OCS EIS/EA
BOEM 2012-005

Atlantic OCS
Proposed Geological and Geophysical Activities

Mid-Atlantic and South Atlantic Planning Areas

Draft Programmatic Environmental Impact Statement

Volume II: Figures, Tables, Appendices, and Keyword Index

U.S. Department of the Interior
Bureau of Ocean Energy Management
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Author

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Gulf of Mexico OCS Region

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by
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Cover Photo (Whales) – courtesy National Oceanic and Atmospheric Administration/National Ocean Service

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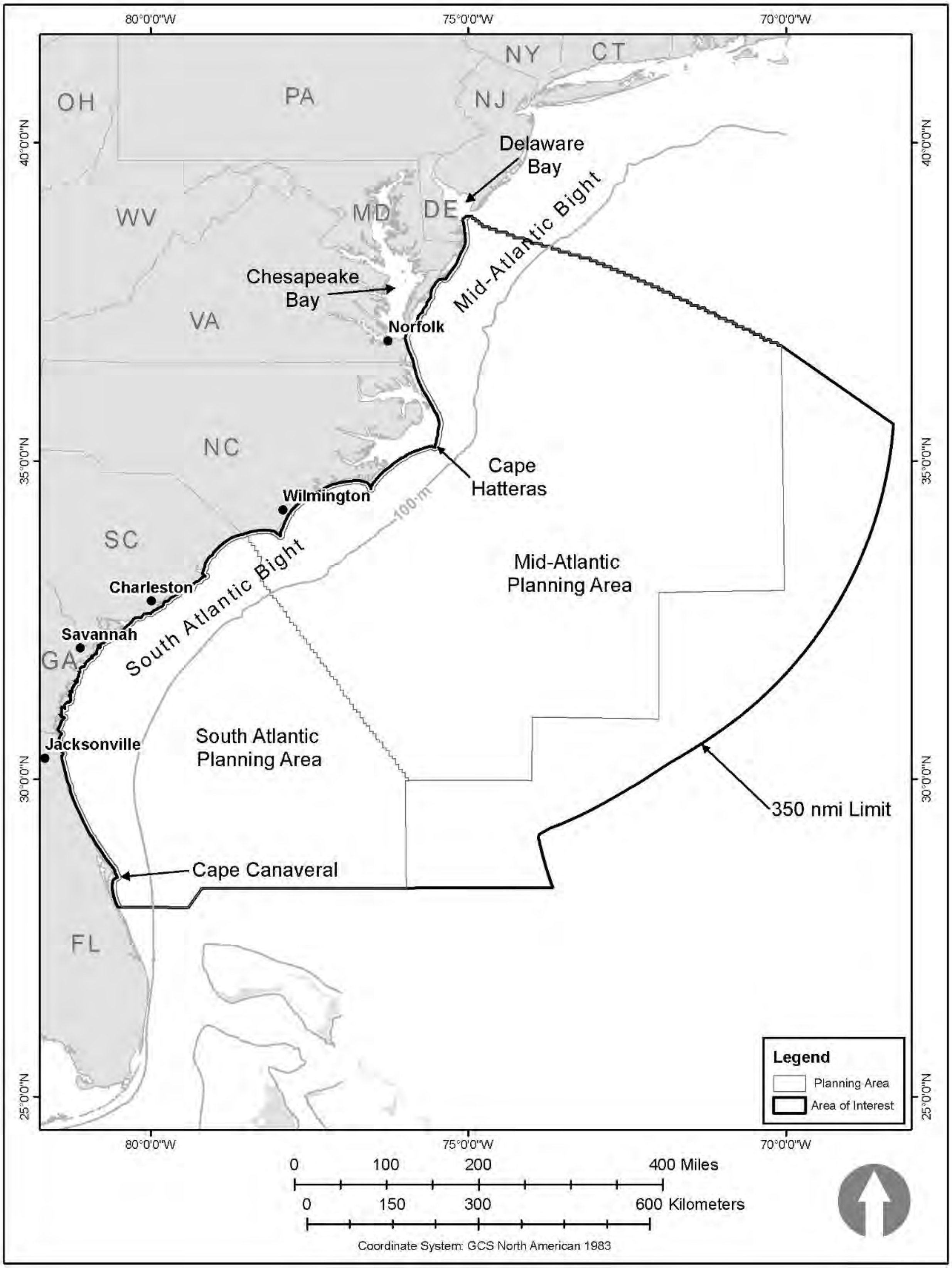

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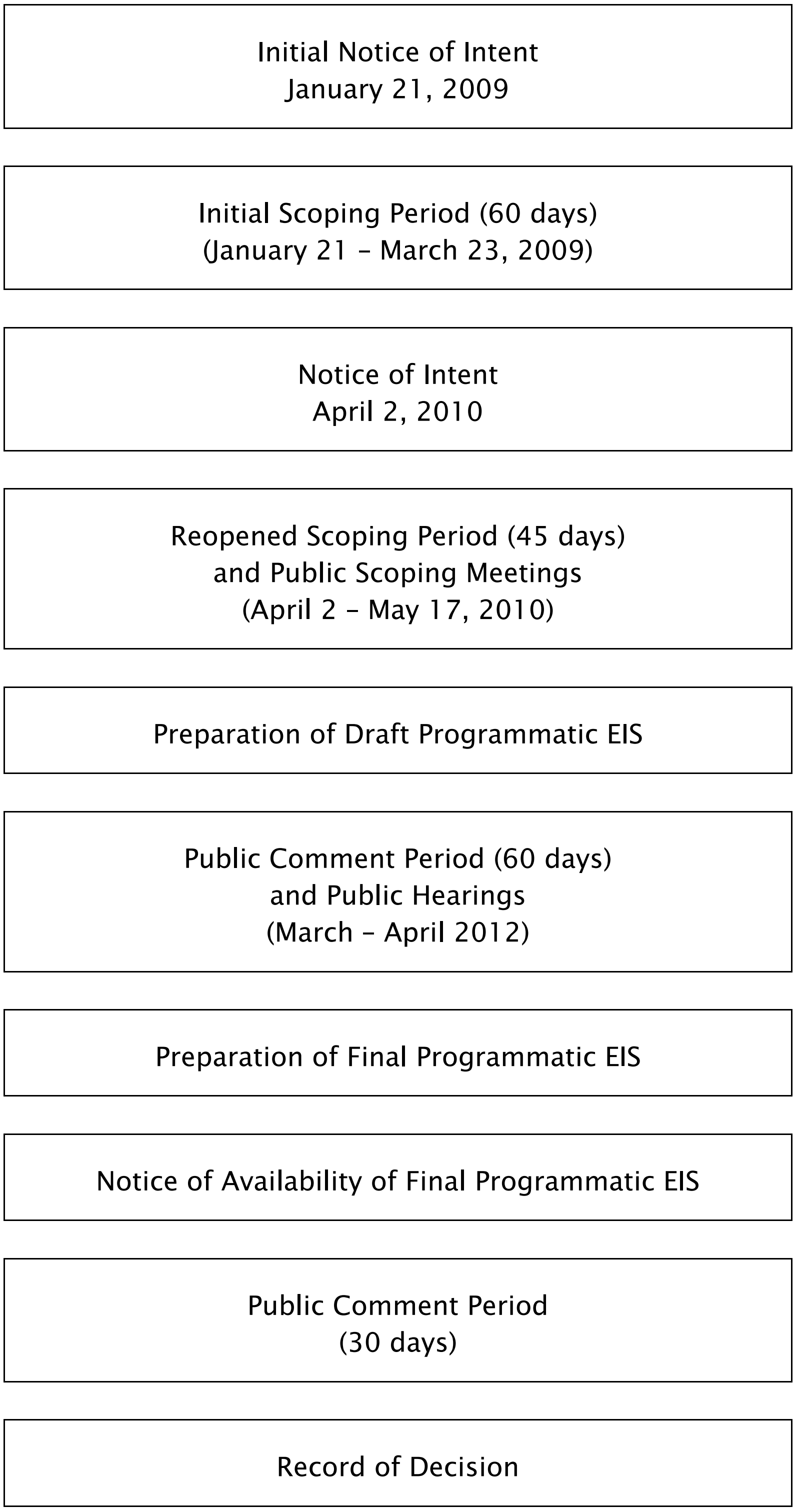

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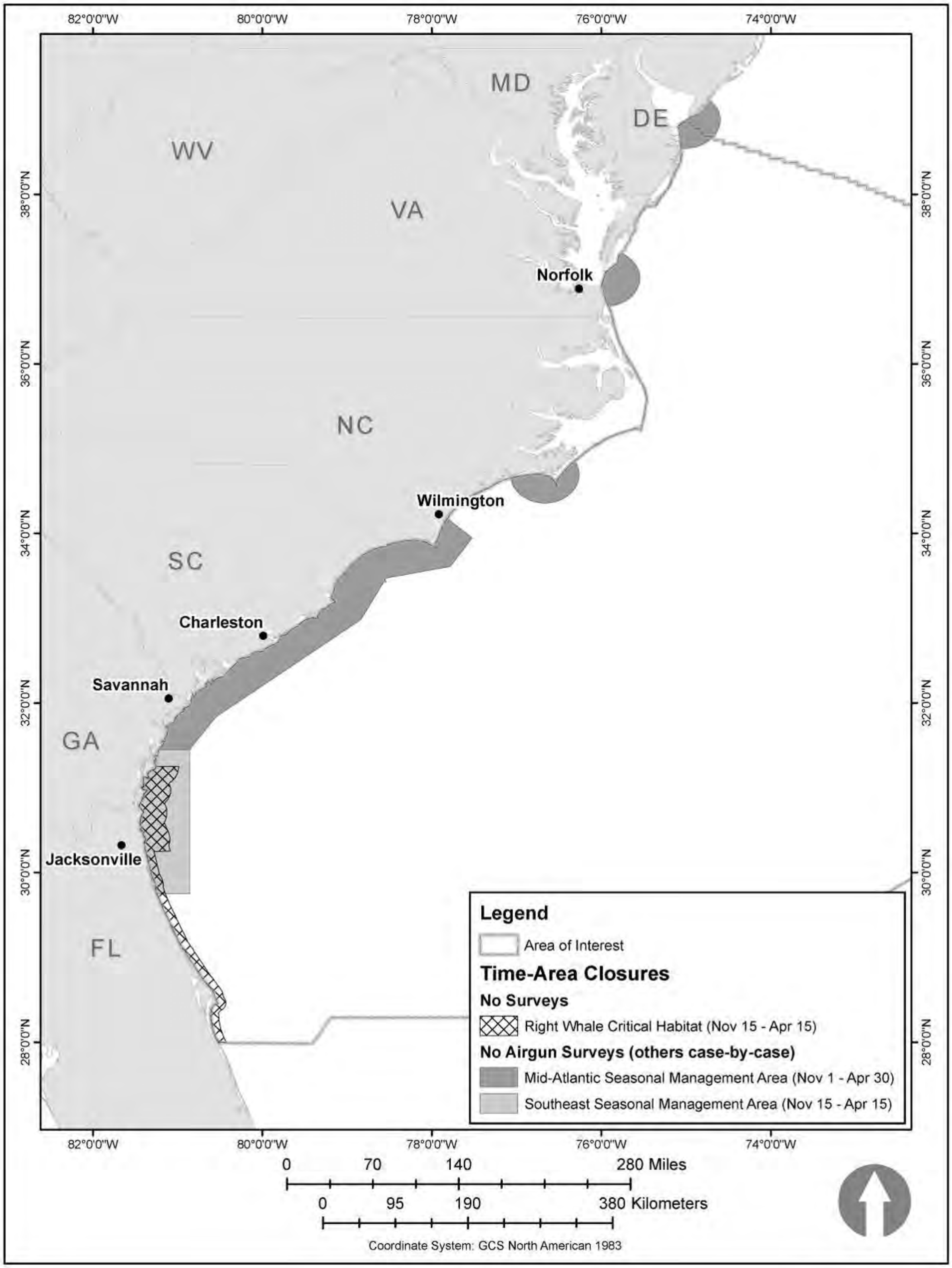

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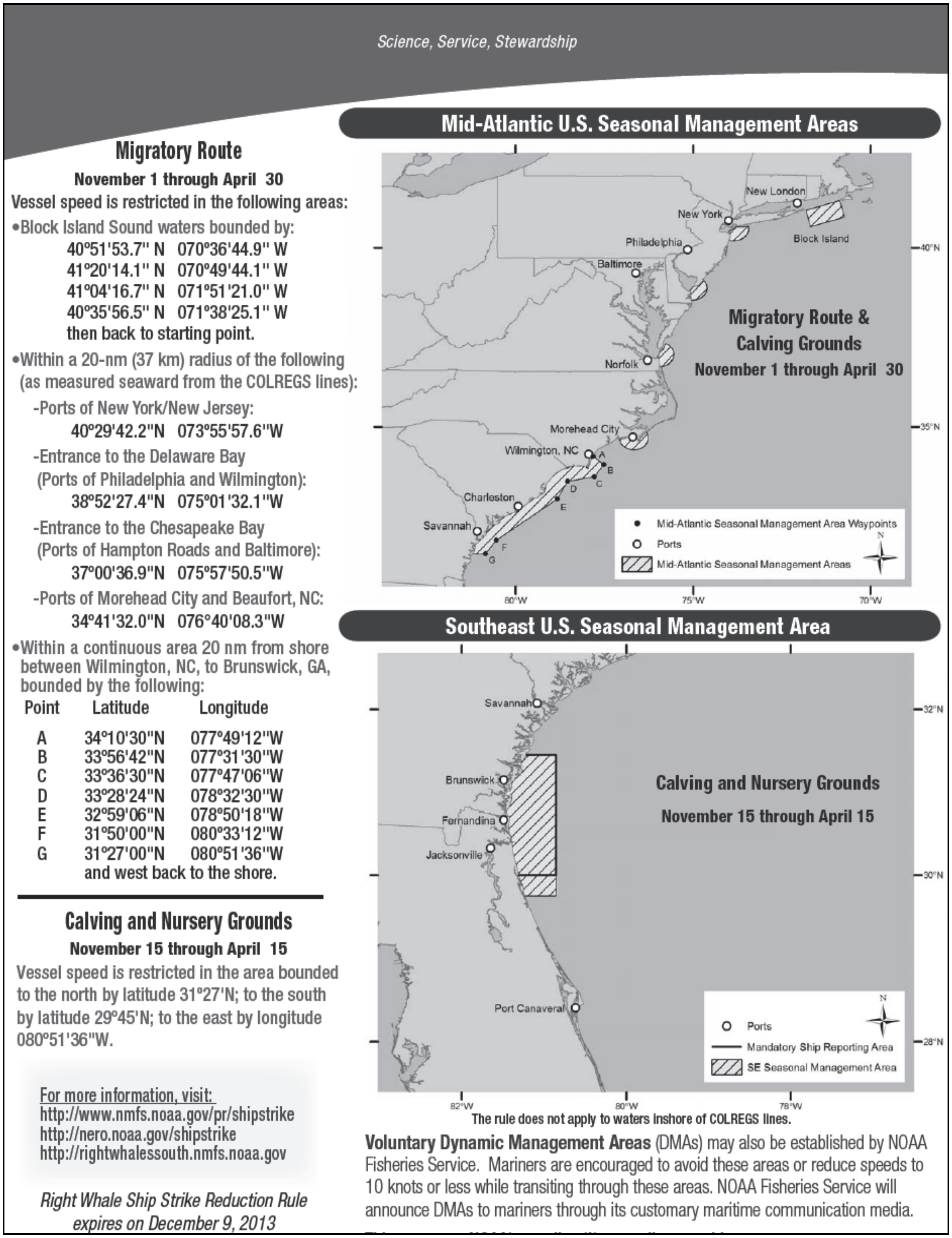

Science, Service, Stewardship

Migratory Route

November 1 through April 30

Vessel speed is restricted in the following areas:

- Block Island Sound waters bounded by:

40°51'53.7" N	070°36'44.9" W
41°20'14.1" N	070°49'44.1" W
41°04'16.7" N	071°51'21.0" W
40°35'56.5" N	071°38'25.1" W

then back to starting point.

- Within a 20-nm (37 km) radius of the following (as measured seaward from the COLREGS lines):
  - Ports of New York/New Jersey:
    40°29'42.2"N 073°55'57.6"W
  - Entrance to the Delaware Bay (Ports of Philadelphia and Wilmington):
    38°52'27.4"N 075°01'32.1"W
  - Entrance to the Chesapeake Bay (Ports of Hampton Roads and Baltimore):
    37°00'36.9"N 075°57'50.5"W
  - Ports of Morehead City and Beaufort, NC:
    34°41'32.0"N 076°40'08.3"W
- Within a continuous area 20 nm from shore between Wilmington, NC, to Brunswick, GA, bounded by the following:

Point	Latitude	Longitude
A	34°10'30"N	077°49'12"W
B	33°56'42"N	077°31'30"W
C	33°36'30"N	077°47'06"W
D	33°28'24"N	078°32'30"W
E	32°59'06"N	078°50'18"W
F	31°50'00"N	080°33'12"W
G	31°27'00"N	080°51'36"W

and west back to the shore.

Calving and Nursery Grounds

November 15 through April 15

Vessel speed is restricted in the area bounded to the north by latitude 31°27'N; to the south by latitude 29°45'N; to the east by longitude 080°51'36"W.

For more information, visit:
http://www.nmfs.noaa.gov/pr/shipstrike
http://nero.noaa.gov/shipstrike
http://rightwhalessouth.nmfs.noaa.gov

Right Whale Ship Strike Reduction Rule expires on December 9, 2013

The rule does not apply to waters inshore of COLREGS lines.

Voluntary Dynamic Management Areas (DMAs) may also be established by NOAA Fisheries Service. Mariners are encouraged to avoid these areas or reduce speeds to 10 knots or less while transiting through these areas. NOAA Fisheries Service will announce DMAs to mariners through its customary maritime communication media.

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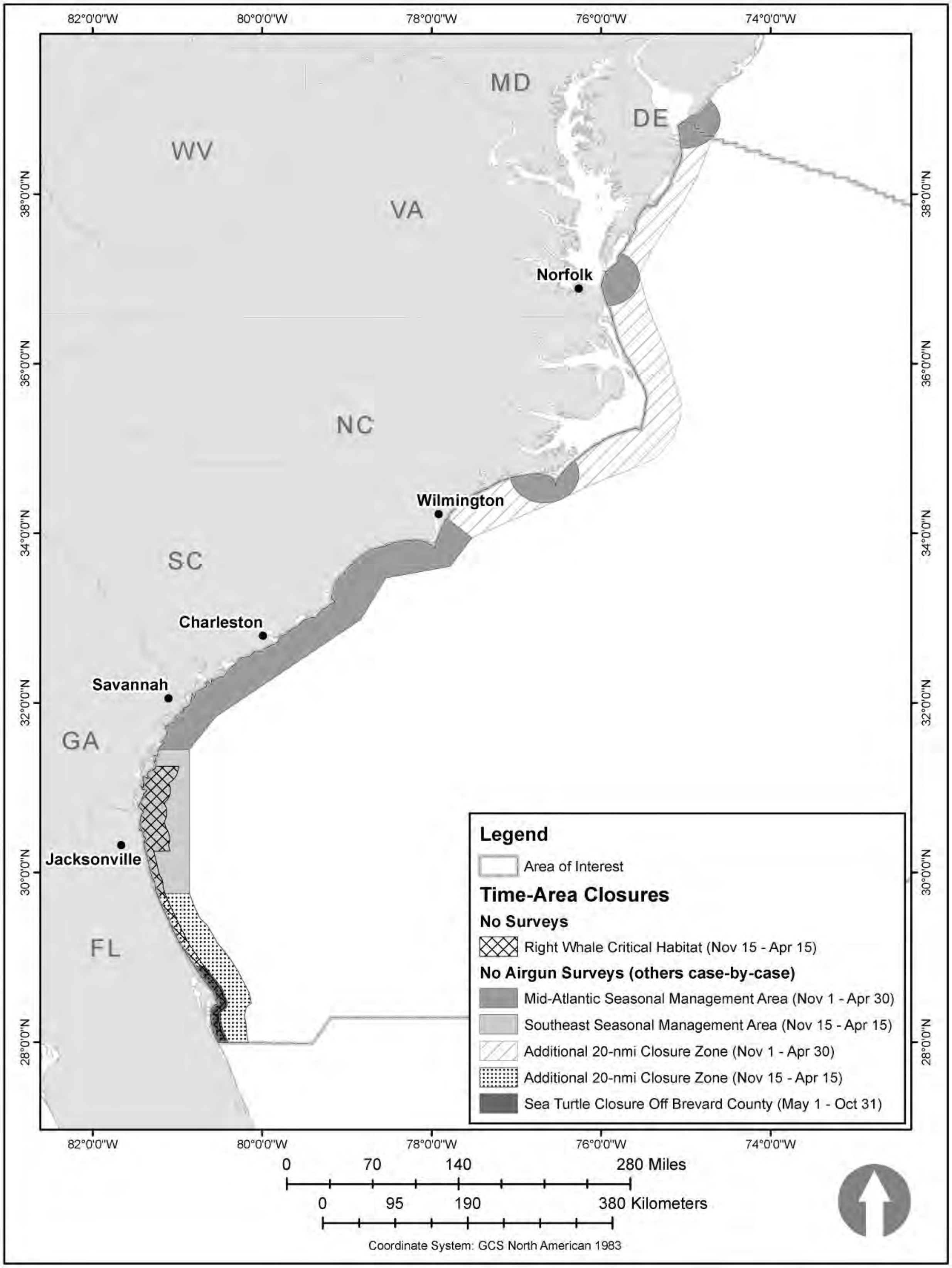

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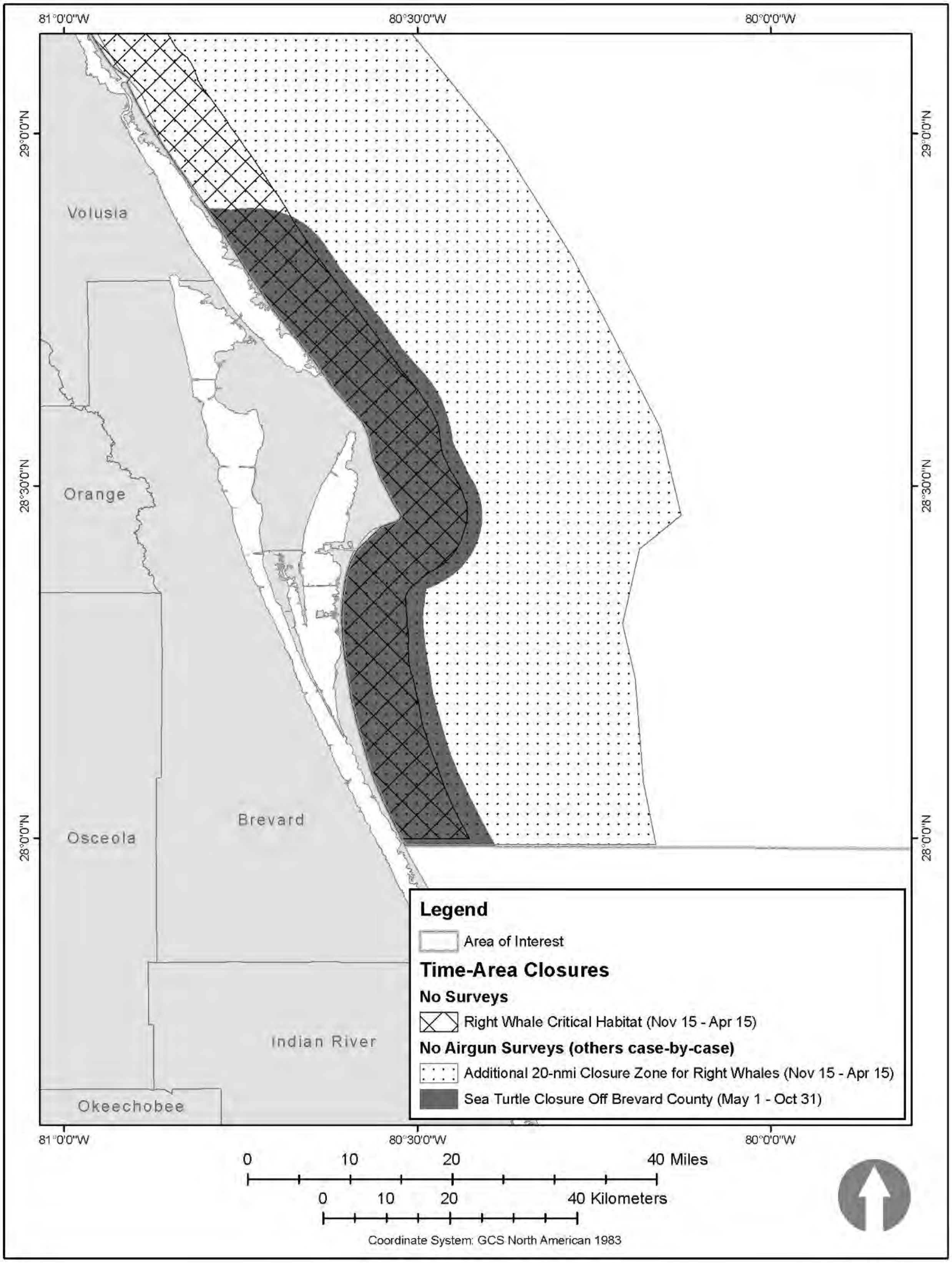

