.9	161.5	23°
6,400	197.8	160.4	18°
8,000	196.1	158.7	14°
10,000	192.8	155.4	11°
12,800	186.8	149.4	9°
16,000	176.8	139.4	8°

6.2.4.3 Chirp Sonar

Chirp sonar signals are shorter than the measured marine mammal integration time. Dolphin integration times have been measured at 264 ms (Au et al. 1988). Therefore the peak and RMS source levels were reduced using a conservative 200 ms value for all species. The reduction was 5 dB for the 3.5 and 12 kHz source and 17 dB for the 200 kHz source.

Table 6.5. Representative chirp sub-bottom profiler specifications (Department of the Interior 2012)**.**

	Frequency		
	3.5 kHz	12 kHz	200 kHz
Beam Pattern	Circular 30°	Rectangular 26° by 38°	Circular 8°
Output power	3 kW	3 kW	0.5 kW
rms SPL (dB re 1 μPa at 1 m)	222	222	215.2
Peak level (dB re 1 μPa at 1 m)	225	225	218.2
SEL (dB re 1 $\mu Pa^2 \cdot s$ at 1 m)	210.1	210.1	191.2
Total peak level (dB re 1 μPa at 1 m)	228.2		
Ping duration (max)	64 ms		4 ms

6.2.4.4 Geotechnical Drilling and Cone Penetrometers

The sound levels associated with geotechnical drilling were estimated using the measured under ice values for a small coring drill and a large casing drill (Mann et al. 2009). A small drill had RMS levels of 127.8 dB re 1 μPa at a distance of five meters. The larger casing drill had a received level of 124.5 dB re 1 μPa at a distance of fifteen meters. Assuming spherical spreading these translate into RMS source levels of 141.8 and 148.0 dB re 1 μPa at 1 meter. Note that the measured peak sound pressure levels at times were over 20 dB higher than these RMS measures, suggesting the presence of transient sounds associated with drilling activity.

Cone penetrometers are used to assess sediment characteristics and stiffness. They are typically comprised of a 60° metal cone at the end of a metal shaft that is driven into the sediment with hydraulic pressure (Lee and Peterson 2001). No description of the noise characteristics of cone penetrometers could be located. However, given the lack of a significant vibration source (as would occur in pile driving or rotational drilling), this activity is not expected to produce substantial acoustic levels.

6.2.4.5 Characterization of Vessel Noise Parameters

The source level of tugs and research vessels were estimated in the band of 71-141 Hz (Hatch et al. 2008b). Three tugs had source levels of 174 ± 3, 175 ± 2 and 166 ± 2 dB re 1 μPa at 1 m. Two research vessels had source levels of 158 ± 2 and 161 ± 2 dB re 1 μPa at 1 m. These two classes of vessels most closely approximate the service vessels expected to support the renewable energy installation construction and maintenance activities.

Overall vessel noise level was examined as a function of vessel length, at a vessel speed of 10 knots (Kipple and Gabriele 2004). Vessels in the length range of 50 to 100 ft had a broadband source level of 169 ± 3 dB re 1μPa at 1 yd, while vessels greater than 100 ft in length had a source level of 177 ± 5 dB re 1μPa at 1 yd.

Numerous fishing vessels have recently been characterized at various speeds (Allen et al. 2012). Fishing vessels are an appropriate representative for support vessels for the construction activity at these locations. Source levels in the 1–2,500 Hz band ranged from 173 to 195 dB re 1 μPa at 1m. There was a strong correlation between vessel speed and source level as shown in Figure 6.4.

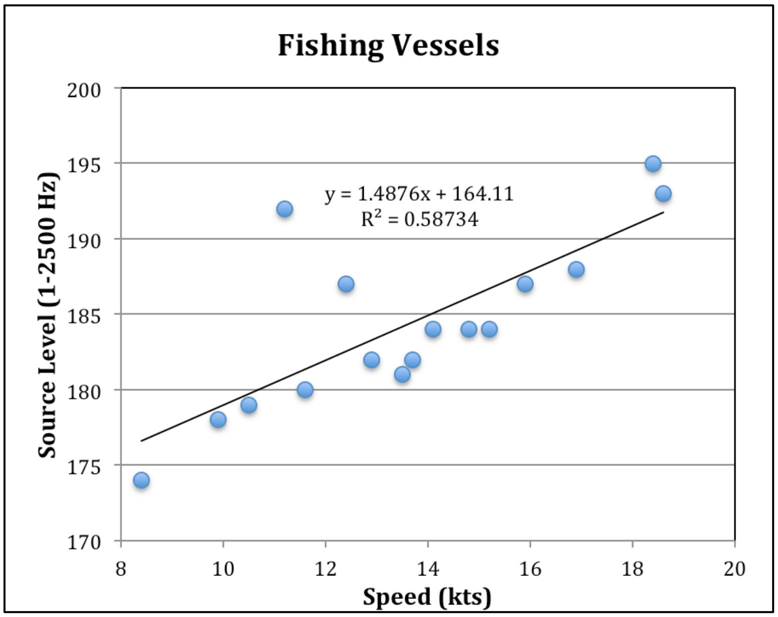

Figure 6.4: Data from Allen et al. (2012) **plotted to show strong relationship between vessel speed and source level (dB re 1 μPa at 1m, 1-2,500 Hz).**

6.2.4.7 Characterization of Vessels in Dynamic Positioning Mode

The characteristics of a vessel using dynamic positioning system (DPS) have not been measured directly. However, a drilling rig support vessel equipped with a bow thruster (a major DPS component) had a measured broadband source level of 137 dB re 1 μPa at a distance of 405 meters (McCauley 1998). Assuming spherical spreading, this gives a broadband source level value of approximately 190 dB re 1 μPa at 1m. Measurement of the bow thruster of the R/V *Healey* found octave-band source levels as high as 193 dB re 1 μPa at 1m (Roth et al. 2013). This value was used for the acoustic modeling for the current study.

6.3 RESULTS

6.3.1 Acoustic Propagation Modeling Results

The results of the acoustic propagation modeling are presented for each source and for each modeling location. For each combination of source and modeling location there are multiple presentations. First will be a transmission loss slice, which is a presentation of sound received level plotted as a function of both range and depth. This presentation gives an overall view of how that particular sort sound source is likely to propagate at each of the modeling areas.

Sound propagation is affected by bathymetry. In general, sound travelling into deeper water will propagate farther than sound that is traveling into shallower water. Some propagation is also bearing dependent. Therefore, the models were run 36 times at 10° intervals, for every location-source combination. These are summarized by plotting the maximum received sound level from all of the bearings in one figure. Thus each TL slice figure represents the “best” possible acoustic propagation.

To describe the bearing dependent component of the acoustic propagation one or more plan view figures will also be presented for each source location combination. These figures represent an overhead view looking down on the sound field; where appropriate, multiple versions of the same analysis represented at different spatial scales are shown. Because propagation is also depth dependent the slices are shown at a nominal depth of 6 m. This depth was chosen, in part, because all marine mammals have to return to the surface and will pass through this depth.

The approximate ranges to the 160 and 180 dB isopleths are determined from these figures and summarized in tables at the end of the results section. Approximate ranges are specified because the exact parameters of the exact construction activities to be conducted have not been specified. Therefore, these distances represent approximate guidelines for a given activity.

6.3.1.1 Boomer Source

The acoustic propagation of boomer was predicted at each of the modeling sites, for frequencies from 200 Hz to 16 kHz. A total of 20 1/3-octave bands were modeled and then combined to produce the broadband transmission loss predictions.

The maximum received for each modeled radial is shown. As seen in Figure 6.5, the sound pressure level varies by depth and range. To illustrate the spatial extent of any particular sound pressure isobath, the maximum sound pressure from all depths was calculated for each range and bearing step. These two-dimensional representations illustrate the maximum range to regulatory thresholds (i.e., 160 dB and 180 dB re 1 μPa (RMS).

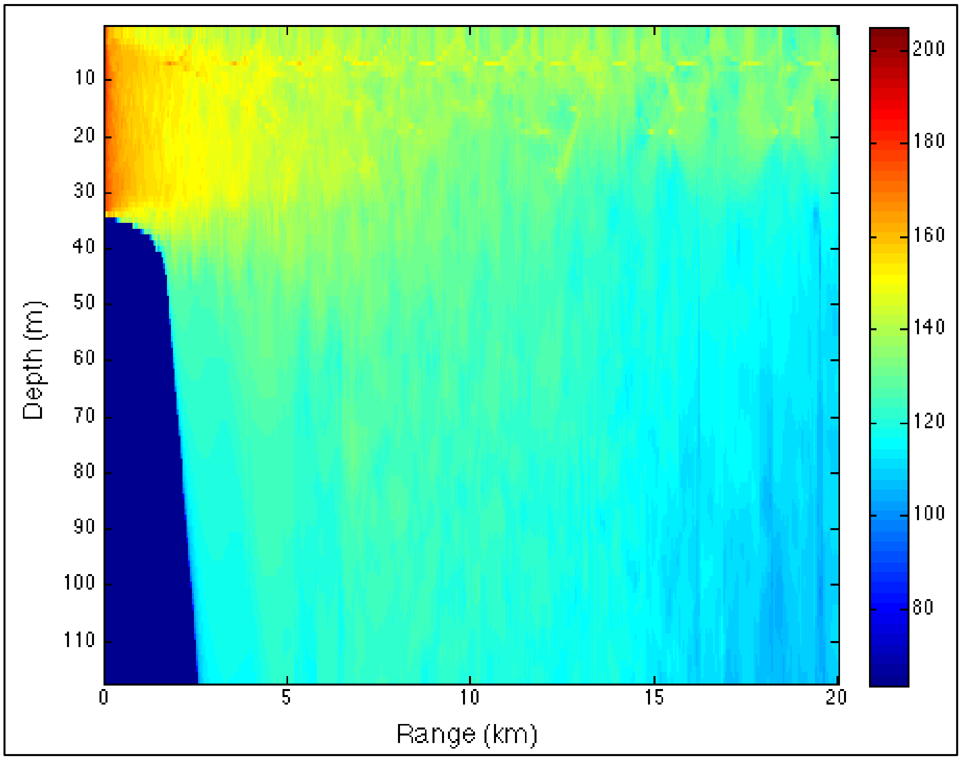

Figure 6.5. The maximum received level from the Georgia site is shown as a function of range and depth.

Figure 6.6 shows the sound pressure level at each range and bearing at a sample depth of 6 meters. The isopleths of 150, 160 and 180 dB are specified. The 150 dB isopleths are shown as the light blue color. The 160 dB isopleth can be easily recognized as the inner greenish circle and a torus at a range of about 2.5 km. The 180 dB isopleth is at a range of about 100 meters.

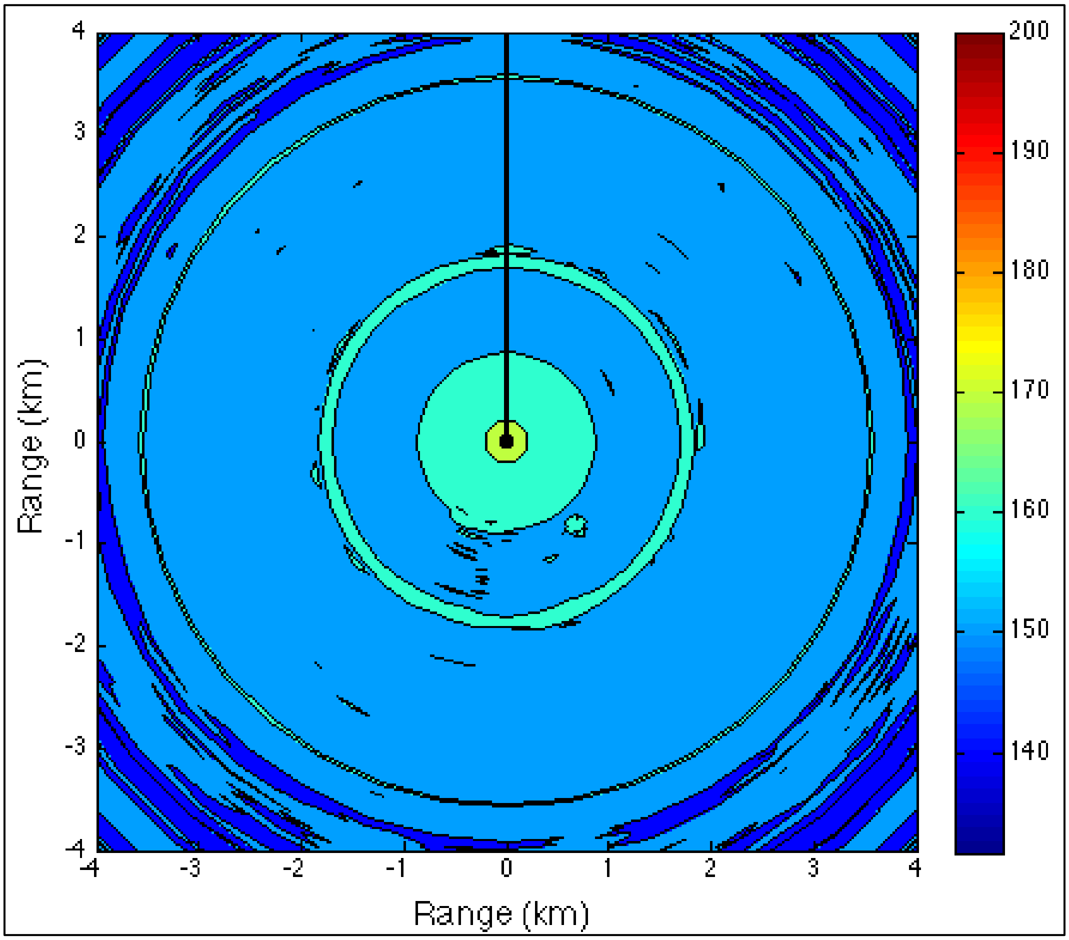

Figure 6.6. Planar view of sound propagation at Georgia site.

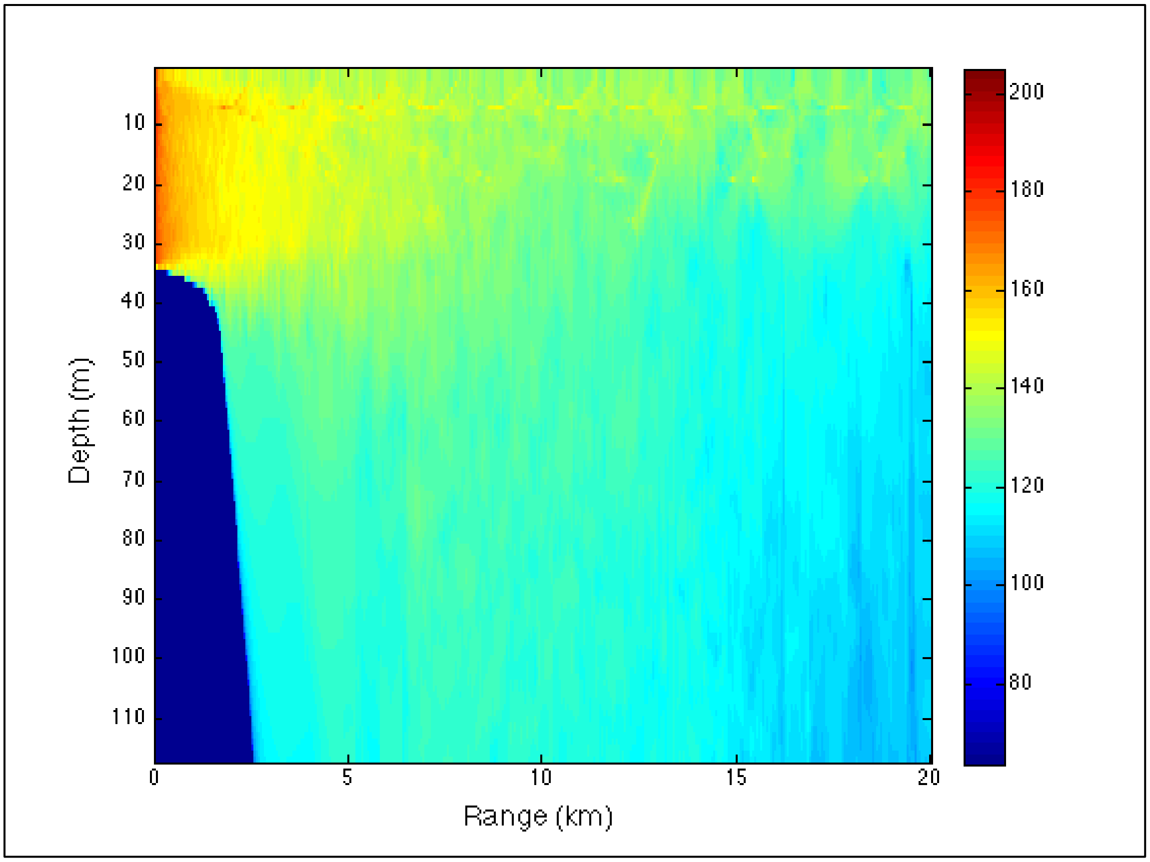

Figure 6.7.The maximum received level from NC-North is shown as a function of range and depth.

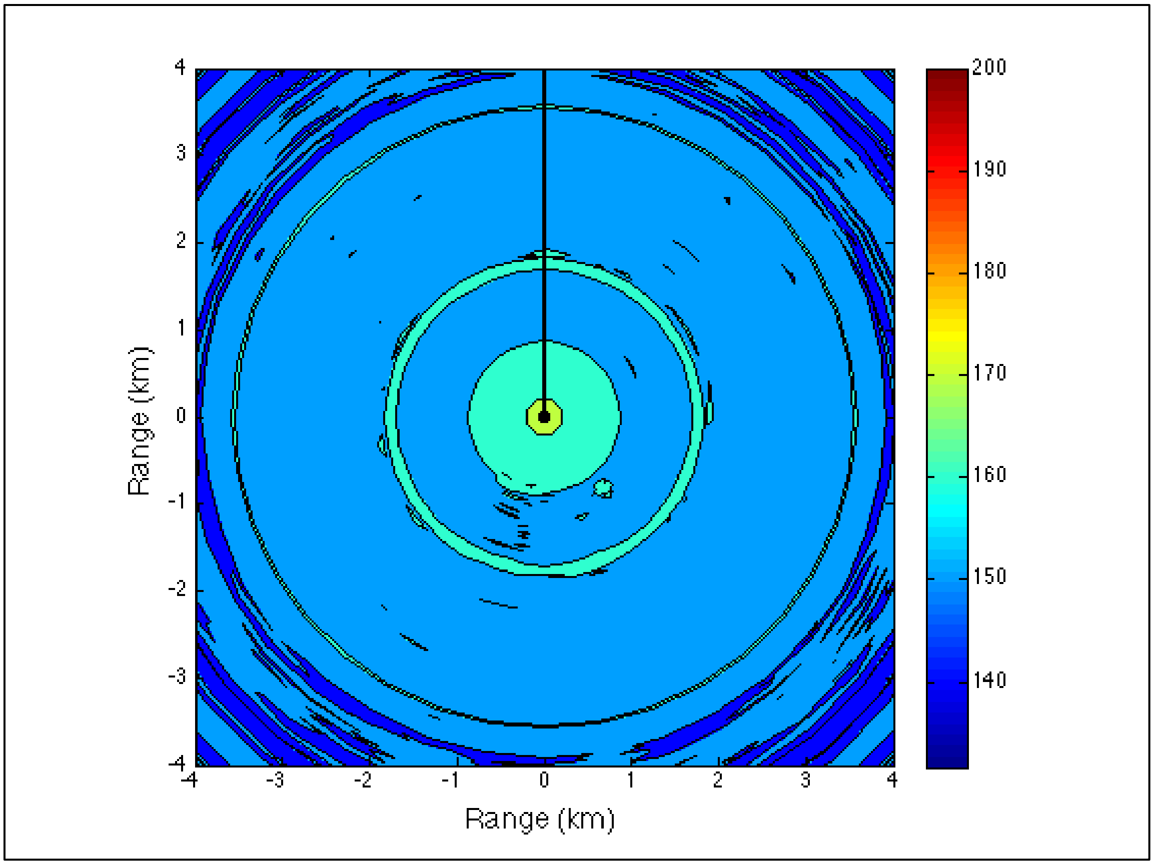

Figure 6.8.The received sound level of the boomer source at the NC site at depth of six meters is shown.
The maximum range of the 160 dB isopleth is ~3.5 km.

These two data presentations are repeated for the North Carolina site #3.

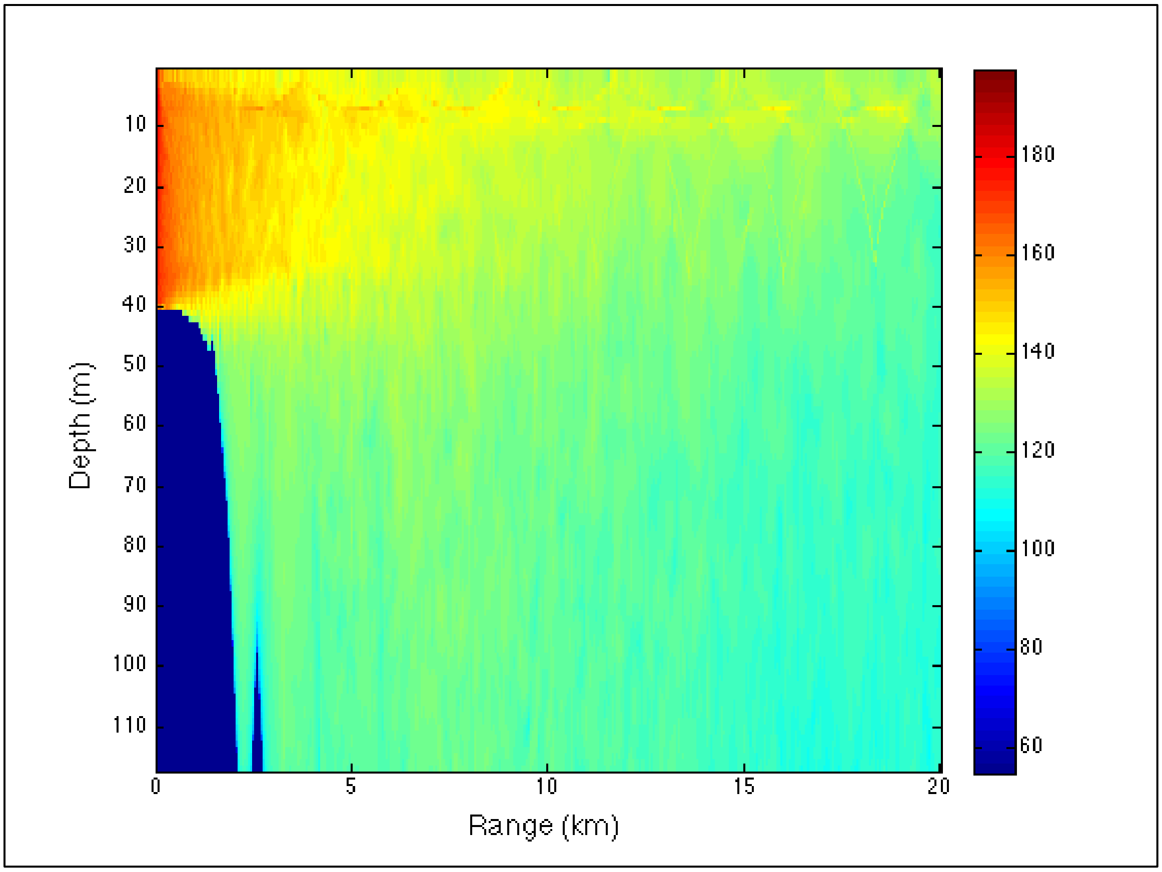

Figure 6.9. The maximum received level of any radial is shown as a function of range and depth at the NC site.

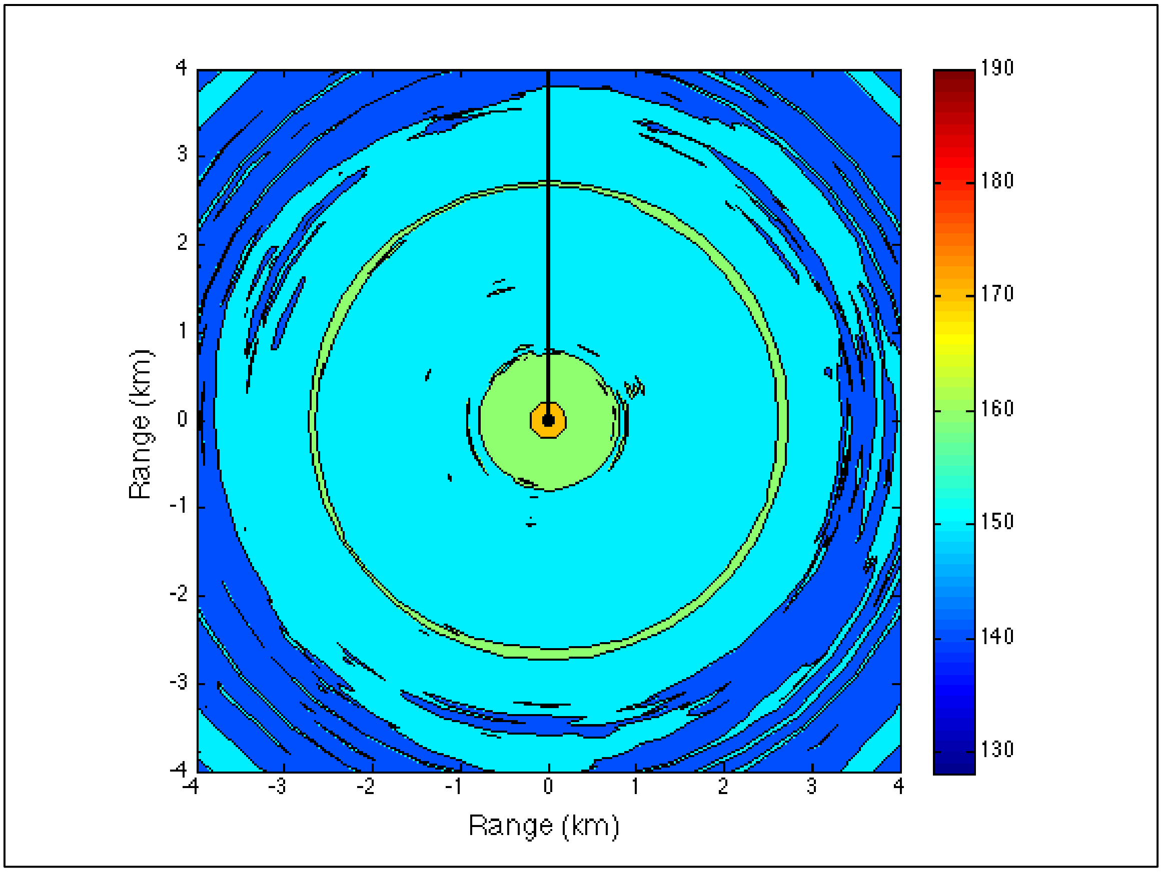

Figure 6.10.The received sound level of the boomer source at the NC site a depth of six meters is shown.
The maximum range of the 160 dB isopleth is ~3.5 km.

6.3.1.2 Chirp Source

Chirp sonars typically have frequencies of 3.5, 12, or 200 kHz. The 3.5 kHz signal will propagate further than the others because of the frequency-dependent effect of sound absorption. The modeling was based on a center frequency of 3.5 kHz. Chirp sonars also have a narrow beam pattern which is focused downward toward the seafloor. This effect is seen in Figure 6.11. The energy hitting the seafloor is reflected upwards, but the downward reflection from the surface is weak, limiting the horizontal extent of these sonars.

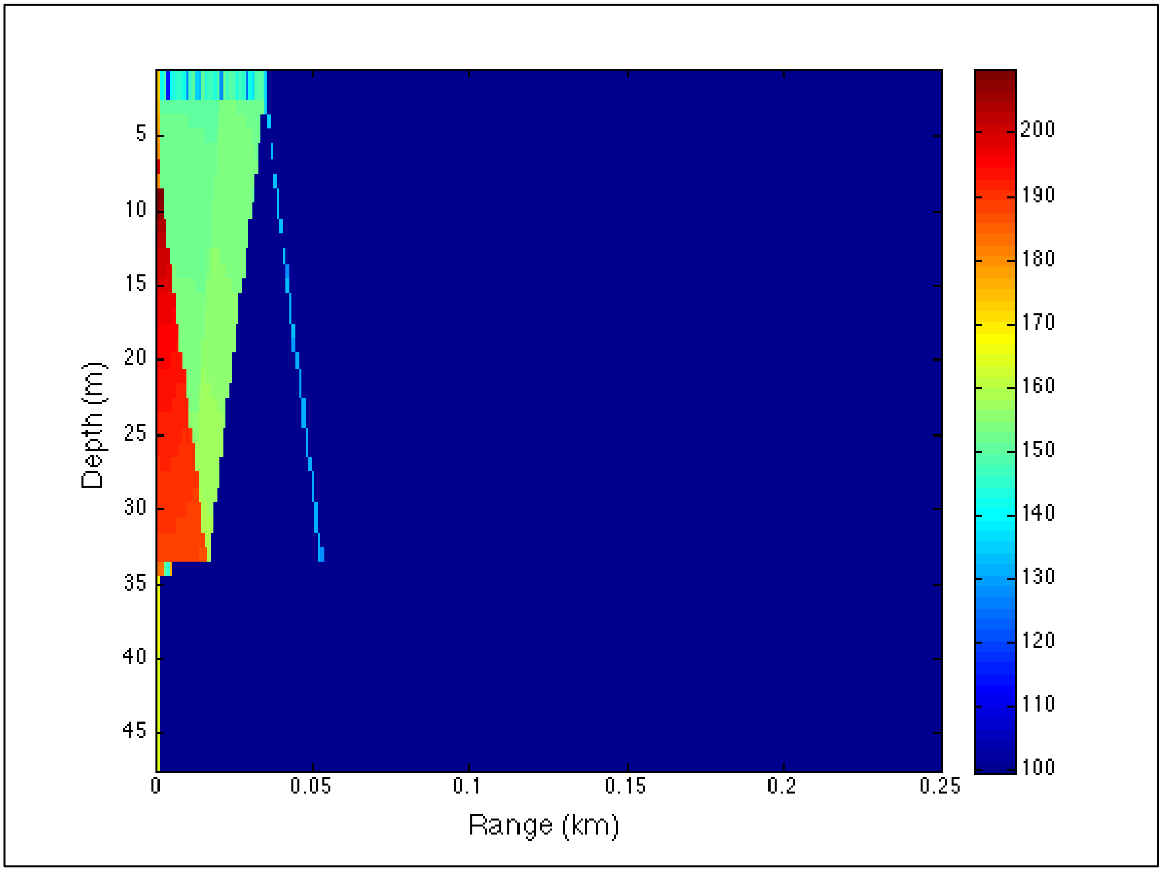

Figure 6.11.The propagation of the chirp sonar source is shown.
Due to the very narrow beam pattern, the range scale of this figure has been reduced.

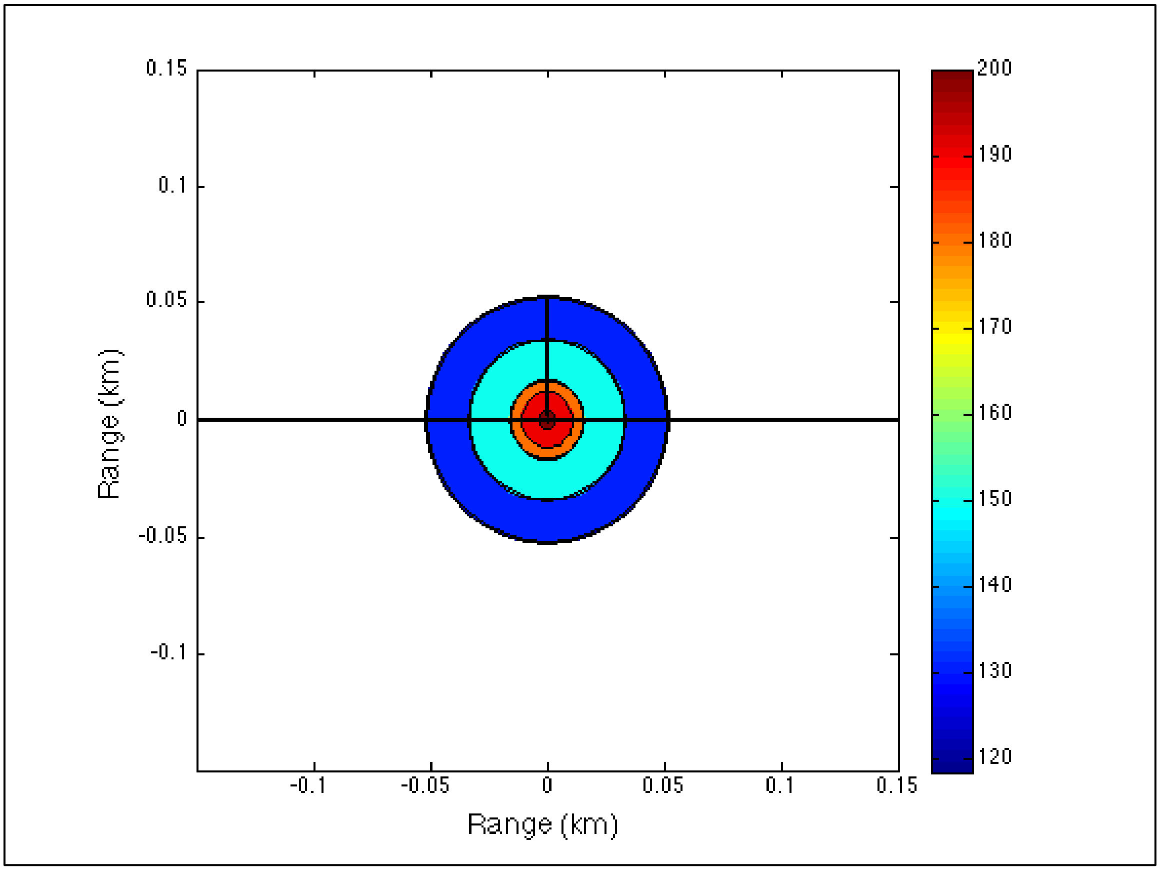

Figure 6.12. The received level at a depth of six meters is shown.
The outer ring shows the 160 dB contour at a range of ~20 meters.

6.3.1.3 Geotechnical Drilling

The low source level identified for geotechnical drilling obviated the need for acoustic propagation modeling, as the source level was less than the 160 dB regulatory threshold.

6.3.1.4 Impact Pile Drivers

Impact pile drivers operate by repeatedly hammering a pile with a large driven weight. The city signal is that of a repeating impulse that can have considerable amplitude. Piles typically take many hours to be completely driven. Thus both the signal duration and event duration qualify them as an "intermittent" activity for which the 160 and 180 dB thresholds clearly apply.

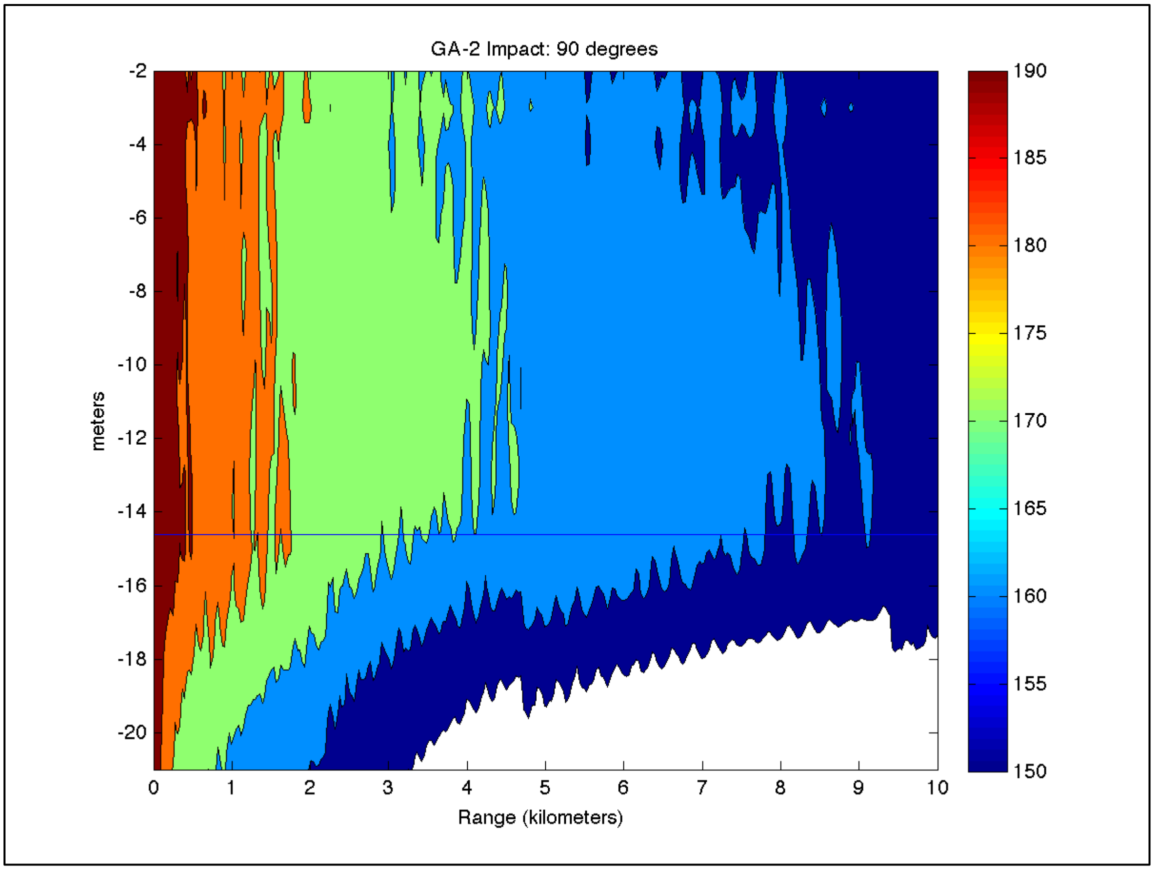

Figure 6.13.The propagation predicted from the RAM model as a function of range and depth for the Georgia site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 10 km and 1800 meters, respectively.

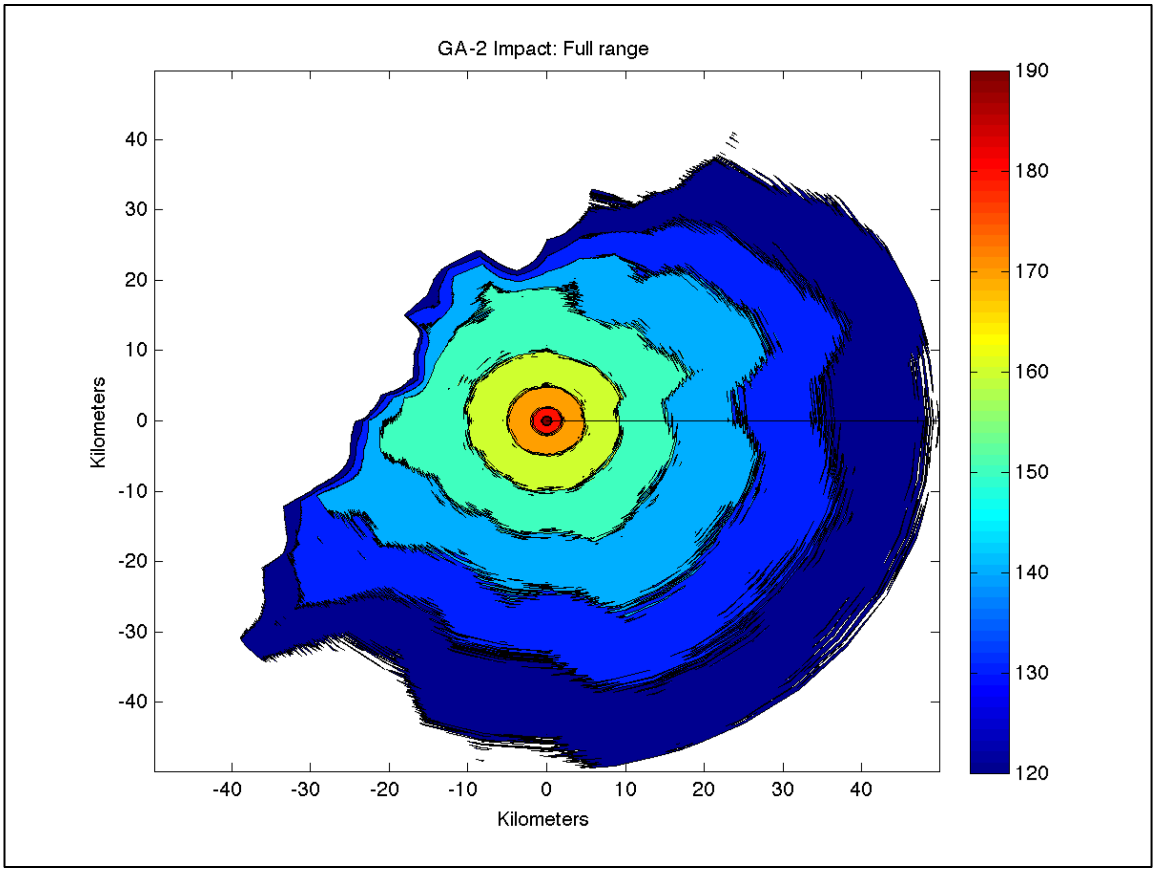

Figure 6.14.The maximum received level at any depth for the Georgia site. The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 10 km and 1800 meters, respectively. The effect of the coastline to the northwest of the site can be readily seen.

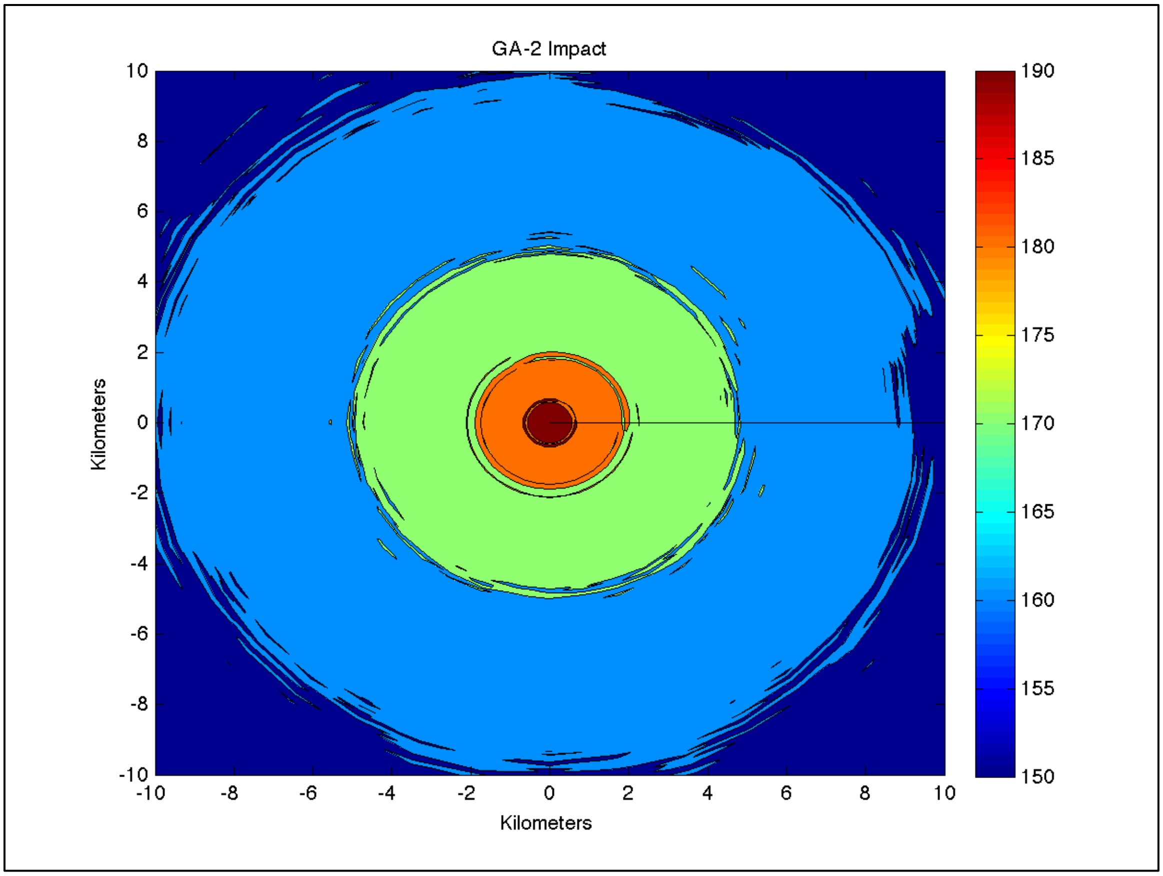

Figure 6.15. The inner portion of the maximum received level at any depth is shown for the Georgia site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 10 km and 1800 meters, respectively.

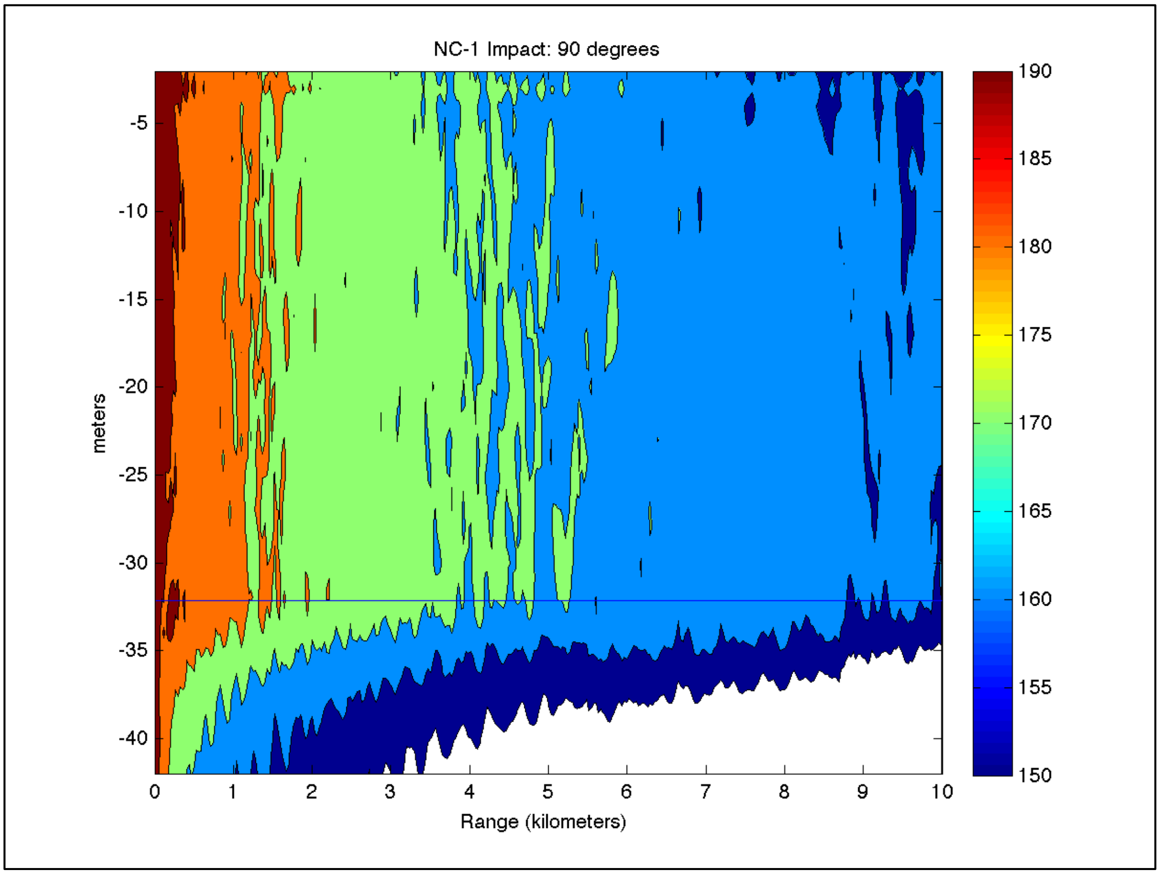

Figure 6.16. The propagation predicted from the RAM model as a function of range and depth for the North Carolina site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately >10 km and 1500 meters, respectively.

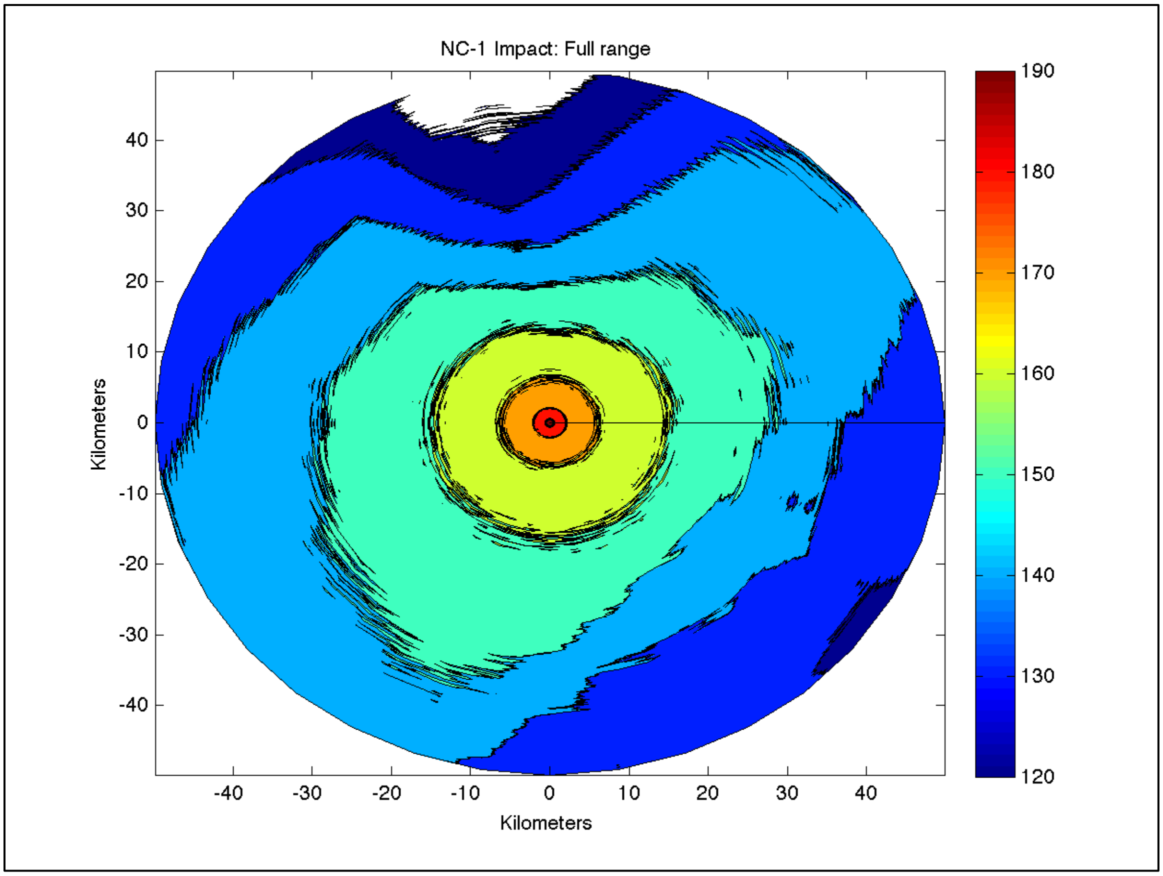

Figure 6.17.The maximum received level at any depth for the North Carolina site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 15 km and 1800 meters, respectively.

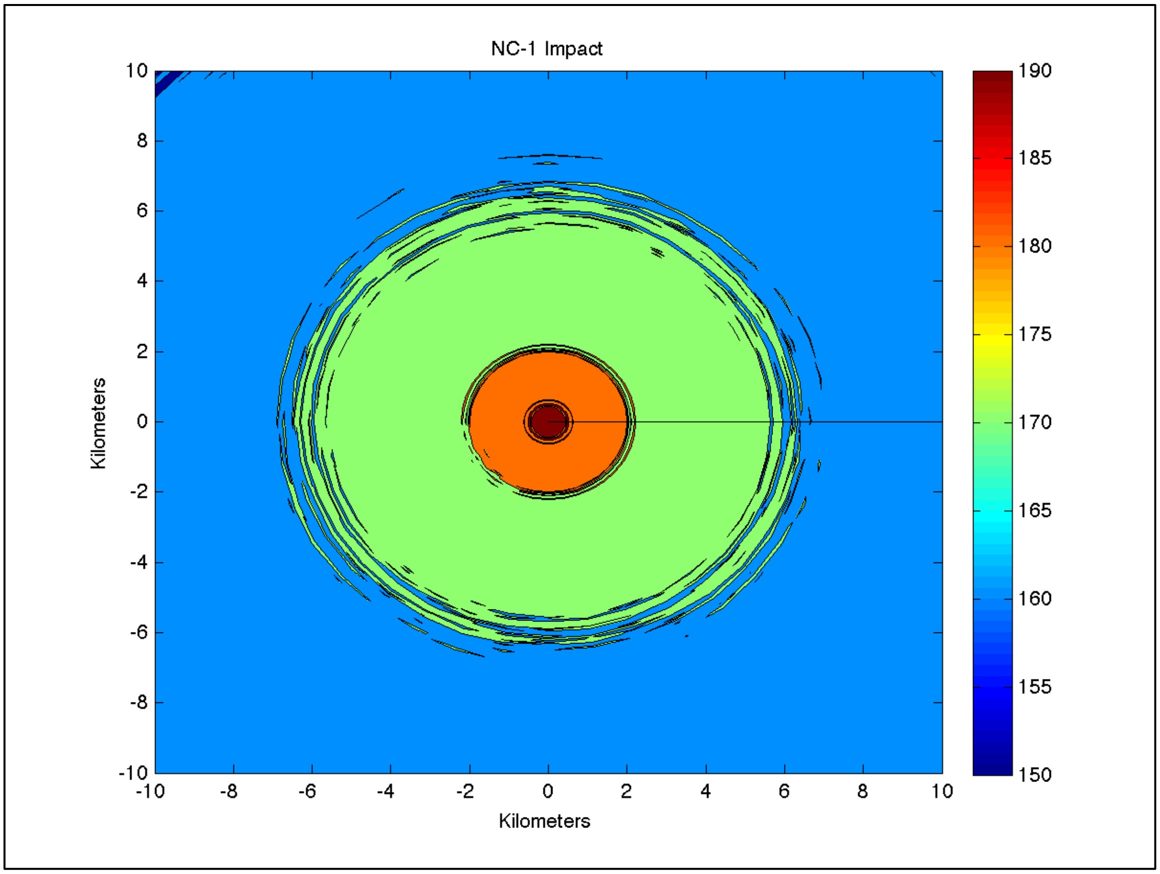

Figure 6.18. The inner portion of the maximum received level at any depth for the NC-North Site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately >10 km and 1500 meters, respectively.

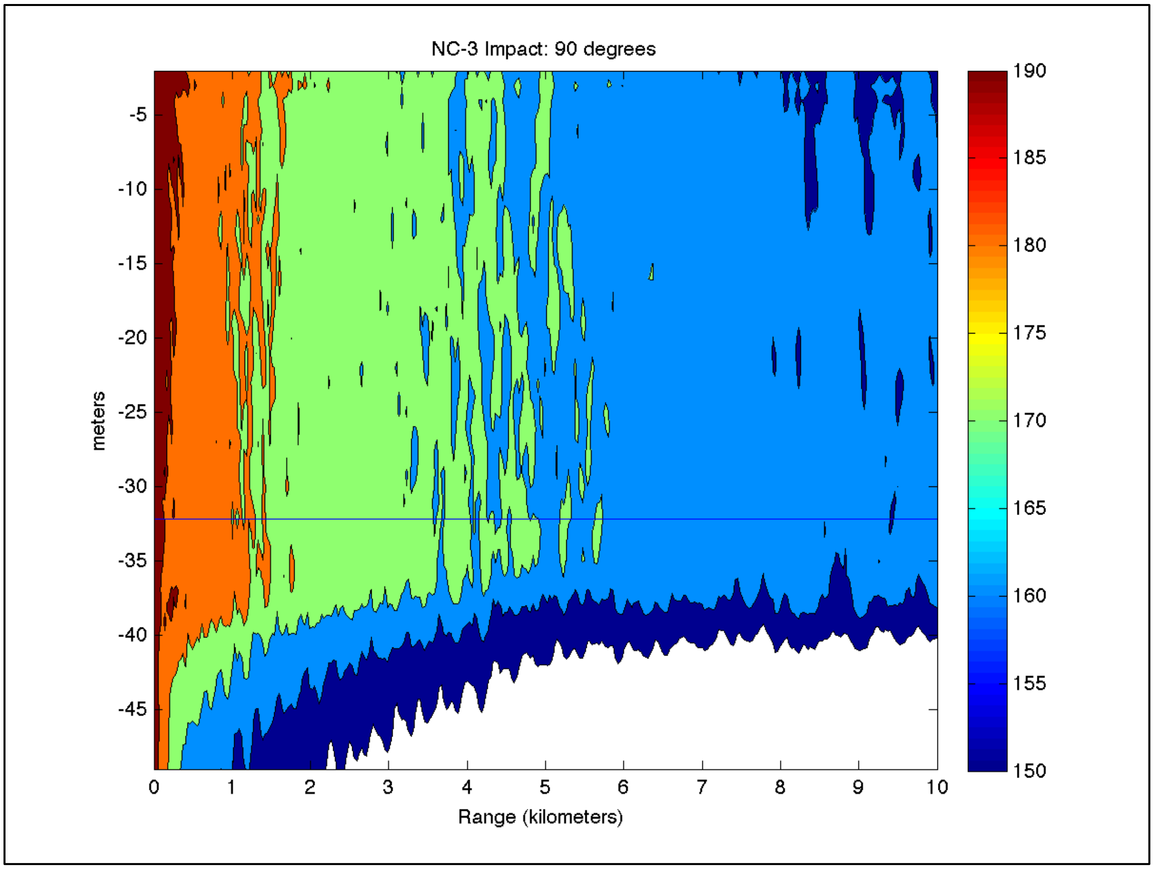

Figure 6.19.The propagation predicted from the RAM model as a function of range and depth for the NC-South site.

The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately >10 km and 1800 meters, respectively.

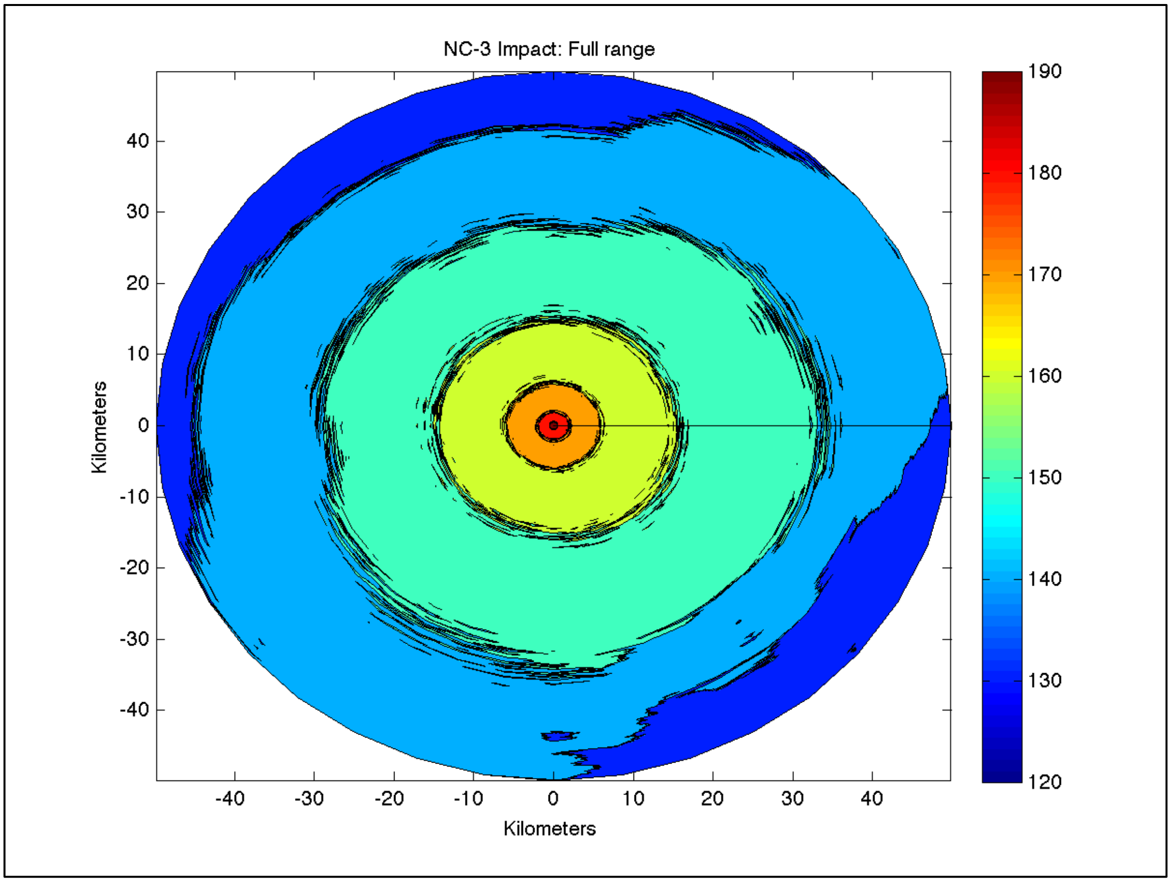

Figure 6.20. The maximum received level at any depth is shown for the NC-South site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 15 km and 1800 meters, respectively.

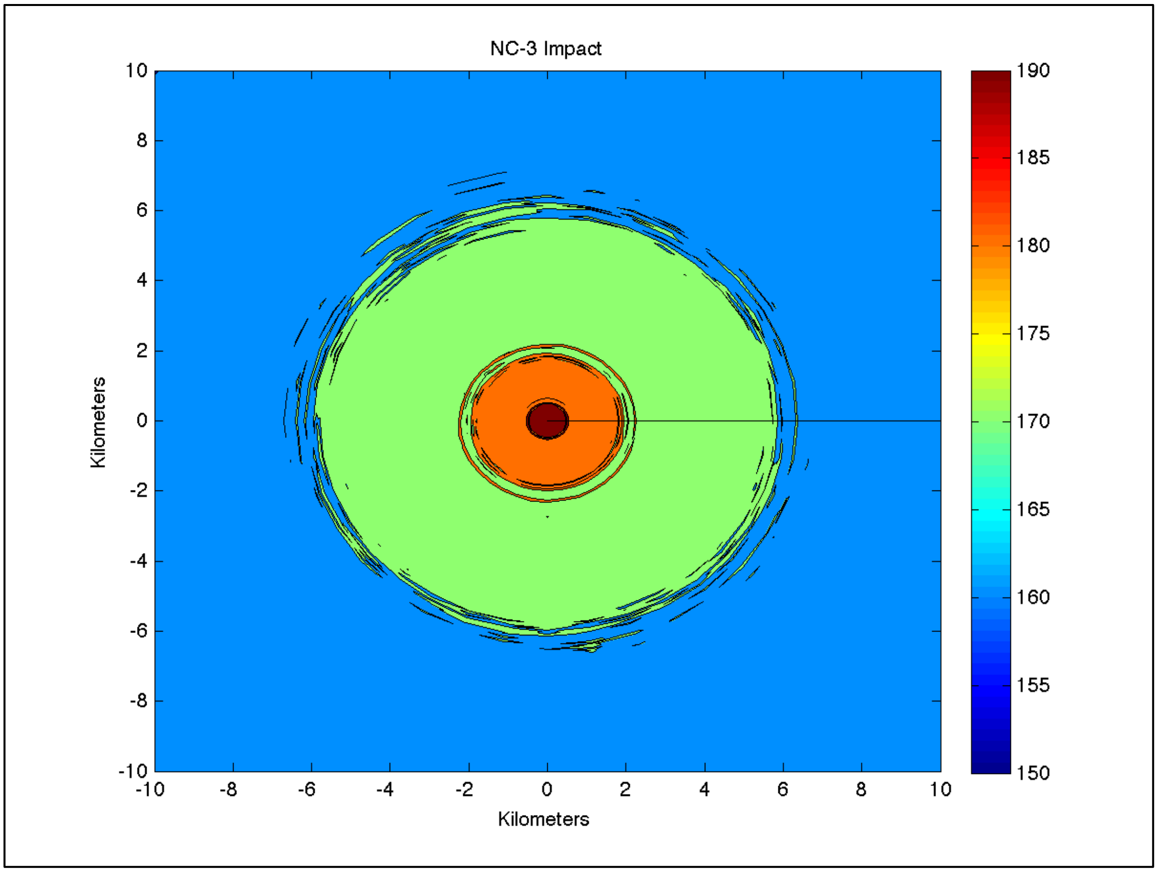

Figure 6.21. The inner portion of the maximum received level at any depth is shown for the NC-South site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately >10 km and 1800 meters, respectively.

6.3.1.5 Vibratory Pile Drivers

Vibratory pile drivers operate by oscillating the pile back and forth to work the pile into the sediment. While they are operating, they represent a continuous sound source. However, the total duration of the activity is typically short, so the 160 and 180 DB thresholds were considered for this activity as well.