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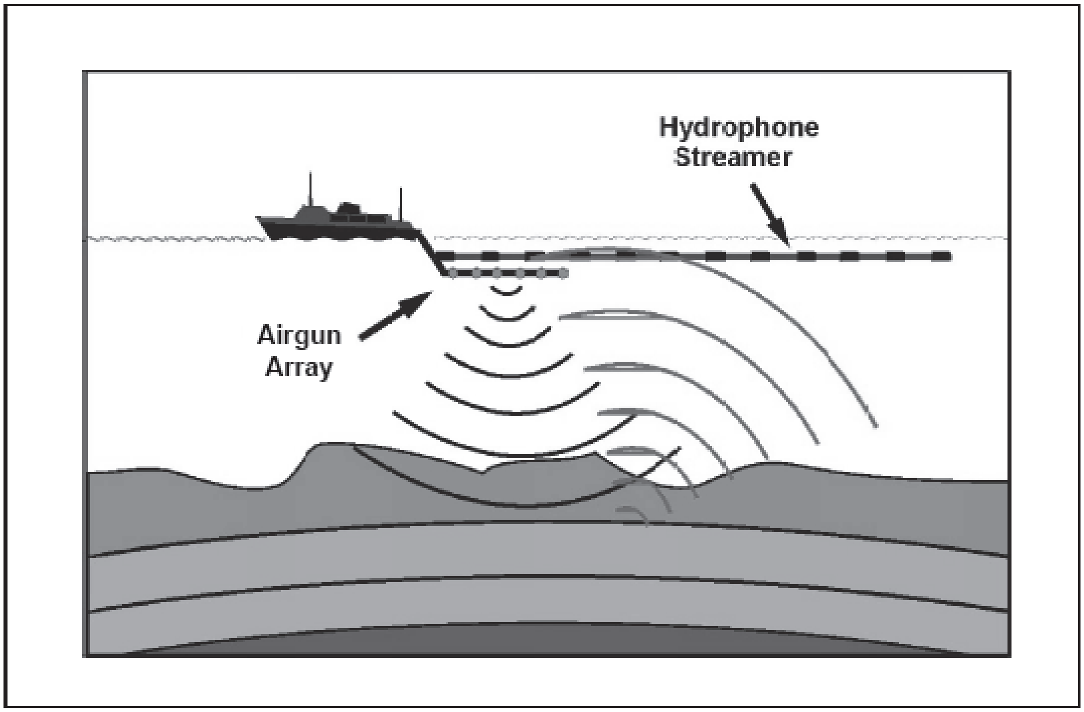

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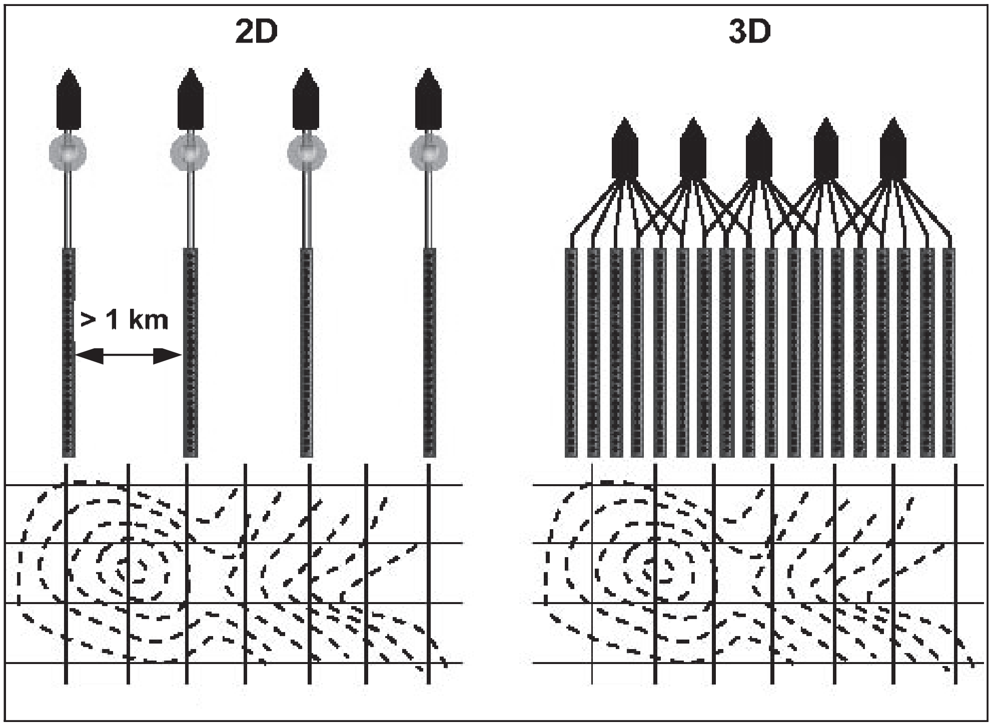

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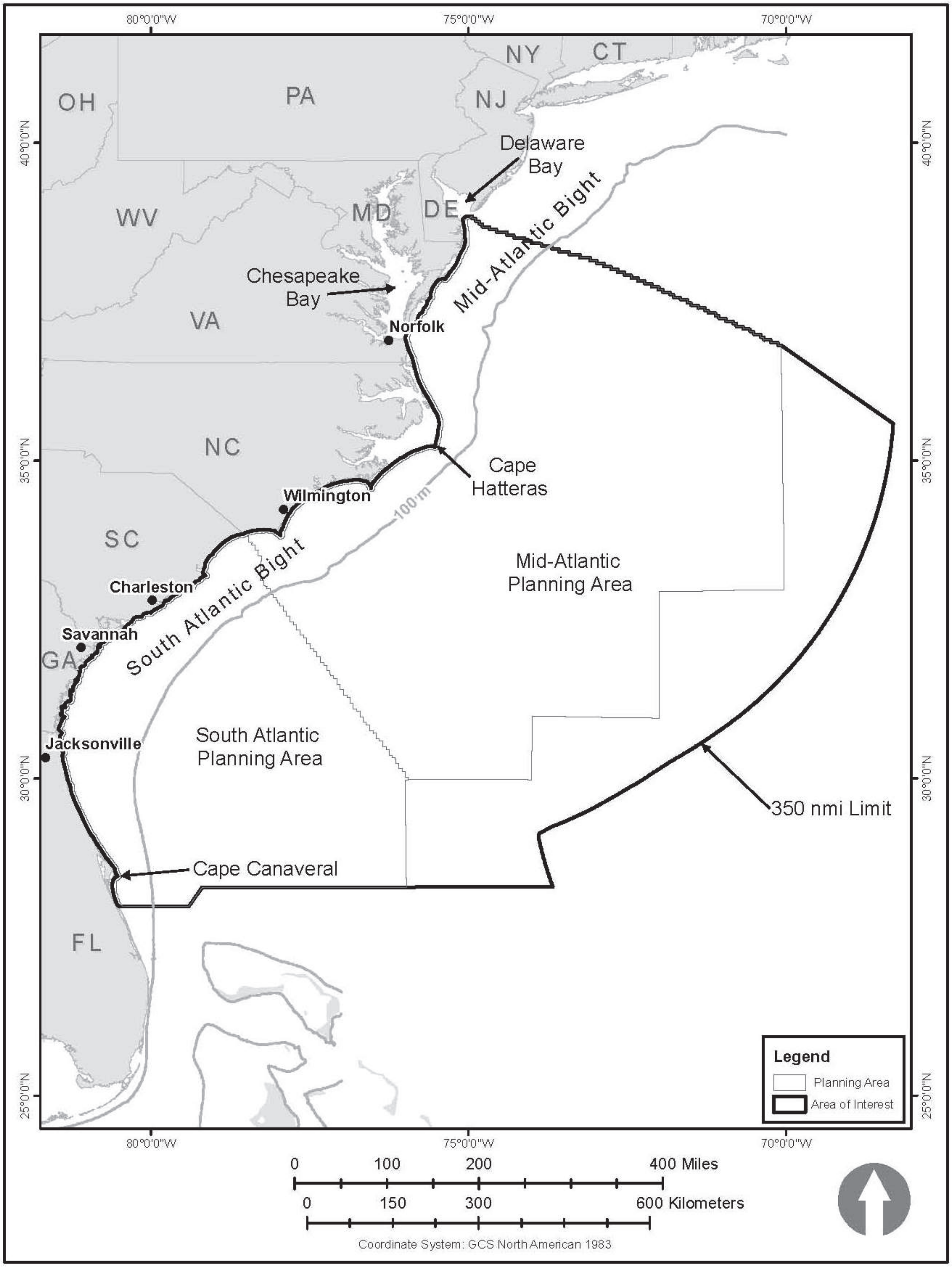

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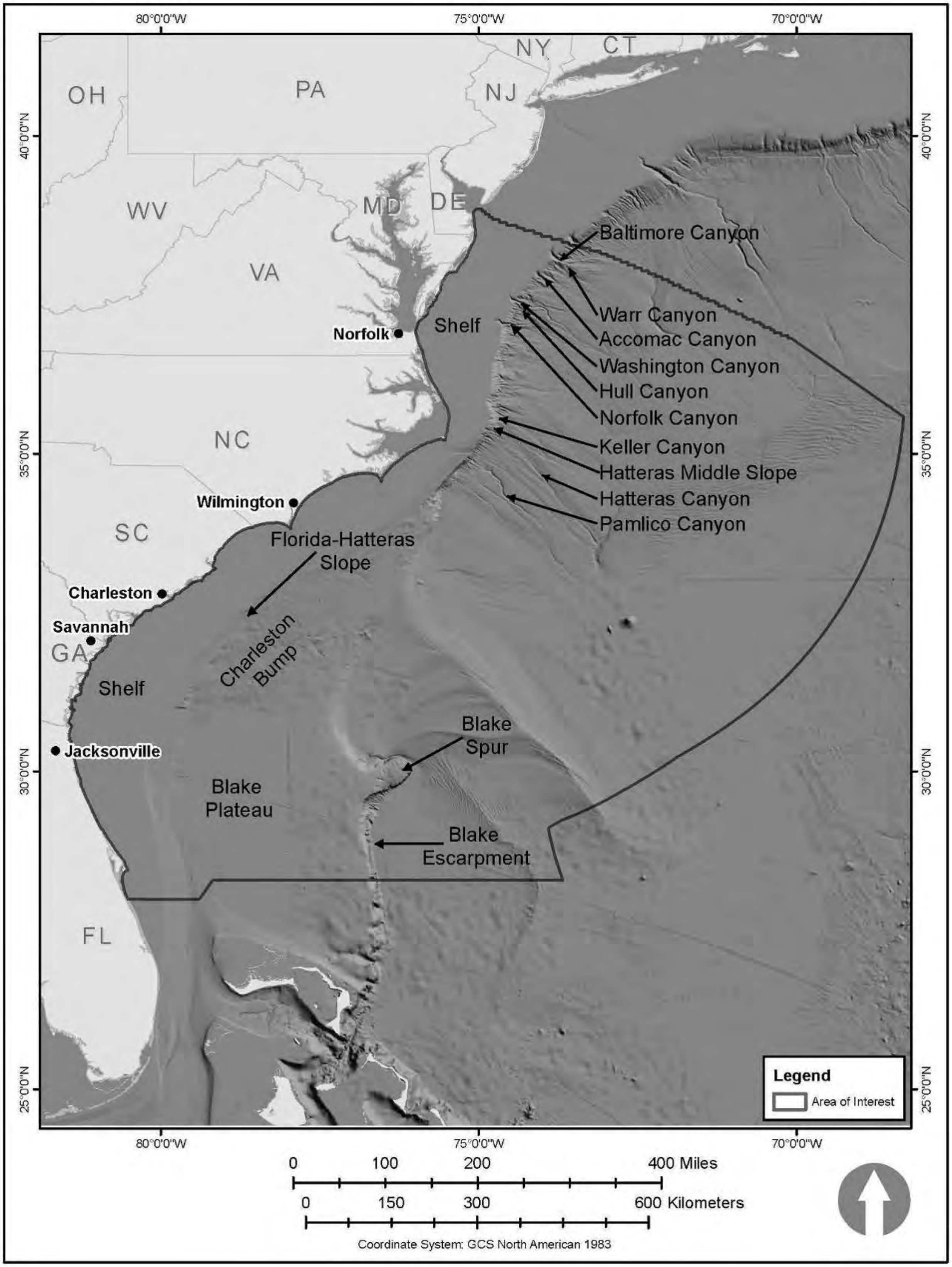

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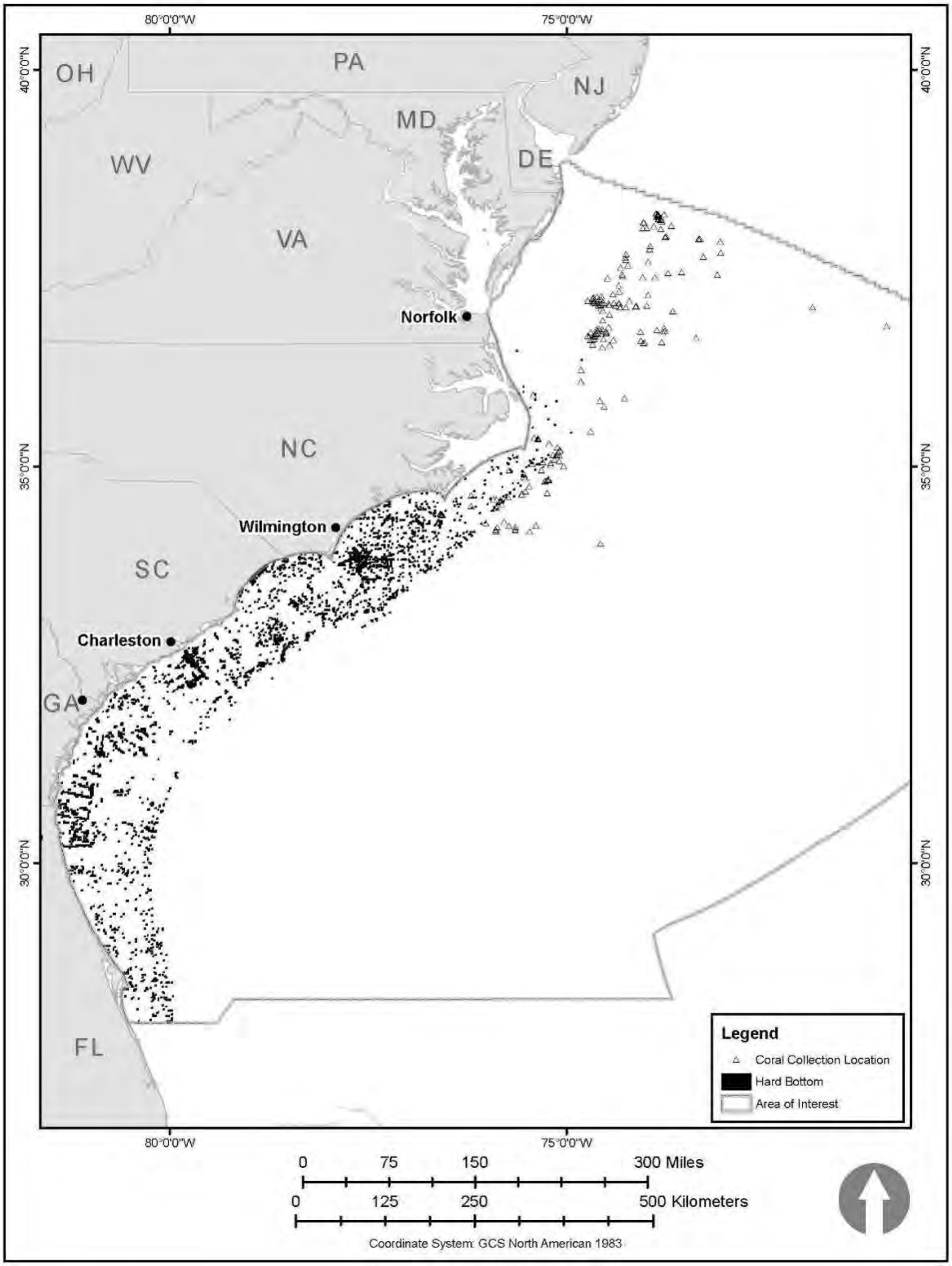

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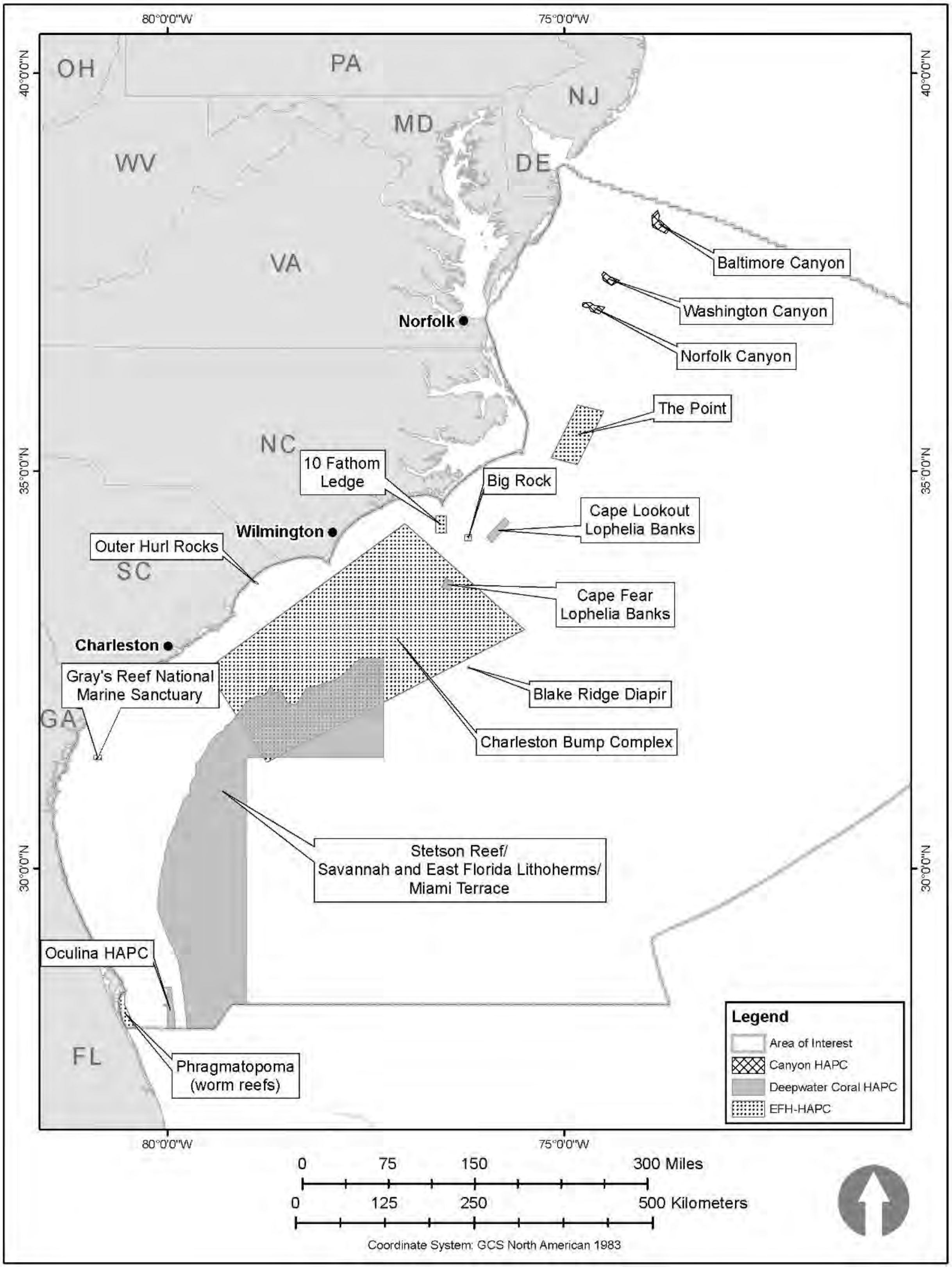

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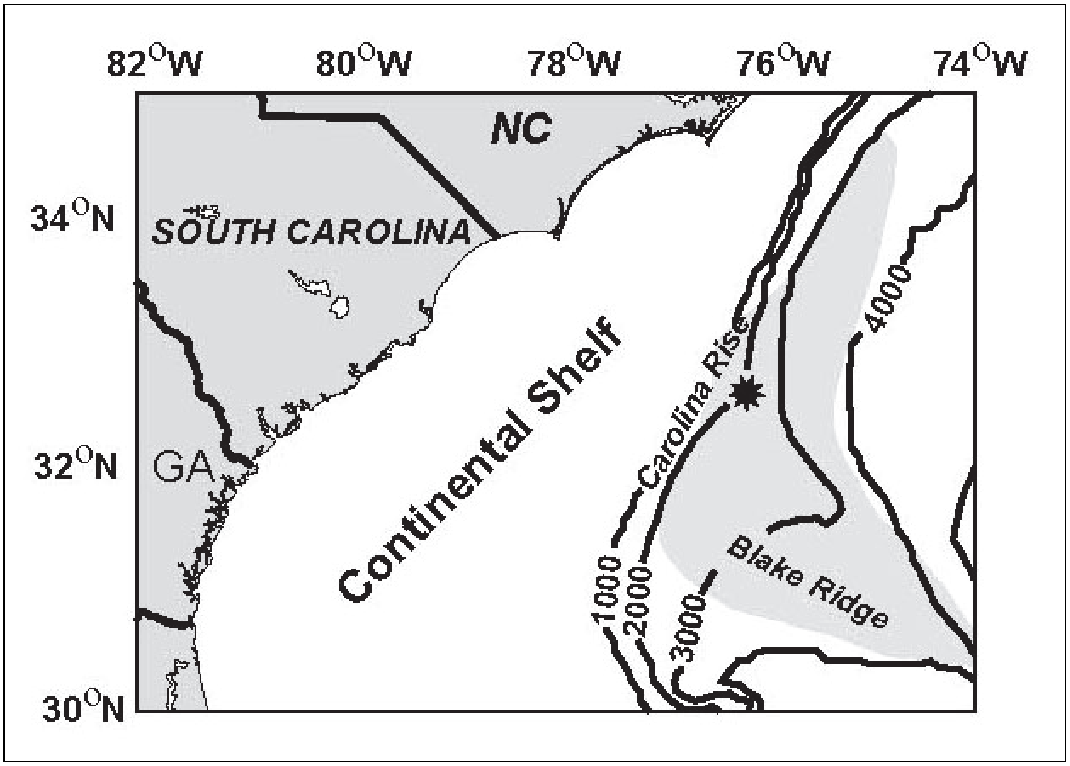

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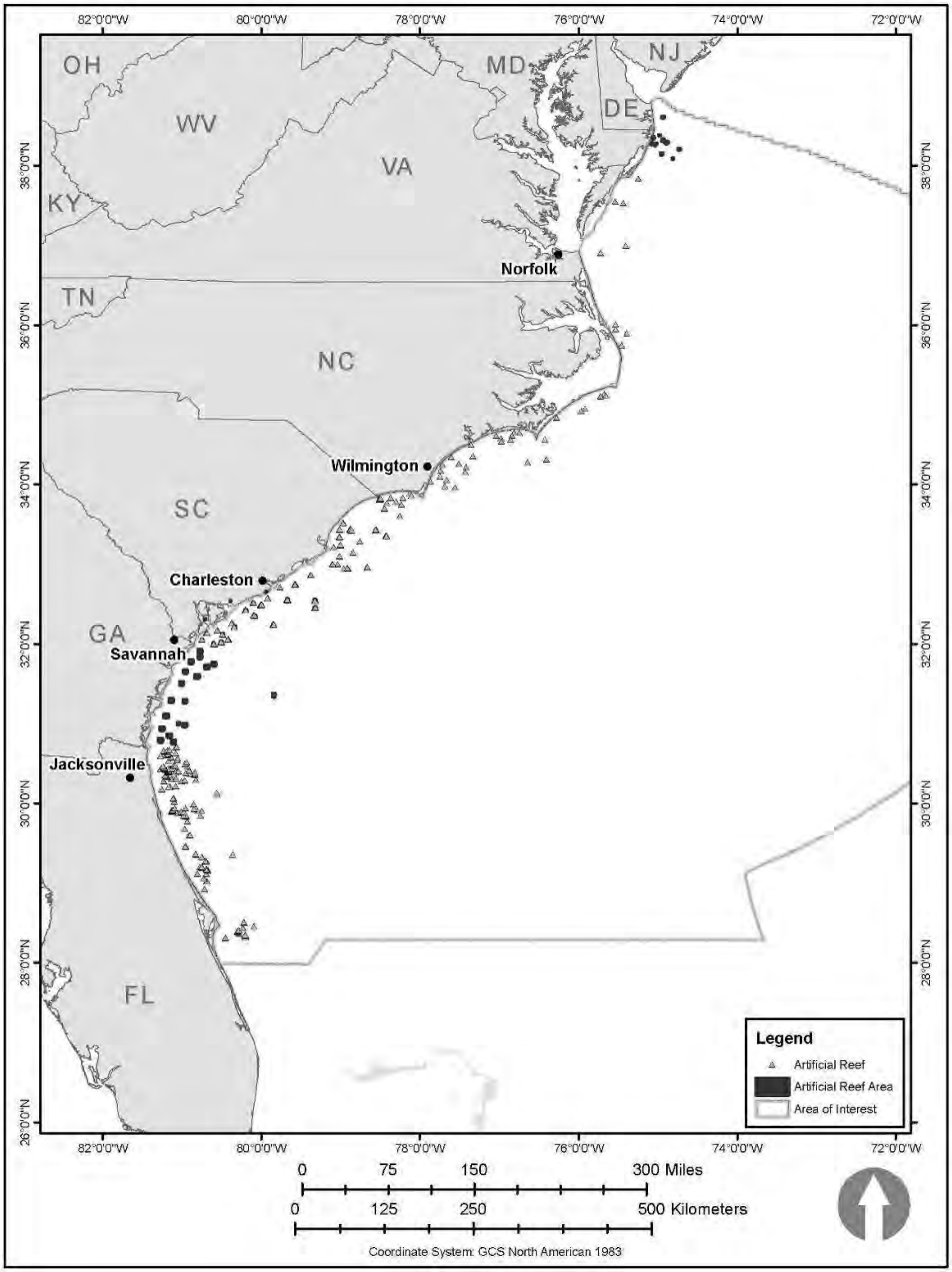