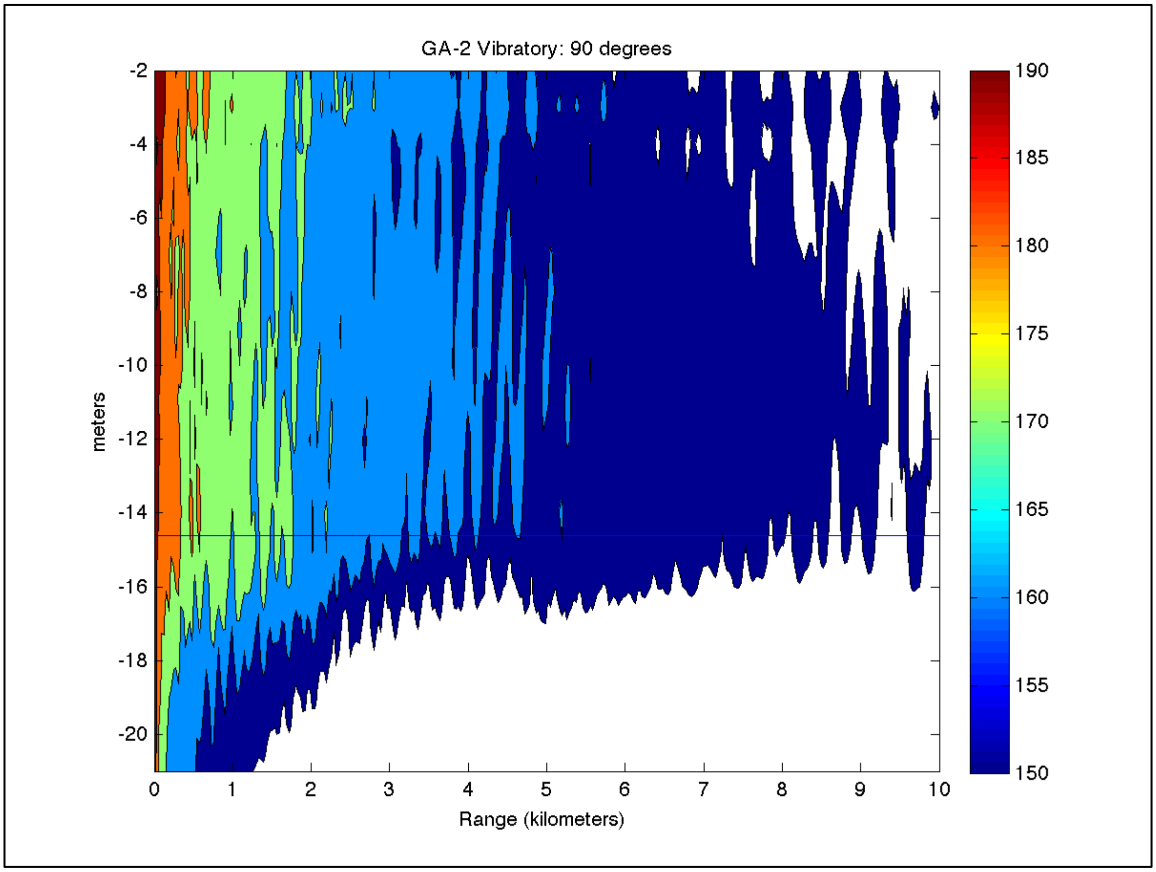

Figure 6.22.The propagation predicted from the RAM model is shown as a function of range and depth for the GA-Central site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 6 km and 750 meters, respectively.

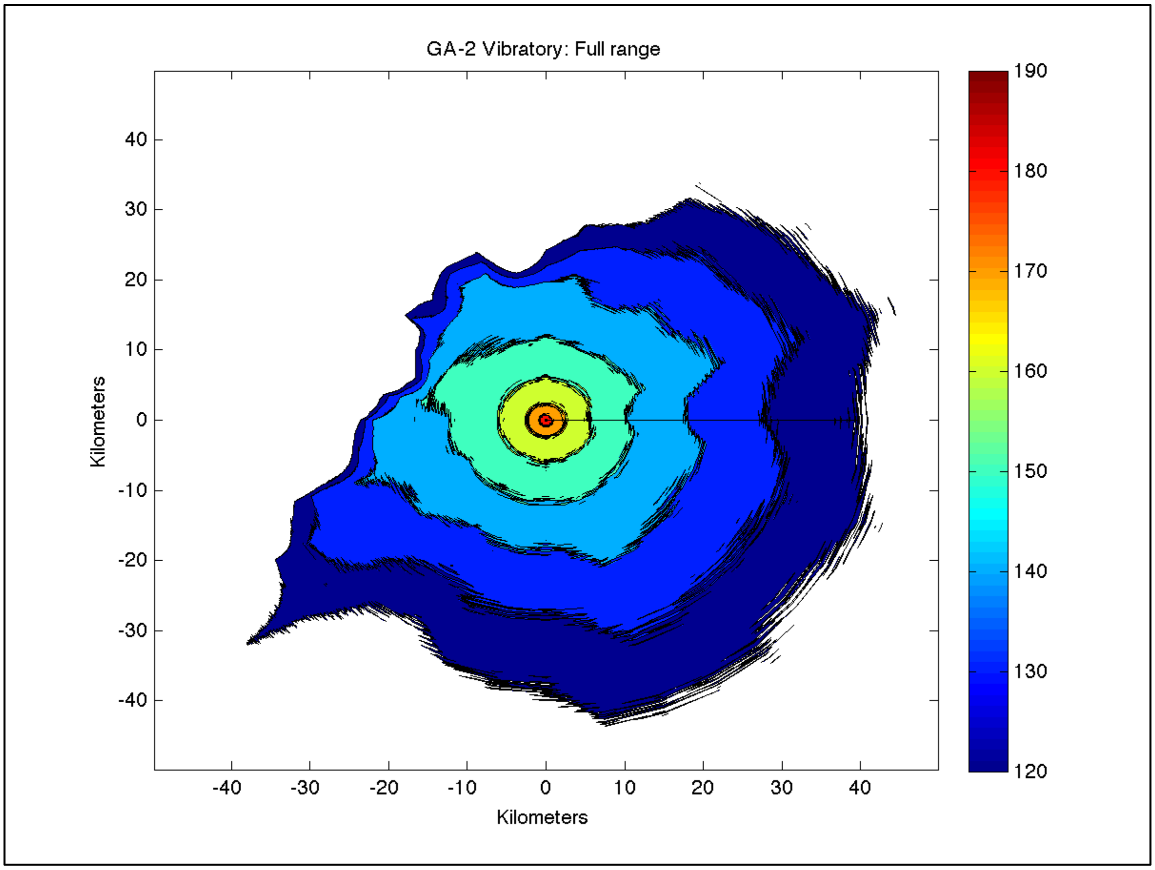

Figure 6.23.The maximum received level at any depth is shown for the GA-Central site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 6 km and 750 meters, respectively.

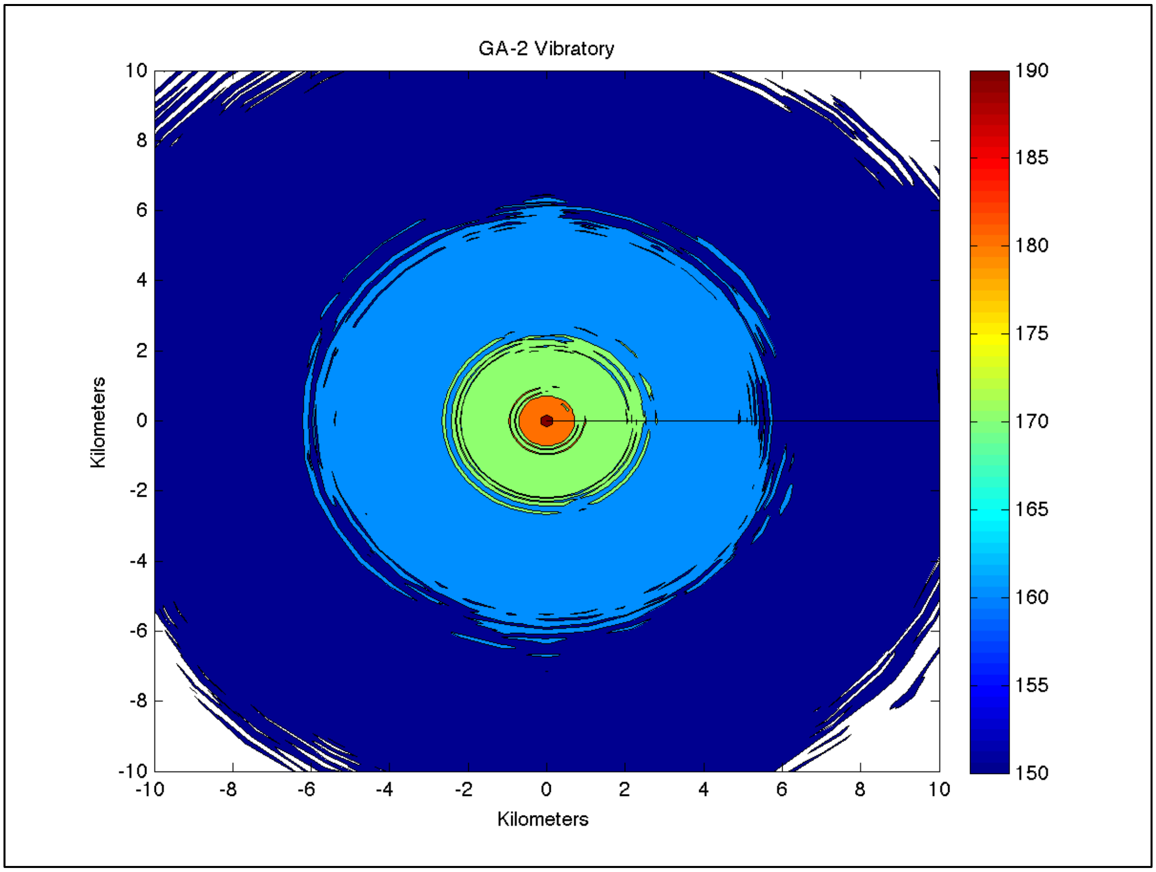

Figure 6.24.The inner portion of the maximum received level at any depth is shown for the GA-Central site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 6 km and 1800 meters, respectively.

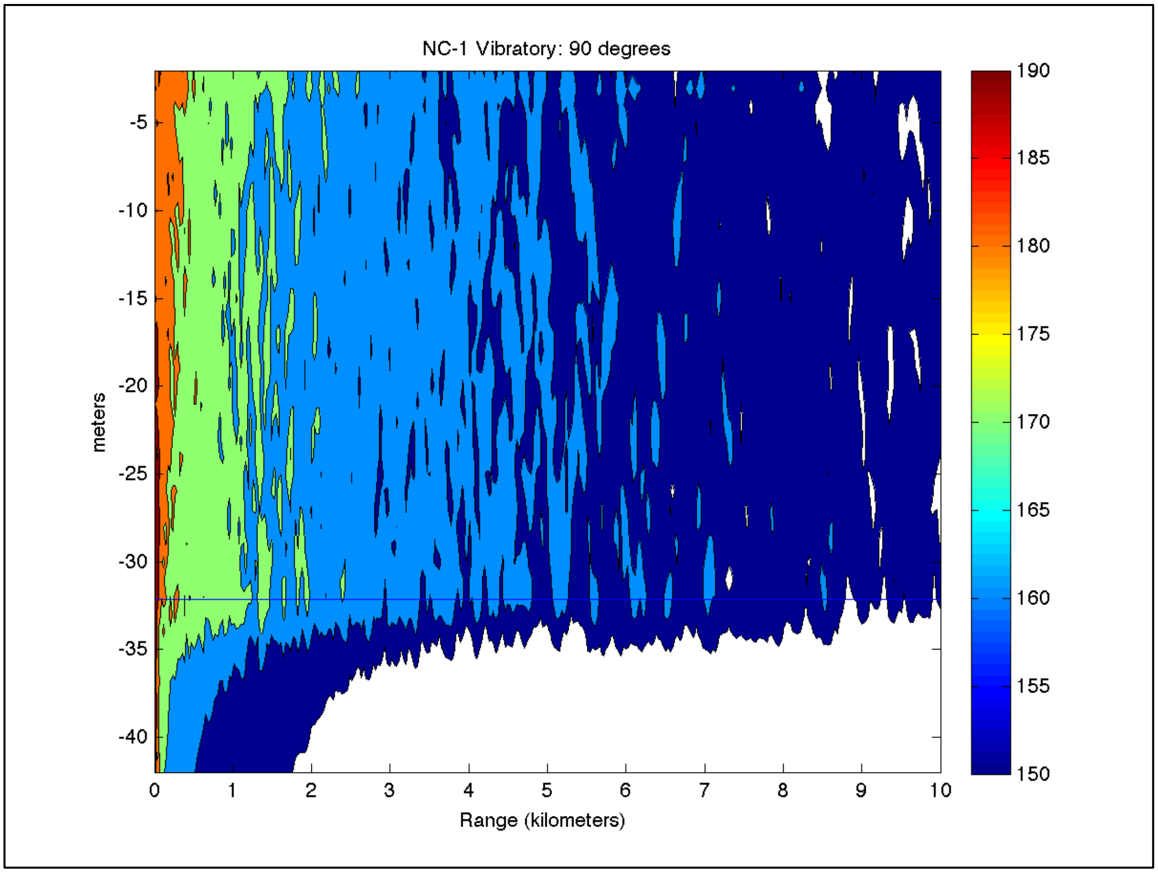

Figure 6.25. The propagation predicted from the RAM model is shown as a function of range and depth for the NC-North site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 7 km and 500 meters, respectively.

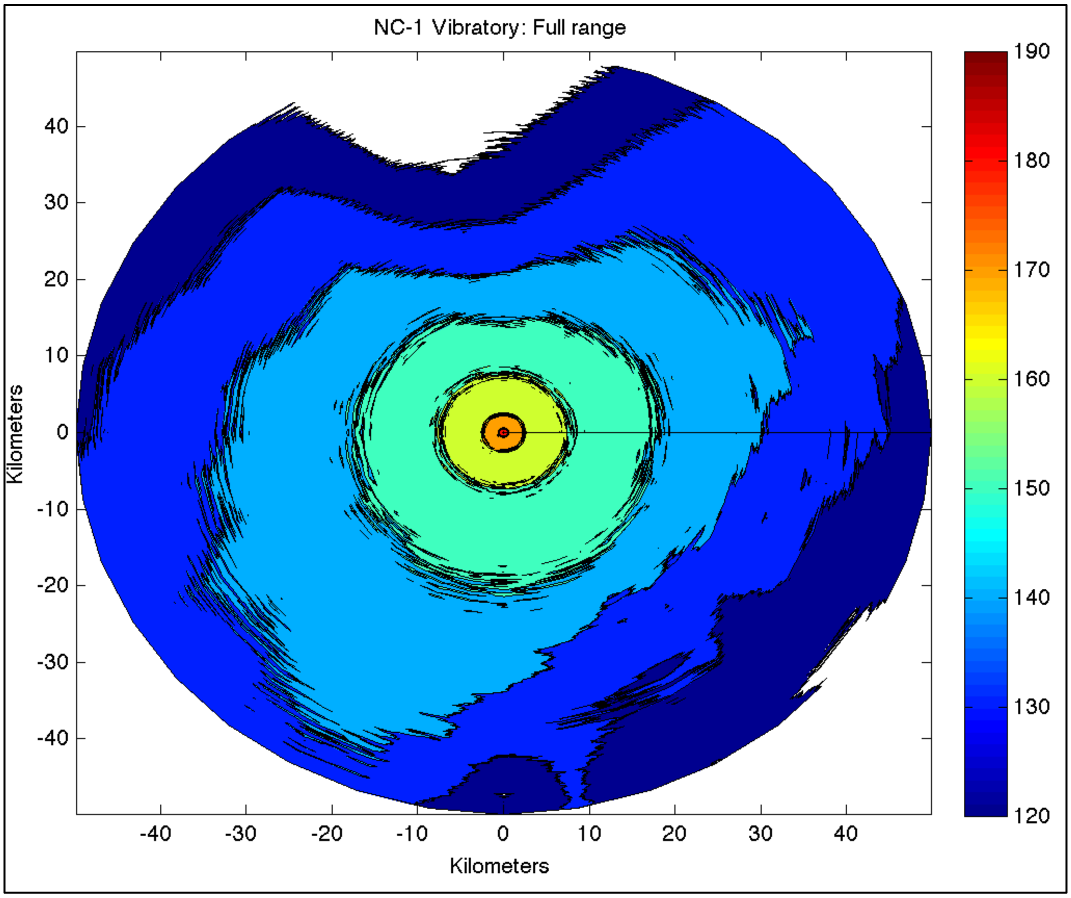

Figure 6.26. The maximum received level at any depth is shown for the NC-North site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 9 km and 500 meters, respectively.

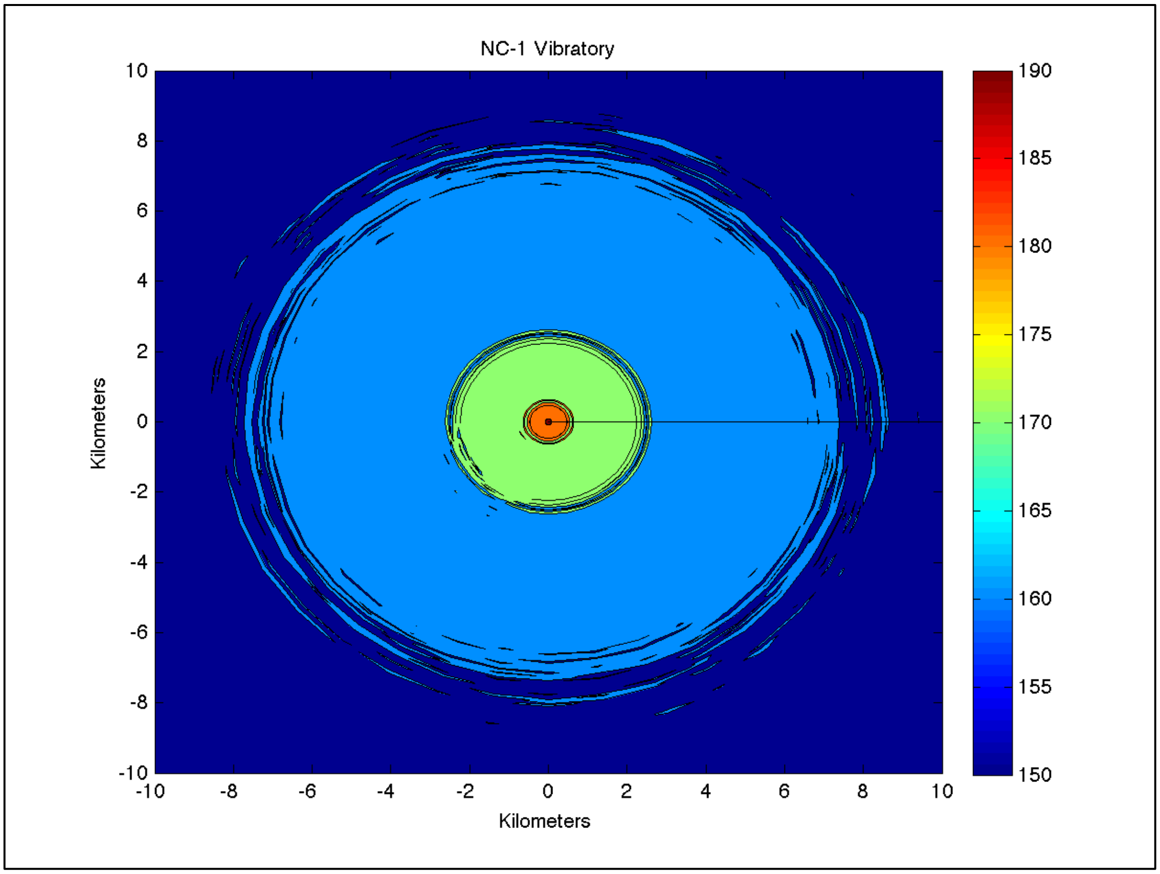

Figure 6.27. The inner portion of the maximum received level at any depth is shown for the NC-North site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 8 km and 1200 meters, respectively.

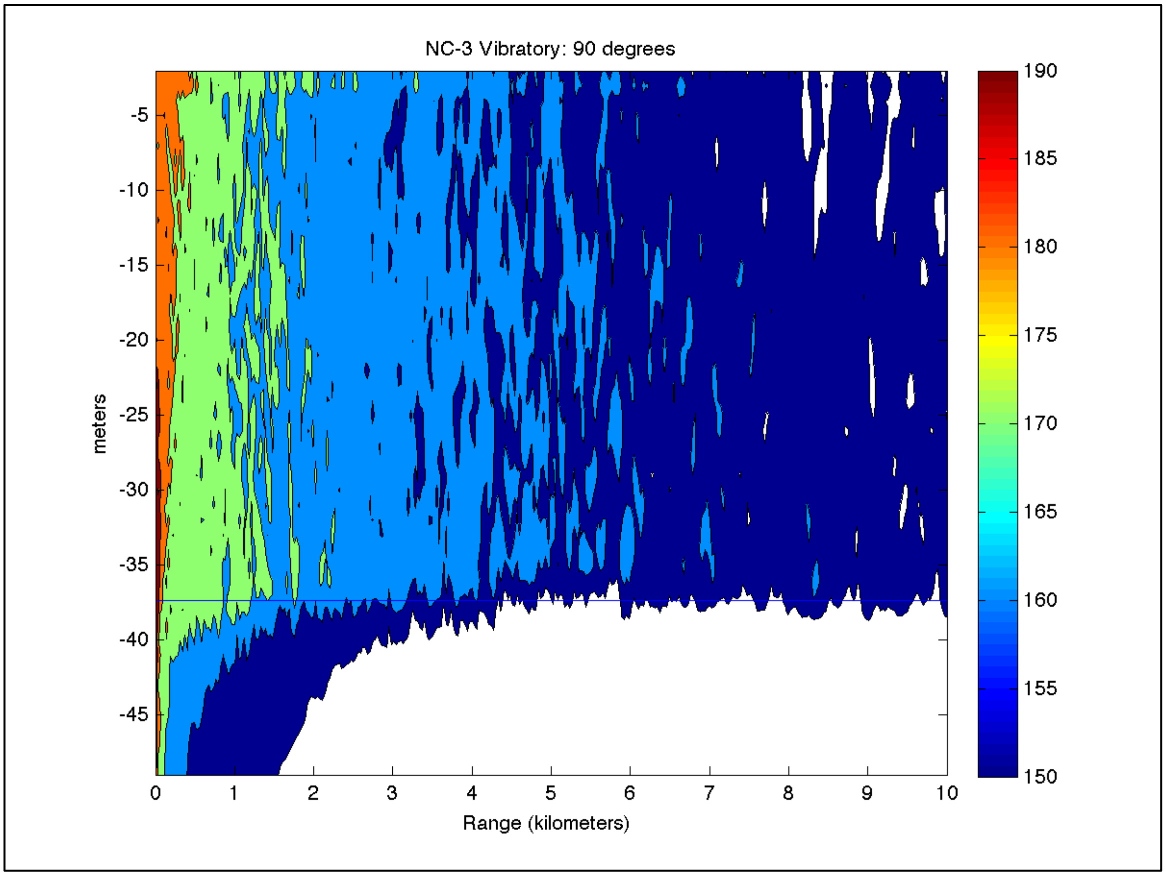

Figure 6.28. The propagation predicted from the RAM model is shown as a function of range and depth for the NC-South site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately >5 km and 500 meters, respectively.

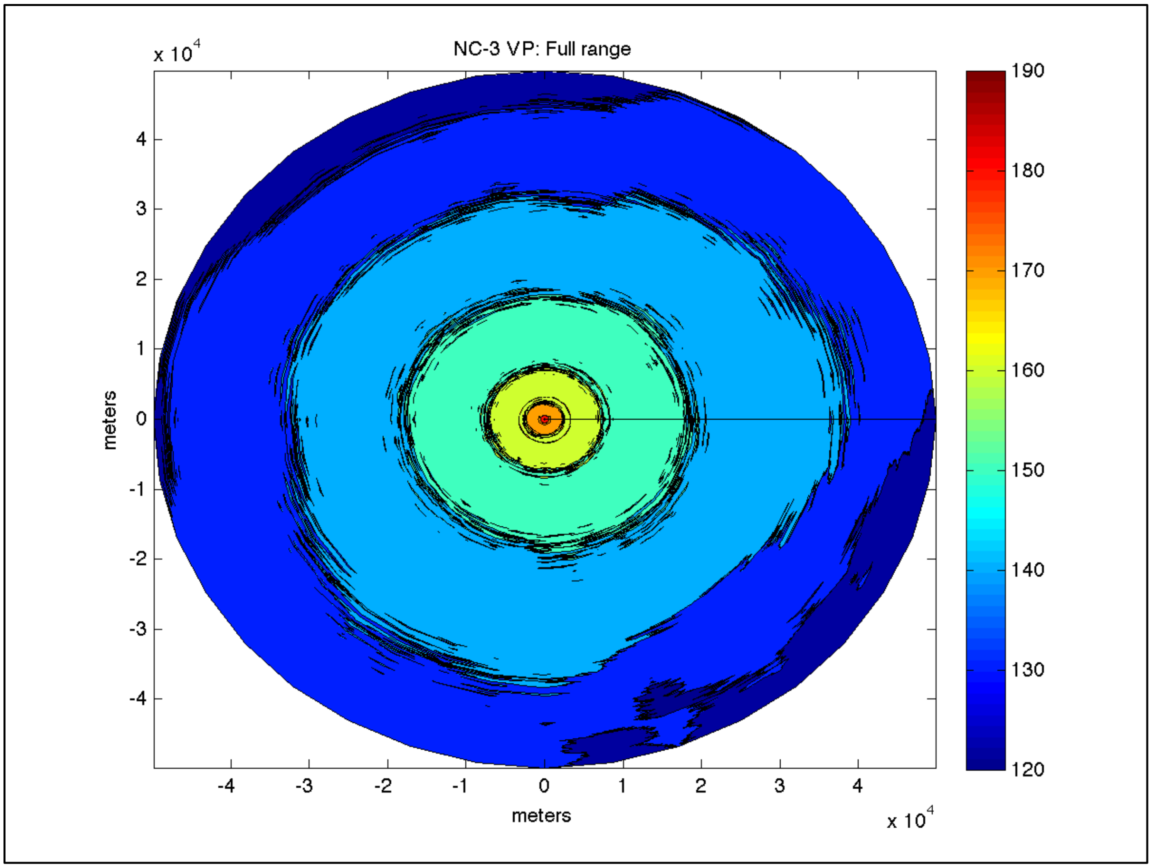

Figure 6.29. The maximum received level at any depth is shown for the NC-South site.

The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately 9 km and 500 m, respectively.

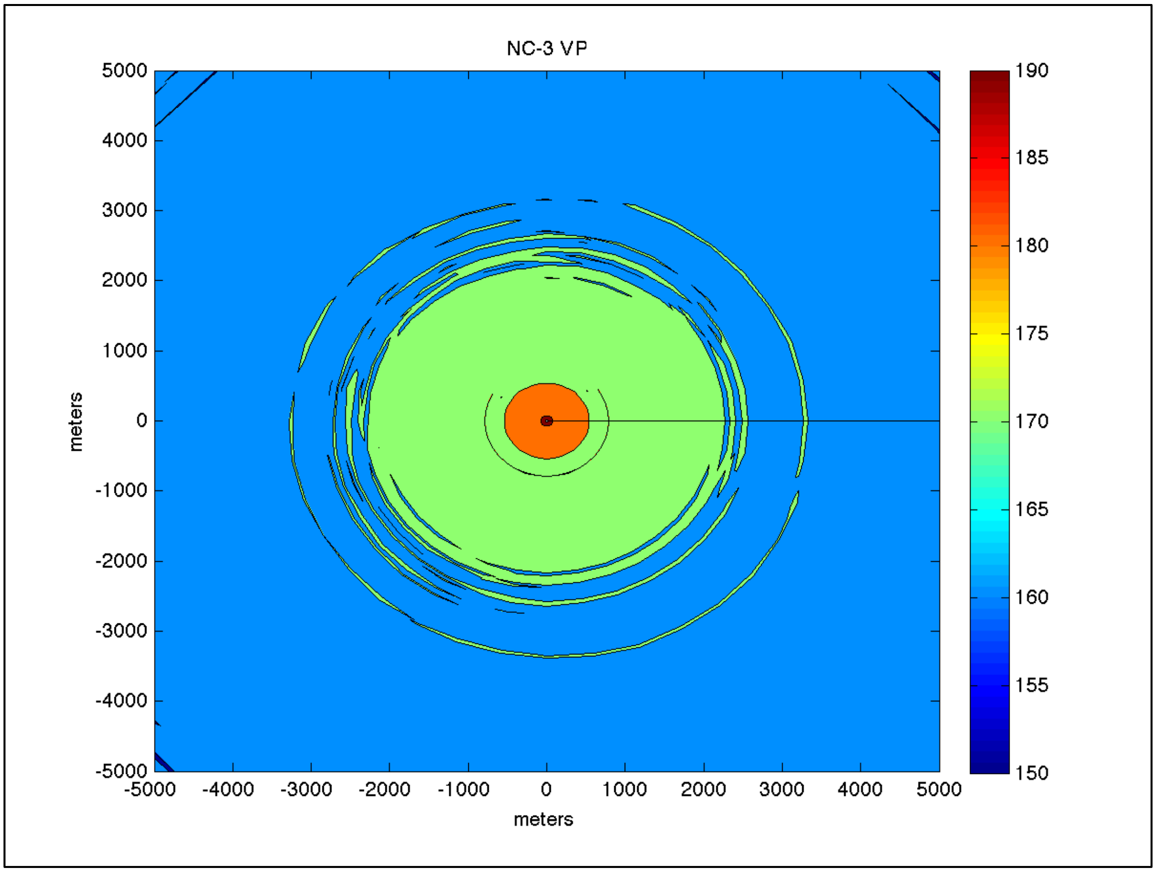

Figure 6.30. The inner portion of the maximum received level at any depth is shown for the NC-South site.
The received levels have been contoured in 10 dB steps to aid readability. The 160 and 180 dB isopleths are reached at ranges of approximately > 5 km and 800 meters, respectively.

6.3.1.6 Vessel Noise

The propagation of vessel noise was considered because it is a component of preconstruction, construction, and operational phases of a renewable energy installation. Both normal and dynamic positioning system vessel signatures were considered. Ranges to the 160 and 180 dB isopleth were estimated, as with the other activities. However, it should be noted that, traditionally, vessel noise itself has not been subject to regulatory thresholds. Therefore the values presented here are for informational purposes. Finally, it should be remembered that vessels are, of course, mobile and their sound footprint will follow them as they move from port to the energy installation and back.

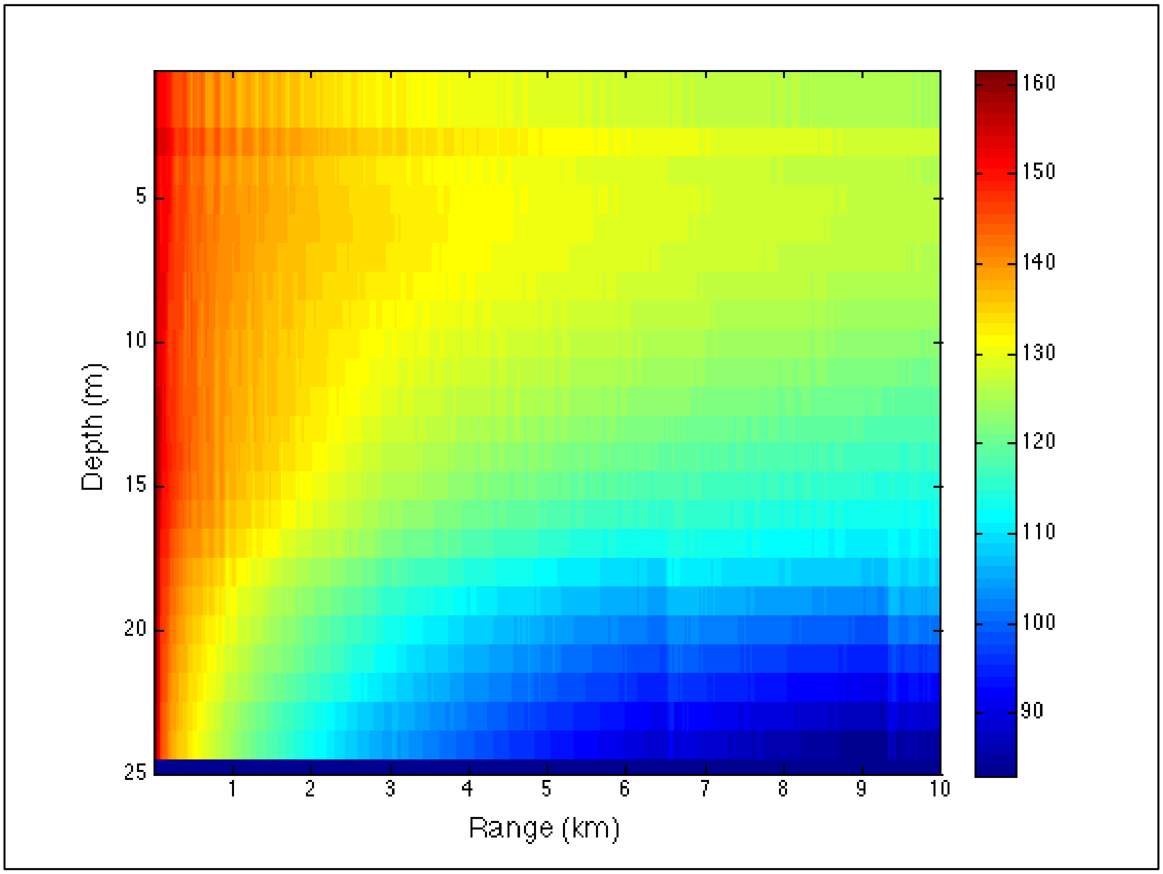

Figure 6.31. The maximum received level for any modeled radial is shown as a function of range and depth for the GA-Central site.
The 160 dB isopleth is only a few hundred meters away from the source.

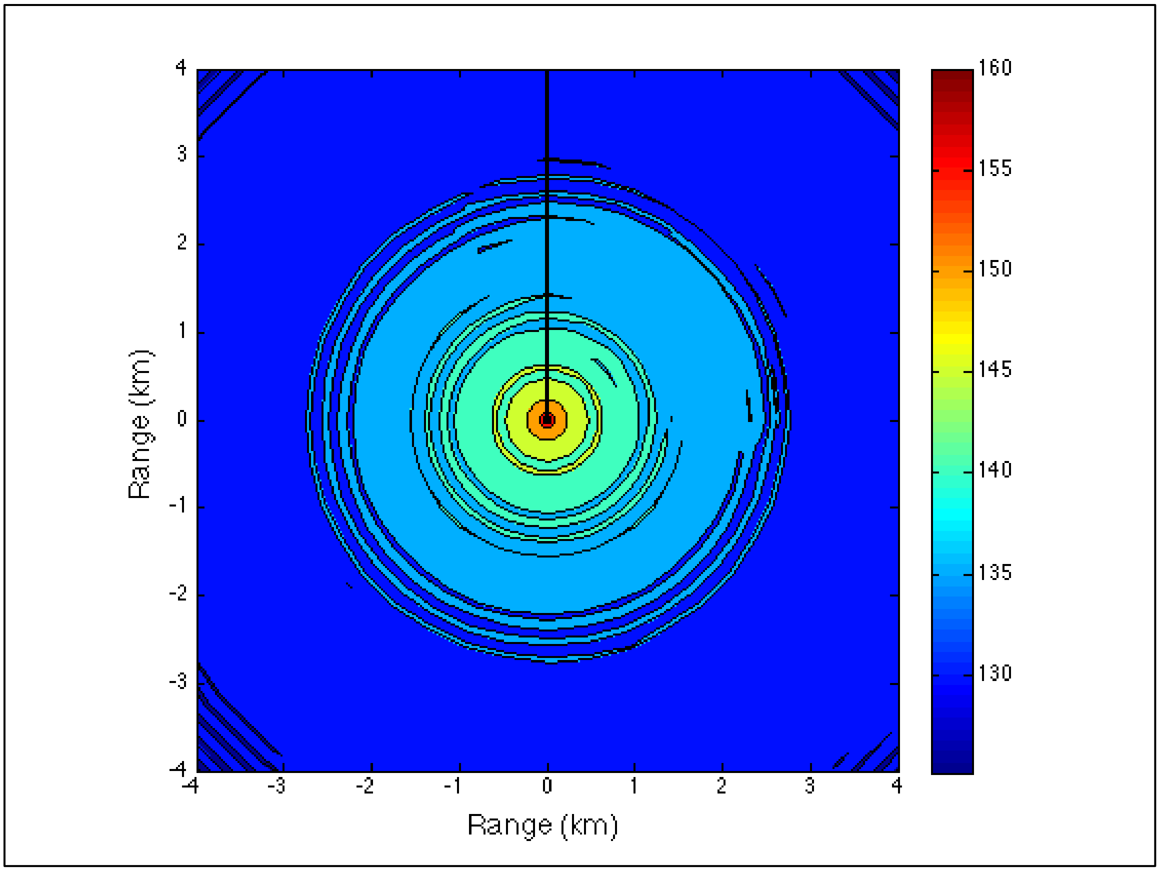

Figure 6.32. The received level at a depth of six meters is shown for the GA-Central site.
The 160 dB isopleth is only a few hundred meters away from the vessel.

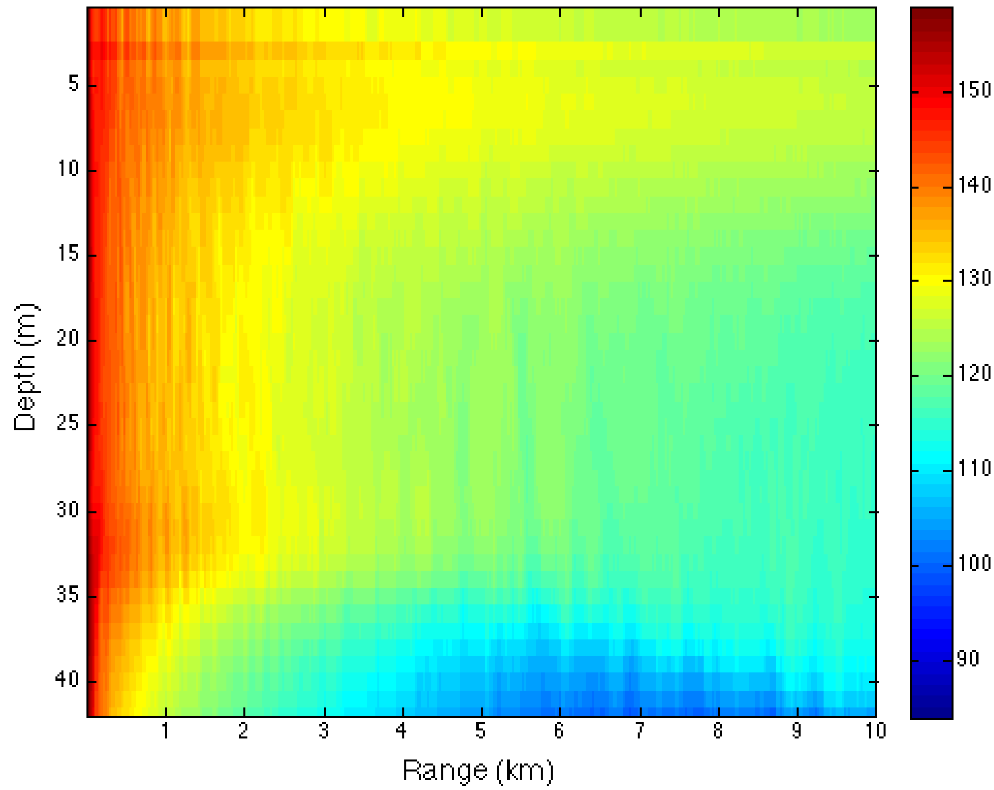

Figure 6.33. The maximum received level for any modeled radial is shown as a function of range and depth for the NC-North site.
The 160 dB isopleth is only a few hundred meters away from the source.

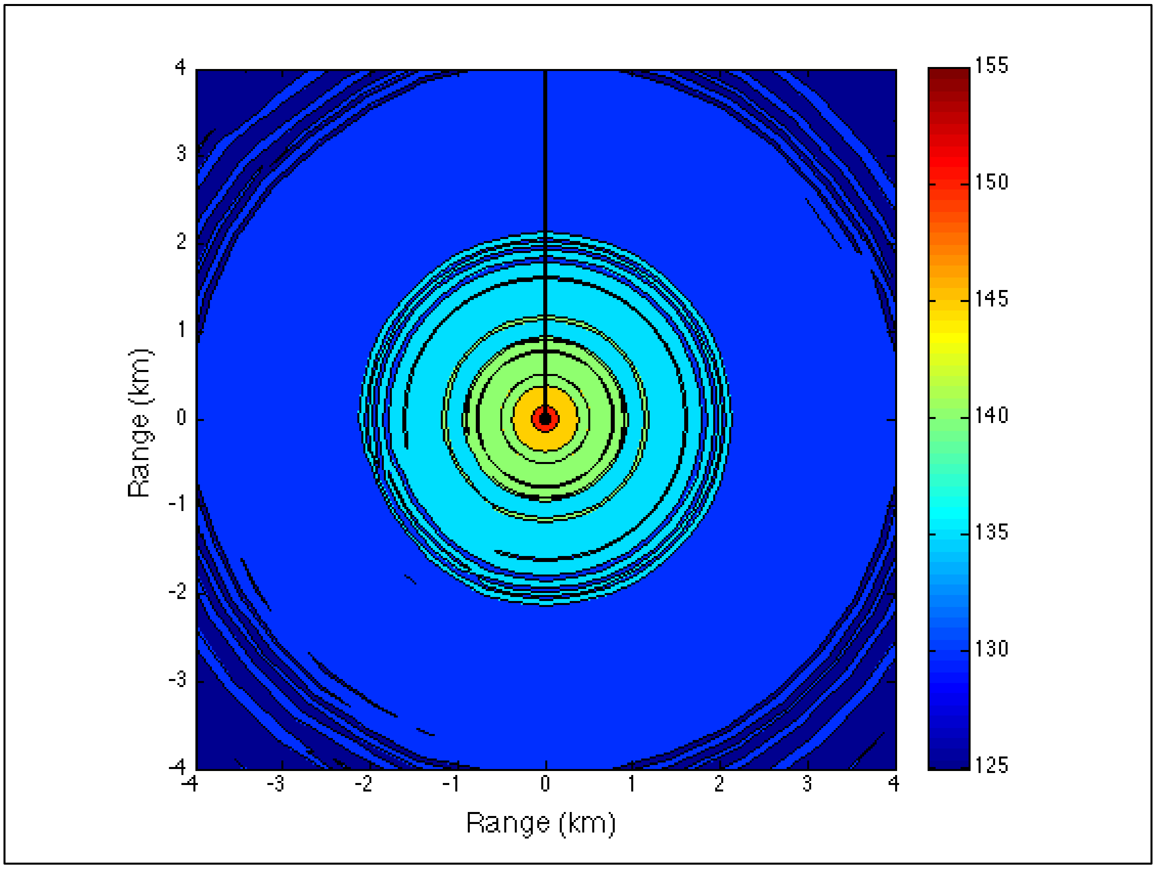

Figure 6.34. The received level at a depth of six meters is shown for the NC-North site.
The 160 dB isopleth is only a few hundred meters away from the vessel.

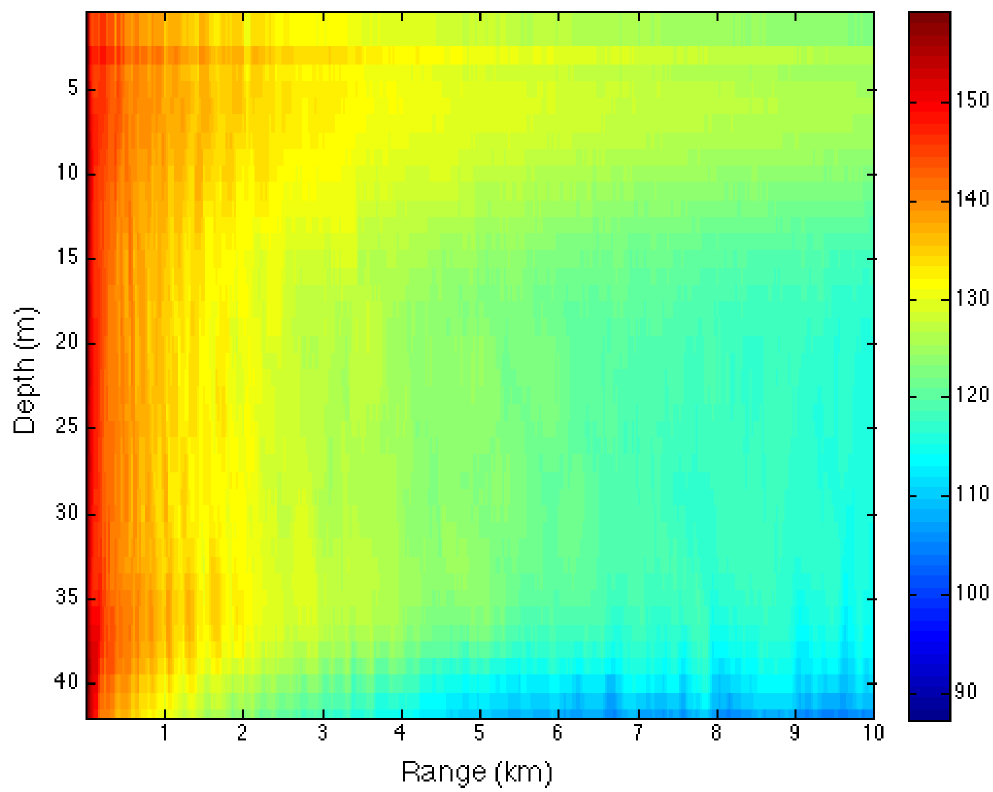

Figure 6.35. The maximum received level for any modeled radial is shown as a function of range and depth for the NC-South site.
The 160 dB isopleth is only a few hundred meters away from the source.

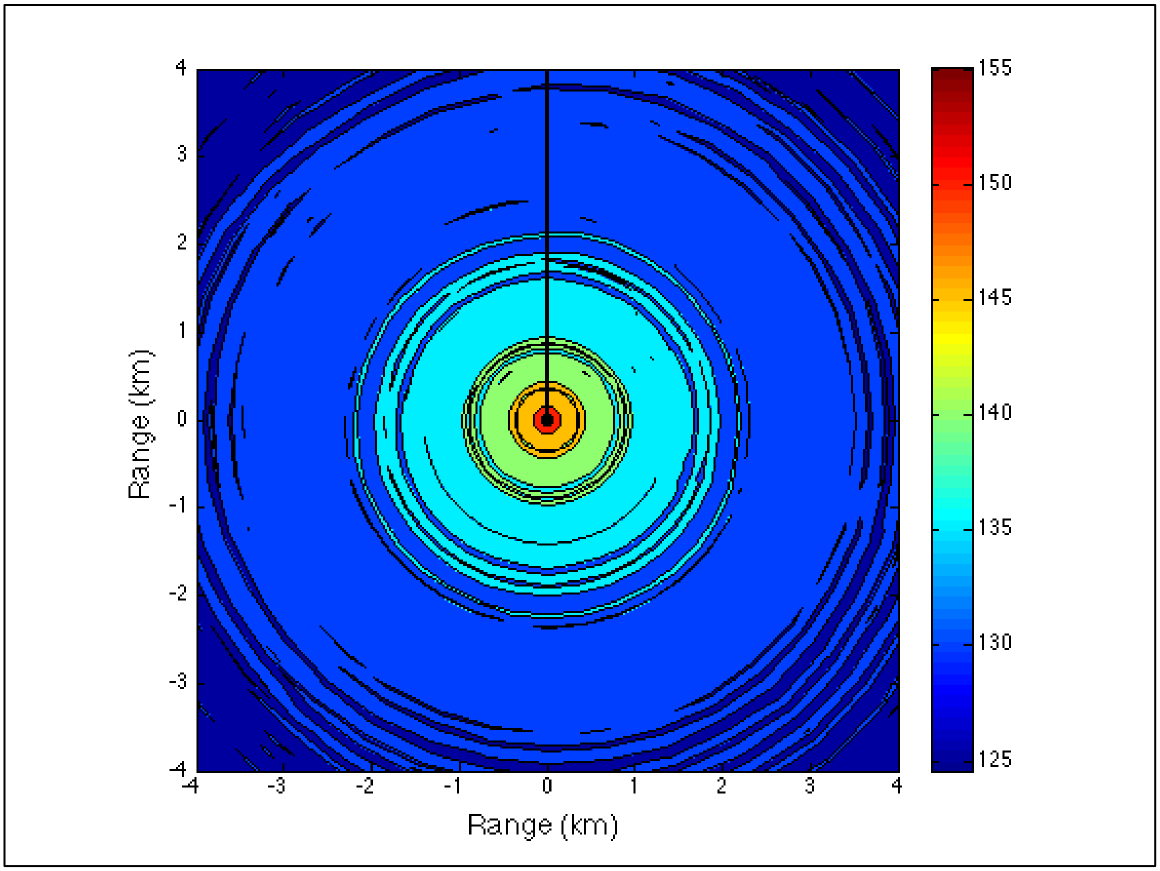

Figure 6.36. The received level at a depth of six meters is shown for the NC-South site.
The 160 dB isopleth is only a few hundred meters away from the vessel.

6.3.2.4 Dynamic Positioning System Vessel Noise

Vessels employing dynamic positioning systems (DPS) are louder than those using only conventional propulsion.

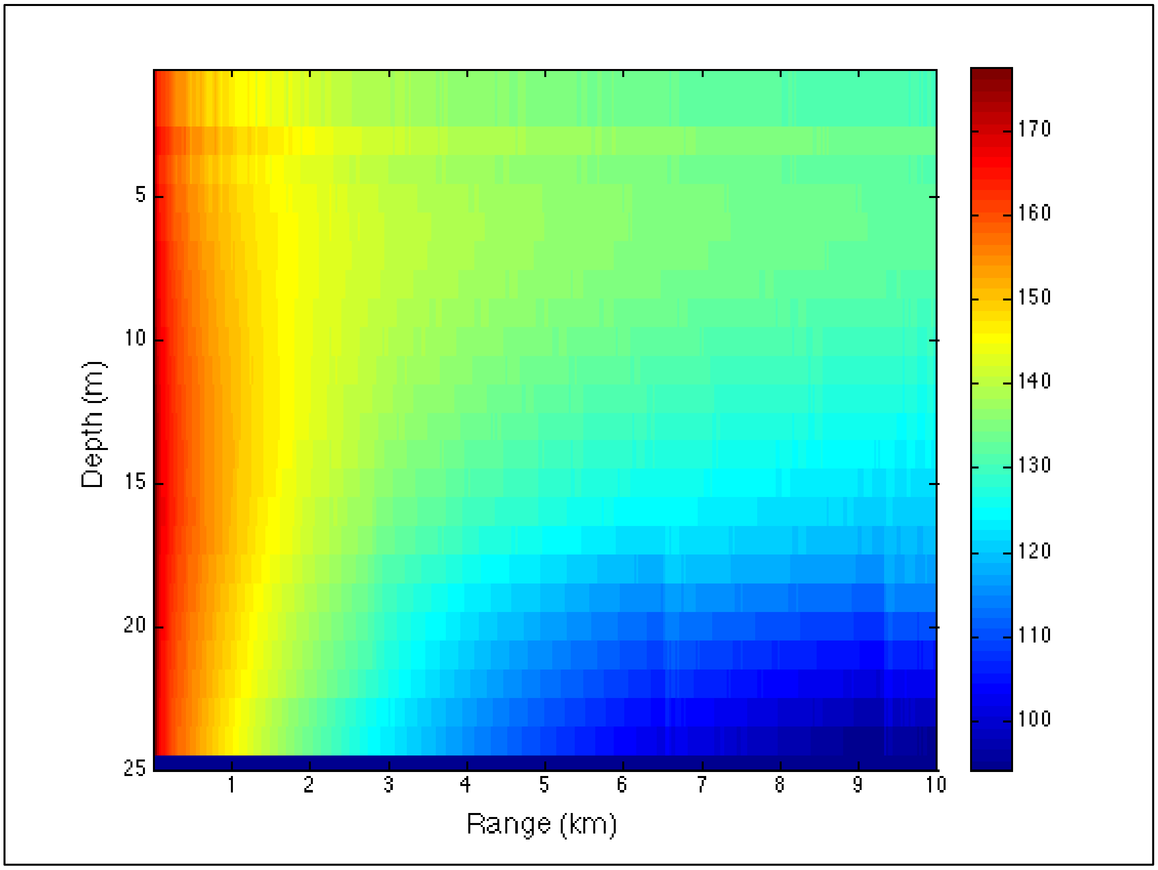

Figure 6.37. The maximum received level for any modeled radial is shown as a function of range and depth for the GA-Central site.
The 160 dB isopleth is approximately 1500 away from the source.

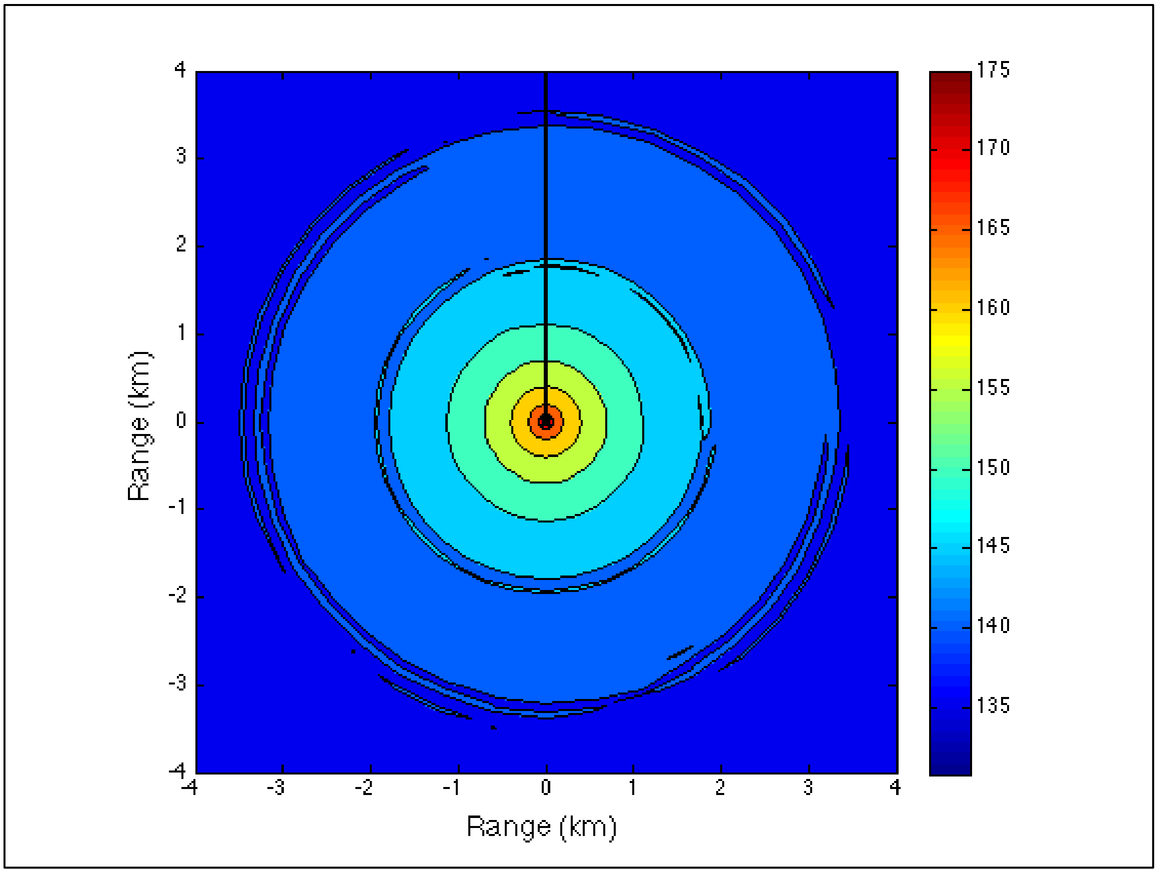

Figure 6.38. The received level at a depth of six meters is shown for the GA-Central site.
The 160 dB isopleth is approximately 800 meters away from the vessel.

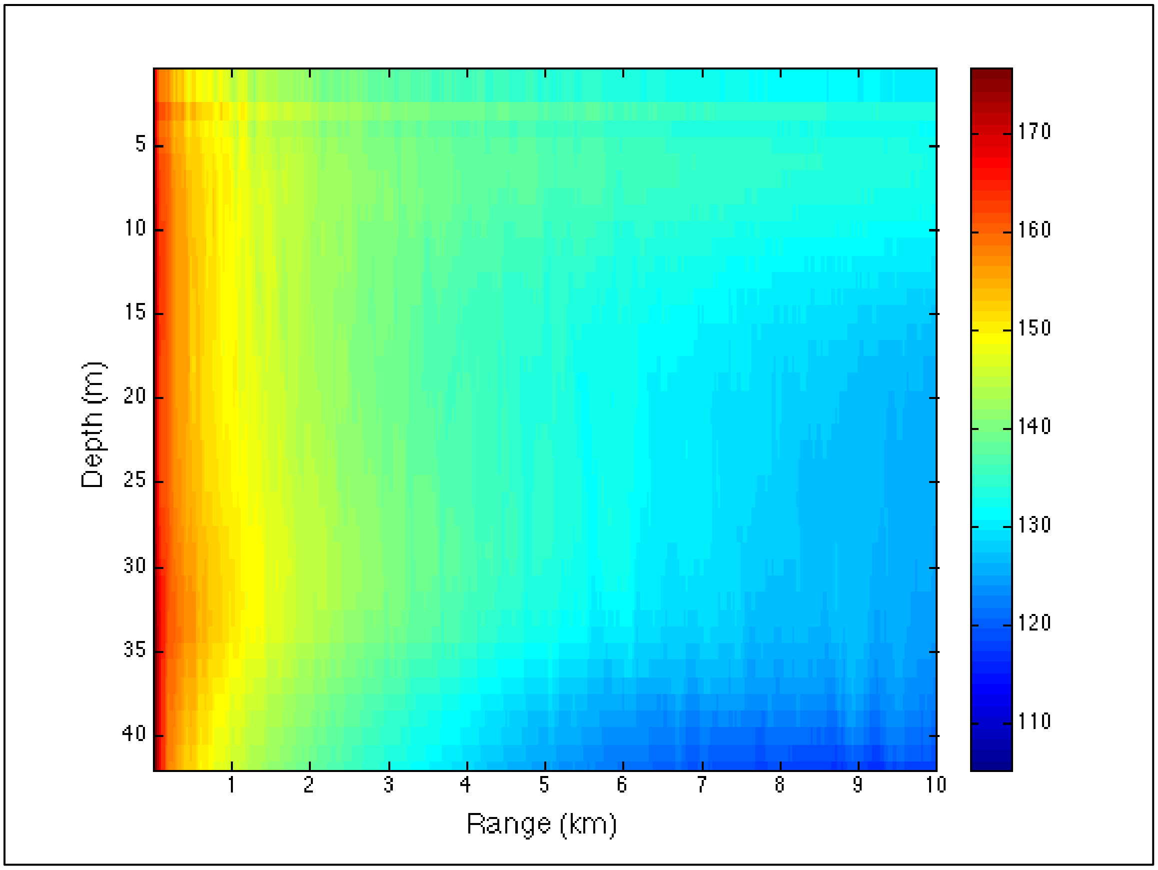

Figure 6.39. The maximum received level for any modeled radial is shown as a function of range and depth for the NC-North site.
The 160 dB isopleth is approximately 1 km away from the source.

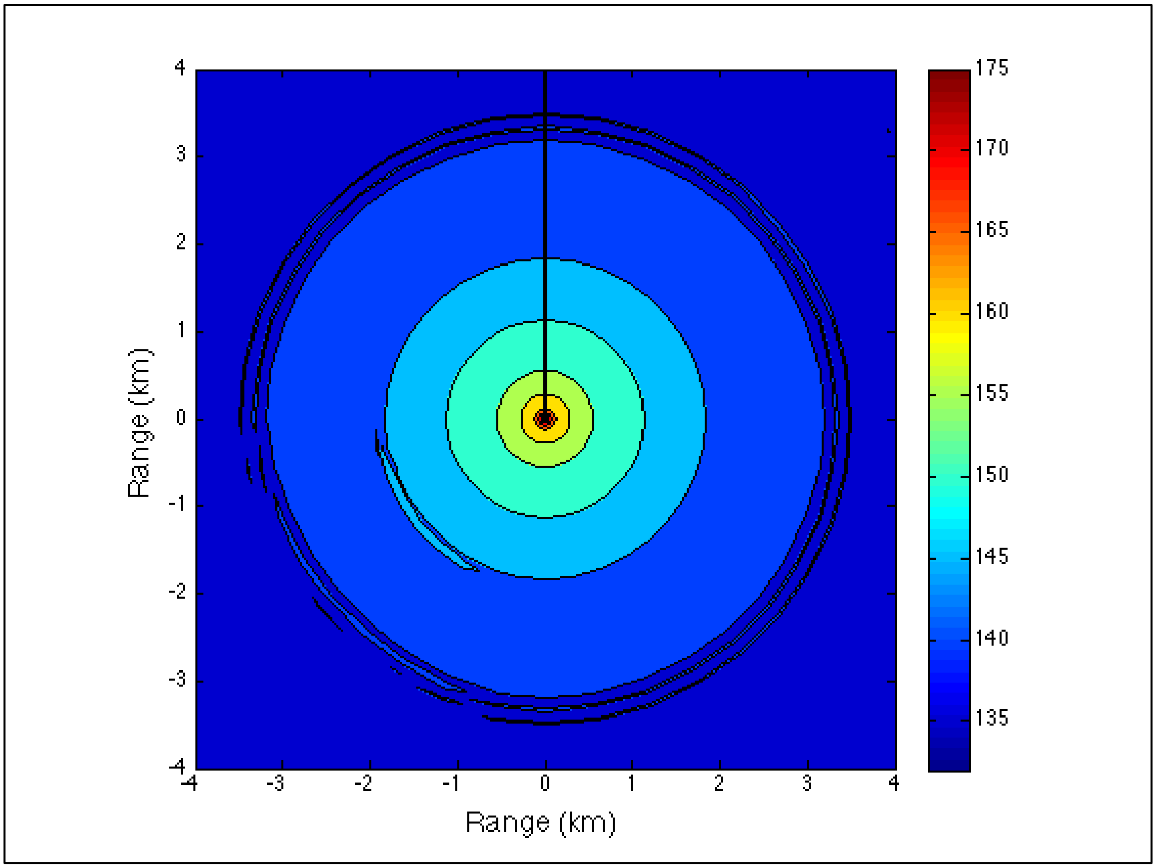

Figure 6.40. The received level at a depth of six meters is shown for the NC-North site.
The 160 dB isopleth is approximately 800 meters away from the vessel.

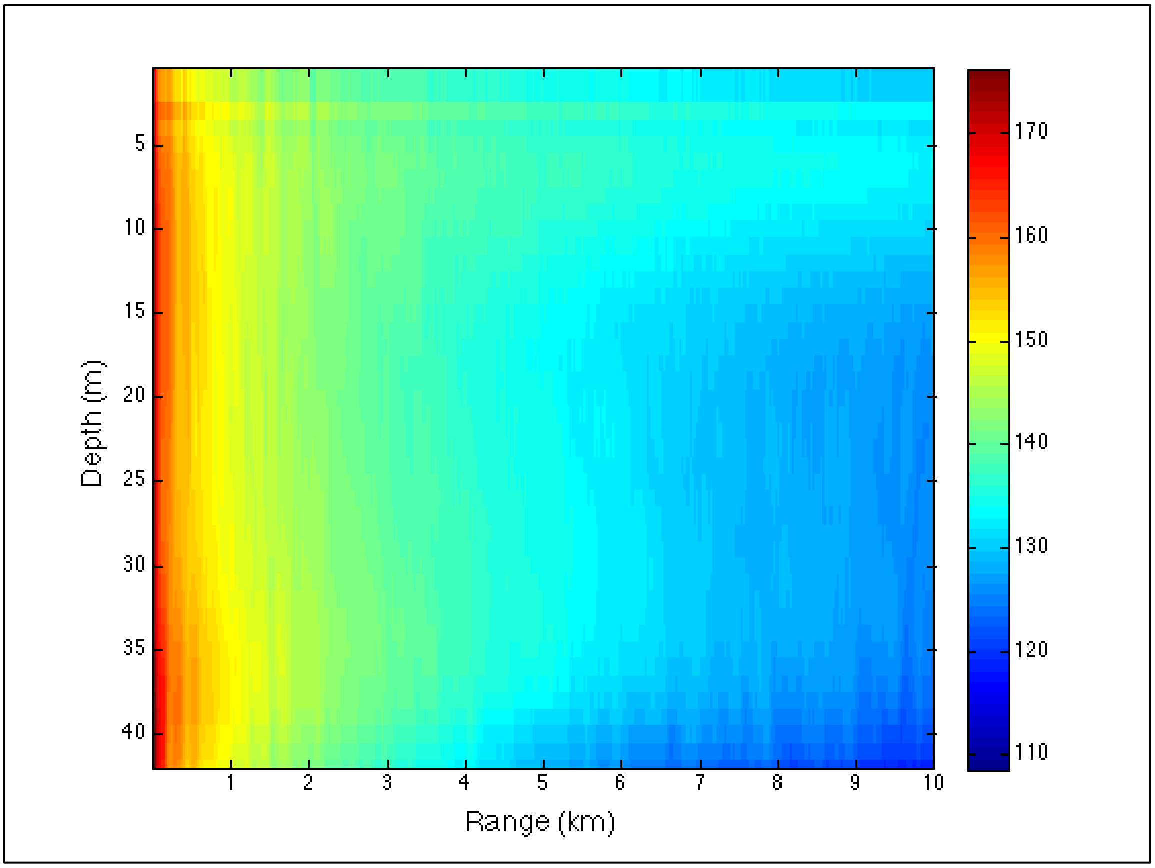

Figure 6.41. The maximum received level for any modeled radial is shown as a function of range and depth for the NC-South site.
The 160 dB isopleth is approximately 1 km away from the source.