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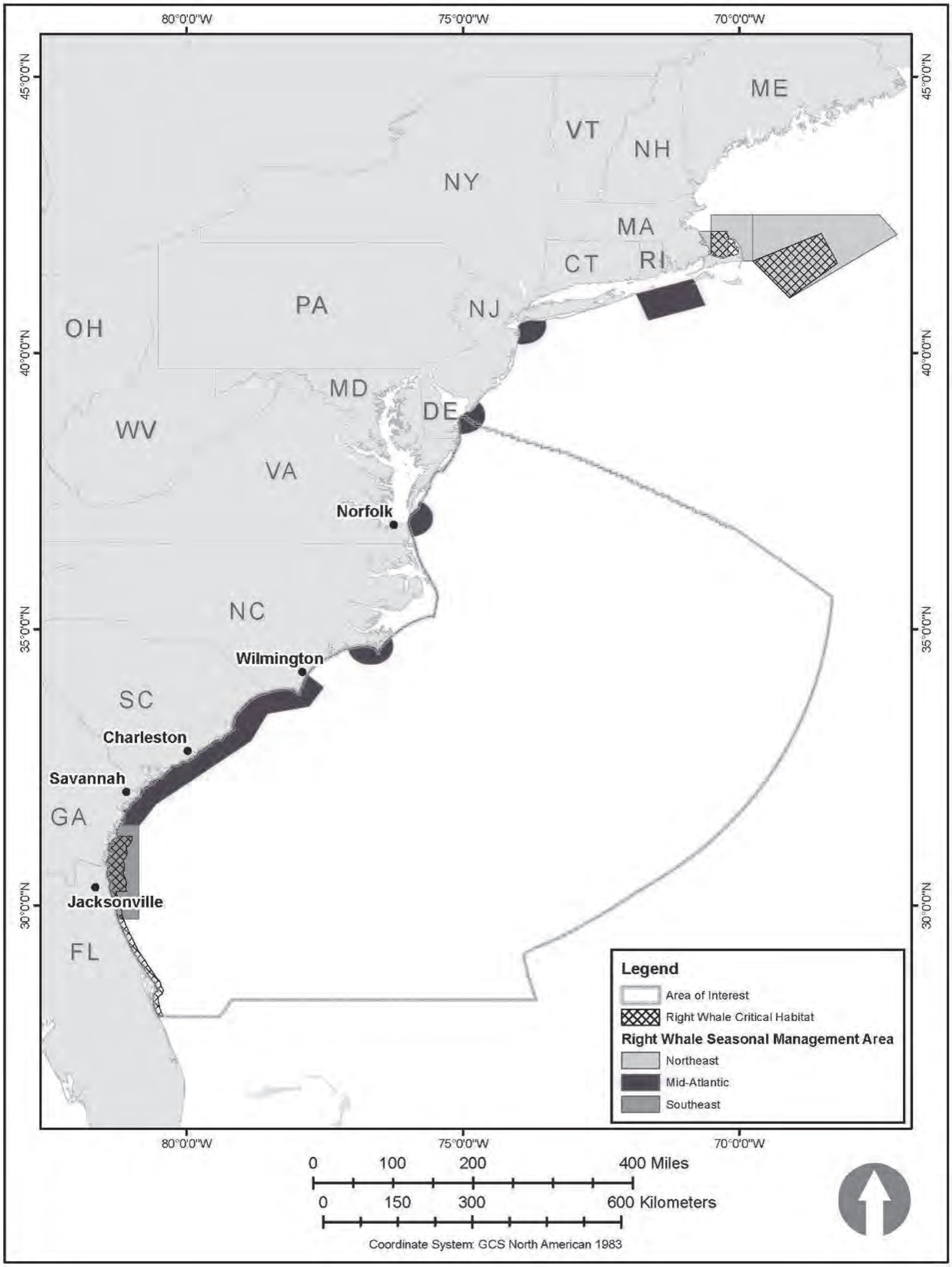

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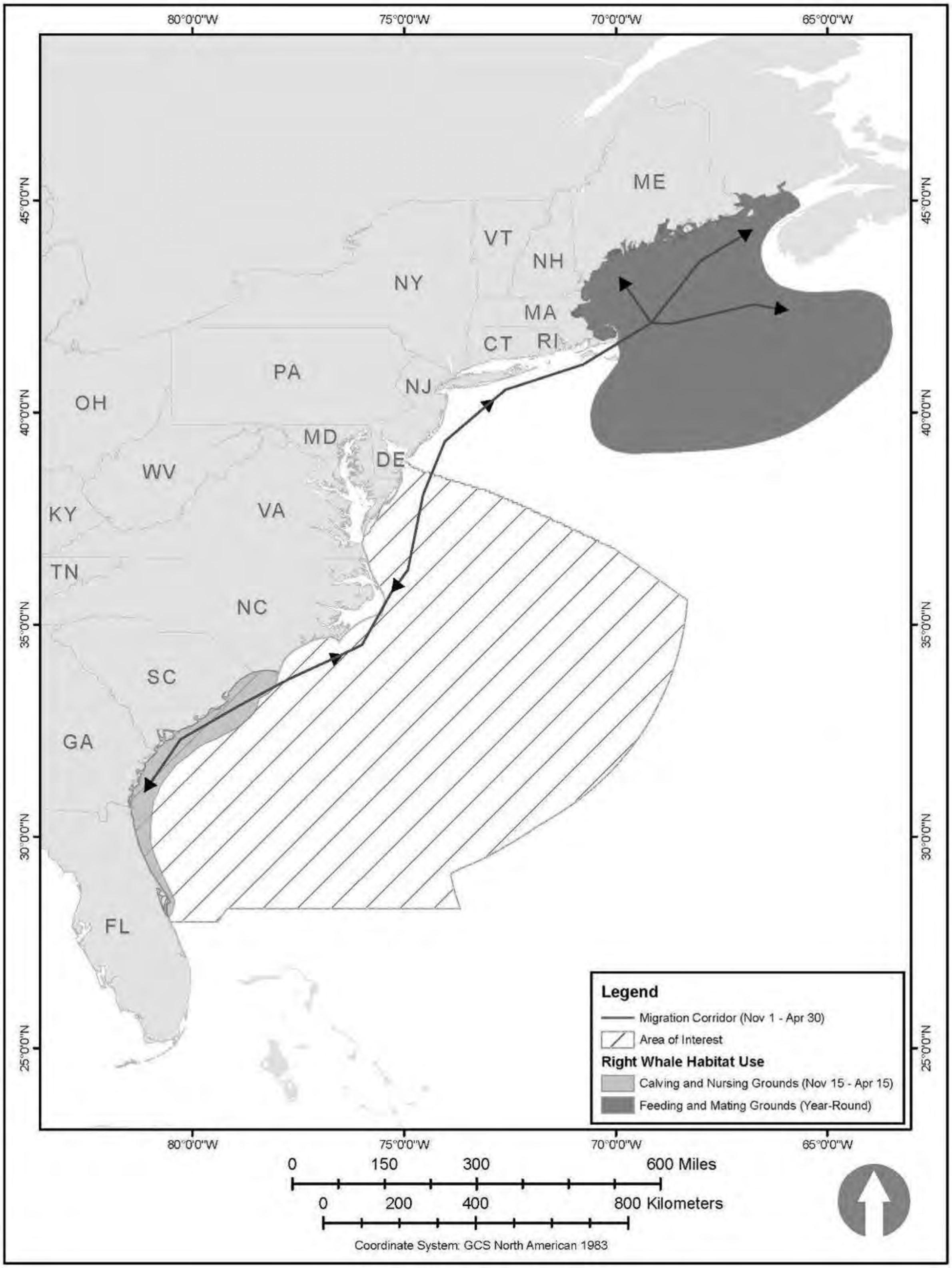

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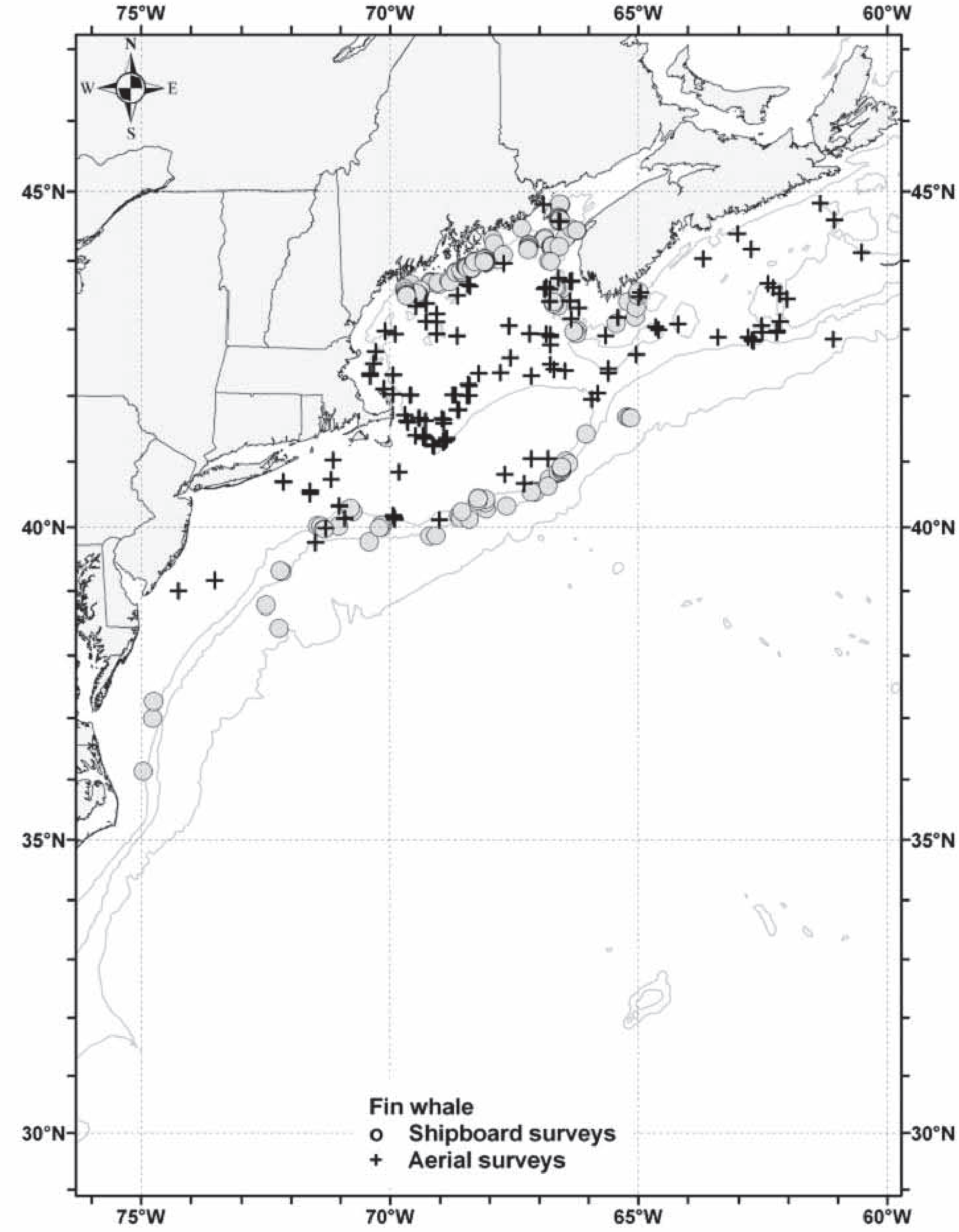

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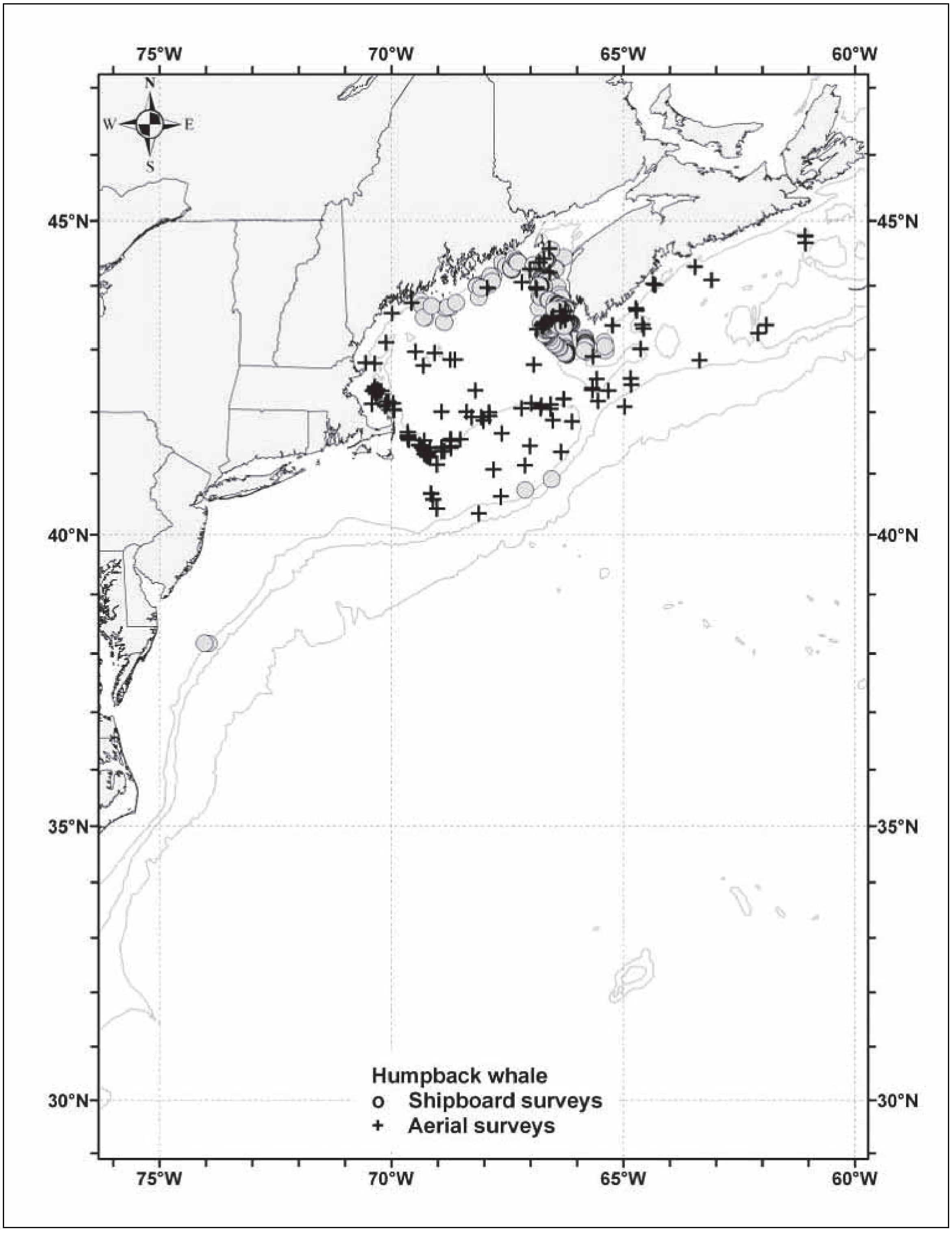

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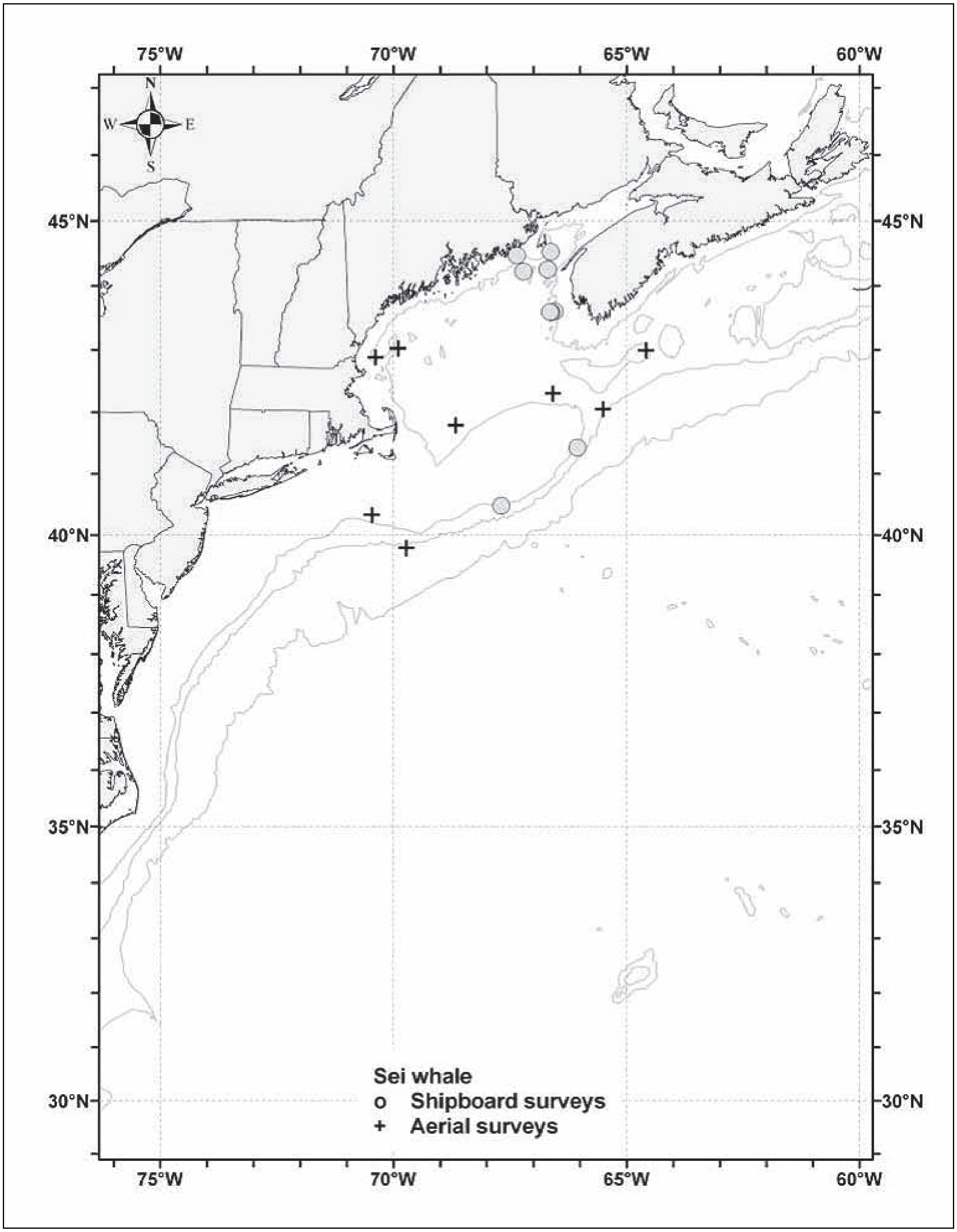

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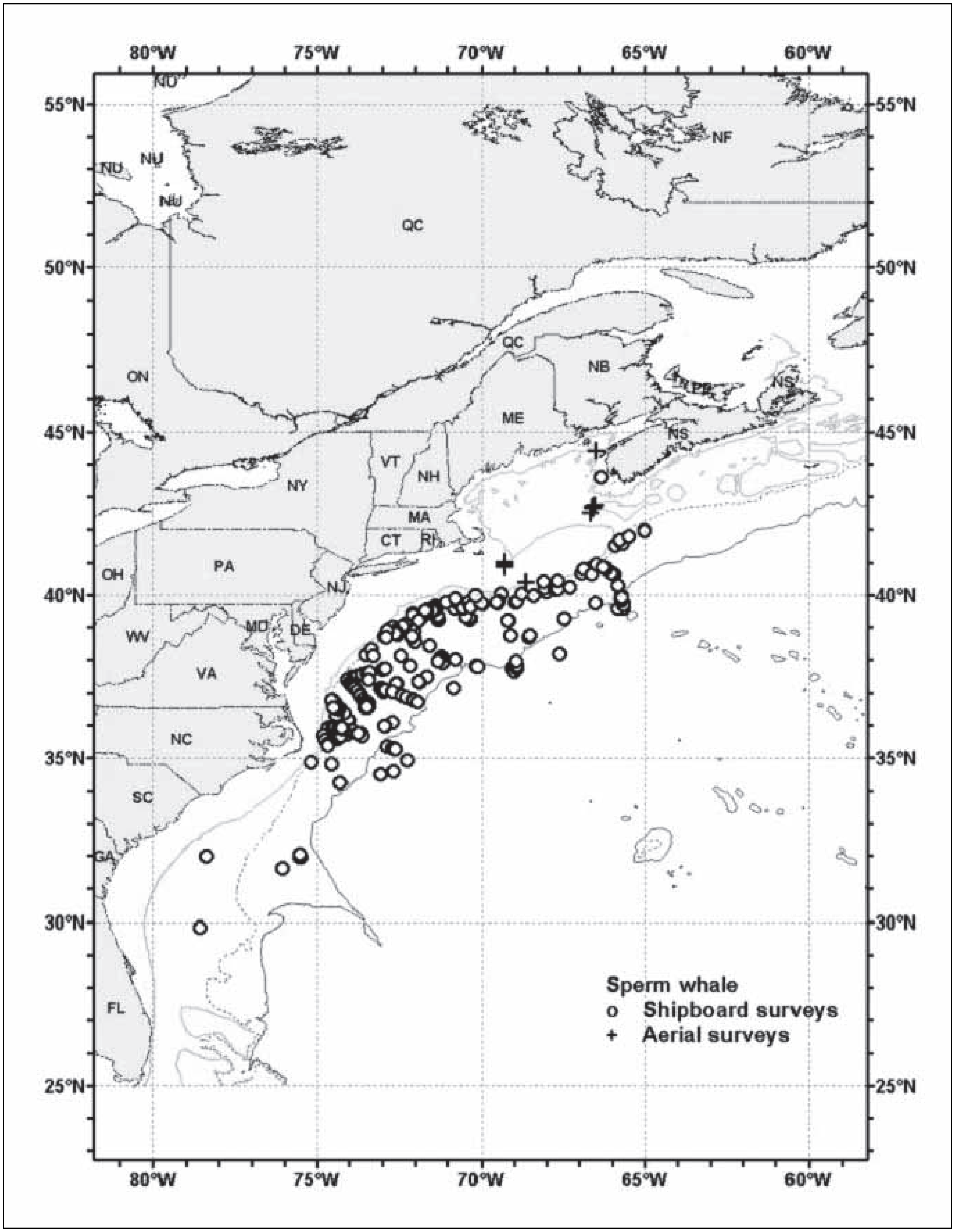

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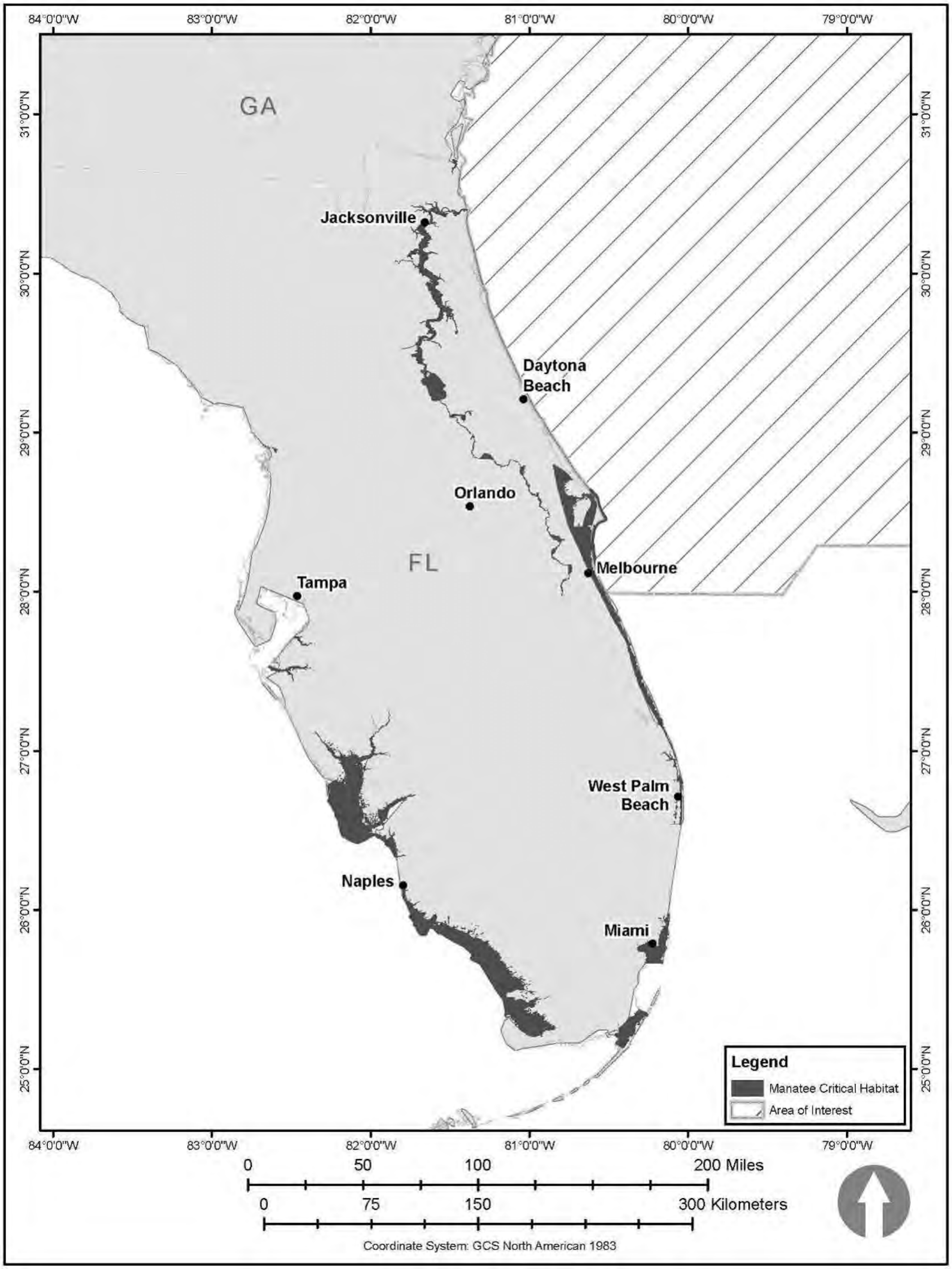

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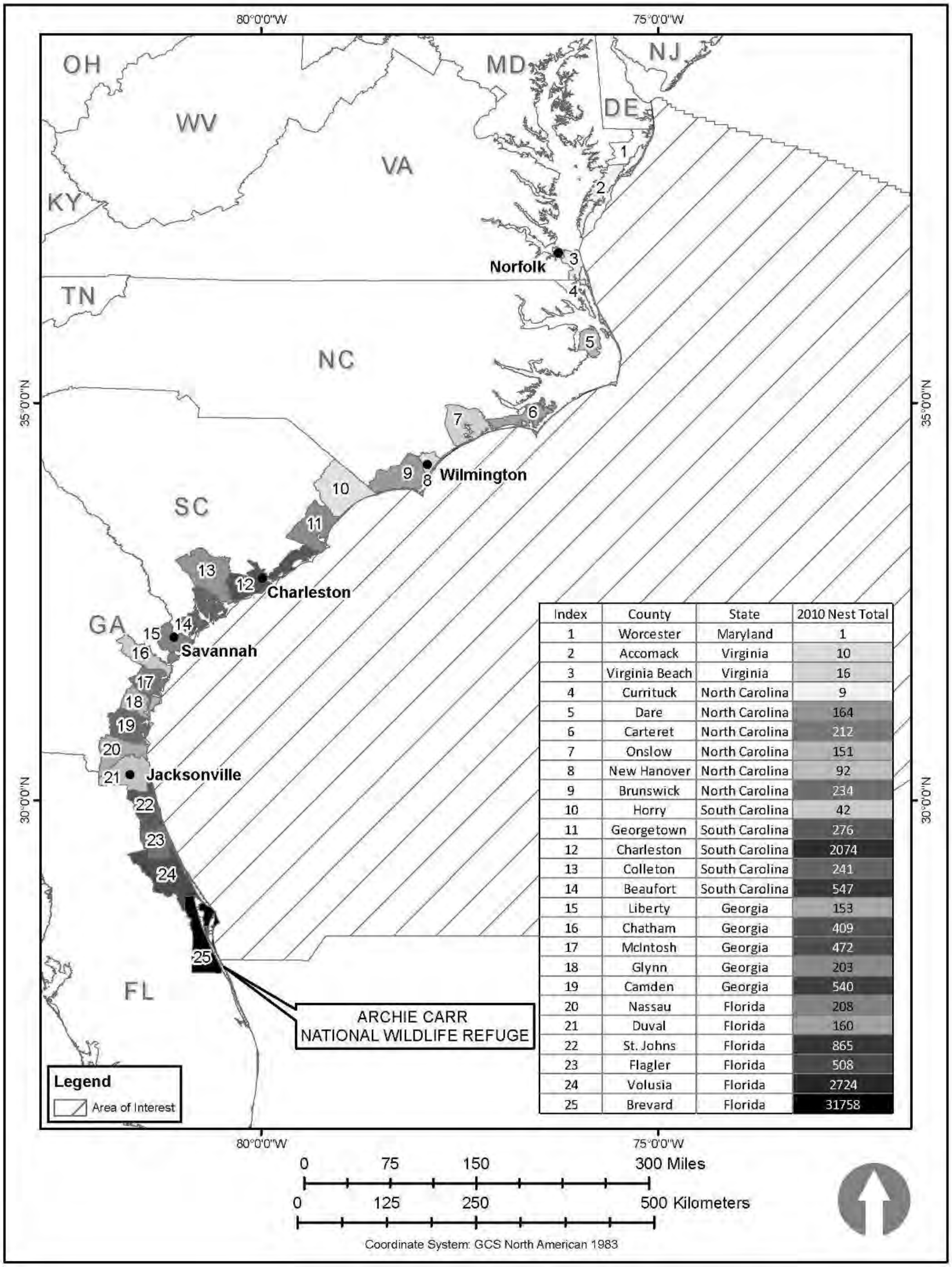
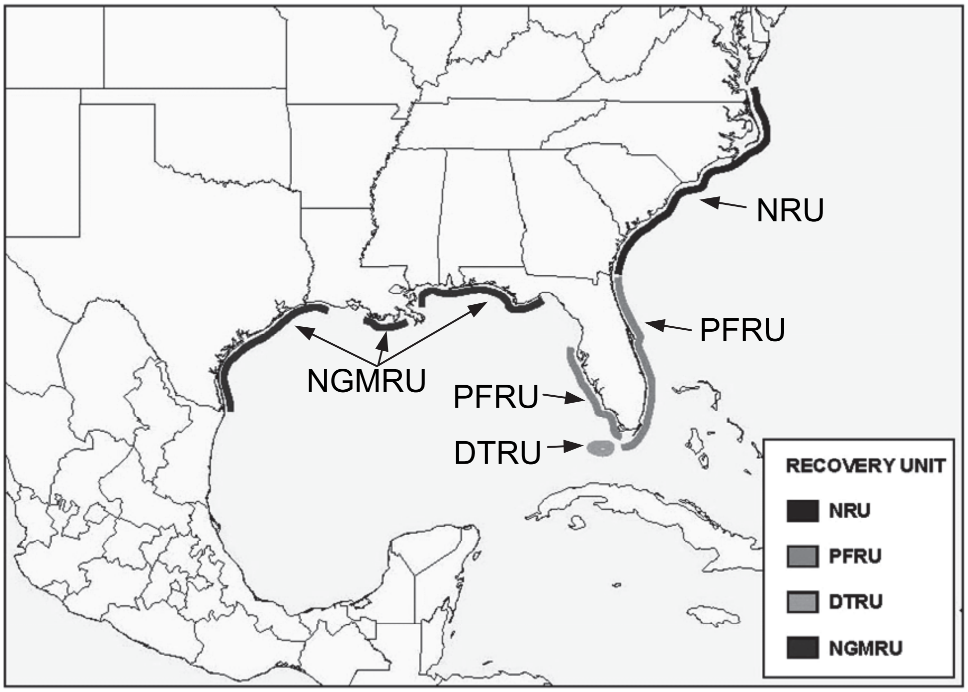


Index	County	State	2010 Nest Total
1	Worcester	Maryland	1
2	Accomack	Virginia	10
3	Virginia Beach	Virginia	16
4	Currituck	North Carolina	9
5	Dare	North Carolina	164
6	Carteret	North Carolina	212
7	Onslow	North Carolina	151
8	New Hanover	North Carolina	92
9	Brunswick	North Carolina	234
10	Horry	South Carolina	42
11	Georgetown	South Carolina	276
12	Charleston	South Carolina	2074
13	Colleton	South Carolina	241
14	Beaufort	South Carolina	547
15	Liberty	Georgia	153
16	Chatham	Georgia	409
17	McIntosh	Georgia	472
18	Glynn	Georgia	203
19	Camden	Georgia	540
20	Nassau	Florida	208
21	Duval	Florida	160
22	St. Johns	Florida	865
23	Flagler	Florida	508
24	Volusia	Florida	2724
25	Brevard	Florida	31758

Figure 4-14. Densities of Sea Turtle Nests Reported for Individual Counties within the Area of Interest for the 2010 Nesting Season (http://www.seaturtle.org/nestdb/ [North Carolina, South Carolina, and Georgia]; http://myfwc.com/research/wildlife/sea-turtles/nesting/ [Florida]).



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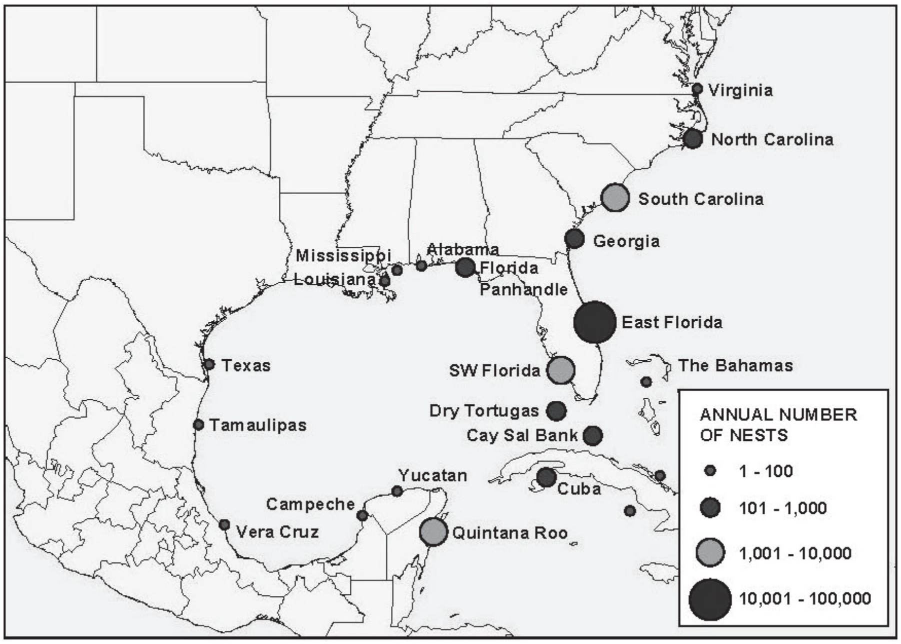

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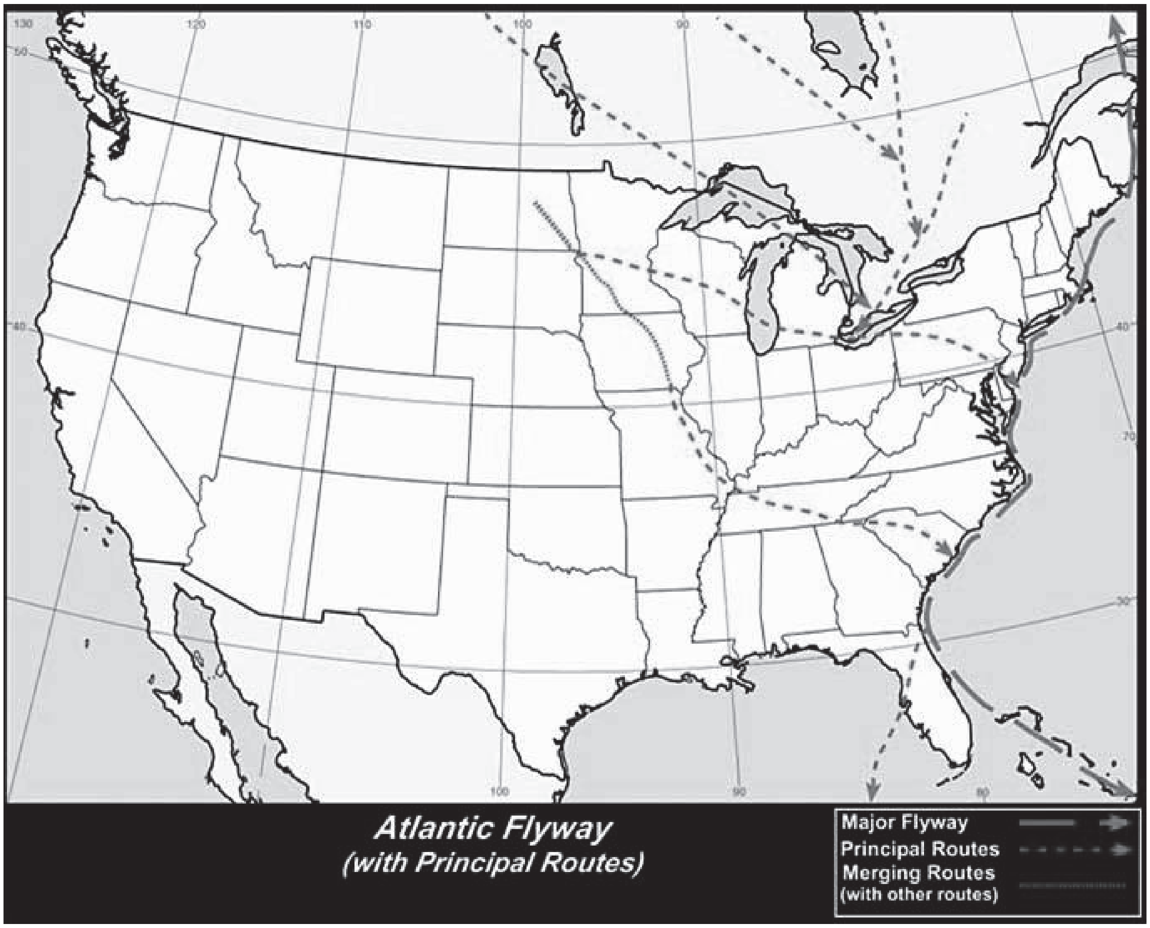

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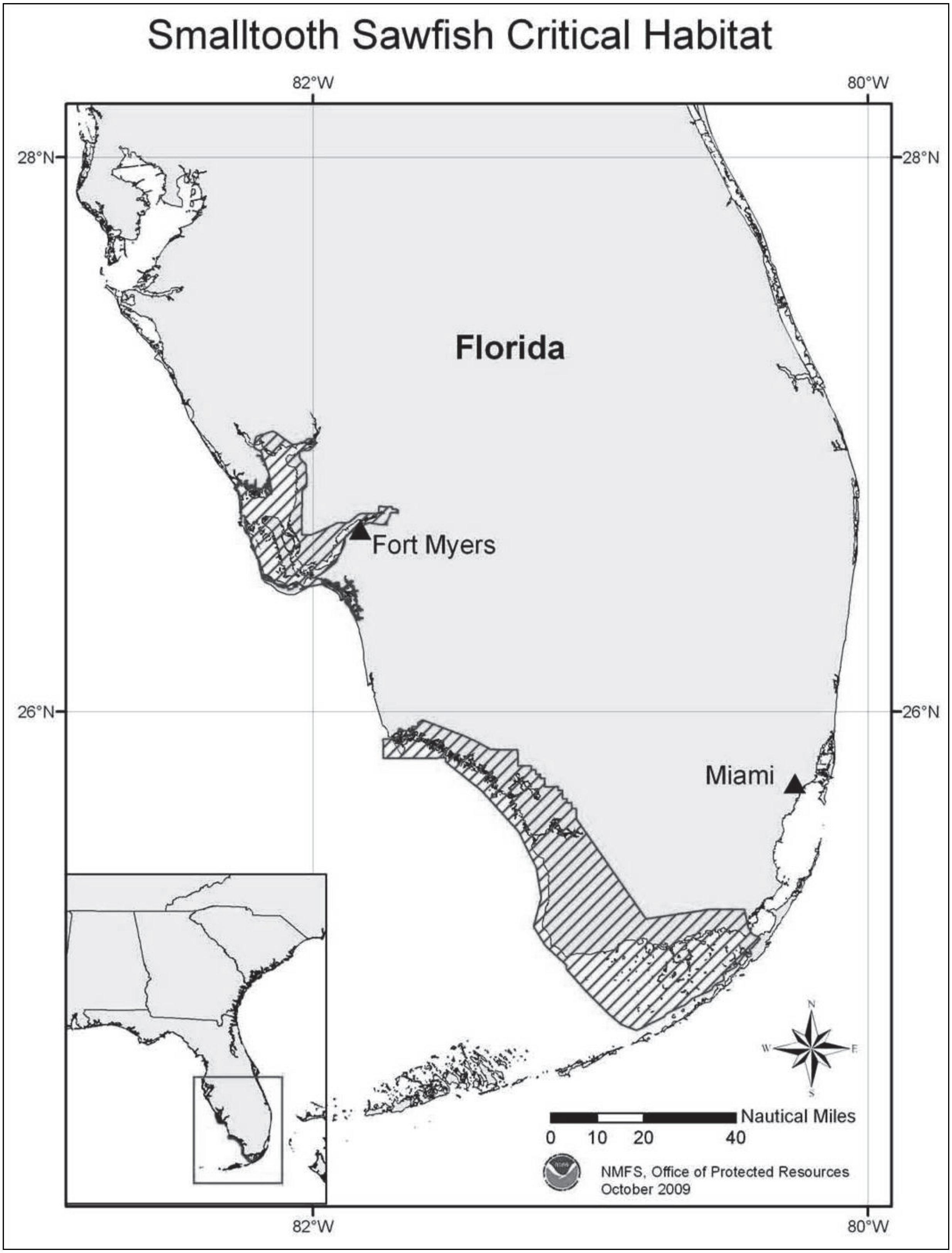

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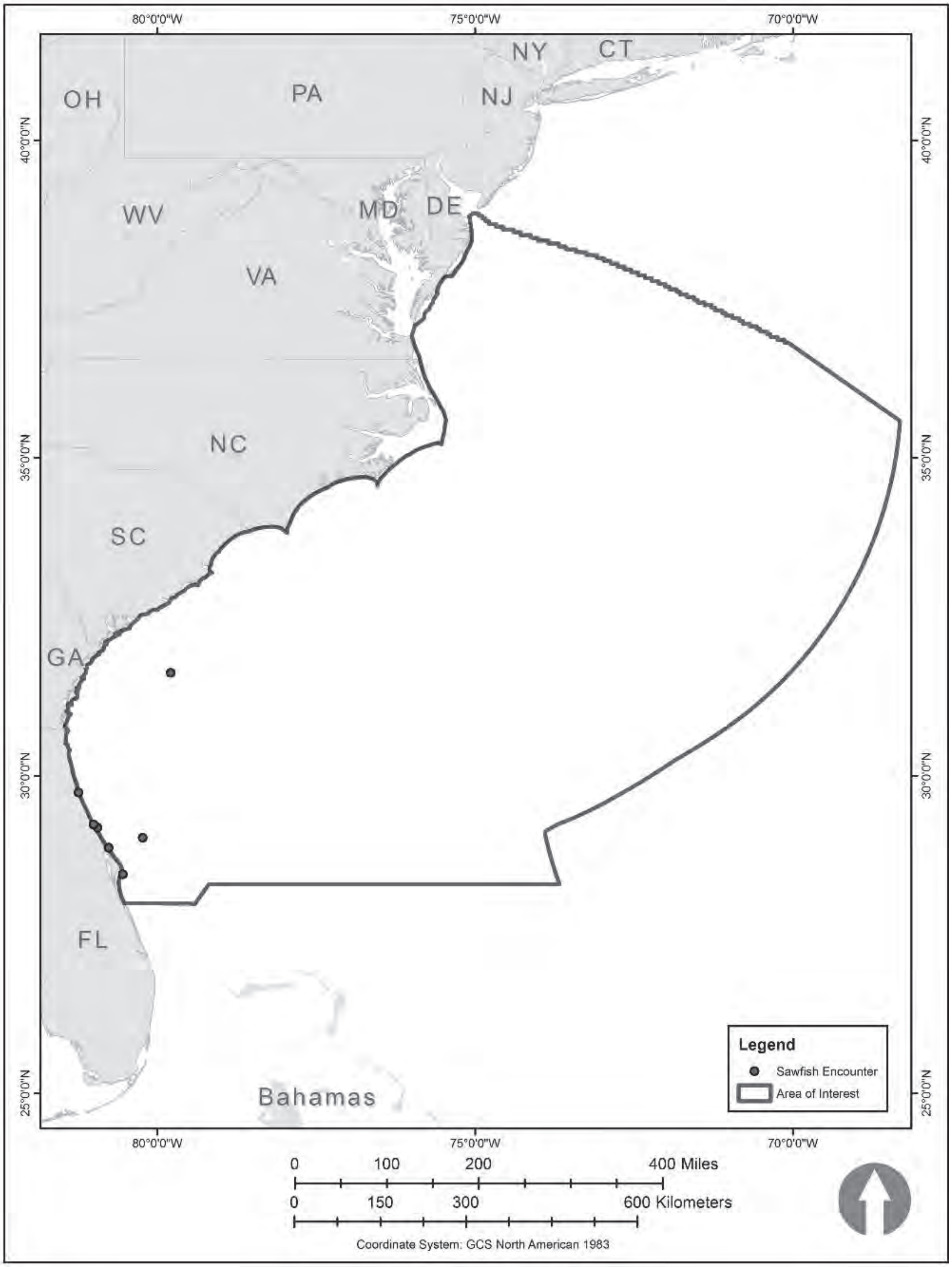

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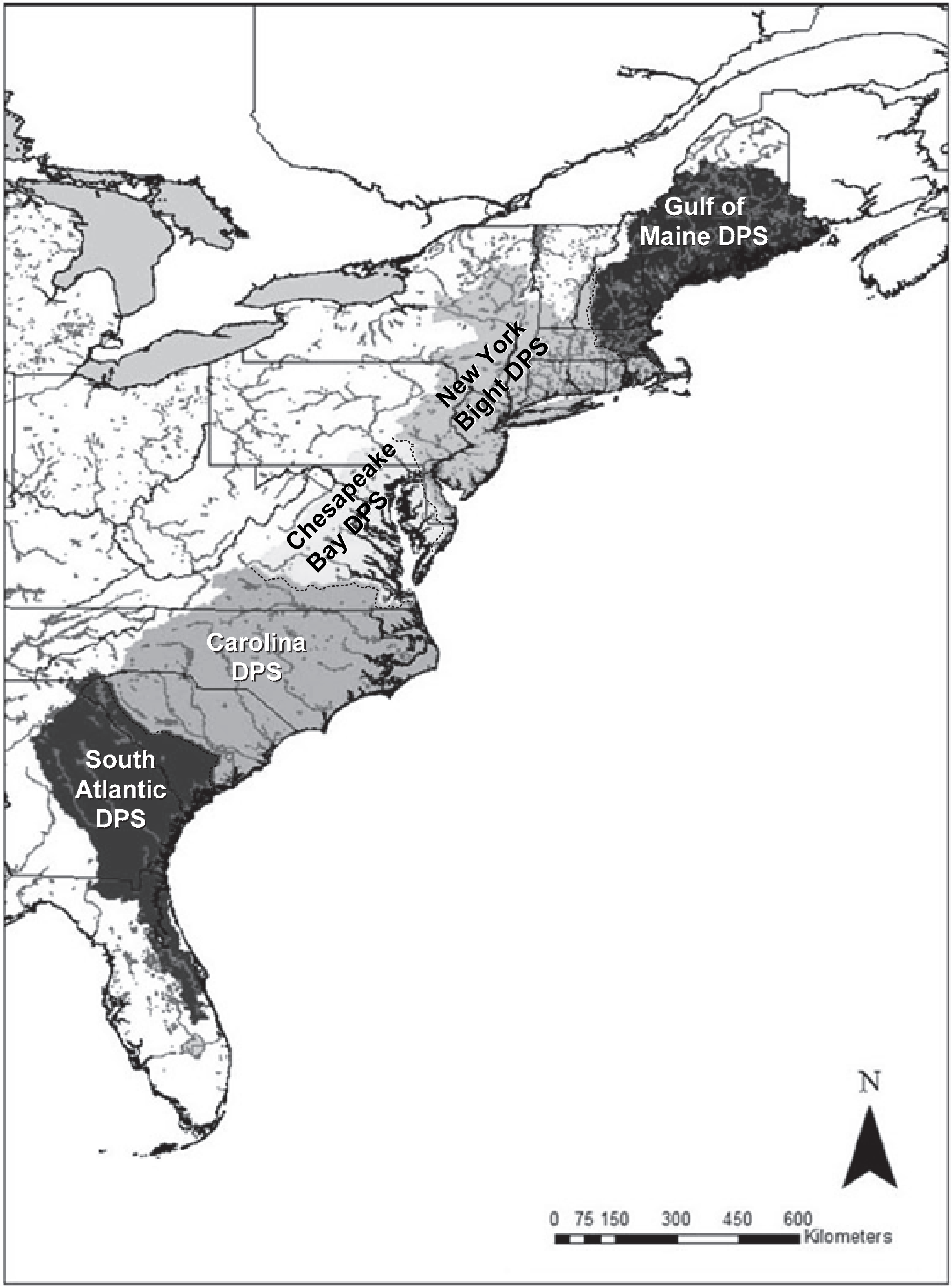

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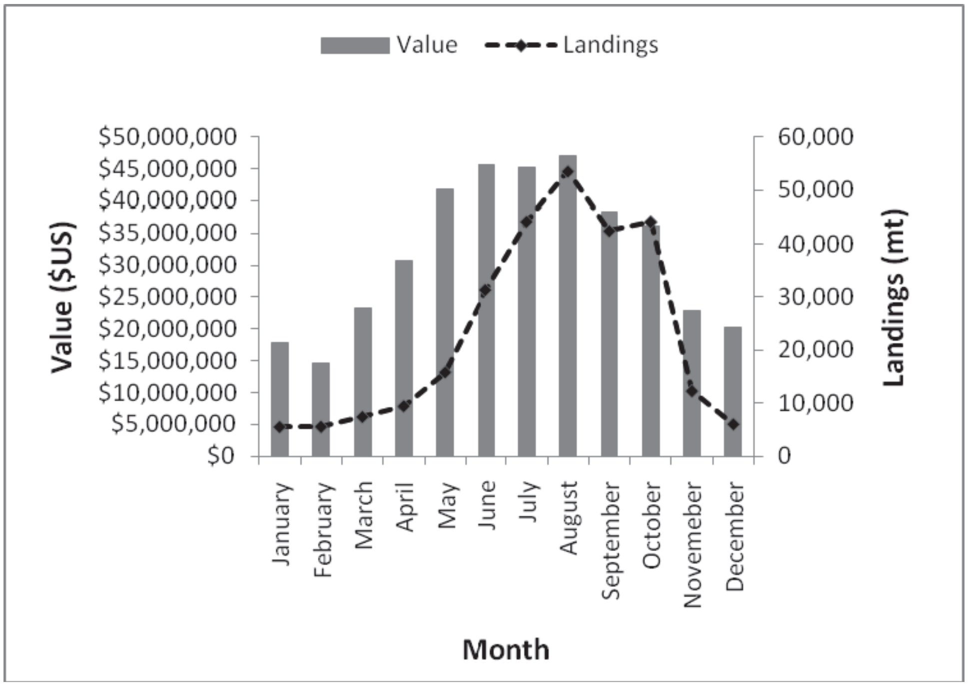

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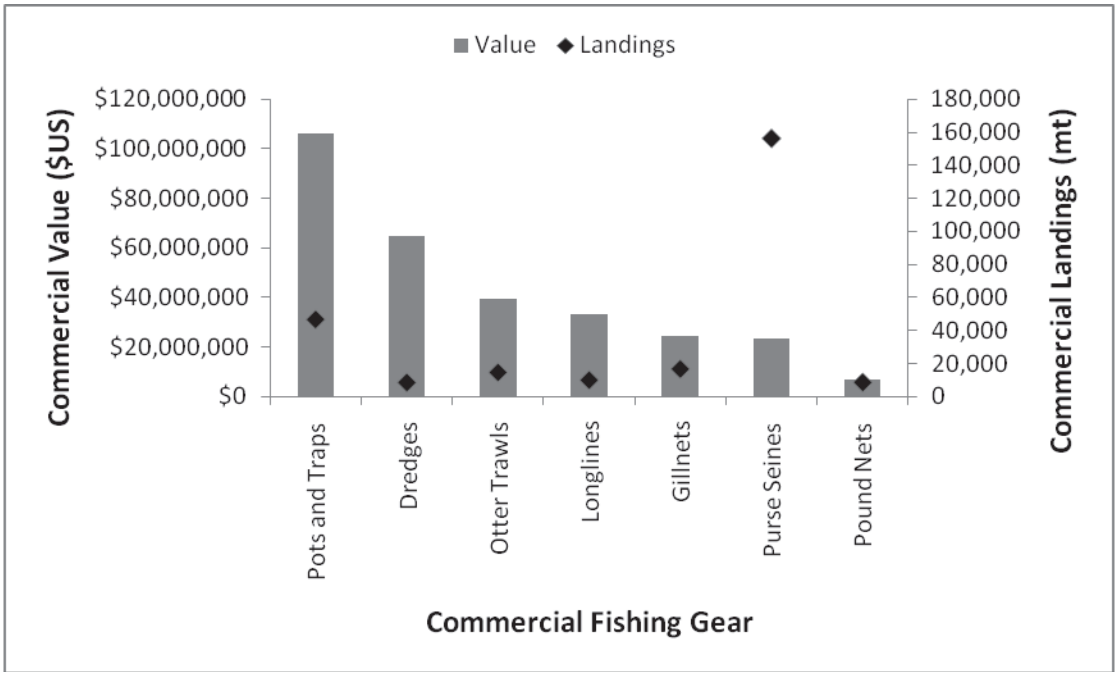