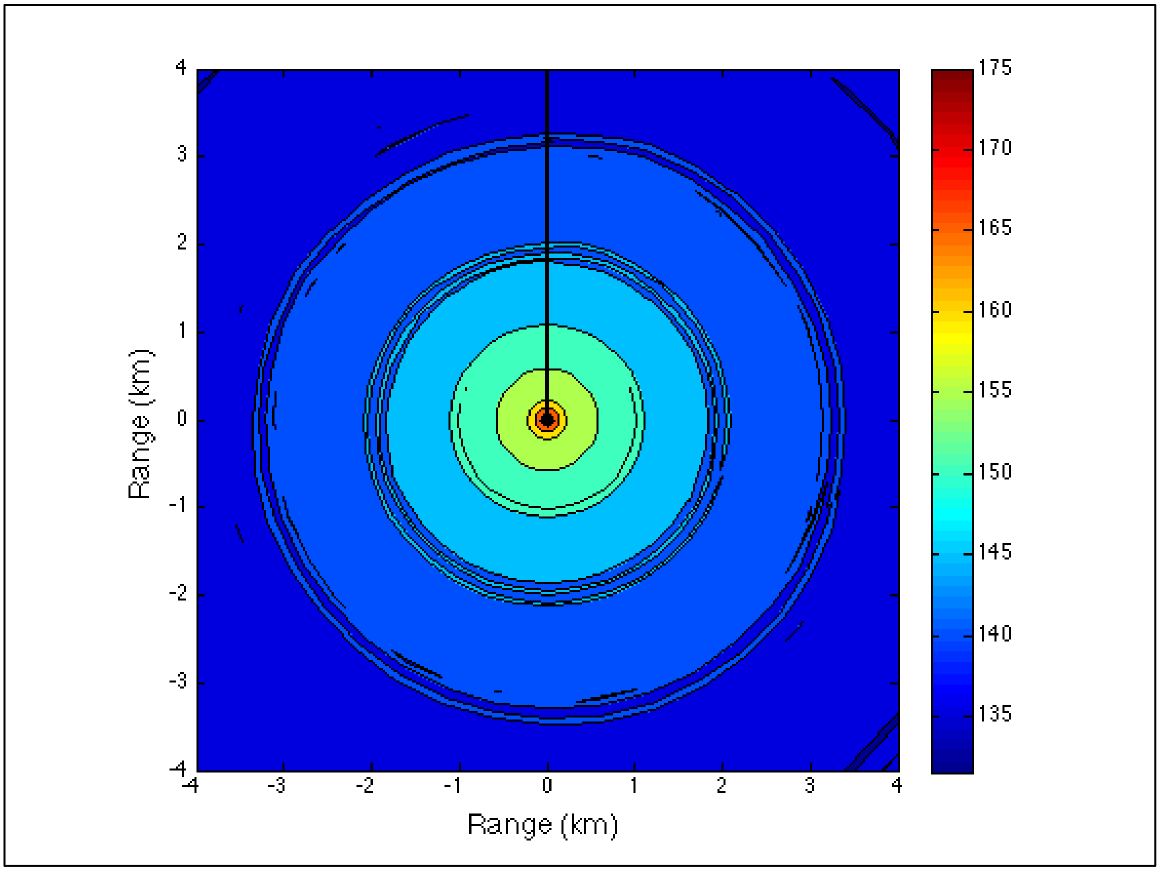

Figure 6.42. The received level at a depth of six meters is shown for the NC-South site.
The 160 dB isopleth is approximately 800 meters away from the vessel.

6.3.2.5 Summary of Affected Ranges

Table 6.6: Georgia isopleth range summary.

Activity	Modeled SL (dB re 1 μPa at 1m)	Modeled Frequency	Distance to 160 dB SPL isopleth (m)	Distance to 180 dB SPL isopleth (m)
Boomer	See Fig X	200 Hz–16 kHz	~3500	-100
Chirp Sonar	217	3.5 kHz	~ 250	~20 (horizontal) ~70 (vertical)
Geotechnical Drilling	145	2–2050 Hz	<1	<1
Impact Pile Driving	See Fig BI	Broadband (10 Hz–10 kHz)	~10,000	~1,800
Vibratory Pile Driving	See Fig BV	Broadband (10 Hz–10 kHz)	~6,000	~800
Vessel Noise	178	Broadband with peak at 100 Hz	~100	<1
DPS Vessel Noise	193	Broadband with peak at 100 Hz	~1,000	~100

Table 6.7: NC-north isopleth range summary.

Activity	Modeled SL (dB re 1 µPa at 1m)	Modeled Frequency	Distance to 160 dB SPL isopleth (m)	Distance to 180 dB SPL isopleth (m)
Boomer	See Fig X	200 Hz–16 kHz	~3500	-100
Chirp Sonar	217	3.5 kHz	~ 250	~20 (horizontal) ~70 (vertical)
Geotechnical Drilling	145	2–2050 Hz	<1	<1
Impact Pile Driving	See Fig BI	Broadband (10 Hz–10 kHz)	~15,000	~1,500
Vibratory Pile Driving	See Fig BV	Broadband (10 Hz–10 kHz)	~7,000	~500
Vessel Noise	178	Broadband with peak at 100 Hz	~100	<1
DPS Vessel Noise	193	Broadband with peak at 100 Hz	~800	~100

Table 6.8: NC-south isopleth range summary.

Activity	Modeled SL (dB re 1 μPa at 1m)	Modeled Frequency	Distance to 160 dB SPL isopleth (m)	Distance to 180 dB SPL isopleth (m)
Boomer	See Fig X	200 Hz–16 kHz	~3500	-100
Chirp Sonar	217	3.5 kHz	~ 250	~20 (horizontal) ~70 (vertical)
Geotechnical Drilling	145	2–2050 Hz	<1	<1
Impact Pile Driving	See Fig BI	Broadband (10 Hz–10 kHz)	~15,000	~1,800
Vibratory Pile Driving	See Fig BV	Broadband (10 Hz–10 kHz)	~7,000	~600
Vessel Noise	178	Broadband with peak at 100 Hz	~100	<1
DPS Vessel Noise	193	Broadband with peak at 100 Hz	~800	~100

6.4 CONCLUSIONS

6.4.1 Comparison of Sources

Current marine mammal regulatory thresholds are based on received sound pressure levels. Renewable energy installation construction activities with higher source levels have greater probability of affecting marine mammals. The loudest source considered for this study was impact pile driving. This study found that the range to the behavioral effects threshold was up to 15 km under current regulatory guidelines. Vibratory pile driving produces less noise and a correspondingly smaller potentially-affected area. These two types of pile driving are the only activities that ensonify a large area to a level that could create potential physiological effects to marine mammals. The range for potential physiological impacts made by the boomer is much smaller, approximately 100 meters. A similar range was predicted for a vessel operating in dynamic positioning mode; however, vessel propulsion noise has not been subject to regulation in the past. Finally, this study's acoustic modeling results indicated that chirp sonar and geotechnical drilling are not expected to have much effect on marine mammal species. This is due to the narrow beam pattern of the chirp sonar and the low source level for geotechnical drilling.

6.4.2 Comparison of Locations

The geographic location will affect the results based on local propagation conditions. The primary differences between the two locations studied here arise from the proximity to shore and the depth of the water column. The Georgia location is both nearer to shore and in shallower water. This results in poorer acoustic propagation than is found at the North Carolina site, and smaller ranges to regulatory thresholds. However, the closer proximity of the Georgia site to the shore may mean that some species will be found in higher abundance, such as the very coastal Northern Right whale. Animal densities need to be considered when or if a choice is to be made between these two potential construction locations.

6.4.3 Future Considerations

The regulatory thresholds considered during this study are those currently in effect, namely 160 dB for behavioral responses and 180 dB for physiological response to intermittent sources. There is also a 120 dB threshold for continuously operated sources. However, NMFS has proposed an additional regulatory threshold that is based on the SEL metric. The proposed metric would either, 1) integrate all of the sound emitted by a source for one hour, or 2) integrate the received levels of modeled animals over a period of 24 hours. These proposed guidelines are still undergoing review.

These proposed new guidelines were not considered during this study. However, a quick comparison between the current and proposed metrics was made using impact pile driving propagation as measured by Blackwell (2005). This comparison assumed 30 hammer blows per minute and a total time of one hour. Under the current regulatory scheme the behavioral threshold would be reached at a range of approximately 5 km and the physiological take threshold would be reached at a distance of approximately 2 km. Under the proposed NMFS SEL metrics, the TTS onset threshold would be reached at a distance of approximately 20 km and the PTS onset threshold would occur at a distance of approximately 4 km. Implementation of the proposed NMFS guidelines may increase the regulated area around offshore alternative energy installation construction activities. It should be noted that this simple modeling approach of integrating source output over one hour is known to produce more conservative results than the more sophisticated animal movement modeling approach (e.g., the Acoustic Integration Model).

Because these new guidelines have not been finalized, they were not considered during the study. However, a quick comparison was made using measured impact piledriving propagation. This comparison assumed 30 hammer blows per minute and a total time of one hour. Under the current regulatory scheme, the behavioral threshold would be reached at a range of approximately 5 km and the physiological take threshold would be reached at a distance of approximately 2 km. Under the proposed SEL metrics, the TTS onset threshold would be reached at a distance of approximately 20 km and the PTS onset threshold would occur at a distance of approximately 4 km. Therefore it is clear that implementation of the proposed NMFS guidelines may increase the area around these activities which are considered to affect marine mammals. It should also be noted that this very simple modeling approach is known to produce more conservative results than the more sophisticated animal movement modeling approach (e.g, the Acoustic Integration Model) (Frankel et al. 2002) that is based on the received sound level of moving animal models.

7. HABITAT ASSESSMENT

As part of the study team, ESS supported Cornell University by conducting habitat assessments to identify marine species potentially impacted by noise producing activities on the Outer Continental Shelf (OCS). The desktop habitat assessments examined the distribution and relative abundance of indigenous subsurface marine species as a baseline study to potential wind energy development. Though the habitat studies will identify a diverse range of potentially affected marine species, it is anticipated the potential noise impacts of wind energy development construction activities will be evaluated with respect to their effects on marine mammals.

The two study sites contain wind planning areas located off the coasts of North Carolina and Georgia (see Chapter 2), referred to as the NC-Site and GA-Site, which are located in federal waters on the Atlantic Outer Continental Shelf. These sites are the potential future locations of offshore renewable energy development activities. From an ecological perspective, the sites are located within the South Atlantic Bight (SAB) on the inner-to-mid portions of the continental shelf in waters less than 45 m in depth. Habitats in these areas are predominantly soft bottom comprised of sandy sediments. Some hardbottom habitats, including live and artificial coral are also found in the general vicinities of the two sites.

Marine vertebrate species composition and usage of the sites for baseline study was determined to be representative of the western North Atlantic south of Cape Hatteras, North Carolina. Factors influencing marine species usage of the study areas are related to habitat characteristics such as depth, circulation, temperature, and salinity, which correlate to distance from shore. It happens that the two study areas are relatively close to shore and lie upon fairly homogenous portions of the continental shelf lacking dramatic variations in oceanographic features.

7.1 INTRODUCTION

This desktop study involves a limited examination of the biological oceanography of NC-Site and GA-Site. It is limited in the sense that the data and discussion presented here are historical in nature; it describes baseline conditions of the marine habitats and species composition associated with these areas from a perspective of what is inherently a dynamic ecosystem. No field work or original data collection and analysis were conducted for this effort and no ongoing monitoring of marine species is underway. This level of study is adequate in support of the current study, however; because it provides background information for the broader project that aims to better understand the potential impacts on marine species from noise-producing activities associated with offshore renewable energy development.

The purpose of this desktop study is to better understand the biological components of the two candidate sites in order to determine the marine vertebrates that are likely to use these areas and consequently, be at risk of exposure to anthropogenic sounds. To achieve this understanding, research efforts focused on technical sources from federal and state agencies, as well as academia, to understand the physical and biological attributes of each site so that habitat types could be characterized. Site habitat characterization was conducted discretely and also within a regional context in order to refer habitat types and species composition with respect to a broader geographic area.

7.1.1 North Carolina Site

BOEM identified 48 OCS Lease Blocks within the BOEM Official Protraction Diagram Beaufort NI18-04 of its South Atlantic Planning Area as the second candidate site to conduct the habitat characterization and further acoustical analysis under this task (Figure 7.1). NC-Site lies approximately 22 miles south of Cape Lookout, North Carolina. NC-Site is located within the SAB in a sub-region known as the Carolina Capes Region. It is also within the Carolinian Atlantic Marine Ecoregion. NC-Site is within an oceanographic setting marked by a relatively narrow continental shelf that is approximately 60 km wide south of Cape Lookout. This region of the OCS lies within the mid-shelf zone between 30 to 40 m of water depth.

7.1.2 Georgia Site

BOEM identified OCS Lease Block 6126 within the BOEM Official Protraction Diagram Brunswick NH 17–02 of its South Atlantic Planning Area as the first candidate site to conduct the habitat characterization and further acoustical analysis under this task. Lease Block 6126 is the subject of an interim lease to the Southern Company to install meteorological measurement set equipment for the purposes of measuring wind speeds.

GA-Site is approximately 3 miles southeast of Little Tybee Island, Georgia with Wassaw Sound and Wassaw Island being two other coastal features geographically associated with the site (Figure 7.2). Georgia site is located within a region of the Atlantic OCS off of the southeastern U.S. referred to as the SAB. The SAB is defined as the shallow-curving geographic landform extending from Cape Hatteras, North Carolina, to Cape Canaveral, Florida. The northern part of the SAB is known as the Carolina Capes Region; the middle and southern areas are called the Georgia Embayment or the Georgia Bight. The International Commission for Environmental Cooperation classifies this area as the Carolinian Atlantic Marine Ecoregion, signifying a distinct assemblage of ecological attributes that will be discussed below.

GA-Site is within an oceanographic setting that conforms with the relatively wide (120 km) and flat portion of the OCS off of Georgia. This region of the OCS is marked by three zones comprising the oceanographic regime of these waters: inner shelf (0 to 20 m in depth), mid-shelf (21 to 40 m in depth), and outer (41 to 75 m in depth). GA-Site sits shoreward of the Florida-Hatteras Slope and the Blake Plateau (NOAA 2004b) on the inner shelf where the oceanographic conditions are dominated by tidal currents, river runoff, local wind forcing, and seasonal atmospheric changes (SAFMC 2009a).

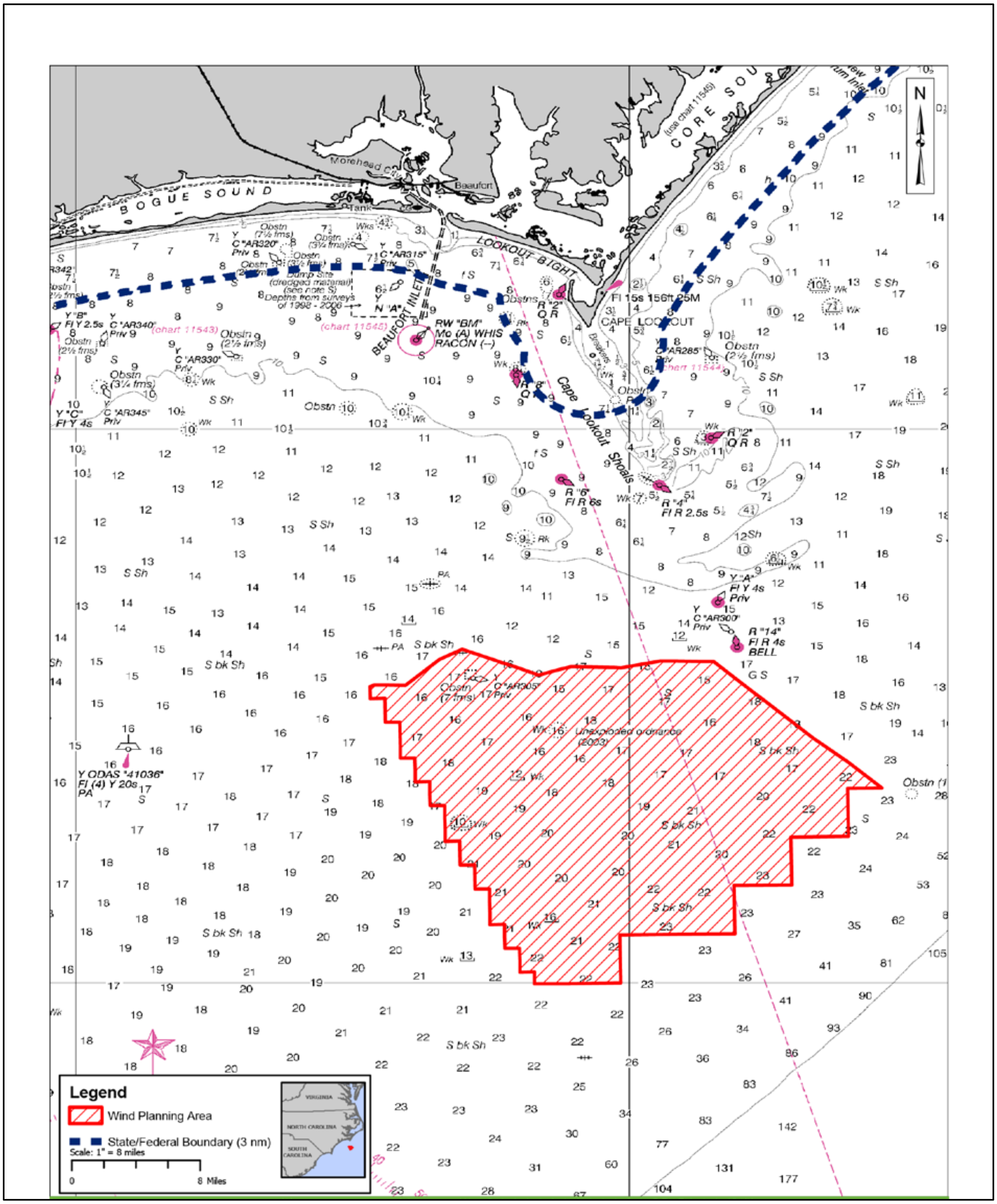

Figure 7.1. North Carolina wind planning area (NC-Site).
Depth and location of wind planning area at the North Carolina site.

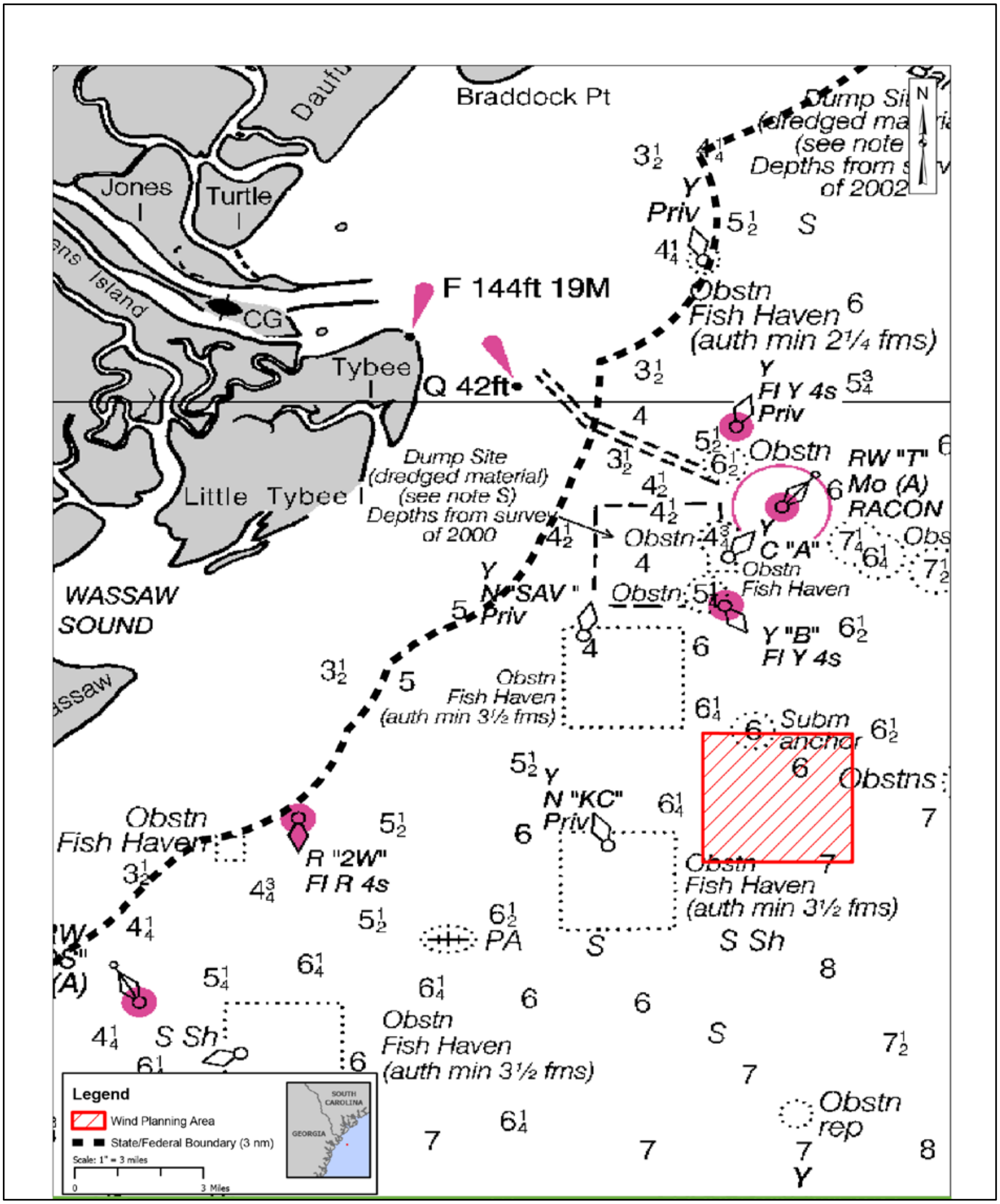

Figure 7.2. Georgia site (GA-Site).
Depth and location of wind planning area at the Georgia site.

7.2 PHYSICAL HABITAT CHARACTERIZATION

This Chapter presents summaries of the physical resources found within the boundaries of the two candidate sites and the region around them. The presentations discuss bathymetry, bottom substrate, water temperature, salinity, and circulation.

7.2.1 North Carolina Site

7.2.1.1 Bathymetry

NC-Site is located in the vicinity of Cape Lookout Shoals. It occupies a relatively flat portion of the continental shelf, shoreward of the Florida-Hatteras Slope (NOAA 2004b). In general, NC-Site sits in waters ranging from 30 to 40 m in depth; shallower waters are generally to the north and west of the Project Area and deeper waters to the south and east (Figure 7.3). Southeast and east of the site water depths increase rapidly to more than 100 m. Between the Project Area and Cape Lookout to the North are the Cape Lookout Shoals. These shoals are a shallow water area, running in southeasterly direction with water depths as low as one to two m (NOAA 1973a; NOAA 1973b; NOAA 1974).

7.2.1.2 Bottom Substrate

The seafloor geology of NC-Site has been identified as sand by the US Geological Survey (USGS 2005) (Figure 7.4). As outlined by the South Atlantic Fisheries Management Council, much of the seafloor of the SAB is composed of a relatively thin layer of mud and sand over carbonate sandstone (SAFMC 2009a). Scattered within this broad coastal plain are often found areas of “live bottom” or areas of dense invertebrate and algal assemblages associated with changes in bottom topography and often times exposed bedrock or hard bottom. These outcroppings are normally found in water depths between 30 to 70 m. However, the Fisheries Ecosystem Plan for the South Atlantic Region cites observations that additional live bottom areas in shallower waters are more prevalent than previously believed (SAFMC 2009a). Parker et al. (1983) estimated that in North Carolina waters, hard bottom assemblages covered approximately 14% of the seafloor in the depth range of 27 to 101 m between the geographic areas of Cape Hatteras and Cape Fear.

Areas of Essential Fish Habitat-Habitat Areas of Particular Concern (EFH-HAPC) pertaining to Coral Reefs and Hard/Live Bottom have been identified in the area surrounding NC-Site (FFWCC 2005). Additionally, Southeast Area Monitoring and Assessment Program—South Atlantic (SEAMAP-SA) mapping efforts in 2001 indicate numerous hard bottom locations within the overall Project Area (SEAMAP-SA 2001). Based on these maps, two major areas of coral reefs, hard bottoms, or live bottoms were identified within the boundaries of NC-Site. Ten Fathom Ledge is a large HAPC located along the northern boundary of NC-Site. Big Rock is identified as an HAPC and is located to the east of the site.

7.2.1.3 Water Temperature and Salinity

Temperature and salinity are known to fluctuate on a seasonal basis throughout the inner continental shelf zone in which NC-Site is located. Water temperatures have been reported to range between 10° to 29°C and salinity has been reported to range between 33.0 and 36.5 ppt (SAFMC 2009a). Further offshore, near the continental shelf break, water temperatures and salinity are influenced more by the Gulf Stream than by freshwater inputs and local weather patterns, and are therefore more stable (18 to 22°C and 36.0 to 36.2 ppt).

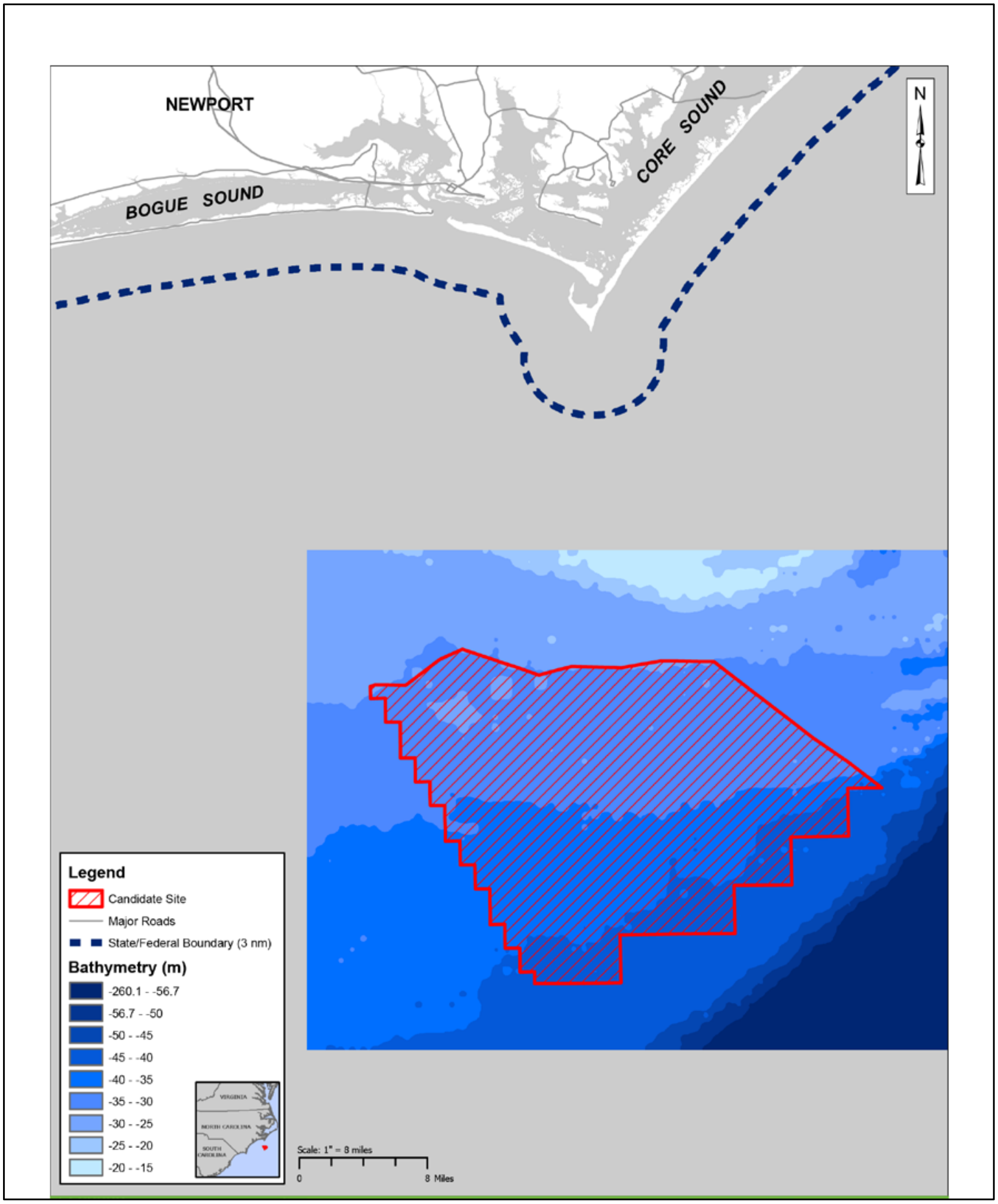

Figure 7.3. NC-Site Bbathymetry.
Bathymetry at NC-Site.

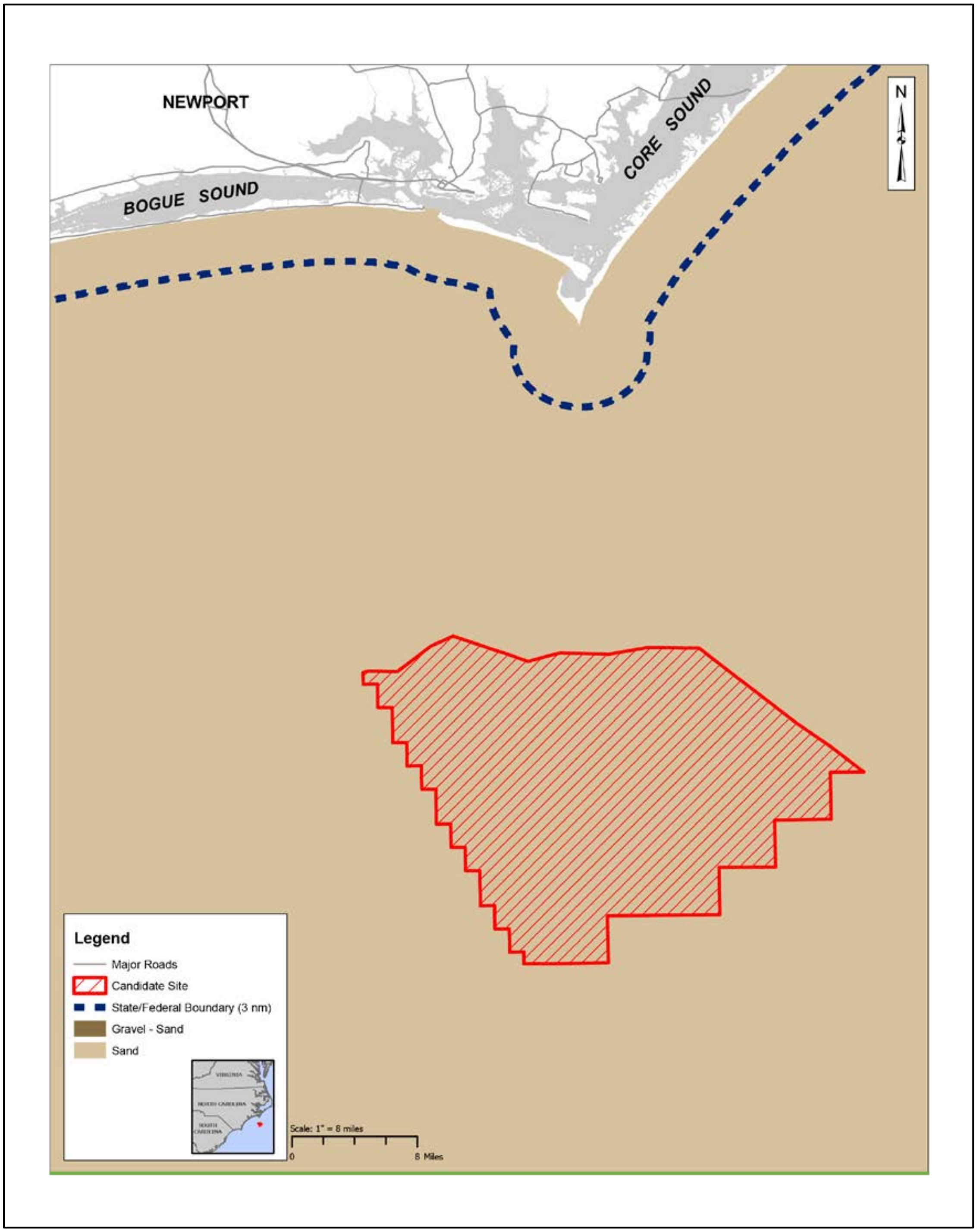

Figure 7.4. NC-Site geology.
Geology at NC-Site.

7.2.1.4 Circulation and Upwelling

Circulation in the inner shelf zone of the continental shelf (0 to 20 m of water depth) in the vicinity of NC-Site is dominated by tidal currents, fresh water runoff (rivers), and seasonal weather patterns (SAFMC 2009a). A major influx of fresh water into the North Carolina coastal system is from the Cape Fear River; additional southern flowing fresh water from Chesapeake Bay also influences North Carolina coastal waters. Offshore of Cape Hatteras, there is a major confluence of the Gulf Stream and the Virginia Coastal Labrador Current (CHPP 2010). This meeting of warm southerly waters and cold northern waters effectively separates the middle and southern Atlantic. Further out on the continental shelf, the wind patterns and the Gulf Stream's influence increases, as tidal effects and freshwater runoff weaken. Given the area's many shoals, and the major confluence of currents discussed above, the coastal area adjacent to Cape Hatteras is the most likely location for upwelling currents (CHPP 2010).

7.2.2 Georgia Site

7.2.2.1 Bathymetry

The bathymetry of GA-Site, according to NOAA National Ocean Service data, resembles that of the surrounding area with waters depths that generally increase moving away from the coastline in a southeasterly direction (NOAA 1973a; 1973b; 1974; 2004a). The site occupies waters ranging from 13 to 15 m in depth. A small area of slightly shallower water (12 to 13 m) runs across the center of the site, and small pockets of deeper water (15 to 17 m) can be found along the southeastern boundary of the site (Figure 7.5).

7.2.2.2 Bottom Substrate

The seafloor geology of GA-Site has been identified as sand by the US Geological Survey (USGS 2005) (Figure 7.6). The South Atlantic Fisheries Management Council classifies much of the seafloor of the South-Atlantic Bight as being composed of a relatively thin layer of mud and sand over carbonate sandstone (SAFMC 2009a). Scattered within this broad coastal plain are commonly found areas of "live bottom" or areas of dense invertebrate and algal assemblages associated with changes in bottom topography and often times exposed bedrock or hard bottom. These outcroppings are normally found in water depths between 30 and 70 m. However, the Fisheries Ecosystem Plan of the South Atlantic Region cites reports that additional live bottom areas in shallower waters are more prevalent than had been previously believed (South Atlantic Fishery Management Council 2009a).

7.2.2.3 Water Temperature and Salinity

Temperature and salinity throughout the upper continental shelf area are known to fluctuate on a seasonal basis. Water temperatures have been reported to range between 10° to 29°C and salinity has been reported to range between 33.0 parts per thousand (ppt) and 36.5 ppt (SAFMC 2009a). Further offshore, near the continental shelf break (55 to 110 m of water depth), water temperatures and salinity are influenced more by the Gulf Stream than by freshwater inputs and local weather patterns, and are therefore more stable (18 to 22°C and 36.0 to 36.2 ppt). GA-Site is found within the inner shelf area, and is exposed to the seasonably variable conditions described above.

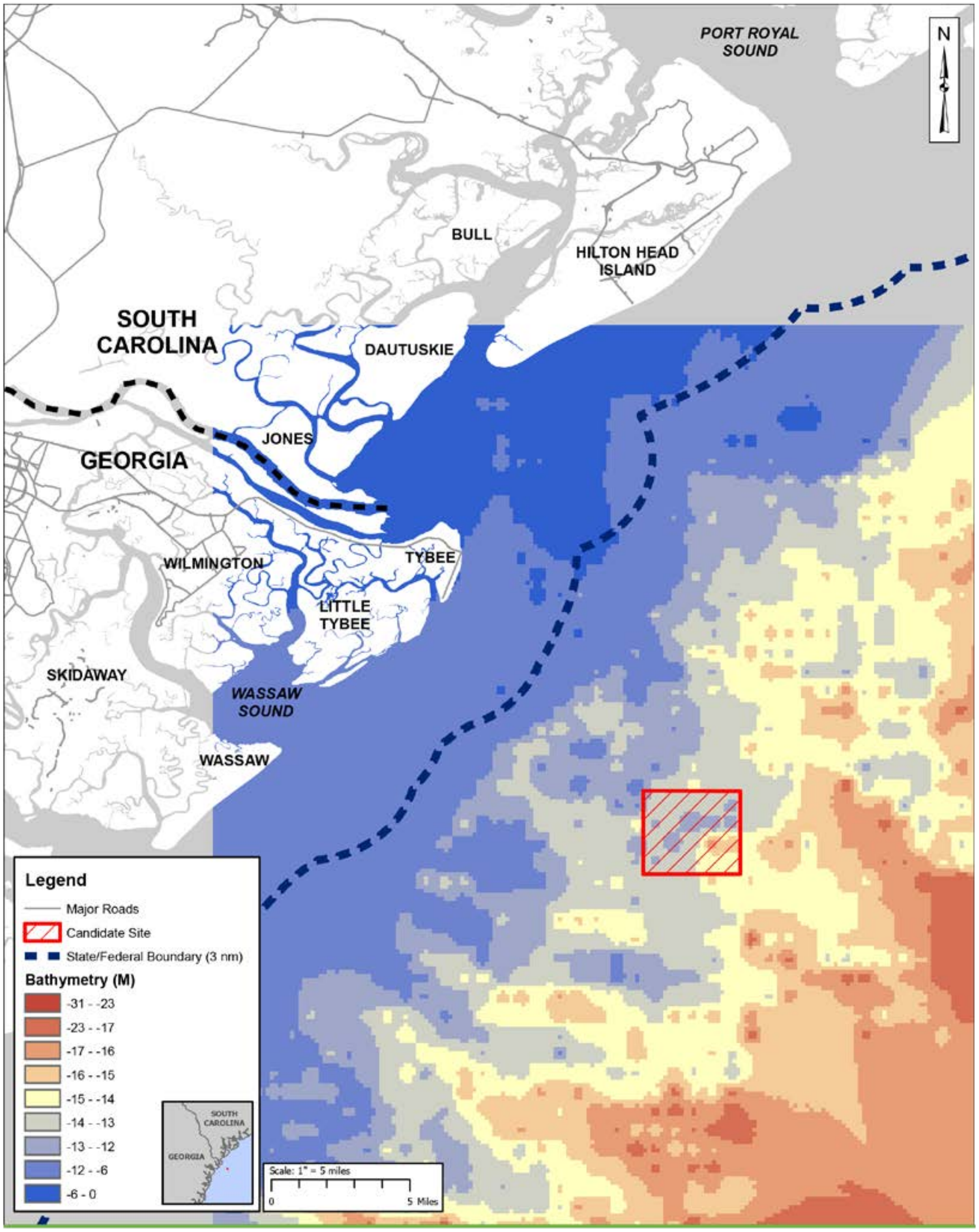

Figure 7.5. GA-Site bathymetry.
Bathymetry at GA-Site.

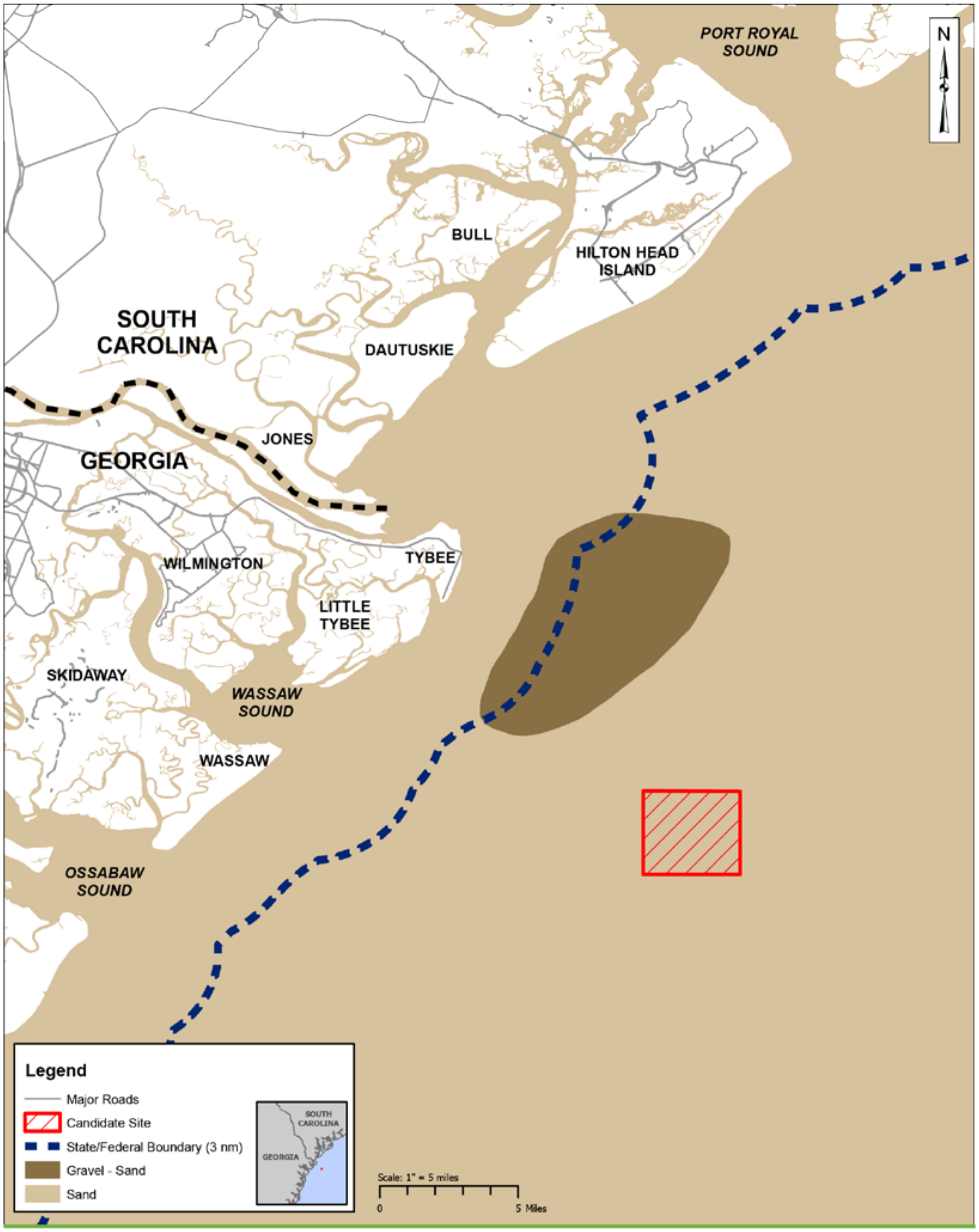

Figure 7.6. GA-Site geology.
Geology at GA-Site.

7.2.2.4 Circulation and Upwelling

Circulation in the inner shore zone of the continental shelf (0 to 20 m of water depth) in the vicinity of the Project Area is dominated by tidal currents, fresh water runoff (rivers), and seasonal weather patterns (SAFMC 2009a). Further out on the continental shelf the wind patterns and the Gulf Stream's influence increase, as tidal effects and freshwater runoff weaken.

Southeast of Charleston, South Carolina a geologic feature known as the Charleston Bump rises from the seafloor and redirects the Gulf Stream to the northeast. This redirection allows for the formation of the Charleston Gyre, which is considered an important nursery habitat for certain offshore fish species (SAFMC 2009a). The Charleston Gyre causes upwelling of nutrient rich water from the ocean floor, which supports a wide variety of biological process. Though the Charleston Bump and Gyre are not located in the immediate vicinity of the candidate site, their influence is considered to be regional in nature.

7.3 BIOLOGICAL HABITAT CHARACTERIZATION

7.3.1 North Carolina Site

Marine offshore systems encompass a diversity of habitats off the coast of North Carolina. These habitats are either benthic or pelagic and vary both laterally and longitudinally with distance from shore. Benthic habitats are categorized into three major groups:

1. Coral, coral reefs and live/hardbottom habitat
2. Artificial reefs
3. Marine soft bottom habitat

Pelagic habitats are primarily categorized as Marine Water Column or sargassum habitat.

The continental shelf off the coast of North Carolina lies at an important physical, chemical, and biological boundary between the Mid-Atlantic Bight (MAB) and SAB. Here, the Gulf Stream is diverted away from the southeastern U.S. coastline and directed out to sea. As a result, the MAB and SAB have drastically different water sources, water temperatures and biological composition. Cape Hatteras in North Carolina is the upland geographic point that divides these two marine systems. Because the candidate site lies to the south of Cape Hatteras, the SAB habitat and species will be the focus of this report.

Water depth within NC-Site ranges from approximately 30 to 40 m. In general, water depth increases from the north to the south, with the shallowest depths in the northwest of the site and the deepest areas in the southeast.

7.3.1.1 Coral, Coral Reefs, and Live/Hardbottom Habitat

Coral and hardbottom habitats are scattered throughout the waters off the coast of North Carolina (SAFMC 2009a). Approximately 109 square km or 1% of the shelf within NC-Site consists of live bottom habitats (Figure 7.7). Within the site are several patches of coral or live/hardbottom habitat. These hardbottom habitats are not characterized as coral communities because of their low diversity of coral species, but still harbor several species of coral. Furthermore, these rocky habitats provide substrates for many ascidians, hydroids, bryozoans, and sponges to attach. These organisms provide both food and refuge for a number of invertebrate and vertebrate species to survive. As a result, habitat areas of particular concern for commercial snapper and grouper fish species strongly overlap with these hard bottomed ecosystems.

7.3.1.2 Artificial Reefs

Artificial reefs are managed by the North Carolina Department of Environment and Natural Resources Division of Marine Fisheries. The goals of the artificial reef program are aimed at fishery and habitat conservation and improvement and fishing or diving recreation. Artificial reefs are scattered throughout the continental shelf bordering North Carolina's coast and consist of many different materials (concrete, steel, old ships, etc.). Two mapped artificial reefs are located close to NC-Site and one mapped artificial reef lies within it. All three of these artificial reefs are a combination of sunken ships or sunken ships and concrete pipes.

7.3.1.3 Marine Soft Bottom Habitats

A majority of the benthic habitat in North Carolina's coastal waters is marine soft bottom habitat. NC-Site is almost entirely soft bottom habitat with small patches of hardbottom habitat as mentioned earlier. The physical structure of marine soft bottom habitat is characterized by sandy sediments. This habitat is extensive off the coast of North Carolina and harbors many species of benthic invertebrates. The invertebrate community is dominated by species tolerant of disturbance as storms over the continental shelf have the ability to disturb the soft bottom substrate in waters as deep as 35 m. These invertebrates are also an important prey item for many fish species.

7.3.1.4 Sargassum Habitat

Sargassum habitat is built by two species of floating brown algae (*Sargassum natans* and *S. fluitans*). These brown algae float near the surface of the water and provide a substrate where many other organisms live and take refuge. It is estimated that at least 145 species of invertebrates, 100 species of fish, four species of sea turtles, and many marine birds all use floating sargassum habitat (SAFMC 2009a). Sargassum is considered essential fish habitat for the snapper-grouper complex according to the SAFMC. The presence of sargassum is likely in the waters off the coast of North Carolina. Because it is transient (floating habitat that moves based on ocean currents and winds), it is hard to determine how much sargassum habitat would be in the candidate site at the time of any offshore renewable energy development activities.

7.3.1.5 Marine Water Column

The continental shelf off the coast of North Carolina extends for just 51.5 km from Cape Hatteras to as many as 128.7 km off the coast near Wilmington, North Carolina. Along this shelf three major zones (inner-, mid- and outer- shelf habitats) can be identified, based on the water column depth and the sources of water feeding that environment. The Gulf Stream dominates the outer shelf (40 to 75 m deep) habitat with only minor effects from winds and tides. Water column mixing by the Gulf Stream, winds and tides equally contribute to the characterization of the mid-shelf habitat (20 to 40 m deep). The inner shelf water column (0 to 20 m deep) habitat is primarily influenced by freshwater runoff, tides, wind and bottom friction. NC-Site off the coast of North Carolina spans both the mid-shelf and outer shelf habitat depths. However, the majority of the NC-Site corresponds to the mid-shelf habitat depth range and is the most characteristic of the site.

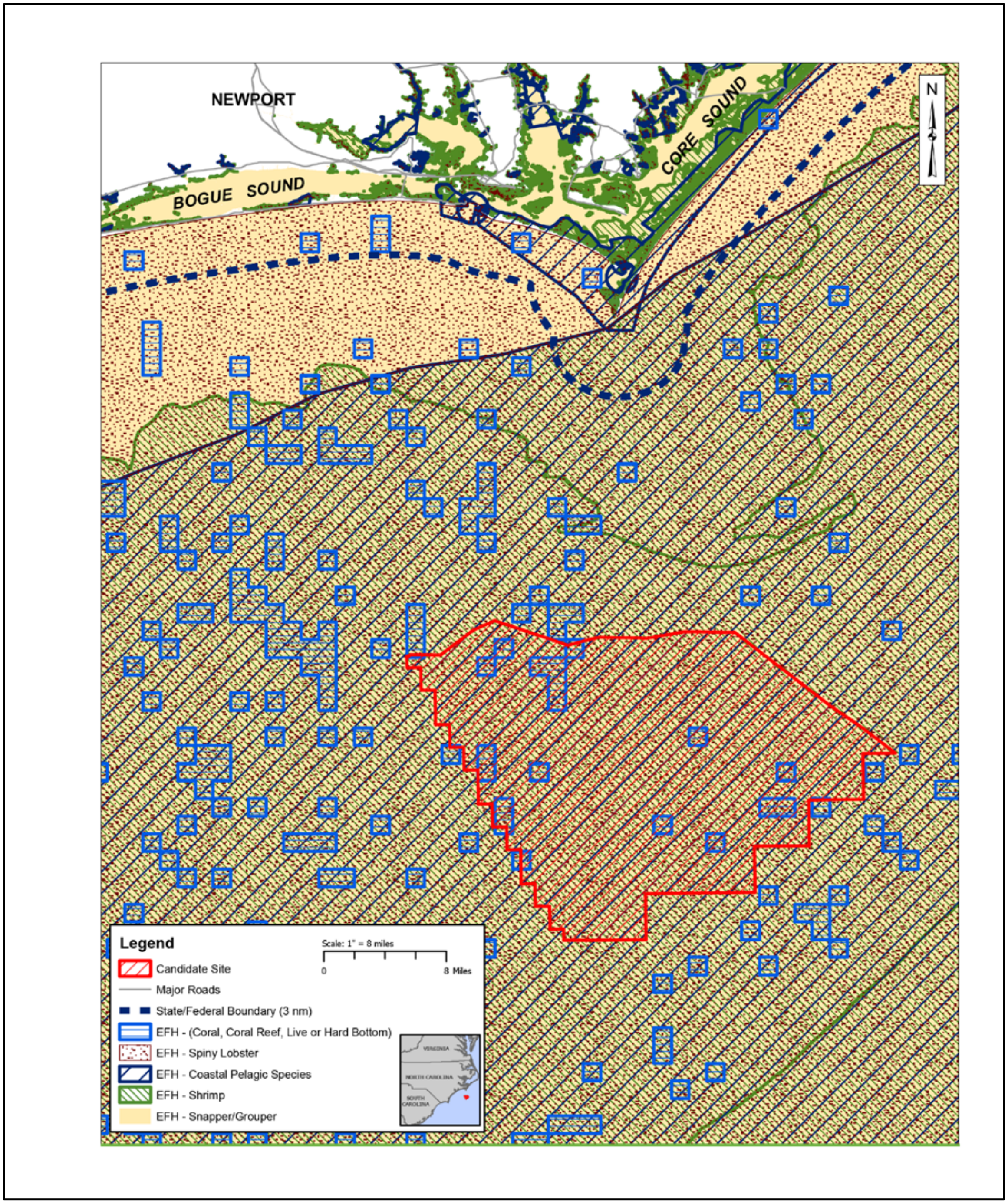

Figure 7.7. NC-Site essential fish habitats.
Essential fish habitats (EFH), characterized by benthic habitat types, at NC-Site.

7.3.2 Georgia Site

Marine offshore systems encompass a diversity of habitats off the coast of Georgia. Either benthic or pelagic in nature, these habitats vary both laterally and longitudinally with distance from shore. The benthic habitats found off the Georgia coast are categorized into three major groups:

1. Coral, coral reefs and live/hardbottom habitat
2. Artificial reefs
3. Marine soft bottom habitat

Pelagic habitats found in coastal Georgia waters are primarily categorized as Marine Water Column or sargassum habitat.

7.3.2.1 Coral, Coral Reefs, and Live/Hardbottom Habitat

Coral and hardbottom habitats (live bottom) are sparsely scattered throughout the waters off the coast of Georgia (SAFMC 2009a). Areas of these habitats are predominantly hardbottom with a low diversity and abundance of coral species. It is estimated that only 5% of the continental shelf off the coast of Georgia consists of these live bottom habitats. The patches of live bottom are found in waters of approximately 10 m in depth, or greater, which corresponds to waters outside of the three-nautical-mile state jurisdictional limit.

There are no identified patches of coral or live/hardbottom habitat with the boundaries of GA-Site but there are mapped coral and/or live/hardbottom habitats at similar depths along the Georgia coastline (Figure 7.8). These patches constitute less than 5% of the benthic habitat within the candidate site. Furthermore, these rocky habitats provide substrates for many ascidians, hydroids, bryozoans and sponges to attach. These organisms provide both food and refuge for a number of invertebrate and vertebrate species to survive, including fish species of commercial importance. Mapped locations of federally-designated Habitat Areas of Particular Concern for commercial snapper and grouper fish species strongly overlap with these hard bottomed ecosystems.

7.3.2.2 Artificial Reefs

Twenty-three artificial reefs exist off the coast of Georgia (GADNR 2011). Two artificial reefs are located close to the GA-Site. One artificial reef (Reef ID: KC), lying 9 to 16.6 km southeast of Wassaw Island, Georgia, is within 5 km of the southwestern corner of GA-Site. It was created mostly of vessel hulks and concrete pipes. A second artificial reef is located 6 km to the northwest of GA-Site. This reef comprises concrete pipes and barge hulks and lies 11.1 km southeast of Tybee Island, Georgia (Reef ID: SAV). These artificial reefs are managed by the Georgia Department of Natural Resources Coastal Resources Division. The goals of the artificial reef program are aimed at fishery and habitat conservation, fishing recreation, and economic growth for coastal communities.

7.3.2.3 Marine Soft Bottom Habitats

The physical structure of marine soft bottom habitat is dynamic in nature and is characterized by sandy sediments. This habitat type is extensive off the coast of Georgia and harbors many species of benthic invertebrates. The invertebrate community is dominated by species groups such as polychaetes and amphipods tolerant of disturbance as storms over the continental shelf have the ability to disturb the soft bottom substrate in waters as deep as 35 m. These invertebrates are also an important prey item for many fish species including the tomtate (*Haemulon aurolineatum*), whitebone porgy (*Calamus leucosteus*), cubbyu (*Equetus umbrosus*), black sea bass (*Centropristis striata*), and scup (*Stenotomus chrysops*) (Lindquist et al. 1994).

The greater proportion of the benthic habitat in Georgia's coastal waters is marine soft bottom habitat. However, there is an area approximately three miles east of Tybee and Little Tybee Island where the benthic habitat comprises gravelly-sand. GA-Site is almost entirely over soft bottom habitat (with the exception of the two hardbottom habitat patches mentioned earlier).

7.3.2.4 Sargassum Habitat

Sargassum habitat is built by two species of floating brown algae (*Sargassum natans* and *S. fluitans*). These brown algae float near the surface of the water and provide a substrate for many other organisms to live, rest, and take refuge. It is estimated that at least 145 species of invertebrates, 100 species of fish, four species of sea turtles, and many marine birds all use floating sargassum habitat (South Atlantic Fishery Management Council 2009a). Sargassum is considered essential fish habitat for the snapper/grouper complex, according to the SAFMC. The presence of sargassum is likely in the waters off the coast of Georgia. Because it is transient (floating habitat that moves based on ocean currents and winds) , it is hard to determine how much sargassum habitat is associated with the waters in and around GA-Site.

7.3.2.5 Marine Water Column

The continental shelf off the coast of Georgia extends 120 km to the east. Along this shelf three major zones can be identified based on the water column depth and the sources of water feeding that environment. The Gulf Stream dominates the outer shelf (40 to 75 m deep) habitat with only minor effects from winds and tides. Water column mixing by the Gulf Stream, winds and tides equally contribute to the characterization of the mid-shelf habitat (20 to 40 m deep). The inner shelf water column (0 to 20 m deep) habitat is primarily influenced by freshwater runoff, tides, wind, and bottom friction. Because GA-Site is located off the coast of Georgia and reaches only 17 m in depth, it is predicted that it comprises inner shelf water column habitat.

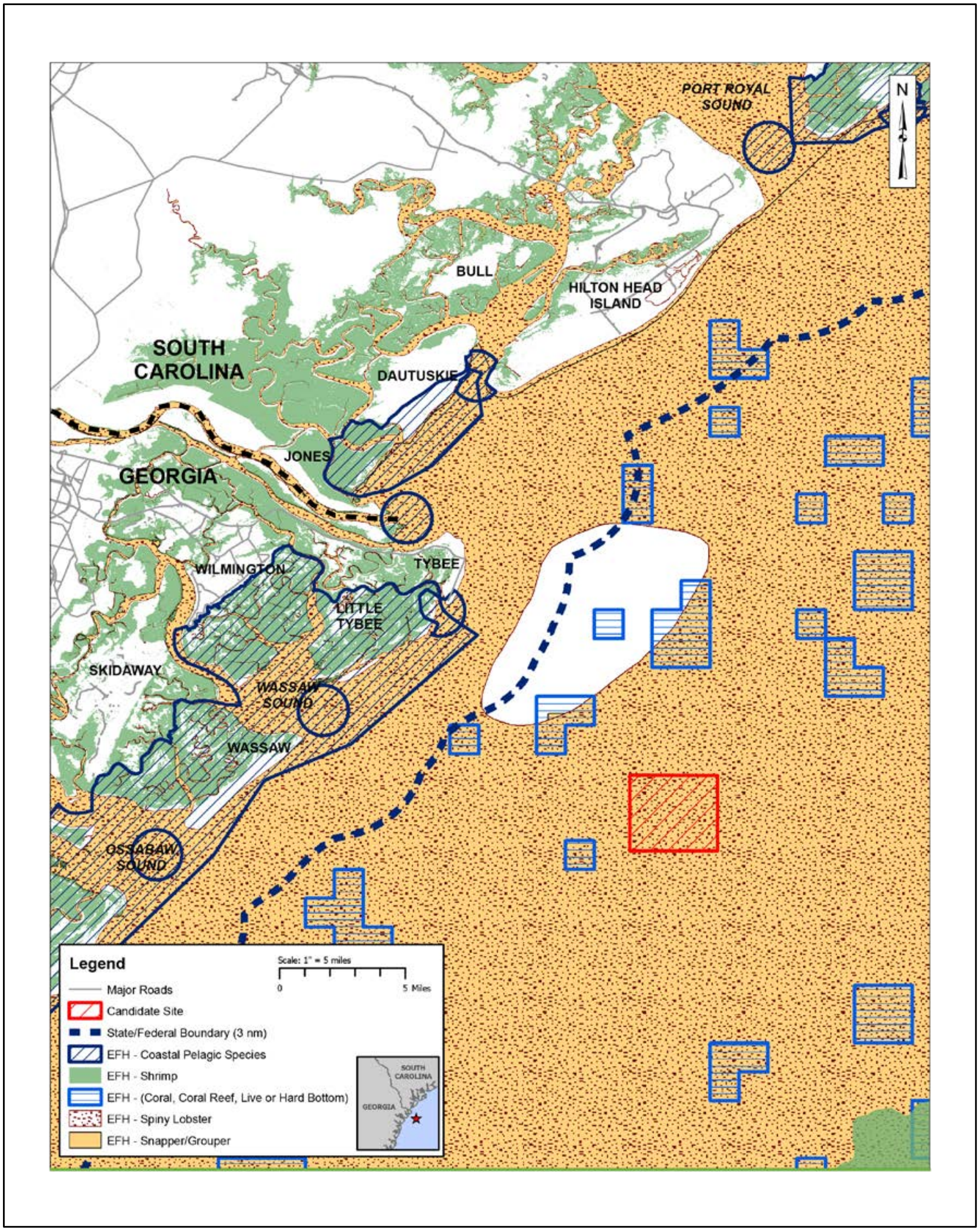

Figure 7.8. GA-Site essential fish habitat.
Essential fish habitats (EFH), characterized by benthic habitat types, at GA-Site.

7.4 MARINE VERTEBRATE SPECIES' USE OF THE SITES

This Chapter provides the results of the assessment of marine vertebrate species' use of the two candidate sites. For the Georgia and North Carolina sites, population, ecological, and management information for fish and fisheries, marine mammals and sea turtles was reviewed. No sources of information reviewed contained marine species data at the site-level. Data included in this assessment describe species population and habitat association at much larger scales. However, the available data does allow room for inferences about species composition with the site boundaries and relative abundance based on factors, such as time of year, as discussed below.

7.4.1 Fish and Fisheries

A number of fish species' ranges encompass both NC-Site and GA-Site (Table 7.1); these species could be influenced by sound-producing activities within either site. The list of fishes in Table 7.1 does not represent the community of fish species at both sites, but is simply a list of potential fishes that, given their population ranges, could be encountered at either site. Table 7.1 is a very liberal description of potential species using each site. Many of these species are seasonal or pelagic migrants, or both, of the SAB and would likely be present for only short durations throughout the year. Furthermore, many of these fish have specific habitat requirements or preferences. These preferences can be both structural and temporal. Though the unique habitat of a given species might not be within each candidate site, if the potential for this species to move through a site exists, it was still included in this list of fishes. The true fish community regularly using each candidate site is likely a small subset of species from the list in Table 7.1. A shortage of data restricts the evaluation of fish density within each site and so inhibits any discussion of fisheries impacts from anthropogenic activity at either site.

7.4.1.1 Essential Fish Habitat

Essential Fish Habitat (EFH) judged to be particularly important to the long-term productivity of populations of one or more managed species, or to be particularly vulnerable to degradation, is often identified as "habitat areas of particular concern" (HAPC) to help provide additional focus for conservation efforts. Figures 7.7 and 7.8 illustrate documented EFH and HAPC with respect to the locations of NC-Site and GA-Site. The general vicinity of the two sites includes EFH and HAPC for shrimp; snapper and grouper; spiny lobster; coral, coral reef, live or hard bottom; coastal pelagic species.

Table 7.1. List of fish species present in the South Atlantic Bight.