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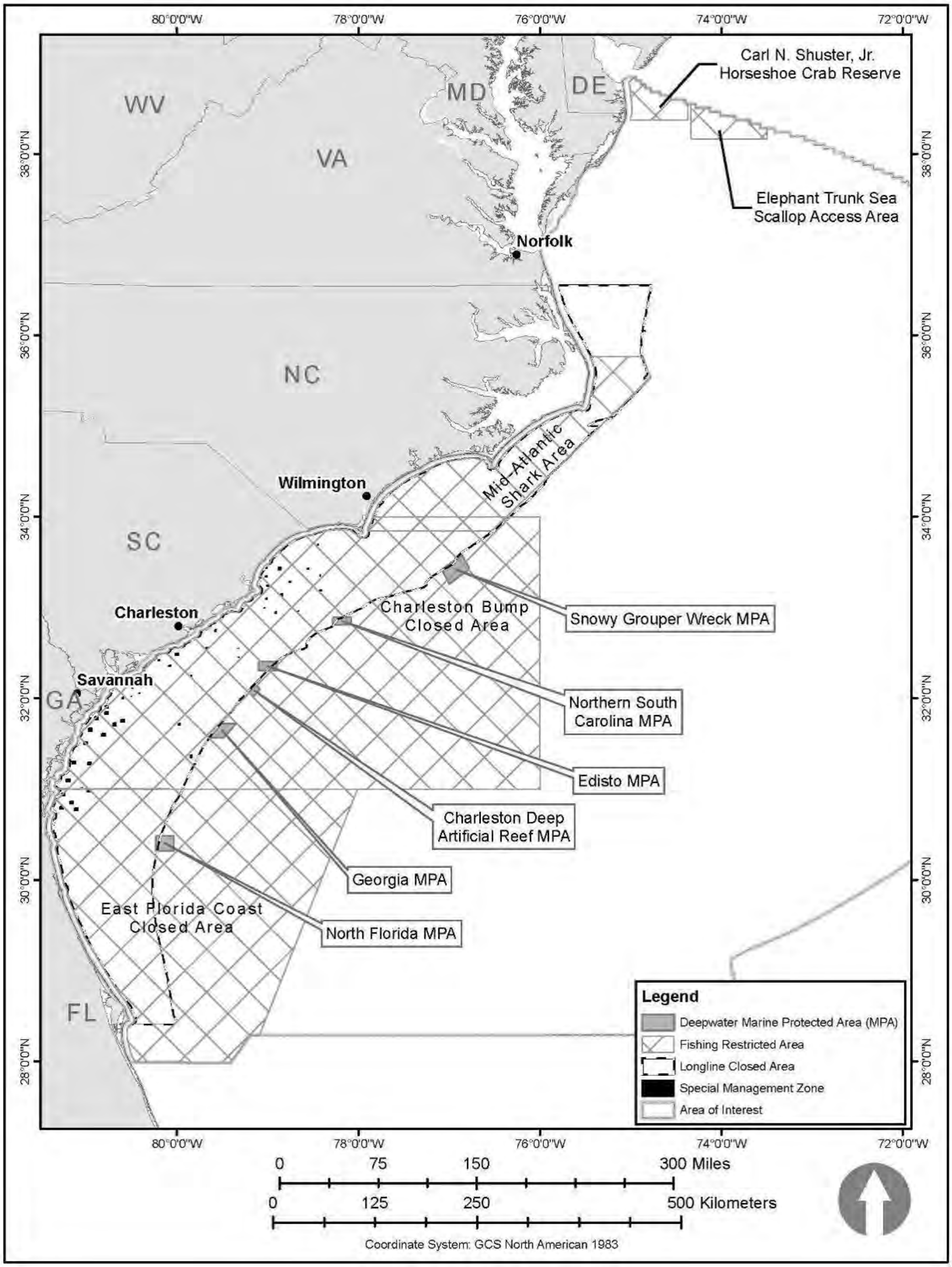

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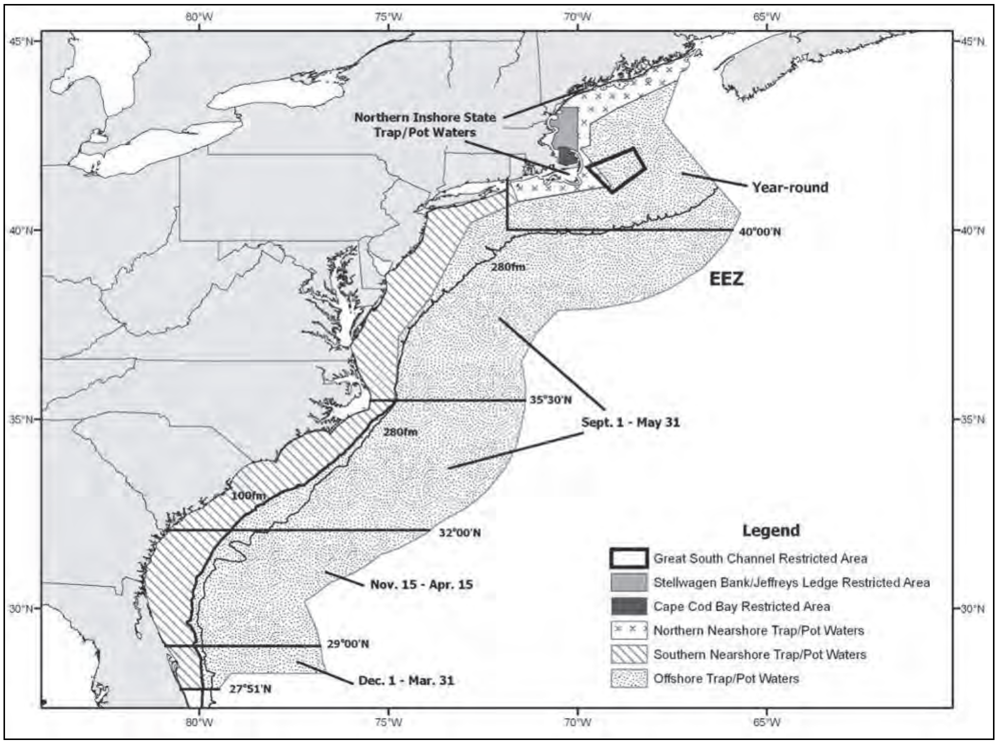

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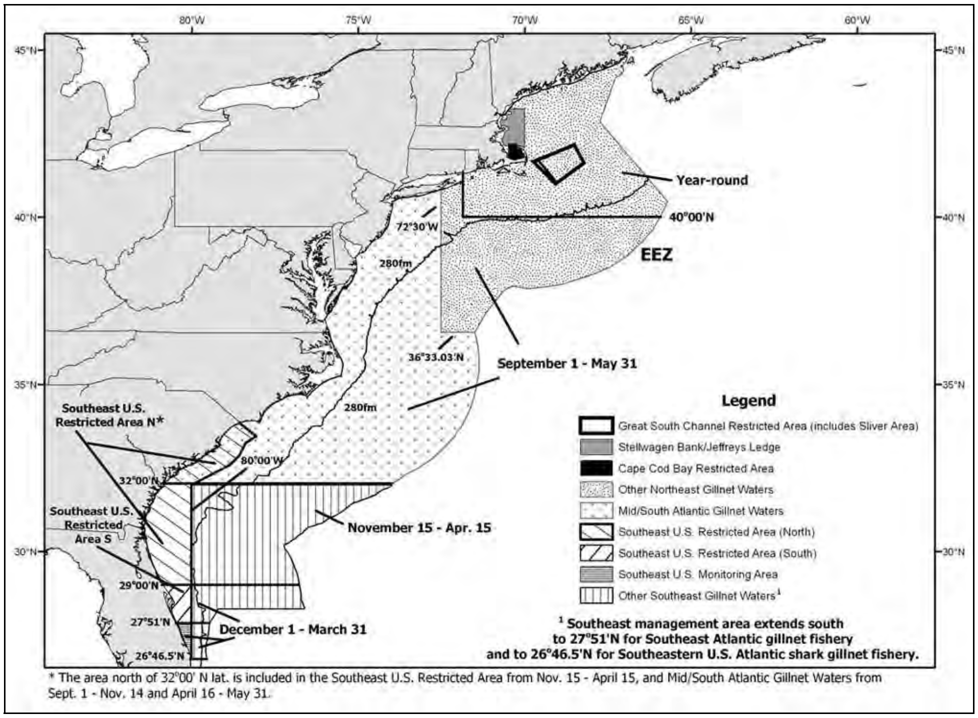
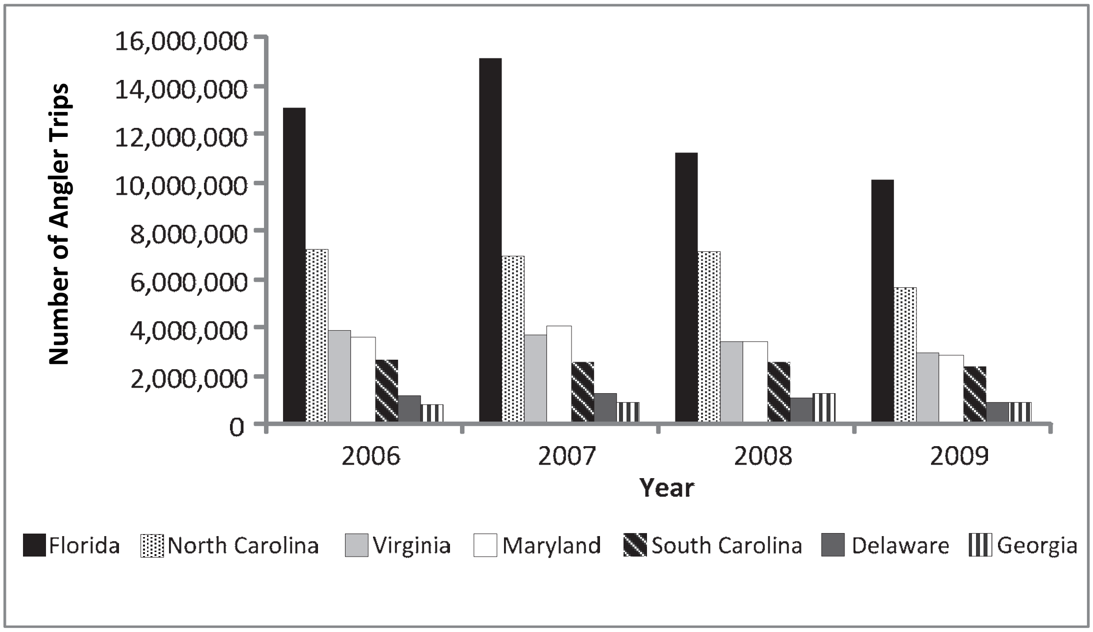


[1] Southeast management area extends south to 27°51'N for Southeast Atlantic gillnet fishery and to 26°46.5'N for Southeastern U.S. Atlantic shark gillnet fishery.

* The area north of 32°00' N lat. is included in the Southeast U.S. Restricted Area from Nov. 15 - April 15, and Mid/South Atlantic Gillnet Waters from Sept. 1 - Nov. 14 and April 16 - May 31.

Figure 4-25. Regulated Gillnet Areas under the Atlantic Large Whale Take Reduction Plan (USDOC, NMFS, 2010e).



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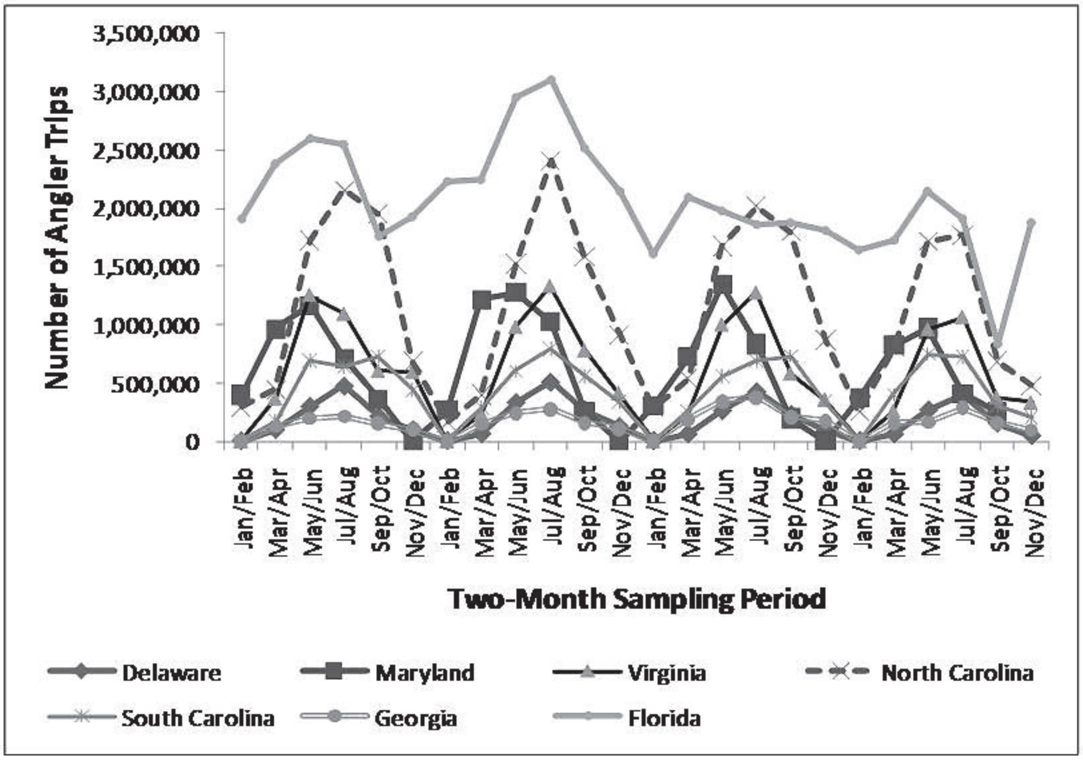
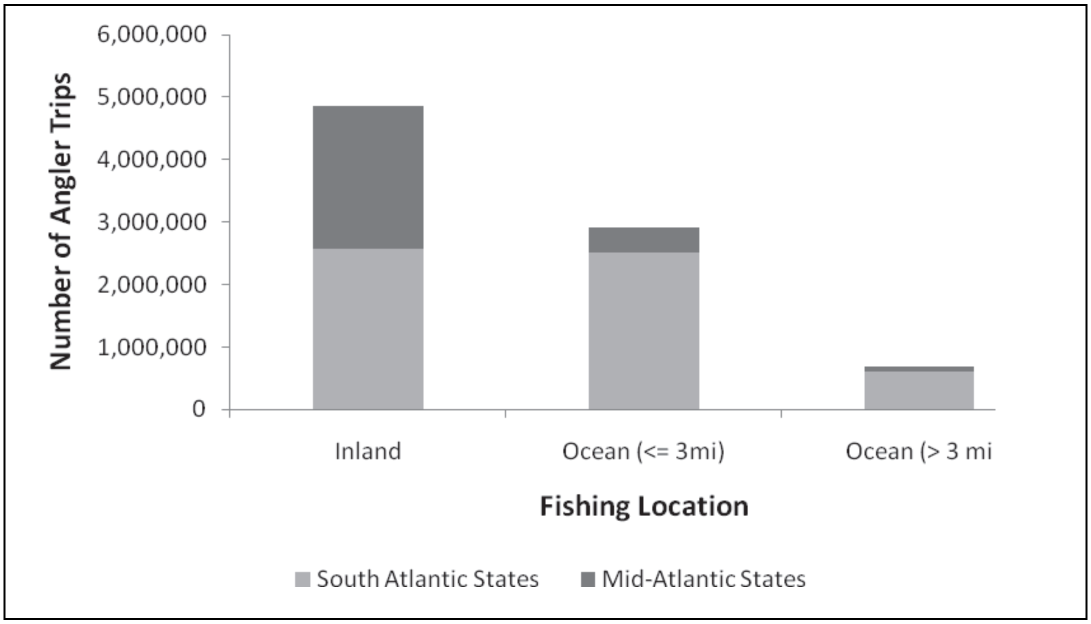


Figure 4-27. Numbers of Recreational Angler Trips by Month within the Area of Interest from 2006 through 2009 (USDOC, NMFS, 2011l).



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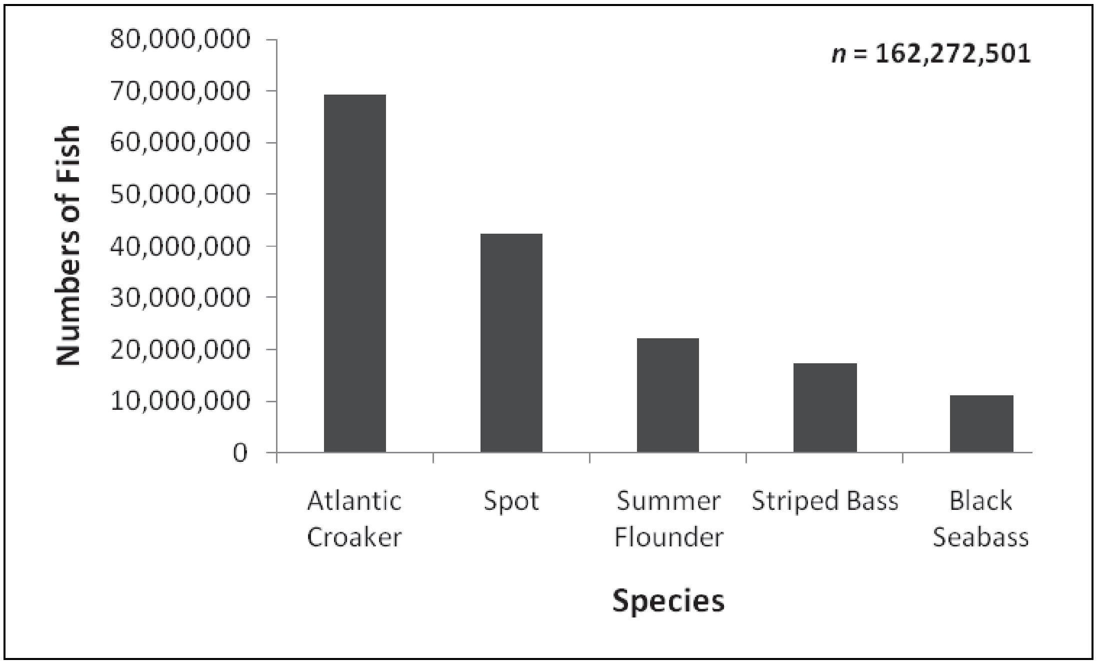

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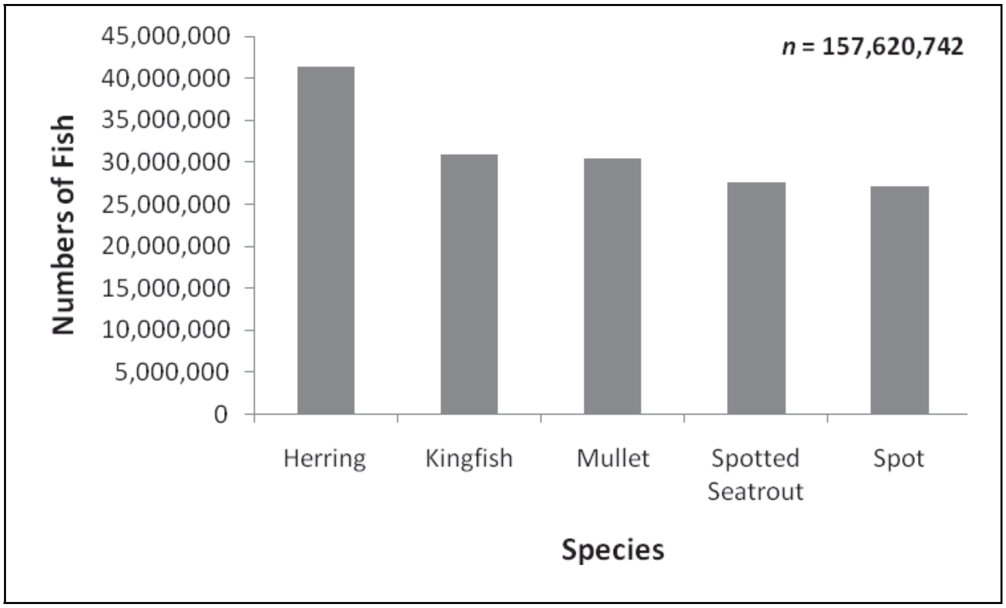


Figure 4-30. Numbers and Types of Fishes Landed by Recreational Anglers in the South Atlantic States (North Carolina, South Carolina, Georgia, and the Florida East Coast) from 2006 through 2009 (USDOC, NMFS, 2011l).

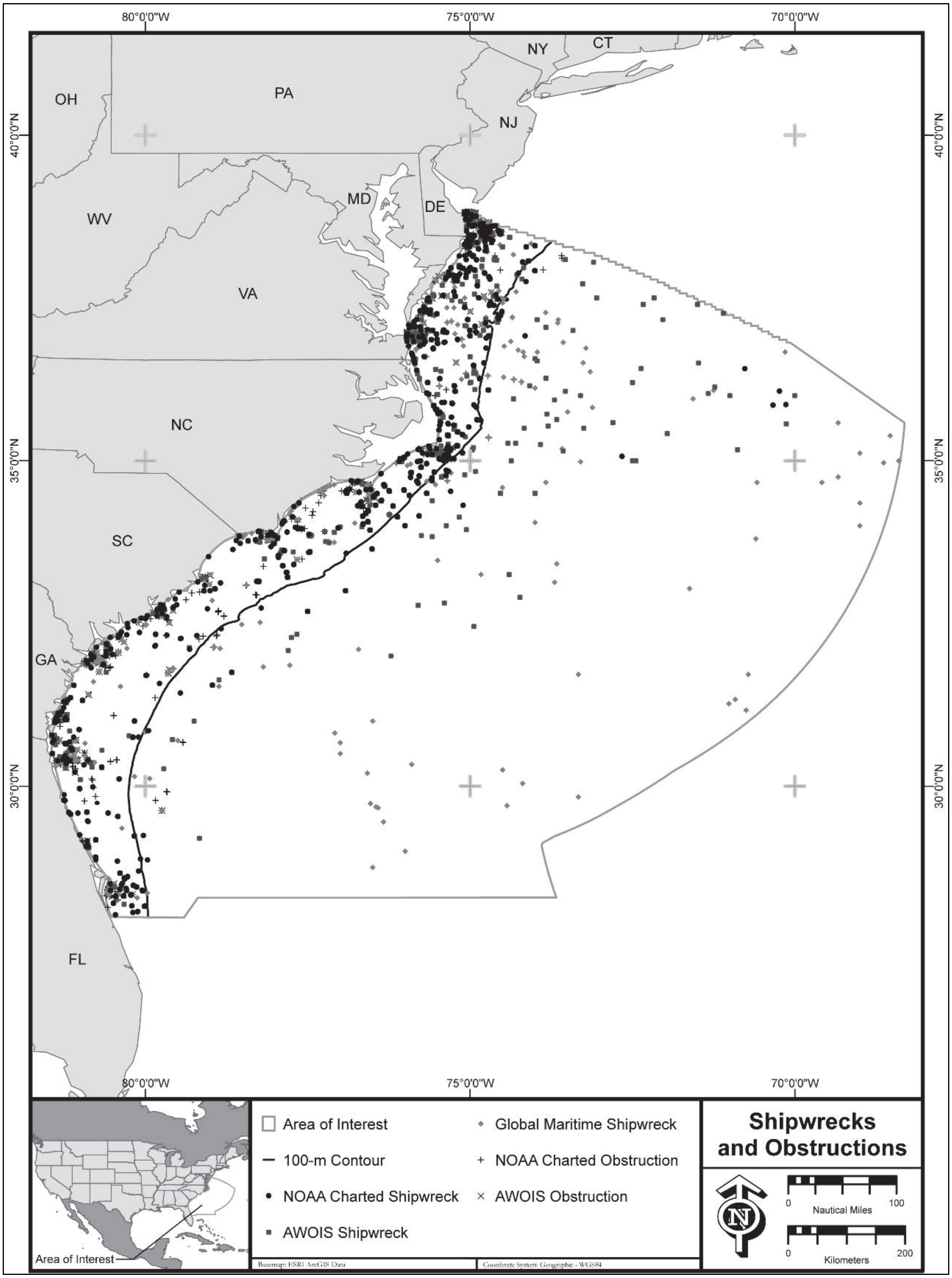


Figure 4-31. Shipwrecks and Obstructions in the Area of Interest.

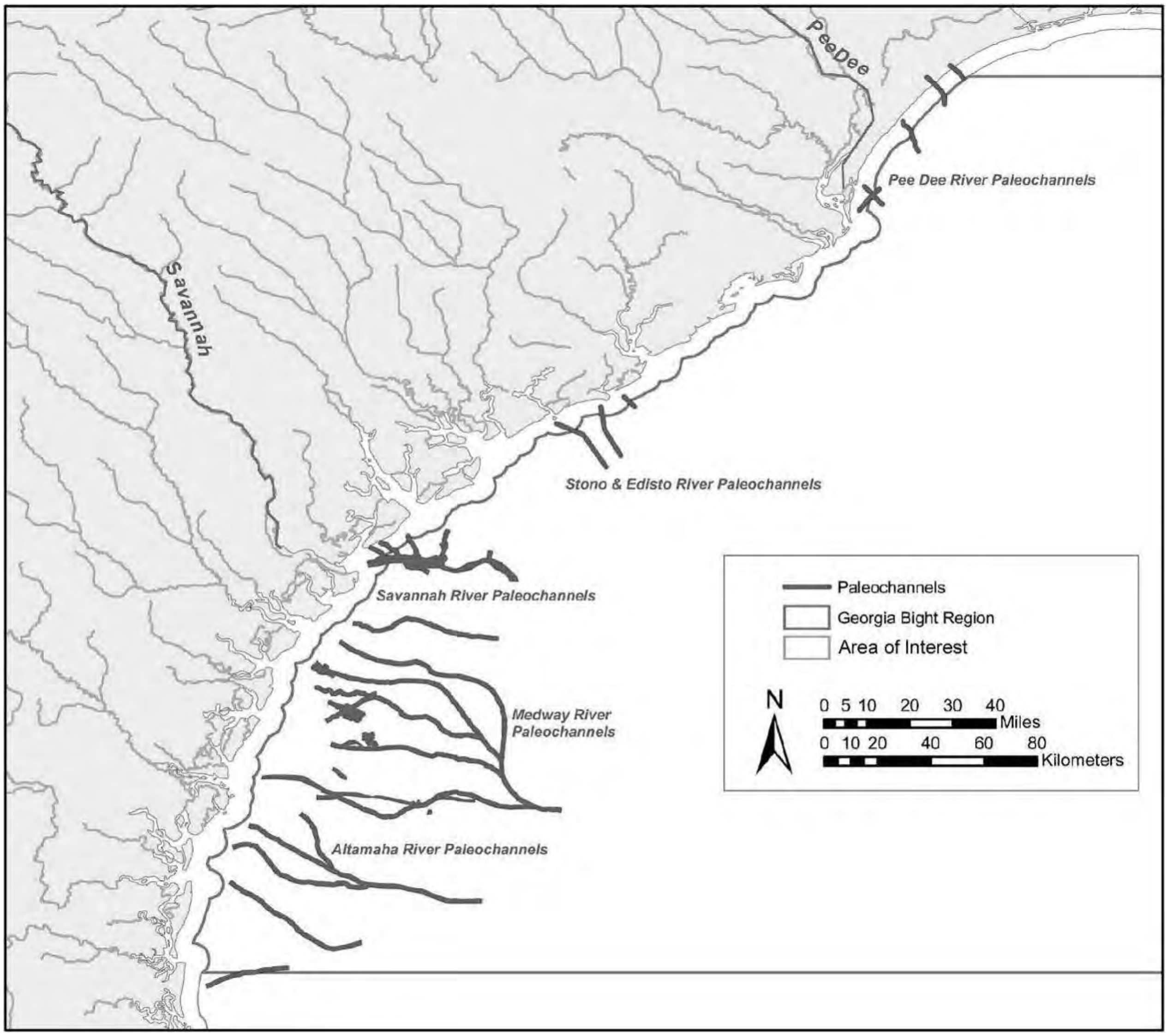
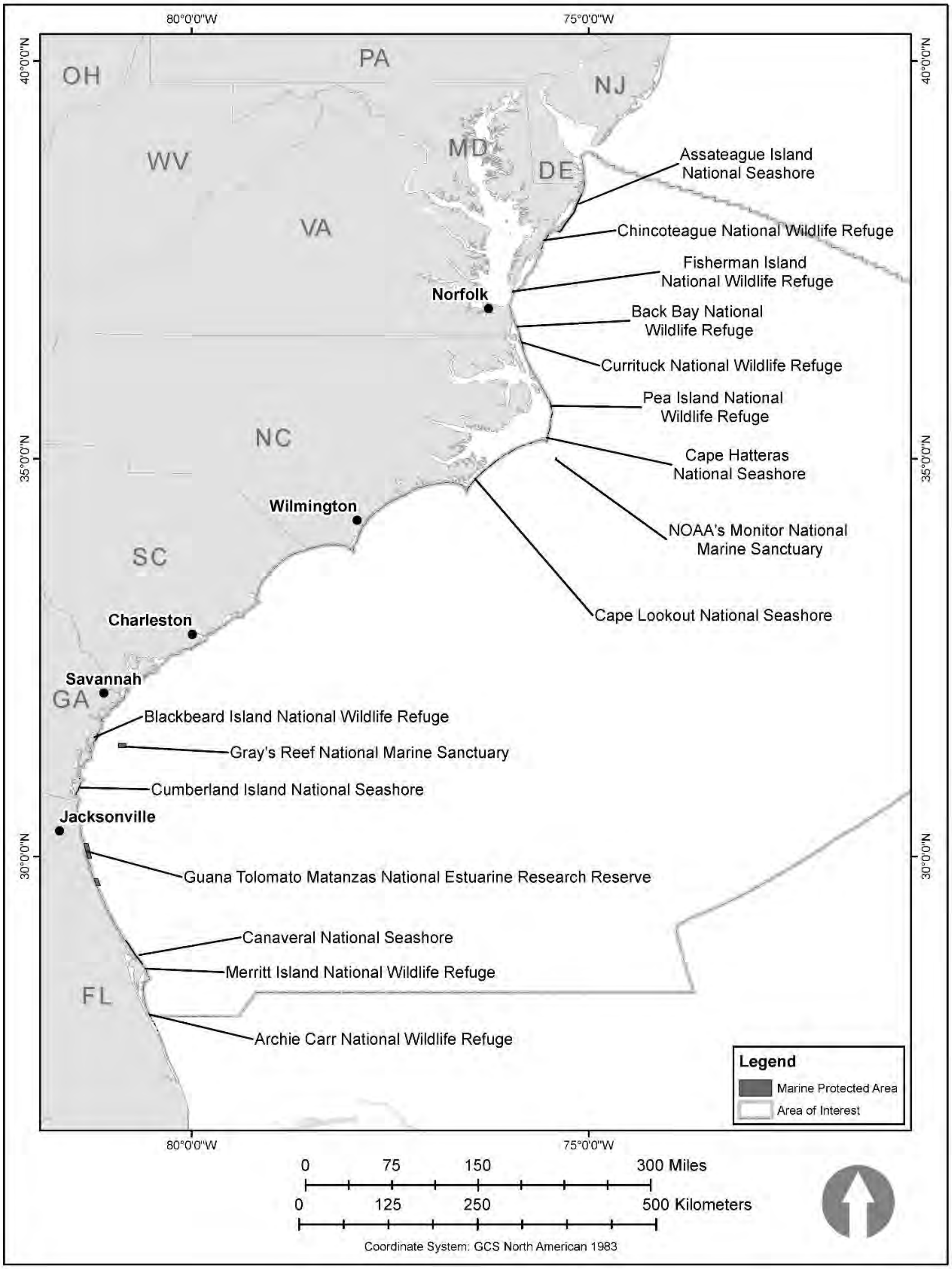


Figure 4-32. Model Showing Location of Paleochannels within the Georgia Bight (TRC Environmental Corporation, 2011).



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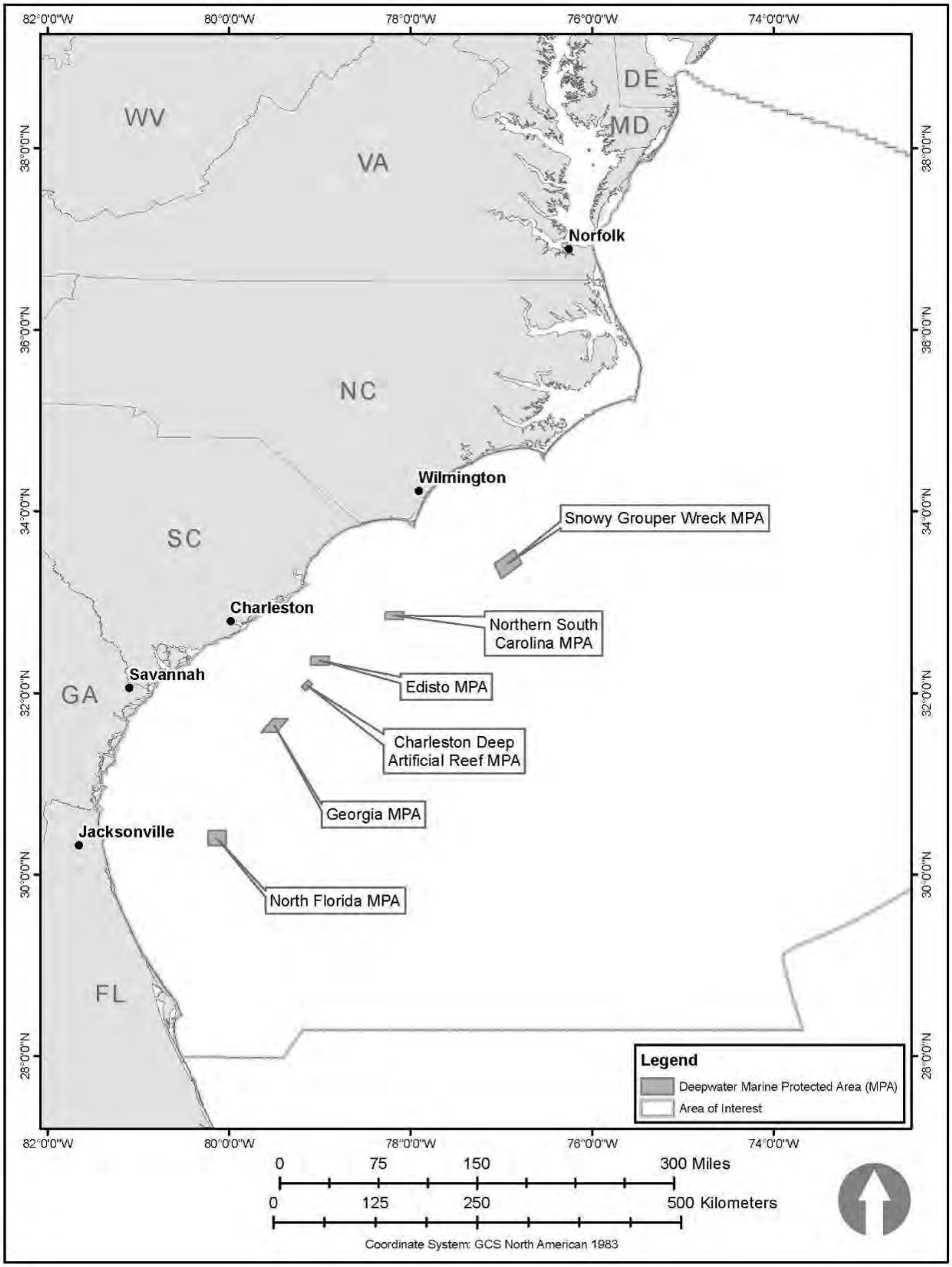

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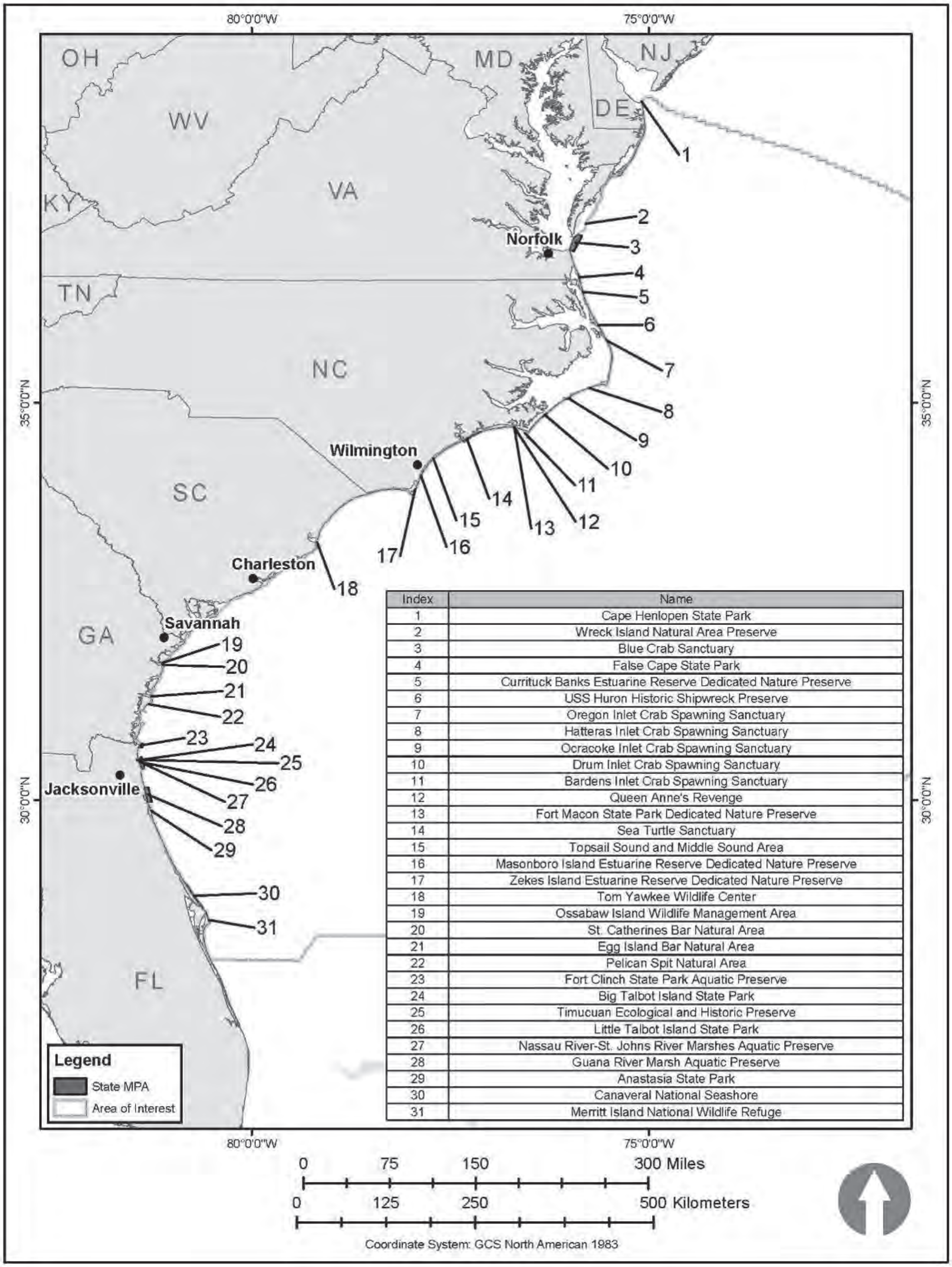

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1	Cape Henlopen State Park
2	Wreck Island Natural Area Preserve
3	Blue Crab Sanctuary
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11	Bardens Inlet Crab Spawning Sanctuary
12	Queen Anne's Revenge
13	Fort Macon State Park Dedicated Nature Preserve
14	Sea Turtle Sanctuary
15	Topsail Sound and Middle Sound Area
16	Masonboro Island Estuarine Reserve Dedicated Nature Preserve
17	Zekes Island Estuarine Reserve Dedicated Nature Preserve
18	Tom Yawkee Wildlife Center
19	Ossabaw Island Wildlife Management Area
20	St. Catherines Bar Natural Area
21	Egg Island Bar Natural Area
22	Pelican Spit Natural Area
23	Fort Clinch State Park Aquatic Preserve
24	Big Talbot Island State Park
25	Timucuan Ecological and Historic Preserve
26	Little Talbot Island State Park
27	Nassau River-St. Johns River Marshes Aquatic Preserve
28	Guana River Marsh Aquatic Preserve
29	Anastasia State Park
30	Canaveral National Seashore
31	Merritt Island National Wildlife Refuge

Figure 4-35. State-Designated Marine Protected Areas along the Mid-Atlantic and South Atlantic Coasts (USDOC, NOAA, National Marine Protected Areas Center, http://www.mpa.gov).

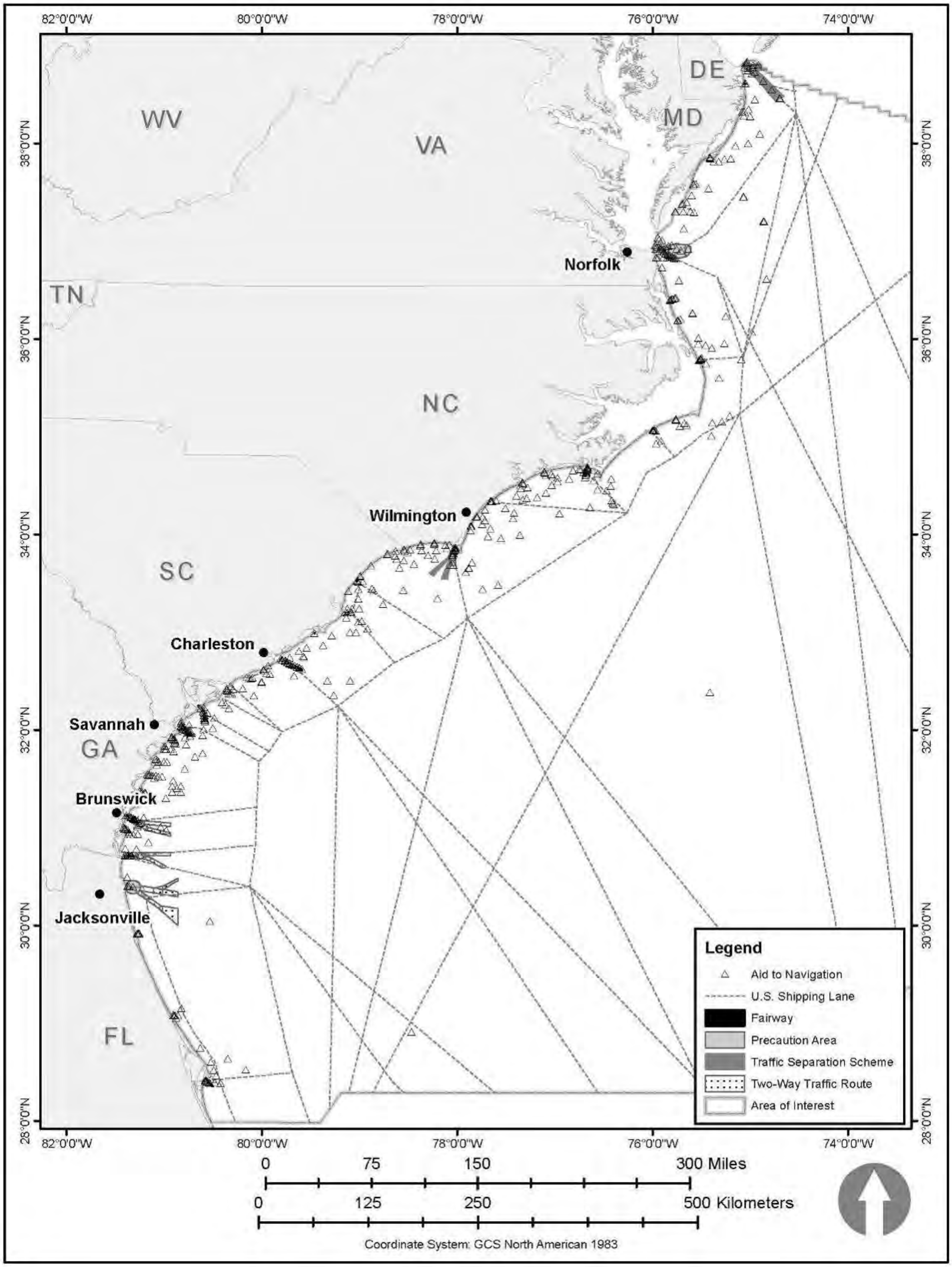

Figure 4-36. Aids to Navigation, Shipping Lanes, Precaution Areas, Fairways, and Traffic Separation Schemes along the Atlantic Coast (Multipurpose Marine Cadastre, 2011).

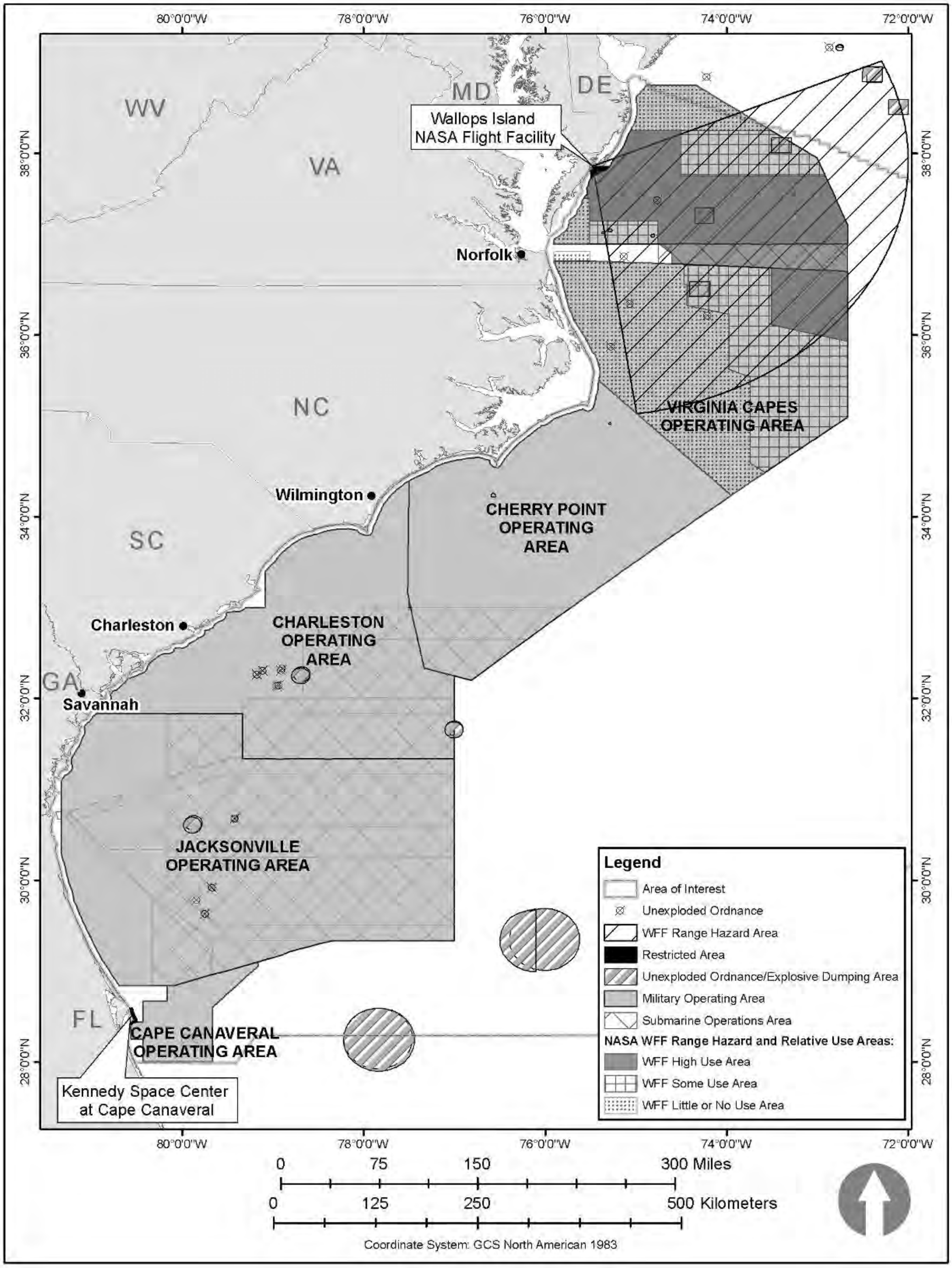

Figure 4-37. Military Use, National Aeronautics and Space Administration (NASA)-Restricted, and Ordnance Disposal Areas along the Atlantic Coast (Naval Facilities Engineering Command; 33 CFR 334.595; 33 CFR 334.130).

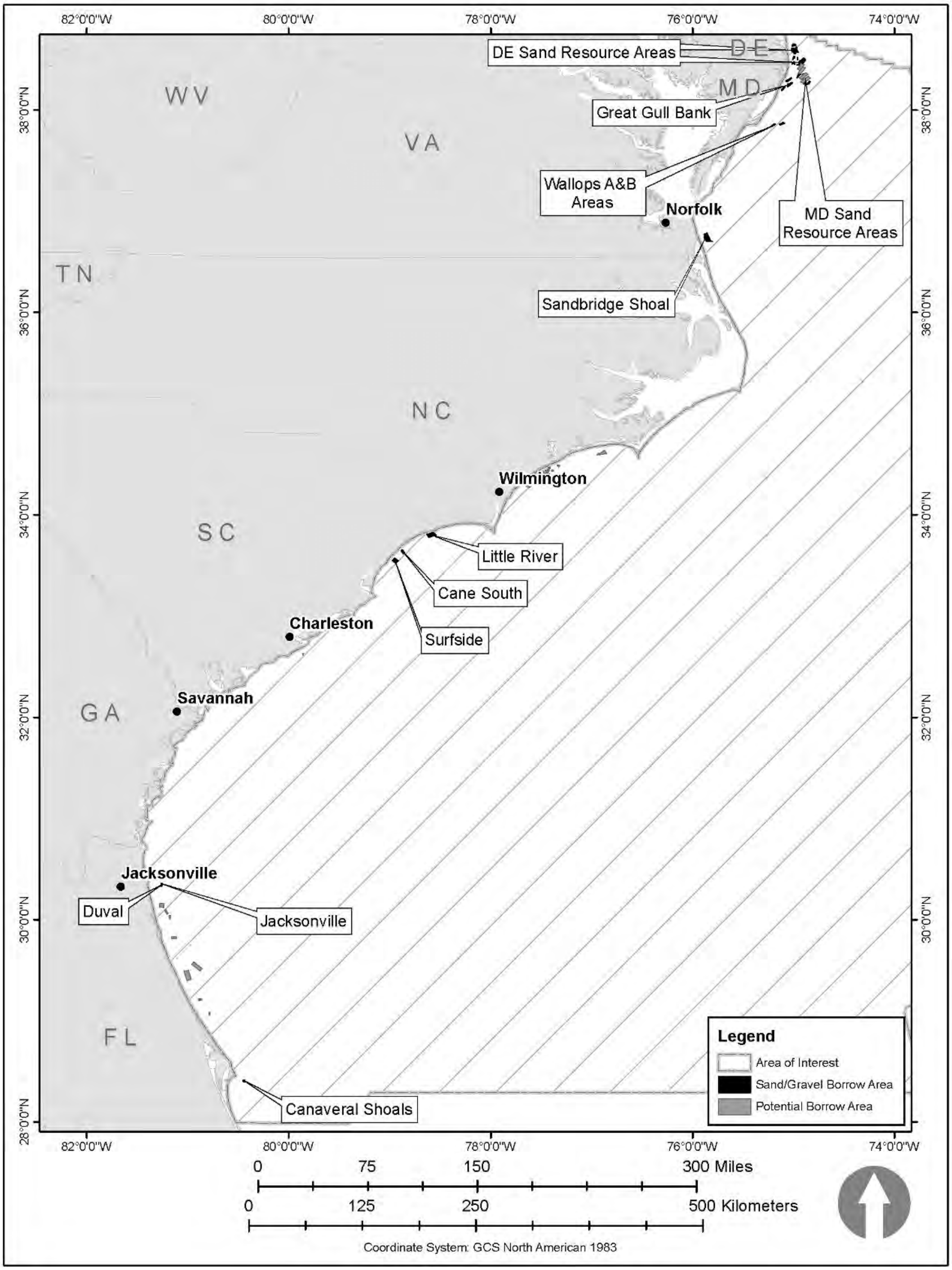

Figure 4-38. Outer Continental Shelf Sand and Gravel Borrow Areas along the Mid-Atlantic and South Atlantic Coasts.