Group	Family	*Genus*	*Species*	Common Name	Spawning Period[α]	Juvenile Presence[α]	Adult Presence[α]	Abundance Data[β]
Grouper or Snapper								
	Balistidae			Triggerfishes				
		Balistes	*capriscus*	Gray triggerfish	April–Aug	All Year	All Year	
			vetula	Queen triggerfish		All Year	All Year	
		Canthidermis	*sufflamen*	Ocean triggerfish	All Year	All Year	All Year	
	Carangidae			Jacks				
		Caranx	*bartholomaei*	Yellow jack	Feb–Oct	All Year	All Year	
			crysos	Blue runner	Feb–Sept	All Year	All Year	
			hippos	Crevalle jack		All Year	All Year	
			ruber	Bar jack				
		Seriola	*dumerili*	Greater amberjack	Jan–June	All Year	All Year	
			fasciata	Lesser amberjack				
			rivoliana	Almaco jack		All Year	All Year	
			zonanta	Banded rudderfish		All Year	All Year	
	Eppiphidae			Spadefishes				
		Chaetodipterus	*faber*	Atlantic spadefish	May–Sept	All Year	All Year	
	Haemulidae			Grunts				
		anistotremus	*surinamensis*	Black margate*				
		Haemulon	*aurolineatum*	Tomtate	March–July	All Year	All Year	
			flavolineatum	French grunt*				
			plumieri	White grunt	March–Sept		All Year	

Group	Family	*Genus*	*Species*	Common Name	Spawning Period[α]	Juvenile Presence[α]	Adult Presence[α]	Abundance Data[β]
	Labridae			Wrasses				
		Halichoeres	*radiatus*	Puddingwife		All Year	All Year	
		Lachnolaimus	*maximus*	Hogfish	Sept–April	All Year	All Year	
	Lutjanidae			Snappers				
		Apsilus	*dentatus*	Black snapper*				
		Etelis	*oculatus*	Queen snapper				
		Lutjanus	*analis*	Mutton snapper		All Year		
			apodus	Schoolmaster		All Year	All Year	
			buccanella	Blackfin snapper		All Year		
			campechanus	Red snapper	May–Oct	All Year	All Year	
			cyanopterus	Cubera snapper*				
			griseus	Gray (mangrove) snapper				
			jocu	Dog snapper				
			mahogoni	Mahogany snapper				
			synagris	Lane snapper			All Year	
			vivanus	Silk Snapper				
		Ocyurus	*chrysurus*	Yellowtail snapper	Summer			YES
		Rhomboplites	*aurorubens*	Vermilion snapper	April–Sept	All Year	All Year	YES
	Malacanthidae			Tilefishes				
		Caulolatilus	*microps*	Blueline tilefish	Feb–Oct	All Year	All Year	
		Lopholatilus	*chamaeleonticeps*	Golden tilefish				
		Malacanthus	*plumieri*	Sand tilefish		All Year		
	Polyprionidae	*Polyprion*	*americanus*	Wreckfish				

Group	Family	*Genus*	*Species*	Common Name	Spawning Period[α]	Juvenile Presence[α]	Adult Presence[α]	Abundance Data[β]
	Serranidae			Sea basses and grouper				
		Centropristis	*ocyurus*	Bank sea bass	Jan–April		All Year	
			philadelphica	Rock sea bass				
			striata	Black sea bass	March–July	All Year	All Year	YES
		Cephalopholis	*cruentata*	Graysby				
		Epinephelus	*adcensionis*	Rock hind*				
			drummondhayi	Speckled hind		All Year	All Year	
			guttatus	Red hind				
			morio	Red grouper	Feb–June	NA**	All Year	
			nigritus	Warsaw grouper		All Year		
			niveatus	Snowy grouper				YES
		Mycteroperca	*bonaci*	Black grouper*				
			interstitialis	Yellowmouth grouper				
			microlepis	Gag	NA**	Sept to Oct	All Year	YES
			phenax	Scamp†	Feb to July	NA**	All Year	
			venenosa	Yellowfin grouper‡				
	Sparidae			Porgies				
		Archosargus	*probatocephalus*	Sheepshead*				
		Calamus	*bajonado*	Jolthead porgy		All Year	All Year	
			calamus	Saucereye porgy			All Year	
			leucosteus	Whitebone porgy	April–Aug	All Year	All Year	
			nodosus	Knobbed porgy	March–July	All Year	All Year	
			pagrus	Red porgy	Dec–May	All Year	All Year	YES

Group	Family	*Genus*	*Species*	Common Name	Spawning Period[α]	Juvenile Presence[α]	Adult Presence[α]	Abundance Data[β]
		Pagrus	*caprinus*	Longspine porgy			All Year	
		Stenotomus	*chrysops*	Scup				
Migratory Pelagics and Other Managed Fishes								
	Acipenseridae			Sturgeons				
		Acipenser	*brevirostrum*	Shortnose Sturgeon				YES
			oxyrinchus	Atlantic sturgeon	NA**	NA**	All Year	YES
	Anguillidae	*Anguilla*	*rostrata*	American eel				YES
	Clupeidae			Herring				
		Alosa	*aestivalis*	Blueback herring				YES
			mediocris	Hickory shad				YES
			pseudohargengus	Alewife*				YES
			sapidissima	American shad				YES
		Brevoortia	*smithi*	Yellowfin menhaden				YES
			tyrannus	Atlantic menhaden				YES
	Istiophoridae			Marlins				
		Istiophorus	*platypterus*	Sailfish				YES
		Makaira	*migricans*	Blue marlin				YES
		Tetrapturus	*albidus*	White marlin				YES
			pfluegeri	Longbill spearfish				YES
	Moronidae	*Morone*	*saxatilis*	Striped bass		NA**	All Year	YES

Group	Family	*Genus*	*Species*	Common Name	Spawning Period[α]	Juvenile Presence[α]	Adult Presence[α]	Abundance Data[β]
	Pomatomidae	*Pomatomus*	*saltatrix*	Bluefish	March–June	Nov-March	All Year	YES
	Paralichthyidae	*Paralichthys*	*dentatus*	Summer flounder	Oct–March	NA**	All Year	YES
	Pristidae	*Pristis*	*pectinata*	Smalltooth sawfish				YES
	Sciaenidae			Drums and croakers				
		Cynoscion	*regalis*	Weakfish*				YES
		Leiostomus	*xanthurus*	Spot	Oct–March	NA**	Oct–March	YES
		Micropogonias	*undulatus*	Atlantic croaker	Aug–Nov	NA**	All Year	YES
		Sciaenops	*ocellatus*	Red drum	Aug–Oct	NA**	Dec–April	YES
	Scombridae			Tunas and mackerels				
		Acanthocybium	*solandri*	Wahoo				
		Scomberomous	*cavalla*	King mackerel				YES
			maculatus	Spanish mackerel				YES
			regalis	Cero mackerel				
		Euthynnus	*alleterattus*	Little tunny				
		Rachycentron	*canadum*	Cobia				
		Thunnus	*alalunga*	Atlantic albacore tuna				YES
			albacares	Atlantic yellowfin tuna*				YES
			obesus	Atlantic bigeye tuna				YES

Group	Family	*Genus*	*Species*	Common Name	Spawning Period[α]	Juvenile Presence[α]	Adult Presence[α]	Abundance Data[β]
			pelamis	Atlantic skipjack tuna				YES
			thynnus	Atlantic bluefin tuna				YES
	Xiphiidae			Swordfishes				
		Xiphias	*gladius*	Atlantic swordfish				YES

[α] Spawning Period, Juvenile, and Adult Presence information is given for species likely present in the Candidate site only. Blank cells indicate a lack of data for species that have presence information in other categories.

[β] Blank cells indicate the availability of abundance data is "unknown," rather than abundance data are "not available."

*Species may not be found in either NC or GA waters because distribution boundary is ambiguous.

** NA indicates that lifestage is not present in the candidate site due to habitat restrictions.

† Species likely found in NC, but not in GA.

‡ Species likely found in GA, but not in NC.

7.4.2 Marine Mammals

Several species of marine mammals have the potential to occur in the SAB (Table 7.2); however, only some of these species are likely to occur within the boundaries of GA-Site or NC-Site. The relatively shallow water and lack of developed feeding habitat decrease the likelihood that many of the marine mammals known to occur in the SAB would be found with regularity in the candidate site.

The marine mammals listed as "rare species" in the SAB (Table 7.2) consist of ten species that are rarely seen in the SAB (SAFMC 2009a) and therefore are also unlikely to occur within GA-Site or NC-Site. Seven of these species (false killer whale, pygmy killer whale, killer whale, melon-headed whale, rough-toothed dolphin, Fraser's dolphin, and spinner dolphin) either occur in low numbers naturally, or occur in the waters adjacent to the SAB (such as the Gulf of Mexico or waters off the northeastern U.S.), and either occasionally or never appear in the SAB (SAFMC 2009a). The harbor porpoise and spinner dolphin may occur in the SAB when they travel to the southernmost portions of their ranges; however, sightings of these species are much more common north of Cape Hatteras, North Carolina or in deeper waters than found at NC-Site or GA-Site (Waring et al. 2007; Waring et al. 2010). Cuvier's beaked whale could potentially occur in the SAB; however, little is known about its distribution (South Atlantic Fishery Management Council 2009a). As a result, it is unlikely that these species would occur in the vicinity of GA-Site or NC-Site and no further assessment of these species was conducted.

The marine mammals listed as "occasional or offshore species" in the SAB in Table 7.2 consist of 12 species whose range includes the northern portions of the SAB (north of Cape Hatteras, North Carolina). When these species occur in the SAB, they are generally found at or beyond the continental shelf (≥ 200 m) (South Atlantic Fishery Management Council 2009a), well outside the boundaries of GA-Site or NC-Site. Because these species tend to occur north of and in much deeper offshore waters than the two candidate sites, they are not likely to occur in the vicinity of NC-Site or GA-Site, and no further assessment of these species was conducted.

Eleven of the marine mammals listed in Table 7.2 are considered "common" in the SAB; however, only five of these species (humpback whale, Northern right whale, West Indian manatee, bottlenose dolphin [coastal stock] and Atlantic spotted dolphin) have a high probability of occurring within the two candidate sites. The bottlenose dolphin, the Atlantic spotted dolphin, and the humpback whale have the potential to occur in the vicinity of the candidate sites year-round; the Northern right whale and the West Indian manatee use the southeast Atlantic during portions of the year. A brief summary of the distribution and estimated population size for the five marine mammal species that have a higher probability of occurring in the vicinity of GA-Site and NC-Site is included below.

Humpback Whale

In the western North Atlantic Ocean, most humpbacks winter in the West Indies, where they mate and calve. These whales then migrate to summer feeding grounds from the Gulf of Maine to Iceland. However, a notable number of humpbacks do not undertake this extensive seasonal migration but instead overwinter in mid- and high latitude regions (Clapham et al. 1993 and Swingle et al. 1993 cited in SCDNR 2006a). There have been increased sightings of this species off the U.S. mid-Atlantic and southeastern states since the mid-1980s (Wingle et al. 1993 and Wiley et al. 1995 cited in SCNDR 2006a). Historical records do contain sightings within the study areas (Figure 7.9). In this region, sightings have been reported in all seasons but are more predominant from January to March (Barco et al. 2001 cited in SCDNR 2006a). Therefore, although humpbacks have the possibility of occurring off the coast of Georgia or North Carolina year-round, they are most likely to be present between January and March. The humpback whale is considered a pelagic and coastal species. They are typically encountered over shallow banks and in shelf waters while feeding or breeding but may traverse open waters during migration (SCNDR 2006a). The best available estimate of the population size for the North Atlantic population of the humpback whale is 11,570 humpback whales (Waring et al. 2010).

Table 7.2. Marine mammal species that may occur in the South Atlantic Bight.
(*) ESA-listed species; (**) The U.S. Fish and Wildlife Service have ESA jurisdiction for manatees.

Common Name	Scientific Name	Relative Abundance re: Project Sites
Rare Species		
False killer whale	*Pseudorca crassidens*	Rare
Pygmy killer whale	*Feresa attenuate*	Rare
Cuvier's beaked whale	*Ziphius cavirostris*	Rare
Killer whale	*Orcinus orca*	Rare
Harbor porpoise	*Phocoena phocoena*	Rare
Melon-headed whale	*Peponocephala electra*	Rare
Rough-toothed dolphin	*Steno bredanensis*	Rare
Fraser's dolphin	*Lagenodelphis hosei*	Rare
Spinner dolphin	*Stenella longirostris*	Rare
Striped dolphin	*Stenella coeruleoalba*	Rare
Occasional/Offshore Species		
Dwarf sperm whale	*Kogia sima*	Rare
Pygmy sperm whale	*Kogia breviceps*	Rare
Long-finned pilot whale	*Globicephala melas*	Rare
Short-finned pilot whale	*Globicephala macrorhynchus*	Rare
Risso's dolphin	*Grampus griseus*	Rare
Common dolphin	*Delphinus delphis*	Rare
True's beaked whale	*Mesoplodon mirus*	Rare
Gervais' beaked whale	*Mesoplodon europaeus*	Rare
Blainville's beaked whale	*Mesoplodon densirostris*	Rare
Sowerby's beaked whale	*Mesoplodon bidens*	Rare
Pantropical spotted dolphin	*Stenella attenuata*	Rare
Clymene dolphin	*Stenella clymene*	Rare
Common/ESA Protected Species		
Blue whale*	*Balaenoptera musculus*	Rare
Fin whale*	*Balaenoptera physalus*	Rare
Humpback whale*	*Megaptera novaeangliae*	Common (winter). May occur year-round.
Northern right whale*	*Eubalaena glacialis*	Common (winter). May occur year-round.
Sei whale*	*Balaenoptera borealis*	Rare
Sperm whale*	*Physeter macrocephalus*	Rare
West Indian manatee (Florida stock)**	*Trichechus manatus latirostris*	Frequent (summer)
Atlantic spotted dolphin	*Stenella frontalis*	Common (year-round)
Bottlenose dolphin (Coastal stock)	*Tursiops truncatus*	Common (year-round)
Bottlenose dolphin (Offshore stock)	*Tursiops truncatus*	Unlikely
Minke whale	*Balaenoptera acutorostrata*	Limited information available

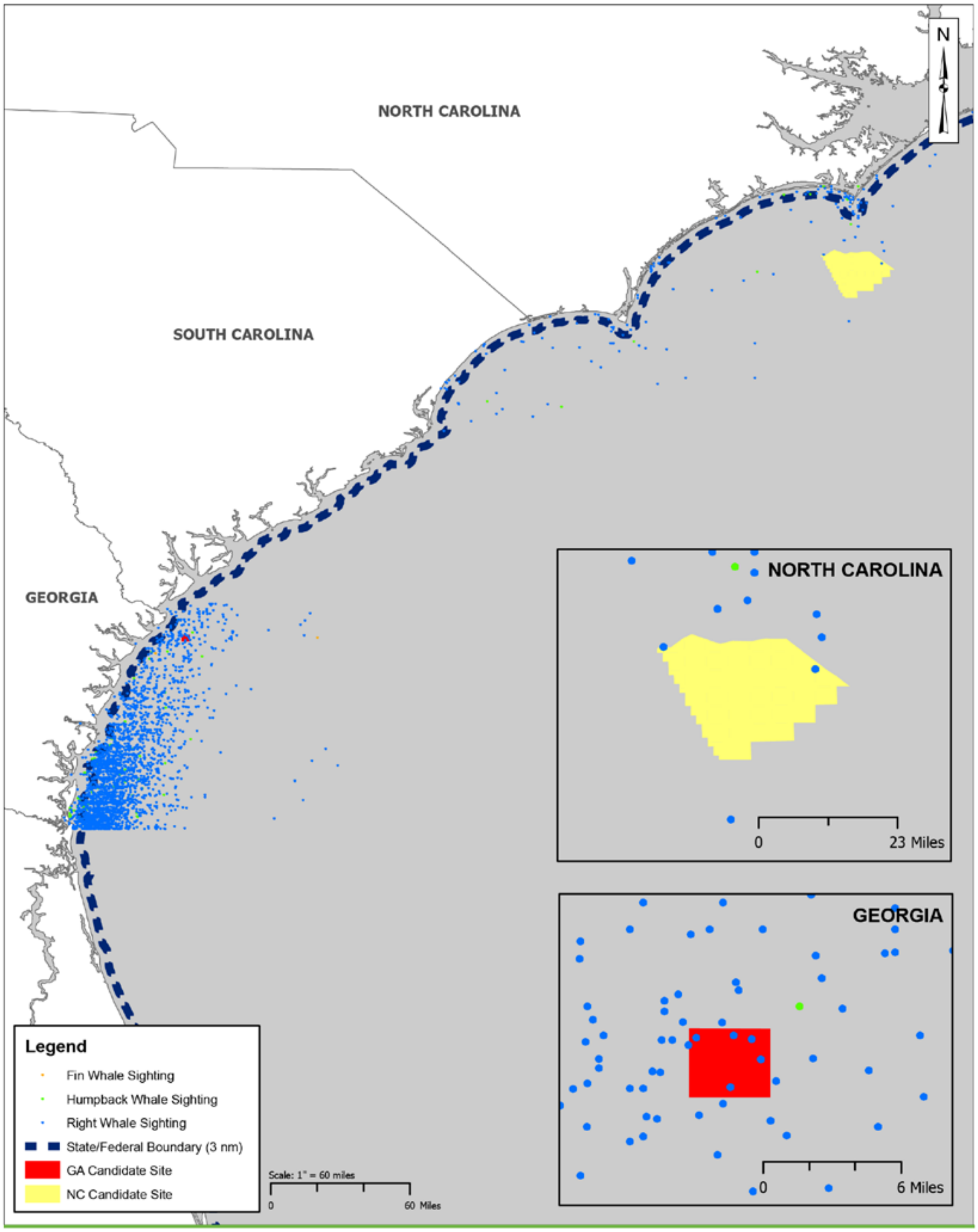

Figure 7.9. Sightings of fin, humpback, and right whales.
Sightings of fin, humpback, and right whales in relation to the wind planning areas.

North Atlantic Right Whale

North Atlantic right whales in the western North Atlantic range from winter calving and nursery areas off the southeastern U.S. to summer feeding grounds off New England and north to the Bay of Fundy and Scotian Shelf (SCDNR 2006b). Other than calving females and a few juveniles that winter off the coasts of Georgia and Florida, the wintering location of the remaining individuals in the population is unknown. In October, a portion of the population, mostly pregnant females, migrates southward to waters off southern Georgia and northern Florida to calve. Currently, the southeastern U.S. is the only known calving ground for the western North Atlantic right whale (SCDNR 2006b). Historical records do contain many sightings of right whales in the study areas (Figure 7.9). One of the important habitat areas for right whales is found off of southern Georgia and north Florida in nearshore waters. This area serves as a nursery ground and is characterized by large shallow embayments that provide safe areas for females to calve in the winter (SCDNR 2006b). Calving occurs from December through March in the known wintering area that is located along the southeastern U.S. coast (SAFMC 2009a). NMFS has designated five critical habitats for the North Atlantic Right Whale. One of these habitats, the Southeast Atlantic Critical Habitat is approximately 60 miles south of GA-Site and 500 miles south of NC-Site (Figure 7.10). Neither of the candidate sites is located within any of the NMFS identified critical habitats.

The population size of the North Atlantic right whale is at a critical level with an estimated population size of 400 animals or less remaining in western North Atlantic waters (SCDNR 2006b). According to Waring et al. (2010), a review of the photo-ID recapture database as of June 24, 2009 indicated that 361 individually recognized whales in the catalog were known to be alive during 2005. This number represents a minimum population size (Waring et al. 2010).

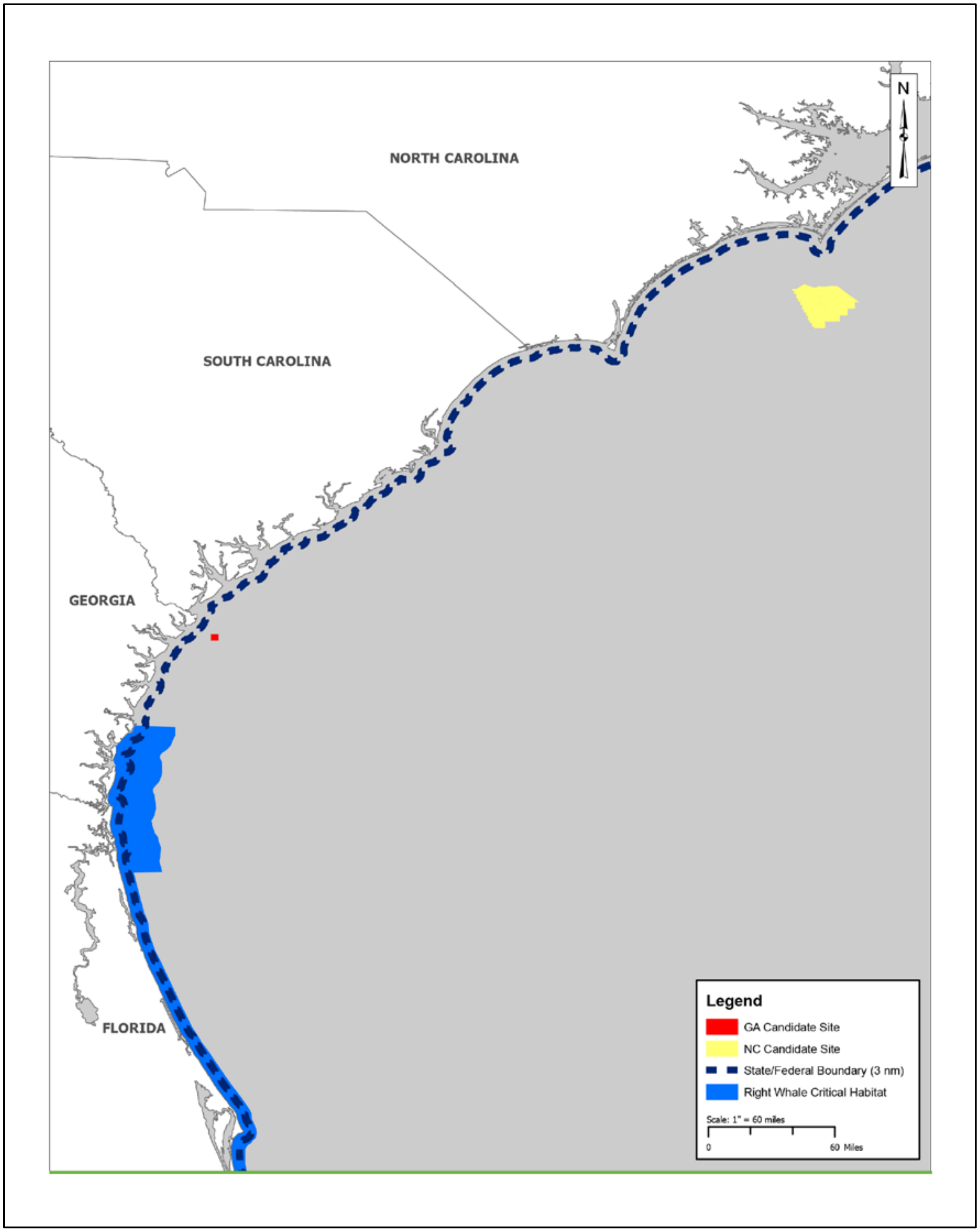

Figure 7.10. Right whale critical habitat.
Right whale critical habitat in relation to NC-Site and GA-Site.

West Indian Manatee
The West Indian manatee (Florida stock) is found throughout the southeastern U.S. and is the stock that has the potential to occur in the vicinity of the proposed candidate sites. These manatees do not tolerate cold well and are generally restricted to the inland and coastal waters of peninsular Florida during the winter where they shelter in or near (or both) warm-water springs, industrial effluents, and other warm water sites. In warmer months, manatees leave these sites and can travel great distances. Individuals have been sighted as far north as Massachusetts, as far west as Texas, and in all states in between. Warm weather sightings are most common in Florida and coastal Georgia (Waring et al. 2009).

The best available count of the Florida stock of West Indian manatees is 3,802 animals, based on a single synoptic survey of warm-water refuges in January 2009 (Waring et al. 2009). This is not a complete count because it does not include the number of manatees located away from the wintering sites on the day of the count.

Bottlenose Dolphin (Coastal Stock)
The Southern Migratory stock of the bottlenose dolphin is defined primarily on satellite tag telemetry studies and is thought to migrate south from waters of southern Virginia and north central North Carolina to waters south of Cape Fear and as far south as coastal Florida during winter months. During summer months when the Southern Migratory stock is found in waters north of Cape Fear, North Carolina, bottlenose dolphins are still seen in coastal waters of South Carolina, Georgia, and Florida, which indicates the presence of additional stocks of coastal animals (Waring et al. 2010).

The best population estimate for the South Carolina-Georgia Coastal stock of bottlenose dolphins is 7,738 as reported in Waring et al. (2010). Most survey effort to date has been concentrated in waters shallower than 20 m deep (Waring et al. 2010). The coastal ecotype prefers waters less than 30 m in depth and is adapted for warm, shallow waters (SCDNR 2006c). Because GA-Site occurs in waters from 13 to 15 m in depth and NC-Site occurs in waters from 30 to 40 m in depth, it is assumed that the coastal stock of bottlenose dolphins would be the likely stock to occur in each of the candidate sites.

Atlantic Spotted Dolphin
Atlantic spotted dolphins regularly occur in the inshore waters south of Chesapeake Bay and near the continental shelf edge and continental slope waters north of this region (Waring et al. 2007). The best recent abundance estimate for Atlantic spotted dolphins according to Waring et al. (2007) is 50,978 (the sum of the estimates from the two 2004 western U.S. Atlantic surveys). Another survey of the U.S. Atlantic Outer Continental Shelf and continental slope (water depths >50 m) was conducted during June through August 2004, where the abundance estimate for this species between Florida and Maryland was 47,400 during this survey (Waring et al. 2007).

7.4.3 Sea Turtles
Five species of sea turtles occur in the SAB. These species are the green turtle (*Chelonia mydas*), Kemp's Ridley turtle (*Lepidochelys kempii*), leatherback turtle (*Dermochelys coriacea*), loggerhead turtle (*Caretta caretta*) and, rarely, the hawksbill turtle (*Eretmochelys imbricate*) (SAFMC 2011a). All of these species are either listed as endangered or threatened under the Endangered Species Act.

Green Sea Turtle
Green sea turtles are listed as threatened in U.S. waters except for the Florida breeding population, which is listed as endangered. However, because it is not possible to distinguish between the populations away from nesting beaches, green sea turtles are considered endangered wherever they occur in U.S. waters (SAFMC2011b). In the U.S., the primary nesting area is located along the eastern coast of Florida;

nesting occurs from June through early October (SAFMC 2011b). According to SAFMC (2011b), green turtle nests have also been recorded on both North and South Carolina beaches.

The Sea Turtle Nest Monitoring System managed by Seaturtle.org reported that three green sea turtle nests were recorded on Georgia beaches in 2011 and six green sea turtle nests were recorded on Georgia beaches in 2010. Zero nests were observed in 2009 and no data are available for years prior to 2009 for Georgia beaches (Seaturtle.org 2011a). For North Carolina beaches, the Sea Turtle Nest Monitoring System reported that 15 green sea turtles nests were recorded in 2011, 18 in 2010, three were reported in 2009, and zero were reported in 2008. No data are available for years before 2008 for North Carolina beaches (Seaturtle.org 2011b). Although some nests have been recorded on Georgia and North Carolina beaches, the primary nesting in the continental U.S. is on the east coast of Florida. No critical habitat has been designated by NOAA Protected Resources for the green turtle in the continental U.S. The NOAA-designated critical habitat for the green turtle are the coastal waters surrounding Culebra Island, Puerto Rico (NOAA Fisheries Office of Protected Resources 2011a).

Green turtles are reported to be found in fairly shallow waters (except when migrating) and are attracted to lagoons and shoals with high densities of marine grass and algae. Adults migrate between nesting and foraging habitats along corridors adjacent to coastlines and reefs (SAFMC 2011b). Because sea grasses are not abundant in the coastal waters of Georgia or North Carolina near NC-Site or GA-Site, these areas are not likely to be a high concentration area for green turtles. Green turtles would occur in higher abundance south of the site in nearshore coastal waters of eastern Florida.

Hawksbill Sea Turtle

Hawksbill sea turtles are listed as endangered under the Endangered Species Act. These turtles are the most tropical of the marine turtles and typically range from 30^{o}N to 30^{o}S, well south of the two candidate sites. Although hawksbills are found primarily in Florida and Texas within the continental U.S., they have been recorded in all the Gulf States and along the east coast as far north as Massachusetts (NOAA Fisheries Office of Protected Resources 2011b).

Zero hawksbill nests were reported on Georgia and North Carolina beaches from 2009 to 2011 by The Sea Turtle Nest Monitoring System managed by Seaturtle.org (Seaturtle.org 2011a; Seaturtle.org 2011b). No critical habitat has been designated by NOAA Protected Resources for the hawksbill turtle in the continental U.S. The NOAA-designated critical habitat for the hawksbill turtle are the coastal waters surrounding Mona and Monito Islands, Puerto Rico (NOAA Fisheries Office of Protected Resources 2011a).

Given the habitat and distribution characteristics of the hawksbill turtle, it is unlikely that hawksbills would be found with any frequency in the vicinity of the two candidate sites. There is the potential for some hawksbill sea turtles to be found in waters offshore of the two sites on a transient basis, but most likely in small numbers.

Kemp's Ridley Sea Turtle

Kemp's ridley sea turtles are listed as Endangered under the Endangered Species Act throughout their range (NOAA Fisheries Office of Protected Resources 2011c). Kemp's ridley turtles range from the Gulf coasts of Mexico and the U.S.to the Atlantic coast of North America as far north as Nova Scotia and Newfoundland (USFWS 2011a). Aside from nesting habitat, the major habitat for these turtles is the nearshore and inshore waters of northern Gulf of Mexico, especially Louisiana waters. They are often found in salt marsh habitats (USFWS 2011a).

The primary nesting beaches for Kemp's ridley turtles are along a beach called Rancho Nuevo in Tamaulipas, Mexico; however, according to SAFMC (2011c), nests have also been recorded in Florida and the Carolinas in recent years. Nesting occurs from April to June. During this time, Kemp's ridleys appear off the Tamaulipas and Veracruz coasts of Mexico (USFWS 2011a). After leaving the nesting beach, hatchlings are believed to become entrained in eddies within the Gulf of Mexico and are then dispersed within the Gulf and Atlantic by oceanic surface currents. After they reach about 20 cm in length, they enter coastal shallow water habitats (USFWS 2011a). According to SAFMC (2011c), post-hatchlings appear to inhabit pelagic waters of the Gulf and North Atlantic for 1–4 years where they feed on sargassum and associated fauna. They are then reported to move into shallow, nearshore waters after one or two years (SAFMC 2011c).

SAFMC (2011a) reports that the nearshore waters of both the Gulf and Atlantic provide important habitat for juvenile Kemp's ridleys. According to capture records from NOAA Fisheries sea turtle trawling research projects in the Southeast, juvenile Kemp's ridleys may overwinter near Cape Canaveral, Florida. The juveniles then move northward along the Atlantic coast as sea temperatures increase and have been found foraging as far north as the New England. In the fall, as sea temperatures begin to cool, these turtles will then migrate southward. These seasonal movements up and down the coast may continue until they reach sexual maturity when most are assumed to return to the Gulf of Mexico to breed (South Atlantic Fishery Management Council 2011c).

Zero Kemp's ridley nests were reported on Georgia beaches from 2009 to 2011 by The Sea Turtle Nest Monitoring System managed by Seaturtle.org (SeaTurtle.org 2011b). This same monitoring system reported that two Kemp's ridley nests were recorded in 2010 on North Carolina beaches. Zero Kemp's ridley nests were reported on North Carolina beaches in 2008, 2009, and 2011 (SeaTurtle.org 2011b). Currently there is no critical habitat designated by NOAA Protected Resources for the Kemp's ridley turtle in the continental U.S.; however, in February 2010, NOAA Fisheries and USFWS were jointly petitioned to designate critical habitat for Kemp's ridley sea turtles for nesting beaches along the Texas coast and marine habitats in the Gulf of Mexico and Atlantic Ocean. The petitioned habitats do not include Georgia or North Carolina beaches or coastal waters (NOAA Fisheries Office of Protected Resources 2011c).

Given the habitat preferences and nesting areas for Kemp's ridley sea turtles, they are not likely to be found in the vicinity of GA-Site or NC-Site except during migration up and down the coast to and from foraging and nesting sites.

Leatherback Sea Turtle
Leatherback sea turtles are listed as Endangered under the Endangered Species Act throughout their range (NOAA Fisheries Office of Protected Resources 2011d). Leatherbacks are distributed worldwide in tropical and temperate waters of the Atlantic, Pacific and Indian Oceans. In the U.S. and its territories, small nesting populations occur on the east coast of Florida, Sandy Point in the U.S. Virgin Islands, and in Puerto Rico. Leatherback nesting activity has also been reported on the beaches of Georgia and the Carolinas; North Carolina is the northernmost state on the east coast with confirmed nesting (SAFMC 2011d). The Sea Turtle Nest Monitoring System reported that 11, four, and seven leatherback sea turtle nests were recorded on Georgia beaches in 2011, 2010, and 2009, respectively. No data are available for years before 2009 (SeaTurtle.org 2011a). This same monitoring system reported that two leatherback nests were recorded in 2010 and one in 2009 on North Carolina beaches. Zero leatherback nests were reported on North Carolina beaches in 2008 and 2011 (SeaTurtle.org 2011b). Nesting areas required by adult females have sandy beaches backed with vegetation and sloped so the crawl to dry sand is not too far. Preferred beaches have proximity to deep water and generally rough seas (USFWS 2011b).

Although some nests (very low numbers) have been recorded on Georgia and North Carolina beaches, the primary nesting in the U.S. occurs in the U.S. Caribbean (Puerto Rico and the U.S. Virgin Islands) and southeast Florida. These areas, far south of the two candidate sites, represent the most significant nesting activity within the U.S. (NOAA Fisheries Office of Protected Resources 2011d). No critical habitat has been designated by NOAA Protected Resources for the leatherback sea turtle in the continental U.S. The NOAA designated critical habitat for the leatherback is the coastal waters adjacent to Sandy Point, St. Croix, U.S. Virgin Islands (NOAA Fisheries Office of Protected Resources 2011a).

In the U.S., nesting occurs from about March to July (USFWS 2011b). SAFMC (2011d) reports that the main nesting area for leatherbacks in the continental U.S. is the eastern coast of Florida, where leatherbacks begin nesting as early as late February and continue into August and early September. Very little is known about the pelagic habits of hatchlings and smaller juveniles because aerial surveys are limited to observations of larger individuals. When hatchlings leave the nesting beaches, they move offshore but have not been documented to associate with rafts of sargassum, as are other species. Eventually they use both coastal and pelagic waters. Large juveniles and adults from the southeastern coast appear to move to the mid-Atlantic in the spring with individuals continuing further north to Canadian waters in the summer. During the fall and winter, leatherbacks travel southward or perhaps further offshore (South Atlantic Fishery Management Council 2011d).

Leatherback sea turtles are the most pelagic of the sea turtles and thus may have a greater chance of occurring in the waters surrounding the two candidate sites. They could be present in the vicinity of GA-Site and NC-Site during migration periods, for foraging, and in small numbers for nesting on Georgia or North Carolina beaches.

Loggerhead Sea Turtle

Loggerhead sea turtles are listed as Endangered under the Endangered Species Act (NOAA Fisheries Office of Protected Resources 2011e). Loggerheads are considered the most abundant species of sea turtle occurring off U.S. shores (SAFMC 2011e). Aerial surveys indicate that 90% of U.S. loggerhead nesting occurs in Florida, 6% in South Carolina, 2% in Georgia and 2% in North Carolina (SAFMC 2011e). The Sea Turtle Nest Monitoring System reported that 1,975, 1,760, and 998 loggerhead sea turtle nests were recorded on Georgia beaches in 2011, 2010, and 2009, respectively (SeaTurtle.org 2011a). This same monitoring system reported that 930, 847, and 290 loggerhead sea turtle nests were recorded on North Carolina beaches in 2011, 2010 and 2009, respectively (SeaTurtle.org 2011b). Loggerhead nests are by far the dominant nests found on Georgia and North Carolina beaches as reported by Seaturtle.org (2011a; 2011b). The nesting season in the U.S. is reported to extend from approximately May through August, with nesting primarily occurring at night (USFWS 2011c). In Florida, nesting is reported to occur from March to August and in North Carolina from mid-May to mid-August(SAFMC 2011e). No critical habitat has been designated by NOAA Protected Resources for the loggerhead sea turtle (NOAA Fisheries Office of Protected Resources 2011a).

According to SAFMC (2011e), loggerheads spend their first 7 to 13 years in the pelagic environment until they reach a size of approximately 16–24 in (40–60 cm). After they reach that size, they move to nearshore and estuarine waters and live in benthic habitats where they feed primarily on invertebrates; however, it has been reported that some loggerheads may alternate between the pelagic and benthic environment. There is little data on the movements of immature loggerheads because it is hard to monitor marine turtles before they return to their nesting beaches. Subadults were the most abundant turtles captured in trawl surveys conducted off east-central Florida; however, there was a shift to a larger size class during April to July as reproductively active adults arrived at the nesting beaches. During this time, immature loggerheads are thought to migrate to foraging grounds as far north as Chesapeake Bay. Adult loggerheads captured in trawl surveys declined by late summer, coinciding with the end of nesting season, whereas the presence of subadult loggerheads increased again with the approach of winter. Juvenile feeding populations are known to occupy the Indian River in Florida, as well as harbors and sounds of Georgia and the Carolinas (SAFMC 2011e).

The loggerhead is the sea turtle that is most likely to occur in the vicinity of GA-Site and NC-Site and is reported to be the most abundant based on nesting data compared to the other species of sea turtles. Loggerhead sea turtles are documented to use Georgia and North Carolina beaches for nesting in greater numbers than the other species and therefore are more likely to occur in greater numbers in the coastal waters and offshore waters of NC-Site and GA-Site.

7.4.4 Discussion

The two sites are located within the SAB, which is formed by the long, bending coastline of the United States from Cape Hatteras, North Carolina to approximately West Palm Beach, Florida. Despite its name, the SAB is a part of the western North Atlantic and is habitat to many of the marine vertebrates found both to the north and the south of the project study areas, including the Gulf of Mexico. The ecological characteristics of the SAB are influenced by many factors, including the relatively narrow (i.e., 40 to 140 km wide) continental shelf and the ever-present northeasterly flow of the Gulf Stream. Unlike the waters north of Cape Hatteras, which are more diverse and dynamic because of the dramatic eastward deflection of the Gulf Stream, the SAB is generally considered less productive ecologically. Eighty percent of the SAB is soft bottom habitat (sand) and 20% live hard bottom habitat, which is made up of rock reefs covered by coral or algae. This habitat supports a wide range of resident fish species from the Lutjanidae and Serranidae families that are common to subtropical waters south of Cape Hatteras to the Gulf of Mexico.

The marine mammals that use the SAB can be generally categorized into two groupings: coastal, residential stocks and migratory stocks. The coastal grouping consists of the bottlenose dolphin and West Indian manatee. These species have defined coastal stocks along Georgia and Florida, respectively, and can occur in the areas of the two sites throughout the year, but are most commonly in the warmer months. In contrast, a wide range of migratory cetaceans, including North Atlantic right whale, fin whale, and humpback whale, pass through the SAB on a seasonal basis. Given that the two sites are in the relatively shallow waters of the inner and mid continental slope, most migratory cetaceans would be expected to pass to the east of these locations about 140 km from shore at the continental slope. The exception to this point is the North Atlantic right whale because of its use of coastal waters along Georgia as nursery habitat. Historical sightings data confirm that this species congregates in these waters on an annual basis and may occur with some regularity in the vicinity of the two sites making it one of, or the, most abundant marine mammal in the study area.

Sea turtles use the waters of the SAB including the nearshore marine environments associated with the two sites. Four species of sea turtles are known to occur in these waters with varying degrees of regularity: hawksbill, Kemp’s Ridley, leatherback, and loggerhead. Any of these species could pass through the two sites during migration. However, loggerheads are known to nest with relatively high density, compared to the other three turtle species, along the coastline from Florida to North Carolina. Although Kemp’s Ridley and leatherback turtles are also known to nest in this region, documented nestings are fewer than for the loggerhead turtle. These nesting species could pass through or in close proximity to the candidate sites, swimming to or from nesting sites along the shoreline.

8. SUMMARY AND CONCLUSIONS

This study was conducted for BOEM as a baseline biological study of focal marine vertebrate species at two wind planning areas in the U.S. Southeast Atlantic coast section of the Outer Continental Shelf (OCS). The wind planning areas are part of the Beaufort (block NI18-04; North Carolina) and Brunswick (block NH 17-02; Georgia) lease blocks, within Onslow Bay and the Georgia Bight, respectively. The study sites are herein referred to as the North Carolina and Georgia sites. These sites are coastal, shallow water habitats that are home to range of fish species, marine mammals, turtles, and sub-tropical coral reefs that have varying degrees of protected status or fisheries importance. Because these sites are highly productive coastal ecosystems, in this study we performed a baseline survey for future research in the environmental impacts of offshore wind energy development.

The Bioacoustics Research Program (BRP) at the Cornell University's Laboratory of Ornithology, in collaboration with ESS Group, Inc. and Marine Acoustics, Inc. (MAI;), conducted an ecological characterization of the North Carolina and Georgia sites with the following approaches:

1. Evaluate the seasonal occurrence of North Atlantic right whales (*Eubalaena glacialis*), fin whales (*Balaenoptera physalus*), and humpback whales (*Megaptera novaeangliae*) as representative, protected marine mammal species, and baleen whales, to understand the environmental risks associated with their presence (BRP).
2. Evaluate the occurrence and spawning behavior of black drum (*Pogonias cromis*) and oyster toadfish (*Opsanus tau*) as representative fish species to understand these populations and evaluate the utility of these two species as ecological indicators of the ecosystems (BRP).
3. Characterize the ambient noise environment around the wind planning areas (BRP) and model the propagation of wind farm construction activities (MAI).
4. Characterize the physical structure of the benthic habitats and associated flora and fauna (ESS).

To address the occurrence of marine mammals and fishes and the ambient noise conditions, acoustic data were collected using marine autonomous recording units (MARUs) (Calupca et al. 2000) at the North Carolina and Georgia sites. At both sites, three MARUs were deployed in a linear formation across the wind energy planning area. Acoustic data were recorded in two consecutive deployments of the MARUs at each site, from 12 June–10 November 2012 and 12 November 2012–15 April 2013 at the North Carolina site and 9 June–8 November 2012 and 10 November 2012–12 April 2013 at the Georgia site. A total of 307 consecutive days were recorded at each site, with the exception of 11 November 2012 in North Carolina and 9 November 2012 in Georgia, when MARUs were replaced for the following deployment. Sound data were sampled at 2 kHz with high-pass and low-pass filters set at 10 Hz and 800 Hz, respectively.

8.1 OCCURRENCE OF BALEEN WHALES

We characterized the occurrence of North Atlantic right whales (*Eubalaena glacialis*), fin whales (*Balaenoptera physalus*), and humpback whales (*Megaptera novaeangliae*) at the North Carolina and Georgia sites. Contact calls, or up-calls, of right whales were detected with an automated detection algorithm (Urazghildiiev et al. 2009), and 20 Hz song notes of fin whales were also detected with an automated detection algorithm (Bioacoustics Research Program 2012). Daily presence of right whales and fin whales was determined by one or more species-specific calls detected in each site. Humpback whales were opportunistically identified during these analyses.

Right whales were detected throughout the study, with peak presence November–April, when whales have previously been described as migrating through the mid-Atlantic (Winn et al. 1986). As presence decreases in Georgia while increasing in North Carolina between January and March, this shift corresponds to the migration of right whales from the calving grounds to the feeding grounds in the northeast U.S. (Kenney et al. 2001). Surprisingly, a secondary peak of right whale presence occurred in June and July in the Georgia site, when right whales typically aggregate in the North Western Atlantic (Winn et al. 1986). Additionally, 14% of daily presence in North Carolina and nearly a third (29%) in Georgia occurred outside of the mid-Atlantic seasonal management area (November 1–April 30) (NOAA 2008). These data suggest that right whales may occur in this region more often than previously documented. Although researchers have discovered right whales in other regions during times of the year when right whales were previously unexpected to be found, or have documented unexpected movement patterns (Mate et al. 1997; Mellinger et al. 2011; e.g., Moore and Clark 1963), without multiple years of acoustic surveys, it is unclear if these results are an aberration in right whale occurrence during this study period or indicate an annual pattern of previously undocumented occurrence.

In Georgia and North Carolina, we did not detect a significant presence of fin whales or humpback whales. Fin whales were detected on only six days in the North Carolina site, in November 2012 and March 2013, consistent with previous records of fin whale occurrence in this region (Nieukirk et al. 2004; Waring et al. 2013b; Webster et al. 1995). Humpback whale vocalizations were opportunistically found on eight days in the Georgia site and twelve days in the North Carolina site, across the year, but primarily in December 2012. Humpback whales can occur in the mid-Atlantic in the autumn and winter, but they primarily migrate from feeding grounds in the North Atlantic to breeding grounds in the West Indies in these seasons (Barco et al. 2002; Waring et al. 2013a).

8.2 OCCURRENCE OF FISHES

The daily presence of black drum (*Pogonias cromis*) and oyster toadfish (*Opsanus tau*) was determined by identifying the loud drum calls of black drum (Mok and Gilmore 1983) and the boat whistle calls of oyster toadfish (Tavolga 1958). Black drum and oyster toadfish were acoustically detected over differing time periods at the North Carolina and Georgia sites. Black drum are predominantly present from the fall through spring (November–April 2013). Oyster toadfish are predominantly present in the early spring and summer (March–April 2013 and June–August 2012).

Chorusing of black drum and oyster toadfish was detected in late June 2012 and late March and April 2013 at the Georgia site, and was visible in multi-day long spectrograms. Black drum chorusing was also detected at NC-North in March–April, but no toadfish chorusing was detected in North Carolina. This seasonal chorusing is consistent with previous research on the winter and spring spawning season for black drum (Macchi et al. 2002; Murphy and Taylor 1989; Saucier and Baltz 1993) and spring to summer for toadfish (Gray and Winn 1961). Toadfish chorused throughout the day and black drum had a strong diel signature, chorusing overnight. Both chorusing patterns are consistent with previous research (Fine et al. 1977; Mok and Gilmore 1983; Saucier and Baltz 1993).

The presence of both fish in our data is related to daily average water temperature, collected at each MARU, which may be one of the environmental triggers for spawning in these fishes. Environmental conditions are cues for the timing of spawning in black drum and toadfish, including light, water temperature, and dissolved oxygen (e.g., Aalbers 2008; Lowerre-Barbieri et al. 2008; Mann and Grothues 2009; Rice and Bass 2009). Specific conditions in salinity and temperature are triggers for black drum spawning (Saucier and Baltz 1993). However, because both species were acoustically detected on fewer days in North Carolina than in Georgia, and there was variability in the presence of each species between MARUs, habitat conditions also likely influence the occurrence of these species. There may be greater availability of preferred habitat in the shallow Georgia site, and this site may be patchy.

Based on the lower acoustic occurrence of black drum and toadfish in North Carolina, these two species would not be effective indicator species at this site. However, other sound signals, likely from unidentified fish species, occurred throughout the study period. With additional research to identify the sources of these signals and the pattern of occurrence, these may be more reliable indicators of the environment than black drum and oyster toadfish.

At the Georgia site, black drum and oyster toadfish occurred regularly, but within different seasons, with some overlap. Therefore, these species may be good indicators of environmental change at different times of the year. By monitoring the occurrence and chorusing of these species over multiple years, these species could be effective indicators of ecological change. Additionally, monitoring these changes within the context of offshore wind energy development would identify the effects of wind farm construction and operation.

8.3 AMBIENT NOISE ENVIRONMENT

To evaluate the ambient noise conditions of North Carolina and Georgia, acoustic data from each MARU were processed (Dugan et al. 2011) and presented in long duration (i.e., multiple weeks or months) spectrograms and power spectra. Overall, summer and fall months (June–November) had higher levels of noise in comparison to winter and spring months (December–April). Geographically, the three MARUs in Georgia showed qualitatively higher levels of noise than the three MARUs in North Carolina. Within each geographic location, there was no significant variation in noise between individual sites.

Sources of noise events in the North Carolina and Georgia environments include weather, biological, anthropogenic, and unknown sources of sounds. Fish chorusing, most notably black drum, is the dominant biological sound source in these sites. In addition, several unknown sources of sound, potentially biological, had significant contributions to the noise environment. Though marine mammal vocalizations were recorded throughout the study, they did not occur frequently enough to be visible on long term spectrograms. Anthropogenic noise, produced predominantly by ship traffic, has the potential to mask biological sounds, but further research is needed to address if masking is a biologically significant impact (i.e., if masking prevent intra-species communication).

Overall, these ambient noise data provide a baseline of the noise conditions in these ecosystems, so that relative contributions to the baseline noise from future increases in ship traffic, construction, and wind farm operation can be measured and the impacts to marine organisms can be assessed.

8.3 HABITAT CHARACTERIZATION

The benthic habitats of the North Carolina and Georgia sites are predominantly soft-bottom substrates comprised of sandy sediments, with some hard-bottom outcroppings, including live and artificial coral. In the region of these sites, there is a diverse assemblage of marine animals, turtles, and fishes. These species have a variety of protected statuses and importance to commercial and recreational fisheries. Habitat characteristics, such as depth, circulation, temperature, and salinity, influence the marine species' use of these sites; therefore, to assess ecological changes, research should monitor the populations of focal species and the influential environmental conditions.

8.4. CONCLUSIONS AND RECOMMENDATIONS

A scientific survey of the ecosystem should be carried out before engaging in activities that may perturb the environment. A baseline understanding of the occurrence of species and quality of the habitat provides information to compare and measure ecosystem changes. This study provided a baseline understanding of the occurrence of focal marine mammal and fish species, ambient noise environment, and habitat characteristics. Additional monitoring of these sites would elucidate inter-annual variability in the occurrence of species and habitat in the North Carolina and Georgia sites.

Passive acoustic monitoring has emerged as a non-invasive, data-intensive, low-cost method to survey the occurrence, abundance and behavior of acoustically active organisms. These techniques have provided previously unknown information about the occurrence of species in these sites. Previously available data on the occurrence of right whales had not identified that right whales occur in the summer. Because the Georgia site is just north of the southeastern U.S. critical habitat and the North Carolina and Georgia sites are part of the migratory corridor, the documented presence of right whales during the winter is useful when evaluating right whale management practices. Passive acoustic monitoring cannot determine behavioral changes in individuals, but it can address population-level behavioral changes. Environmental management decisions are best made with comprehensive data, and so passive acoustic monitoring can be combined with other survey techniques.

Fish species should be considered as indicators of environmental change, and selected species should reflect the habitat requirements and seasonal occurrence of a larger species assemblage with similar ecological requirements in a region. Given that there was a wide range of spatial and temporal variability in the amount and seasonality of calling behavior of black drum and toadfish, future surveys should include spatial replication to demonstrate the degree of micro-scale variability of the focal species' behavior and occurrence. Our acoustic data reflects how little research has been done to identify species-specific calls for many fishes. By identifying sound potentially produced by fish in Onslow Bay, researchers can develop a different set of fishes as possible ecological indicators at the North Carolina site.

To comprehensively assess the North Carolina and Georgia sites, BOEM could coordinate with other state and federal agencies to leverage survey efforts for natural resource inventories and management. For example, the U.S. Naval Facilities Command Atlantic (NAVFAC) has surveyed the habitat, marine mammals, and fish species in Onslow Bay as part of the environmental impact assessment for the Undersea Warfare Training Range (USWTR). This survey location is relatively close to the North Carolina wind planning area, and much of this survey information would be useful in the context of BOEM's efforts. Further interagency cooperation could benefit multiple projects and reduce overall study costs, including biological surveys conducted for the U.S. Navy Onslow Bay Undersea Warfare Training Range (USWTR) and the Gray's Reef National Marine Sanctuary.

Future studies should address how marine organisms respond to potential noise stressors and habitat disturbance introduced by construction and operation of offshore wind farms. This study did not address this, but could be used as baseline information to explore the potential impacts.

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APPENDIX: OTHER BIOLOGICAL SIGNALS

The acoustic environment of the North Carolina and Georgia study sites are rich with biotic and abiotic signals, most of which have not previously been studied. In whale and fish analysis (see Chapters 3 and 4, respectively), we identified signals from known biological sources and signals from unidentifiable sources. Although we did not examine patterns of occurrence of these identifiable species or unknown signals, here we provide examples of our observations, because these may useful for future acoustic research.

A.1 Additional Biological Sources of Acoustic Signals

We identified signals from cusk eel and sei whales in North Carolina and Georgia.

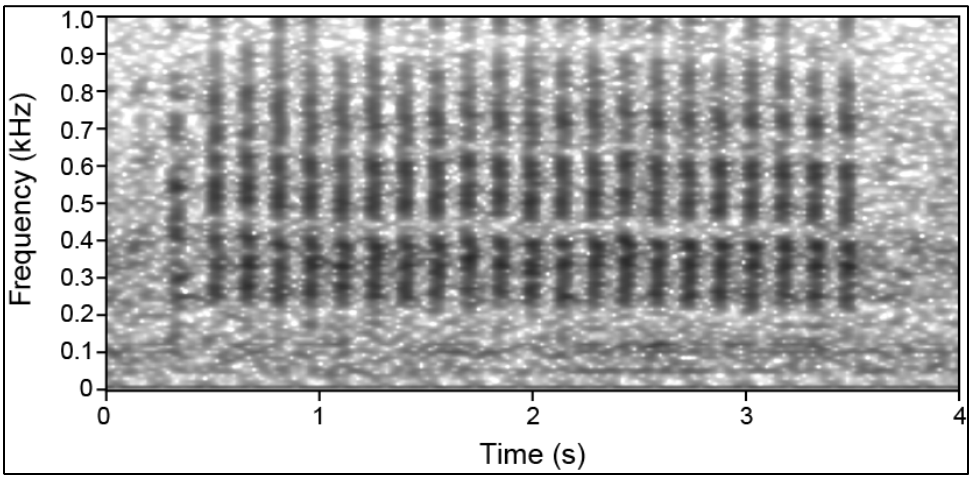

Figure A-1. Cusk-eel
Vocalizations from cusk-eels, unidentified species (Family: Ophidiidae), were seen in the North Carolina and Georgia sites. The signal is a rapid series of broadband bursts and sounds like knocking. The rate is constant within a bout, but the rate may vary between bouts. These are similar to the vocalizations of striped cusk-eel (*Ophidion marginatum*) (Mann et al. 1997). The duration of the series of pulses varies, but the range of duration was not measured. Spectrogram: 256-point Hann window and 89.9% overlap (frequency resolution of 7.81 Hz, time resolution of 13 ms).

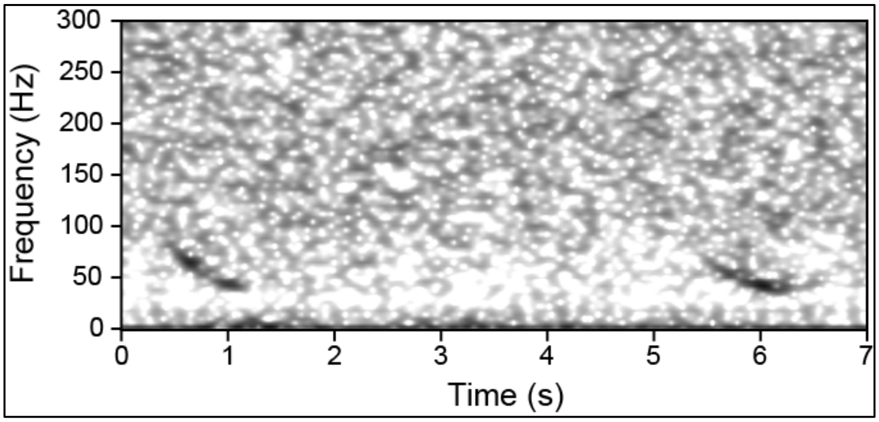

Figure A-2. Sei whale
Vocalizations from sei whales (*Balaenoptera borealis*) were seen in the North Carolina site (Baumgartner and Fratantoni 2008; Baumgartner et al. 2008). Hodge (2011) reported these signals in Onslow Bay. Spectrogram: 512-point Hann window and 90% overlap (frequency resolution of 3.91 Hz, time resolution of 25.5 ms).

A.2 Biological Signals from Unknown Sources

Here we present seven signals that occurred often enough for us to note the signals, and to avoid confusing these signals with signals from the focal study species (black drum, oyster toadfish). Given the irregular pattern and characteristics of the signals, we believe these to be from a biological source, most likely a fish species whose signals have not yet been described.

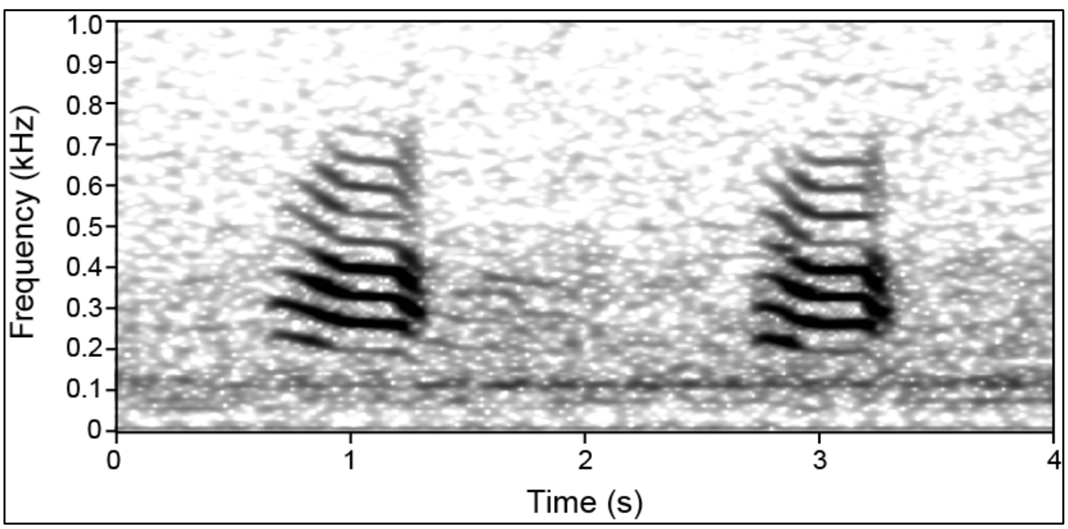

Figure A-3. Sound from an Unknown Source #1
Non-linear signals appear as a stack of downsweeps, approximately 0.6 s duration, and approximately 200–700 Hz. These signals were identified in Georgia and North Carolina. Spectrogram: 256-point Hann window and 89.8% overlap (frequency resolution of 7.81 Hz, time resolution of 13 ms).

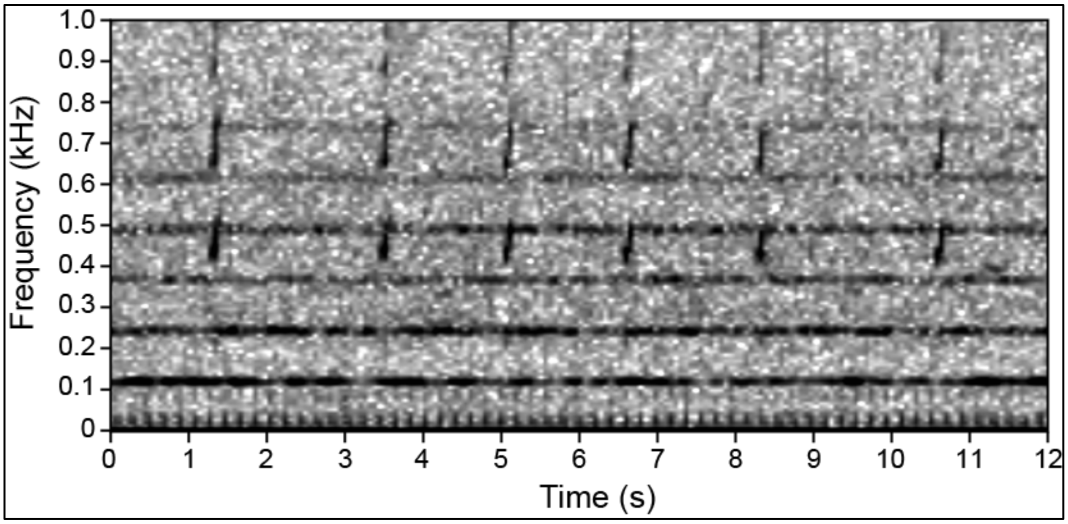

Figure A-4. Sound from an Unknown Source #2
These signals are a very short upsweep, approximately 0.2 s duration, appearing to begin at 430 Hz, but some signal can be visible at approximately 200 Hz. These were identified in Georgia and North Carolina, and noted as a significant sound source in the ambient noise environment in North Carolina (see Chapter 5.3.2.5, Figure 5.13). Spectrogram: 256-point Hann window and 50% overlap (frequency resolution of 7.81 Hz, time resolution of 64 ms).

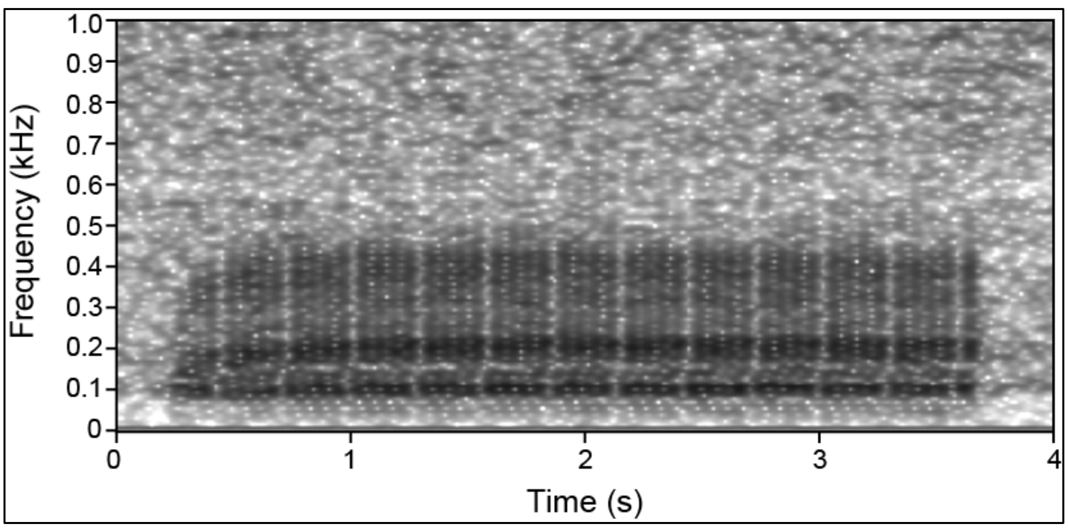

Figure A-5. Sound from an Unknown Source #3
These signals are continuous, very rapid pulse-like, 3-4 s duration, below 500 Hz. These were identified in Georgia and North Carolina. Spectrogram: 256-point Hann window and 89.8% overlap (frequency resolution of 7.81 Hz, time resolution of 13 ms).

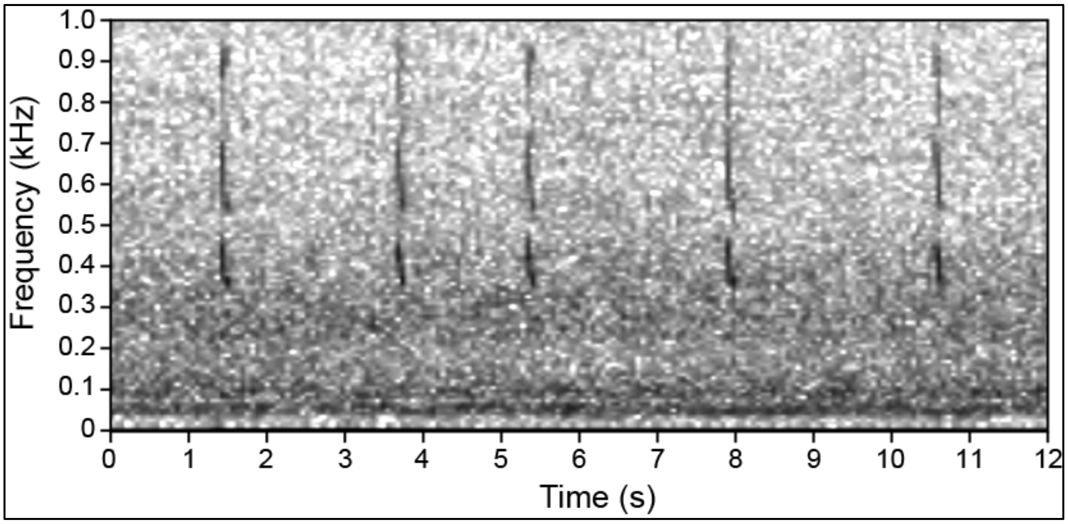

Figure A-6. Sound from an Unknown Source #4
These signals are similar to #2, but are short downsweeps, 0.2 s duration, and begins at 350 Hz. These were identified in Georgia and North Carolina. Spectrogram: 256-point Hann window and 50% overlap (frequency resolution of 7.81 Hz, time resolution of 64 ms).

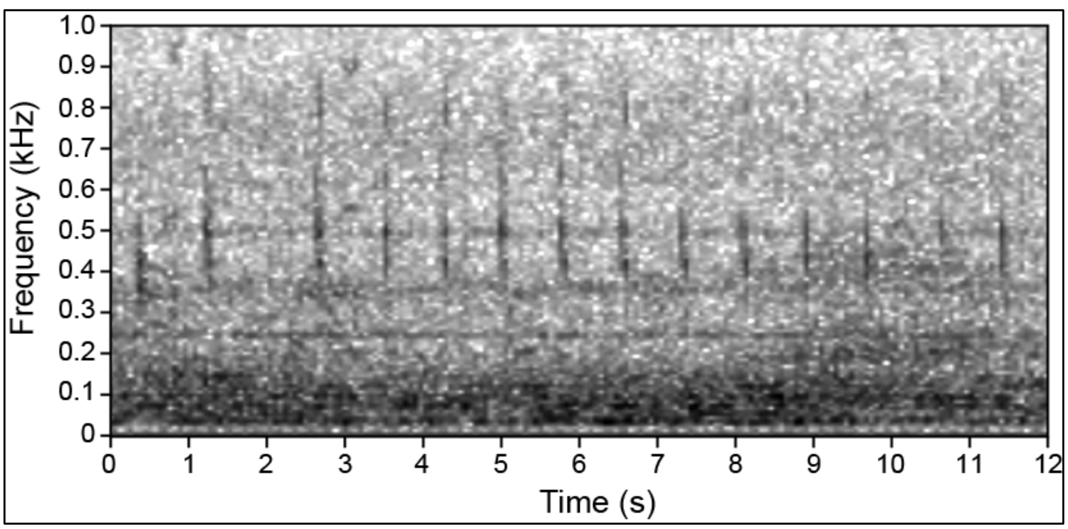

Figure A-7. Sound from an Unknown Source #5
These signals are similar to #2 and #4, but have a different sound quality. They are approximately 0.2 s duration, beginning at 350 Hz, and were identified in Georgia and North Carolina. Spectrogram: 256-point Hann window and 50% overlap (frequency resolution of 7.81 Hz, time resolution of 64 ms).

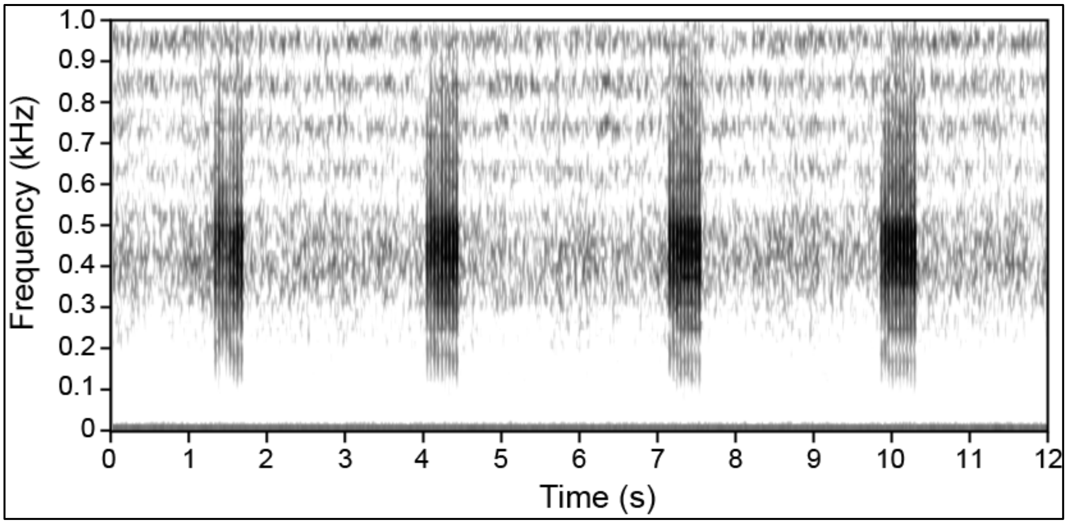

Figure A-8. Sound from an Unknown Source #6
These signals were identified in Georgia and North Carolina. Spectrogram: 128-point Hann window and 89.8% overlap (frequency resolution of 15.6 Hz, time resolution of 6.5 ms).

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island communities.

The Bureau of Ocean Energy Management Mission

The Bureau of Ocean Energy Management (BOEM) works to manage the exploration and development of the nation's offshore resources in a way that appropriately balances economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.