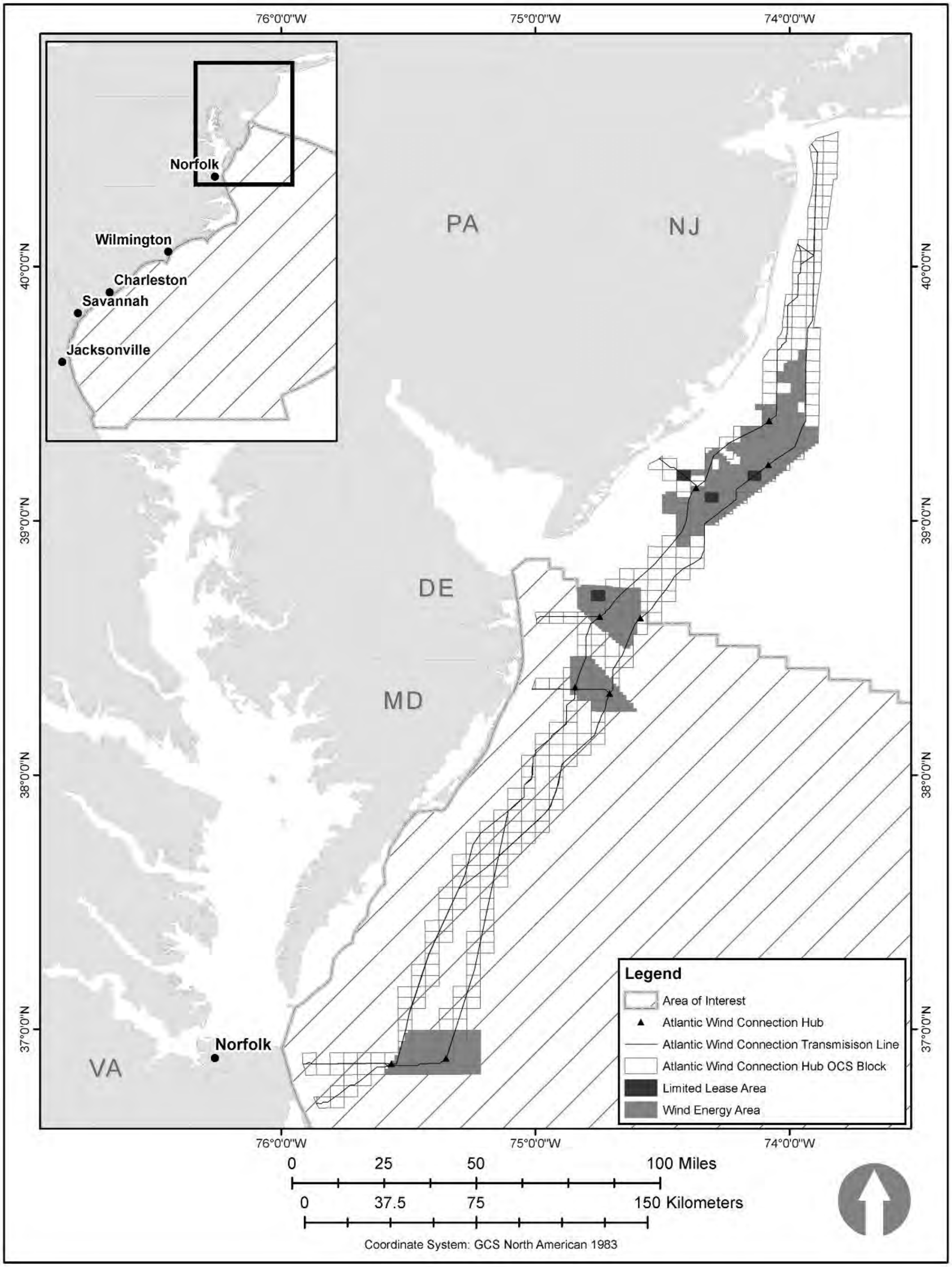

Figure 4-39. Identified Potential Wind Energy Facility Project Areas and Limited Leases for Wind Resource Assessment along the Mid-Atlantic Coast (USDOI, BOEM, 2011k,l,m,n).

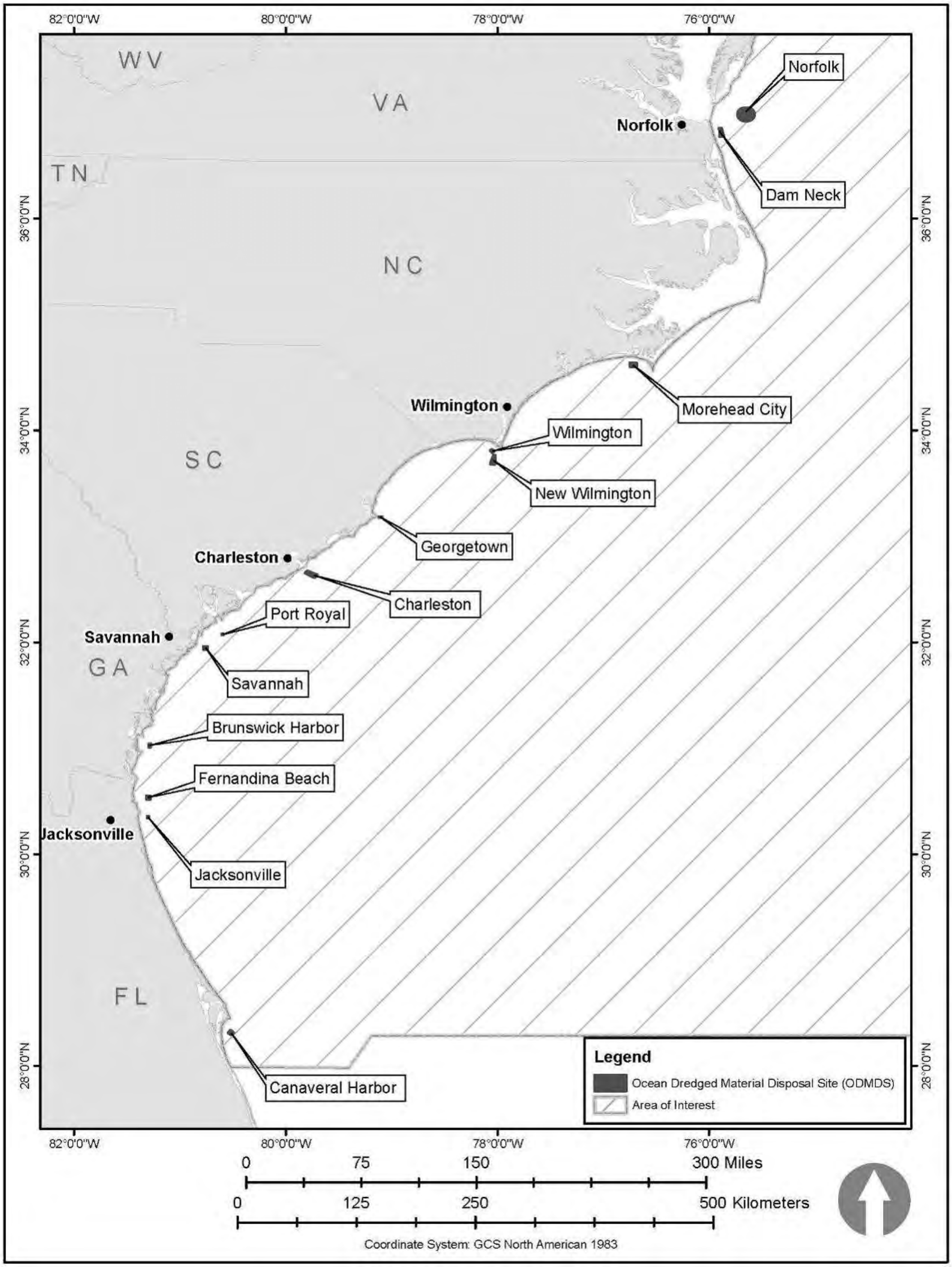

Figure 4-40. Ocean Dredged Material Disposal Sites along the Mid-Atlantic and South Atlantic Coasts.

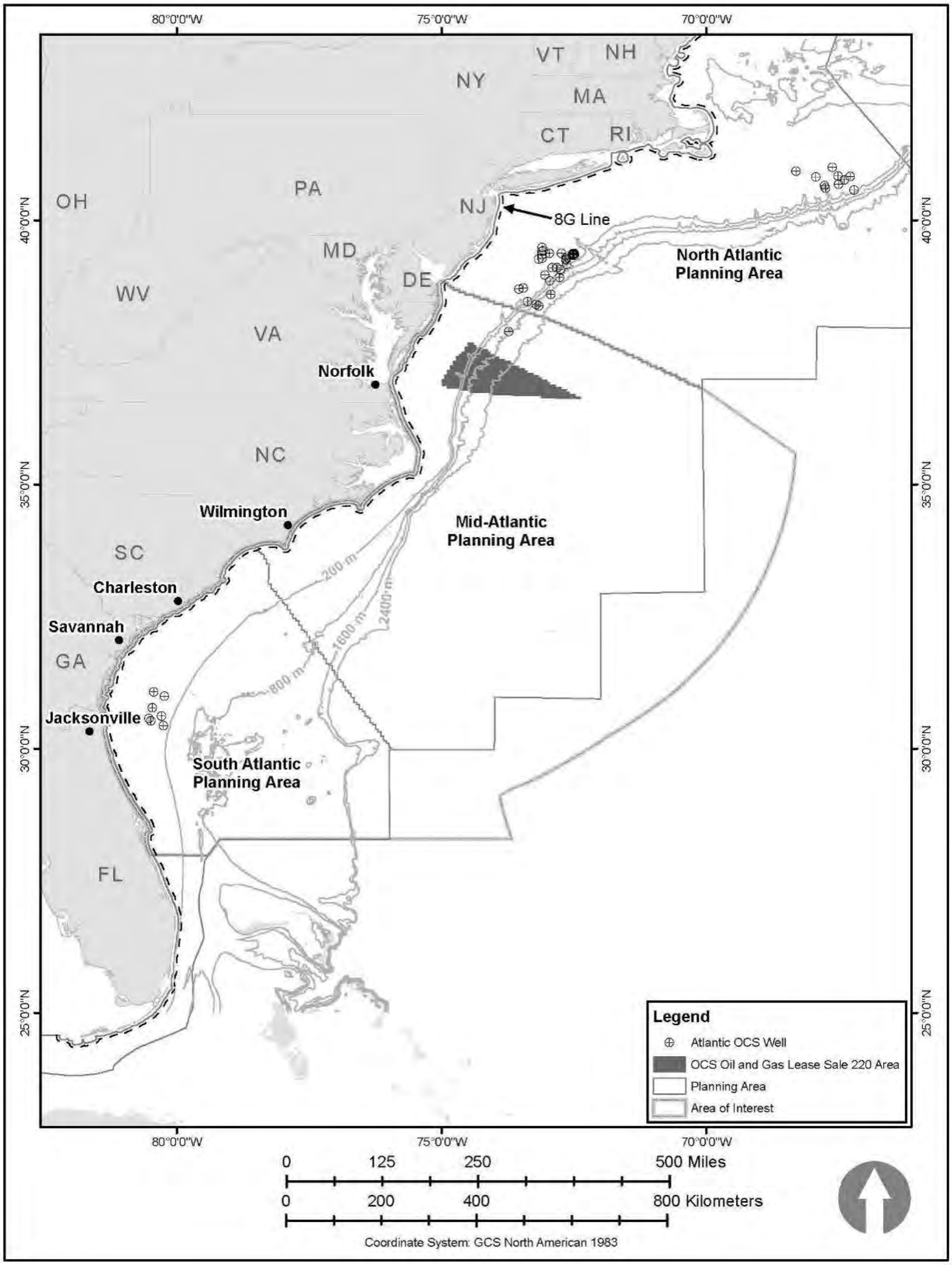

Figure 4-41. Locations of the 51 Wells Drilled on the Atlantic Outer Continental Shelf (OCS) between 1975 and 1984 (also shown is the location of the proposed OCS oil and gas Lease Sale 220 area offshore Virginia [sale canceled July 28, 2010]).

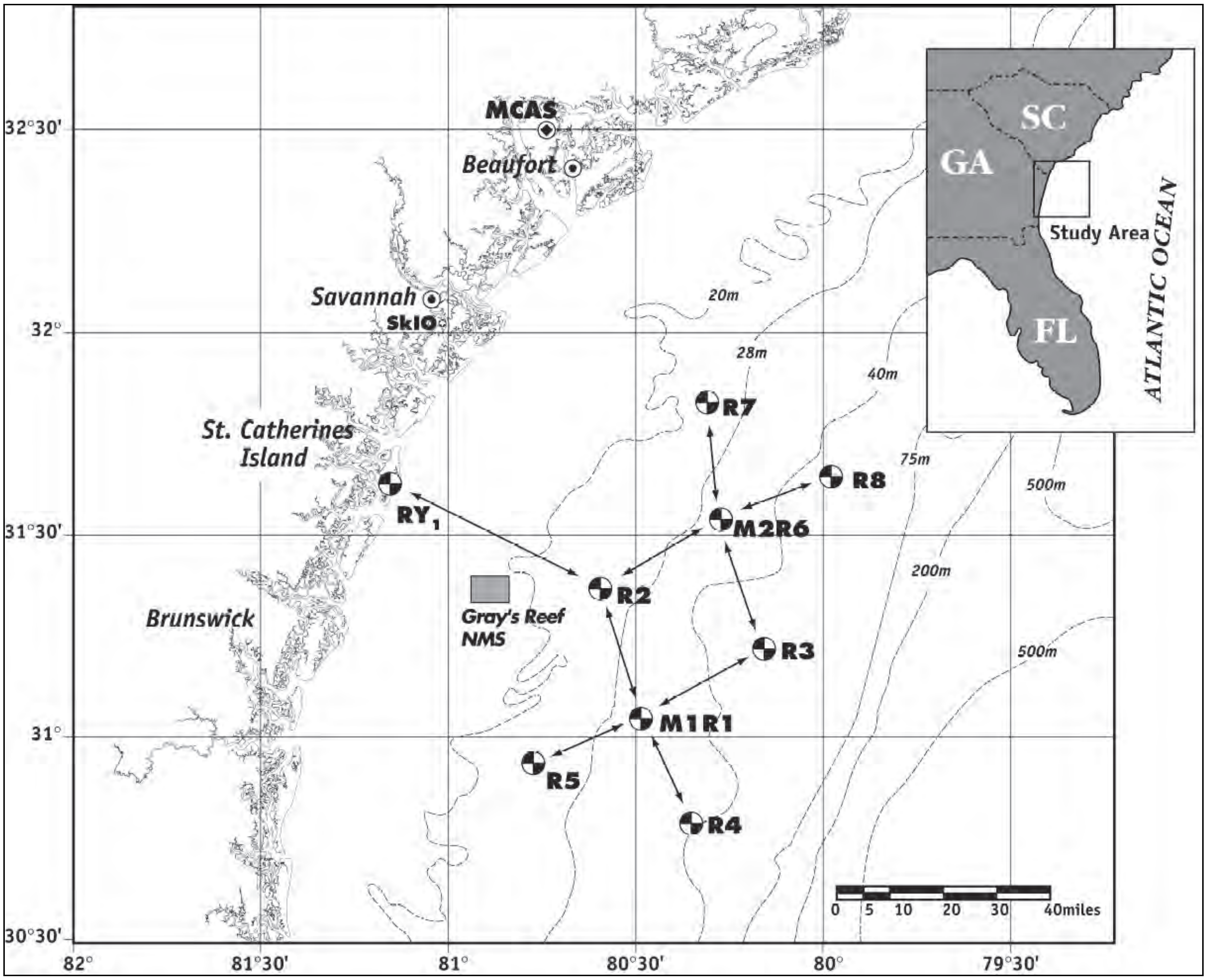

Figure 4-42. Location of U.S. Navy Research Towers in the Georgia Bight that are Part of the South Atlantic Bight Synoptic Offshore Observational Network (SABSOON) Operated by Skidaway Institute of Oceanography (Skidaway Institute of Oceanography, 2011).

Figure 5-1. Map with State-by-State Distribution of Origin of Comments.

TABLES

Table 1-1

Major Federal Laws and Regulations Applicable to the Proposed Action

Regulation or Law	Citation
Outer Continental Shelf Lands Act	43 U.S.C. 1331 et seq.
National Environmental Policy Act of 1969	42 U.S.C. 4321-4347 40 CFR 1500-1508
Coastal Zone Management Act of 1972	16 U.S.C. 1451 et seq., 15 CFR 930.76
Endangered Species Act of 1973	16 U.S.C. 1631 et seq.
Magnuson-Stevens Fishery Conservation and Management Act	16 U.S.C. 1251 et seq.
Essential Fish Habitat	1996 reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act
Essential Fish Habitat Consultation	50 CFR 600.905-930
Marine Mammal Protection Act	16 U.S.C. 1361 et seq.
Clean Air Act	42 U.S.C. 7401 et seq., 40 CFR 55
Clean Water Act	Amendment to Federal Water Pollution Control Act of 1972
Clean Water Act—National Pollutant Discharge Elimination System	Section 316(b) of the Clean Water Act
Harmful Algal Bloom and Hypoxia Research and Control Act	P.L. 105-383
Oil Pollution Act of 1990	33 U.S.C. 2701 et seq., Executive Order 12777
Comprehensive Environmental Response, Compensation, and Liability Act of 1980	42 U.S.C. 9601 et seq.
Resource Conservation and Recovery Act	42 U.S.C. 6901 et seq.
Marine Plastic Pollution Research and Control Act	33 U.S.C. 1901 et seq.
National Fishing Enhancement Act of 1984	33 U.S.C. 2601 et seq.
Fishermen's Contingency Fund	43 U.S.C. 1841-1846
Ports and Waterways Safety Act of 1972	33 U.S.C. 1223 et seq.
Marine and Estuarine Protection Acts	33 U.S.C. 1401 et seq.
Marine Protection, Research, and Sanctuaries Act of 1972	P.L. 92-532
National Estuarine Research Reserves	16 U.S.C. § 1461, Section 315
National Estuary Program	P.L. 104-4
Coastal Barrier Resources Act	16 U.S.C. 3501 et seq.
National Historic Preservation Act	16 U.S.C. 470 et seq.
Rivers and Harbors Act of 1899	33 U.S.C. 401 et seq.
Occupational Safety and Health Act of 1970	29 U.S.C. 651-678q
Energy Policy Act of 2005	P.L. 109-58
Marine Debris Research, Prevention, and Reduction Act	P.L. 109-449
American Indian Religious Freedom Act of 1978	P.L. 95-341, 42 U.S.C. 1996 and 1996a
Federal Aviation Act of 1958	Federal Aviation Act of 1958 was repealed by the recodification of 49 U.S.C. (P.L. 103-272)

Table 1-1. Major Federal Laws and Regulations Applicable to the Proposed Action (continued)

Regulation or Law	Citation
Migratory Bird Treaty Act of 1918	16 U.S.C. 703-712; Ch. 128; 07/13/1918; 40 Stat. 755
Submerged Lands Act of 1953	43 U.S.C. §§ 1301-1315 (2002)
49 U.S.C. 44718: Structures Interfering with Air Commerce	49 U.S.C. 44718
U.S. Coast Guard Regulations	
Marking of Obstructions	
Executive Order 11988: Floodplain Management	42 FR 26951 (1977), amended by Executive Order 12148 (7/20/79)
Executive Order 11990: Protection of Wetlands	42 FR 26961 (1977), amended by Executive Order 12608 (9/9/87)
Executive Order 12114: Environmental Effects Abroad	44 FR 1957 (1979)
Executive Order 12898: Environmental Justice	59 FR 5517 (1994)
Executive Order 13007: Indian Sacred Sites	61 FR 26771-26772 (1996)
Executive Order 13089: Coral Reef Protection	63 FR 32701-32703 (1998)
Executive Order 13175: Consultation and Coordination with Indian Tribal Governments	65 FR 67249-67252 (2000)
Executive Order 13186: Responsibilities of Federal Agencies to Protect Migratory Birds	66 FR 3853 (2001)
Executive Order 13547: Stewardship of the Ocean, Our Coasts, and the Great Lakes	75 FR 43023 (2010)

Source: Matthews and Cameron, 2010.

Table 2-1

Summary of Mitigation Measures Included in Alternatives A and B

Mitigation Measure	Description	Applicable Survey Types	Program Area			Alternative	
			OG	RE	MM	A	B
Time-Area Closure for North Atlantic Right Whales	Under Alternative A, no G&G surveys using air guns would be authorized within the North Atlantic right whale critical habitat area from November 15 through April 15 nor within the Mid-Atlantic and Southeast U.S. Seasonal Management Areas (SMAs) during the times when vessel speed restrictions are in effect under the Right Whale Ship Strike Reduction Rule (50 CFR 224.105). However, HRG surveys proposed in critical habitat and SMAs from November 15 through April 15 may be considered on a case-by-case basis only if: (1) they are proposed for renewable energy or marine minerals operations; and (2) they use acoustic sources other than air guns. The coincidence is necessary because of other biological use windows or project monitoring requirements. Any such authorization may include additional mitigation and monitoring requirements to avoid or significantly reduce impacts on right whales. Other supporting surveys (e.g., biological surveys) would not be affected by this restriction.	All vessel surveys (restrictions vary depending on survey type as indicated)	X	X	X	X	X
Expanded Time-Area Closure for North Atlantic Right Whales	Under Alternative B the expanded time-area closure for North Atlantic right whales would be a 37-km (20-nmi) wide zone from shore extending continuously from Delaware Bay to the southern limit of the AOI. No G&G surveys using airguns would be authorized within these expanded closure areas during the times when vessel speed restrictions are in effect in adjacent SMAs under 50 CFR 224.105. Exceptions for surveys are as stated for the time-areas closures for Alternative A.	All vessel surveys (restrictions vary depending on survey type as indicated)	X	X	X	--	X
Time-Area Closure to Protect Nesting Sea Turtles Offshore Brevard County, Florida	Alternative B would include a time-area closure in near-coastal waters offshore Brevard County, Florida during the sea turtle nesting season (May 1 to October 31). No airgun surveys would be authorized within the closure area during this time. Other surveys in the closure area would be reviewed on a case-by-case basis, and authorizations may include additional mitigation and monitoring requirements to avoid or reduce impacts on sea turtles.	All vessel surveys (restrictions vary depending on survey type as indicated)	X	X	X	--	X
Seismic Survey Protocol	Under both Alternatives A and B, all authorizations for seismic surveys would include a survey protocol that specifies mitigation measures for protected species, including ramp-up, visual monitoring of an exclusion zone by protected species observers prior to and during seismic surveys, and startup and shutdown requirements (see **Appendix L**). The protocol includes the <u>optional</u> use of PAM to help detect vocalizing marine mammals.	All deep penetration seismic surveys and all HRG surveys using airguns as sound source	X	X[a]	--[a]	X	X
Seismic Survey Protocol with Required PAM	Under Alternative B, the use of PAM would be <u>required</u> as part of the seismic survey protocol. The purpose would be to improve detection of marine mammals prior to and during seismic surveys so that impacts can be avoided by shutting down or delaying startup of airgun arrays until the animals are outside the exclusion zone.	All deep penetration seismic surveys and all HRG surveys using airguns as sound source	X	X[a]	--[a]	--	X
HRG Survey Protocol	Under both Alternatives A and B, all authorizations for non-airgun HRG surveys would include a survey protocol that specifies mitigation measures for protected species, including ramp-up, visual monitoring of an exclusion zone by protected species observers prior to and during surveys, and startup and shutdown requirements (see **Appendix L**).	All HRG surveys <u>not</u> using airguns as sound source	--	X	X	X	X
Separation between Simultaneous Seismic Surveys	Under Alternative B, a 40-km (25-mi) separation distance would be maintained between simultaneously operating deep penetration seismic surveys to limit ensonification of large areas of the AOI at the same time.	All deep penetration seismic surveys	X	X[a]	--[a]	--	X

Table 2-1. Summary of Applicable Existing Regulations, Survey Protocols, and Mitigation Measures (continued)

Mitigation Measure	Description	Applicable Survey Types	Program Area			Alternative	
			OG	RE	MM	A	B
Guidance for Vessel Strike Avoidance	Under both Alternatives A and B, all authorizations for shipboard surveys would include guidance for vessel strike avoidance. The guidance would be similar to NTL 2012-JOINT-G01 (*Vessel Strike Avoidance and Injured/Dead Protected Species Reporting*), which incorporates NMFS "Vessel Strike Avoidance Measures and Reporting for Mariners" addressing protected species identification, vessel strike avoidance, and injured/dead protected species reporting. The guidance also incorporates elements of the NMFS Compliance Guide for the Right Whale Ship Strike Reduction Rule (50 CFR 224.105).	All surveys involving ships (in transit and during data collection operations)	X	X	X	X	X
Guidance for Marine Debris Awareness	Under both Alternatives A and B, all authorizations for shipboard surveys would include guidance for marine debris awareness. The guidance would be similar to NTL No. 2012-BSEE-G01 (*Marine Trash and Debris Awareness and Elimination*). The applicant would be required to ensure that its employees and contractors are made aware of the environmental and socioeconomic impacts associated with marine trash and debris and their responsibilities for ensuring that trash and debris are not discharged into the marine environment.	All vessel surveys	X	X	X	X	X
Avoidance and Reporting of Historic and Prehistoric sites	Under both Alternatives A and B, all authorizations for G&G activities that involve seafloor-disturbing activities would include requirements for operators to report suspected historic and prehistoric archaeological resources to the BOEM and to take precautions to protect the resource. BOEM also requires reporting and avoidance for any previously undiscovered suspected archaeological resource and precautions to protect the resource from operational activities while appropriate mitigation measures are developed.	All surveys involving seafloor activities including coring, grab sampling, and placement of bottom cables, nodes, or buoys	X	X	X	X	X
Avoidance of Sensitive Benthic Communities	Under both Alternatives A and B, all authorizations for seafloor-disturbing activities would be subject to restrictions to protect sensitive benthic communities (e.g., hard/live bottom areas, deepwater coral communities, and chemosynthetic communities), including requirements for mapping and avoidance, as well as pre-deployment photographic survey of areas where bottom-founded instrumentation and appurtenances are to be deployed.	All surveys involving seafloor activities including coring, grab sampling, and placement of bottom cables, nodes, or buoys	X	X	X	X	X
Guidance for Activities In or Near National Marine Sanctuaries	Under both Alternatives A and B, all authorizations for G&G activities would include instructions to minimize impacts on NMS resources. Operators would be instructed to exercise caution to ensure that their activities do not endanger any other users of the Sanctuary. Additionally, if proposed activities involve seafloor disturbance near an NMS or moving the surface marker buoys for the Sanctuary, the operator would be required to contact the Sanctuary Manager for instructions. The BOEM would not authorize seafloor-disturbing activities within the boundaries of an NMS, and seafloor-disturbing activities proposed near the boundaries of an NMS would be assigned a setback distance as a condition of permit approval to be determined by BOEM in consultation with the Sanctuary Manager.	All surveys	X	X	X	X	X
Guidance for Military and NASA Coordination	Under both Alternatives A and B, all authorizations for permitted activities would include guidance for military and NASA coordination. The guidance would be similar to NTL No. 2009-G06 (*Military Warning and Water Test Areas*) (USDOI, MMS, 2009c). Vessel and aircraft operators would be required to establish and maintain early contact and coordination with the appropriate military command headquarters or NASA point of contact.	All surveys	X	X	X	X	X

Abbreviations: AOI = Area of Interest; CFR = Code of Federal Regulations; HRG = high-resolution geophysical; MM = marine minerals; NTL = Notice to Lessees and Operators; OG = oil and gas; PAM = passive acoustic monitoring; RE = renewable energy; SMA = Seasonal Management Area.

[a] The BOEM does not expect that airguns would be used in HRG surveys for renewable energy or marine minerals sites. However, the renewable energy scenario includes the possibility of a deep penetration seismic survey to evaluate formation suitability for carbon sequestration.

Table 2-2

Comparison of Impact Levels for Alternatives A, B, and C

Resource and Impact-Producing Factor	Alternative[a]		
	A	B	C
Benthic Communities			
Active Acoustic Sound Sources			
Airguns	Negligible	Negligible	N/A
Electromechanical sources	Negligible	Negligible	Negligible
Trash and Debris	Negligible	Negligible	Negligible
Seafloor Disturbance	Negligible-Minor	Negligible-Minor	Negligible
Drilling Discharges	Negligible	Negligible	N/A
Accidental Fuel Spills	Negligible	Negligible	Negligible
Marine Mammals			
Active Acoustic Sound Sources			
Airguns	**Moderate**	**Moderate**	N/A
Electromechanical sources	Minor	Minor	Minor
Vessel and Equipment Noise	Negligible-Minor	Negligible-Minor	Negligible-Minor
Vessel Traffic	Negligible	Negligible	Negligible
Aircraft Traffic and Noise	Negligible-Minor	Negligible-Minor	N/A
Trash and Debris	Negligible	Negligible	Negligible
Accidental Fuel Spills	Negligible-Minor	Negligible-Minor	Negligible-Minor
Sea Turtles			
Active Acoustic Sound Sources			
Airguns	Negligible-**Moderate**	Negligible-Minor	N/A
Electromechanical sources	Negligible-Minor	Negligible-Minor	Negligible
Vessel and Equipment Noise	Negligible	Negligible	Negligible
Vessel Traffic	Negligible	Negligible	Negligible
Aircraft Traffic and Noise	Negligible	Negligible	N/A
Trash and Debris	Negligible	Negligible	Negligible
Accidental Fuel Spills	Negligible-Minor	Negligible-Minor	Negligible-Minor
Marine and Coastal Birds			
Active Acoustic Sound Sources			
Airguns	Negligible-Minor	Negligible-Minor	N/A
Electromechanical sources	Negligible	Negligible	Negligible
Vessel and Equipment Noise	Negligible-Minor	Negligible-Minor	Negligible
Vessel Traffic	Negligible-Minor	Negligible-Minor	Negligible
Aircraft Traffic and Noise	Negligible-Minor	Negligible-Minor	N/A
Trash and Debris	Negligible	Negligible	Negligible
Accidental Fuel Spills	Negligible-**Moderate**	Negligible-**Moderate**	Negligible-**Moderate**

Table 2-2 Comparison of Impact Levels for Alternatives A, B, and C (continued)

Resource and Impact-Producing Factor	Alternative[a]		
	A	B	C
Fisheries Resources and EFH			
Active Acoustic Sound Sources			
Airguns	Minor	Minor	N/A
Electromechanical sources	Minor	Minor	Negligible
Vessel and Equipment Noise	Minor	Minor	Negligible
Seafloor Disturbance	Negligible	Negligible	Negligible
Drilling Discharges	Negligible	Negligible	N/A
Accidental Fuel Spills	Minor	Minor	Minor
Threatened and Endangered Fishes			
Active Acoustic Sound Sources			
Airguns	Negligible-Minor	Negligible-Minor	N/A
Electromechanical sources	Negligible-Minor	Negligible-Minor	Negligible
Vessel and Equipment Noise	Negligible-Minor	Negligible-Minor	Negligible
Vessel Traffic	Negligible	Negligible	Negligible
Trash and Debris	Negligible	Negligible	Negligible
Seafloor Disturbance	Negligible	Negligible	Negligible
Drilling Discharges	Negligible	Negligible	N/A
Accidental Fuel Spills	Negligible	Negligible	Negligible
Commercial Fisheries			
Active Acoustic Sound Sources			
Airguns	Minor	Minor	N/A
Electromechanical sources	Minor	Minor	Negligible-Minor
Vessel Traffic	Minor	Minor	Negligible
Vessel Exclusion Zones	Minor	Minor	N/A
Seafloor Disturbance	Negligible	Negligible	Negligible
Accidental Fuel Spills	Negligible	Negligible	Negligible
Recreational Fisheries			
Active Acoustic Sound Sources			
Airguns	Negligible-Minor	Negligible-Minor	N/A
Electromechanical sources	Negligible-Minor	Negligible-Minor	Negligible
Vessel Traffic	Negligible-Minor	Negligible-Minor	Negligible
Vessel Exclusion Zones	Negligible	Negligible	N/A
Accidental Fuel Spills	Negligible	Negligible	Negligible
Recreational Resources			
Vessel Exclusion Zones	Negligible	Negligible	N/A
Trash and Debris	Negligible-Minor	Negligible-Minor	Negligible
Accidental Fuel Spills	Negligible-Minor	Negligible-Minor	Negligible-Minor

Table 2-2 Comparison of Impact Levels for Alternatives A, B, and C (continued)

Resource and Impact-Producing Factor	Alternative[a]		
	A	B	C
Archaeological Resources			
Seafloor Disturbance	Negligible	Negligible	Negligible
Drilling Discharges	Negligible	Negligible	N/A
Accidental Fuel Spills	Negligible	Negligible	Negligible
Marine Protected Areas (MPAs)			
Active Acoustic Sound Sources			
Airguns	Negligible-**Moderate**	Negligible-Minor	N/A
Electromechanical sources	Negligible-Minor	Negligible-Minor	Negligible
Trash and Debris	Negligible	Negligible	Negligible
Seafloor Disturbance	Negligible	Negligible	Negligible
Drilling Discharges	Negligible	Negligible	N/A
Accidental Fuel Spills	Negligible-Minor	Negligible-Minor	Negligible-Minor
Other Marine Uses			
Vessel Traffic	Negligible-Minor	Negligible-Minor	Negligible-Minor
Vessel Exclusion Zones	Negligible-Minor	Negligible-Minor	N/A
Aircraft Traffic and Noise	Negligible	Negligible	N/A
Seafloor Disturbance	Negligible	Negligible	Negligible
Accidental Fuel Spills	Negligible	Negligible	Negligible
Human Resources and Land Use			
Onshore Support Activity	Negligible	Negligible	Negligible
Accidental Fuel Spills	Negligible	Negligible	Negligible

Note: Impacts are categorized as Major, Moderate, Minor, or Negligible (see **Chapter 4.1.2** for definitions). Shading indicates impacts that are reduced by at least one category relative to impacts of Alternative A.

N/A = not applicable (the impact-producing factor would not occur under this Alternative).

[a] Alternative A = The Proposed Action. Alternative B = Additional Time-Area Closures and Separation of Simultaneous Seismic Airgun Surveys. Alternative C = No Action for Oil and Gas, Status Quo for Renewable Energy and Marine Minerals G&G Activities.

Table 3-1

Types of G&G Activities Included in This Programmatic EIS

Survey Type	Applicable Program Areas			Purpose(s)
	Oil and Gas	Renewable Energy	Marine Minerals	
Deep Penetration Seismic Surveys				Evaluate subsurface geological formations to assess potential hydrocarbon reservoirs and optimally site exploration and development wells. 4D surveys are used to monitor reservoirs over time during production.
2D Seismic Exploration Surveys	X	x[a]	--	
3D Seismic Exploration Surveys	X	x[a]	--	
Wide Azimuth Surveys	X	--	--	
Nodes and Bottom Cable Surveys	X	--	--	
Vertical Cable Surveys	X	--	--	
4D (Time-Lapse) Surveys	X	--	--	
Vertical Seismic Profile Surveys	X	--	--	
High-Resolution Geophysical Surveys				Assess shallow hazards, archaeological resources, and benthic habitats
With single airgun as seismic source	X	--	--	
With boomer or chirp subbottom profiler as seismic source	--	X	X	
Electromagnetic Surveys				Help distinguish economic hydrocarbon accumulations from other scenarios by using electromagnetic signals to develop a conductivity/resistivity profile of the seafloor.
Controlled Source Electromagnetic Surveys	X	--	--	
Magnetotelluric Surveys	X	--	--	
Deep Stratigraphic and Shallow Test Drilling				COST wells evaluate stratigraphy and hydrocarbon potential without drilling directly into oil and gas bearing strata. Shallow test drilling is conducted to place test equipment into a borehole to evaluate gas hydrates or other properties.
Continental Offshore Stratigraphic Test (COST) wells	X	--	--	
Shallow test drilling	X	--	--	
Bottom Sampling				Collect surface and near-surface sediment samples to assess seafloor properties for siting structures such as platforms, pipelines, or cables.
Cone Penetrometer Tests	X	X	X	
Vibracoring	X	X	X	
Geologic Coring	X	X	X	
Grab Sampling	X	X	X	
Remote Sensing				Gravity and magnetic surveys are used to assess structure and sedimentary properties of subsurface horizons. Radar imaging is used to detect oil slicks on the sea surface (indicative of seepage). Aeromagnetic surveys evaluate deep crustal structure, salt related structure, and intra-sedimentary anomalies.
Gravity Surveys	X	--	--	
Gravity Gradiometry	X	--	--	
Marine Magnetic Surveys	X	--	--	
Radar Imaging	X	--	--	
Aeromagnetic Surveys	X	--	--	

[a] The renewable energy scenario includes the possibility that a deep penetration (2D or 3D) seismic survey would be conducted to evaluate formation suitability for carbon sequestration. However, given the much greater number and extent of seismic surveys included in the oil and gas scenario, a single seismic survey for carbon sequestration is not analyzed separately in this Programmatic EIS.

Table 3-2

Program Area, G&G Activity, Permitting Authority, and Typical NEPA Action

G&G Activity in Support of	On Lease	Off Lease and/or Third Party	Permitting Authority	How Approved		Typical NEPA Action
				OCS Plan[1]	Permit Application	
Oil and Gas						
Exploration (post lease)	X		30 CFR Part 550	EP		EA or EIS
Development (post lease)	X		30 CFR Part 550	DOCD or DPP		EA or EIS
Ancillary Activities (post lease)	X		30 CFR Part 550	Conditional, Plan Revision	Notification	Conditional, EA
Exploration (prelease)		X	30 CFR Part 551	None	X	EA or EIS
Scientific Research		X	30 CFR Part 551	None	X	EA
Renewable Energy						
Site Assessment	X		30 CFR Part 585	SAP		EA or EIS
Renewable Energy Facility Development	X		30 CFR Part 585	COP		EA or EIS
Other Activities	X		30 CFR Part 585	GAP		EA or EIS
Marine Minerals						
Research and Prospecting		X	OCSLA Section 11 30 CFR Part 580[2]	None	Authorization or Notification	EA or EIS
Leasing-Related Monitoring	X		OCSLA Section 8(k) 30 CFR Part 581-582[2]	None	None	None[3]

[1] Plan types defined in **Chapters 3.2.1** and **3.3.1**.
[2] Applies to competitive leasing only, which this Agency has never done for marine minerals.
[3] Addressed in NEPA document for prospecting.

Table 3-3

Projected Levels of G&G Activities for Oil and Gas Exploration in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020

Year	Mid-Atlantic Planning Area						South Atlantic Planning Area					
	2D (km)	3D (blocks)[a]	WAZ (blocks)[b]	HRG (line km)	VSP (line km)	CSEM (line km)	2D (km)	3D (blocks)[a]	WAZ (blocks)[b]	HRG (line km)	VSP (line km)	CSEM (line km)
2012	0	0	0	0	0	0	0	0	0	0	0	0
2013	83,400	0	0	0	0	0	28,450	0	0	0	0	0
2014	160,950	0	0	0	0	0	56,900	0	0	0	0	0
2015	12,875	0	0	0	0	0	8,050	0	0	0	0	0
2016	64,375	400	0	0	0	3,220	48,300	300	0	0	0	1,600
2017	41,800	200	0	0	0	16,100	38,624	200	0	3,220	0	8,050
2018	16,100	200	100	3,220	0	32,200	32,200	200	100	32,200	0	9,650
2019	16,100	200	100	16,100	160	16,100	8,050	200	200	16,100	320	320
2020	800	300	200	64,375	320	32,200	800	300	200	40,250	480	320
TOTAL	**396,400**	**1,300**	**400**	**83,695**	**480**	**99,820**	**221,374**	**1,200**	**500**	**91,770**	**800**	**19,940**

Abbreviations: 2D = two-dimensional; 3D = three-dimensional; CSEM = controlled source electromagnetic; HRG = high-resolution geophysical; VSP = vertical seismic profile; WAZ = wide azimuth.

[a] 3D surveys include ocean bottom cable and nodal surveys, vertical cable surveys, and 4D (time-lapse) surveys. Typically, one OCS block is 9 mi^2 (23.3 km^2, 2,331 ha, or 5,760 ac).

[b] WAZ estimates include coil shooting (exclusive to WesternGeco).

Table 3-4

Projected Levels of Miscellaneous G&G Activities for Oil and Gas Exploration in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020

Survey Type	Number of Sampling Events	Notes
Magnetotelluric Surveys	0-2 surveys	Hundreds to thousands of line km per survey, or ≤9 OCS blocks; 1-6 months per survey
Gravity and Magnetic Surveys (remote sensing)	0-5 surveys	Hundreds to thousands of line km per survey; 4-12 months per survey. Data typically acquired during seismic surveys
Aeromagnetic Surveys (remote sensing)	0-2 surveys	Hundreds to thousands of line km per survey; 1-3 months per survey
Continental Offshore Stratigraphic Test Wells	0-3 wells	Penetration >150 m (500 ft). Requires an Environmental Assessment
Shallow Test Drilling	0-5 wells	Penetration <150 m (500 ft)
Bottom Sampling	50-300 samples	Mainly surficial and near-surface sediments; penetration <30 m (98 ft)

Table 3-5

Locations and Areas for Renewable Energy Site Characterization and Assessment Activities Offshore the Mid-Atlantic and South Atlantic Planning Areas

State	Area[a]	OCS Block Equivalents	Description
Mid-Atlantic Planning Area			
Delaware	122 nmi^2 103,323 ac 41,813 ha	18	The Delaware area rests between the incoming and outgoing shipping routes for Delaware Bay, and is made up of 11 whole OCS blocks and 16 partial blocks. The closest point to shore is approximately 10 nmi from Rehoboth Beach, DE.
Maryland	94 nmi^2 79,706 ac 32,256 ha	14	The Maryland area is defined as 9 whole OCS blocks and 11 partial blocks. The western edge of the WEA is located approximately 10 nmi from the Ocean City, MD coast and the eastern edge is approximately 27 nmi from the Ocean City, MD, coast.
Virginia	164 nmi^2 138,788 ac or 56,165 ha	24	The Virginia area consists of 22 whole OCS blocks and 4 partial blocks. The western edge of the area is approximately 18 nmi from Virginia Beach, and the eastern edge is approximately 37 nmi from Virginia Beach.
North Carolina	510 nmi^2 432,002 ac 174,825 ha	75	In May 2011, North Carolina completed a screening exercise to yield a candidate area of 500 OCS lease blocks meeting their criteria for wind facility development. It was a screening exercise for potential environmental suitability and not an area proposed for wind development at this time. It is the expert judgment of BOEM staff that all 500 lease blocks would not be proposed for leasing, or actually leased to begin site assessment activities within the period covered by the Programmatic EIS. A more likely number is that 75 lease blocks will eventually be assessed beginning in late 2012 or early 2013.
South Atlantic Planning Area			
South Carolina	204 nmi^2 172,800 ac 69,930 ha	30	Estimated 30 lease blocks.
Georgia	204 nmi^2 172,800 ac 69,930 ha	30	Estimated 30 lease blocks.
Florida	204 nmi^2 172,800 ac 69,930 ha	30	Estimated 30 lease blocks.
Atlantic Wind Connection Transmission Cable			
New Jersey, Delaware, Maryland, Virginia	0.23 nmi^2 198 ac 80 ha	--	Proposed transmission cable extending from southern New Jersey to Virginia.

[a] Areal extents for Delaware, Maryland, and Virginia are based on Wind Energy Areas designated offshore these states. For the other states, the area is based on the total number of OCS block equivalents, multiplied by an area of 2,331 ha (5,760 ac) per lease block. Calculations for the Atlantic Wind Connection transmission cable are based on a length of 1,320 km (820 mi) and a right-of-way width of 61 m (200 ft).

Table 3-6

Projected Levels of G&G Activities for Renewable Energy Site Characterization and Assessment in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020

Renewable Energy Area	OCS Block Equivalents	HRG Surveys[a] (max km/hours)	Geotechnical Surveys[b]			Bottom-founded Monitoring Buoys (min-max)	Timing
			CPT (min-max)	Geologic Coring (min-max)	Grab Samples (min-max)		
Delaware	18	16,730/2,710	252–810	252–810	252–810	1–2	2012-2016
Maryland	14	13,030/2,110	196–630	196–630	196–630	1–6	2012-2017
Virginia	24	22,280/3,610	336–1,080	336–1,080	336–1,080	1–6	2012-2017
North Carolina	75	69,455/11,260	1,050–3,375	1,050–3,375	1,050–3,375	1–6	2012-2017
Mid-Atlantic Subtotal	**131**	**121,495/19,690**	**1,834–5,895**	**1,834–5,895**	**1,834–5,895**	**4–20**	**2012-2017**
South Carolina	30	27,830/4,510	420–1,350	420–1,350	420–1,350	1–6	2012-2017
Georgia	30	27,830/4,510	420–1,350	420–1,350	420–1,350	1–6	2013-2018
Florida	30	27,830/4,510	420–1,350	420–1,350	420–1,350	1–6	2013-2018
South Atlantic Subtotal	**90**	**83,490/13,530**	**1,260–4,050**	**1,260–4,050**	**1,260–4,050**	**3–18**	**2012-2018**
Atlantic Connection Transmission Cable	**--**	6,600/820	12–24	12-24	12–24	--	2012-2020
TOTAL	**221**	**211,585/34,040**	**3,106–9,969**	**3,106–9,969**	**3,106–9,969**	**7–38**	**2012-2020**

[a] HRG survey effort per block was assumed to be 925 km (500 nmi), requiring 150 hours to complete. Added 80 km (43 nmi) and 10 hours for surveying one transmission cable route for each state. For the Atlantic Wind Connection transmission cable, the proposed route length of 1,320 km (820 miles) was multiplied by 5 km per kilometer of route.

[b] Geotechnical survey effort was estimated to be 14-45 sampling locations per block based on the potential range of wind turbine densities per block (assuming one sampling location per turbine location). For the Atlantic Wind Connection transmission cable, assumed up to 12 substations with one or two sampling locations per substation.

Table 3-7

Projected Levels of High-Resolution Geophysical Surveys for OCS Sand Borrow Projects in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020

Year	Project	State	Cycle Volume (cubic yd)	Depth (m)	Distance Offshore (km)	Prospecting HRG[a] (line km)		Pre-Lease HRG[a] (line km)		On-Lease HRG[b] (line km)	
						(lower bound)	(upper bound)	(lower bound)	(upper bound)	(lower bound)	(upper bound)
Mid-Atlantic Planning Area											
2012-2013	Wallops Island	VA	3,200,000	9-24	18-20	0	0	0	0	100	501
	Fort Story/Dam Neck	VA	1,000,000	9-20	5	0	0	0	0	31	156
	Sandbridge	VA	2,000,000	9-20	5	0	0	0	0	63	313
2014-2016	Rehoboth/Dewey	DE	360,000	9-20	5	26	642	47	235	11	56
	Bethany/S. Bethany	DE	480,000	9-20	5	34	856	63	313	15	75
	Atlantic Coast of Maryland	MD	800,000	12-16	12-16	0	0	104	522	25	125
	Wallops Island	VA	806,000	9-24	18-20	0	0	0	0	25	126
	Sandbridge	VA	2,000,000	9-20	5	0	0	0	0	63	313
	West Onslow/North Topsail	NC	866,000	13-15	6-9	0	0	0	0	27	135
	Bogue Banks	NC	500,000	13-15	3-5	0	0	65	327	16	78
2017-2020	Rehoboth/Dewey	DE	360,000	9-20	4.8	0	0	0	0	11	56
	Bethany/S. Bethany	DE	480,000	9-20	4.8	0	0	0	0	15	75
	Atlantic Coast of Maryland	MD	800,000	12-16	12-16	0	0	0	0	25	125
	Surf City/North Topsail	NC	2,640,000	12-15	5-8	0	0	0	0	83	413
	Wrightsville Beach	NC	800,000	N/A	N/A	34	856	104	522	25	125
South Atlantic Planning Area											
2012-2013	Patrick Air Force Base	FL	310,000	3-14	3-8	0	0	0	0	10	49
2014-2016	Grand Strand	SC	2,300,000	7-13	4-7	0	0	0	0	72	360
	Brevard County North Reach	FL	516,000	3-14	3-8	0	0	0	0	16	81
	Brevard County Mid-Reach	FL	900,000	3-15	3-8	0	0	0	0	28	141
	Brevard County South Reach	FL	850,000	3-16	3-8	0	0	0	0	27	133
2017-2020	Folly Beach	SC	2,000,000	12-14	5	0	0	261	1306	63	313
	Duval County	FL	1,500,000	14-19	10-11	0	0	0	0	47	235
	St. Johns	FL	N/A	N/A	3-6	NA	NA	NA	NA	NA	NA
	Flagler	FL	N/A	N/A	3-5	NA	NA	NA	NA	NA	NA
TOTAL											
2012-2020	Mid-Atlantic Planning Area		17,092,000			94	2,354	383	1,919	535	2,672
	South Atlantic Planning Area		8,376,000			0	0	261	1,306	263	1,312
	Unknown Projects in Mid- and South Atlantic Planning Areas		8,000,000	N/A	N/A	34	856	209	1,045	125	626
	Mid- and South Atlantic Planning Areas		33,468,000			128	3,210	853	4,270	923	4,610

HRG = high-resolution geophysical; N/A = Not available.

[a] Prospecting and prelease HRG involves the use of subbottom profiler, side-scan sonar, bathymetry (depth sounders), and magnetometer.

[b] On-lease typically involves only a bathymetry (depth sounders).

Table 3-8

Projected Levels of Geotechnical Surveys for OCS Sand Borrow Projects
in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020

Type of Geotechnical Sampling	Number of Deployments	Number of Samples Per Deployment	Number of Samples
Vibracoring	6-24	15-25	90-600
Geologic coring	1-4	1-2	1-8
Grab sampling	2-8	30-40	60-320

Table 3-9

Scenario Elements for Proposed G&G Activities in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020

Activity Type	Purpose	Number of Events or Level of Effort	Primary Platform and Size	Scale of Activity	Penetration Depth	Approximate Duration/ Event	Shore Base[a]	Service Vessel	High-Energy Sound Source(s)	Bottom Area Disturbed
Oil and Gas Exploration										
2D Seismic Survey	Identify geologic structure	1-10	1 ship, ~100 m	617,775 line km	kms to 10s of kms	2-12 months	0 to 1	0 to 1	Airgun array	None
3D Seismic Survey	Identify geologic structure	5-10	1-2 ships, ~100 m	2,500 OCS blocks	kms to 10s of kms	4-12 months	0 to 1	0 to 1	Dual airgun array	None
3D WAZ and 3D FAZ Coil	Better define complex geologic structure	1-2	4 ships, ~100 m	900 line km	kms to 10s of kms	1 year	0 to 2	1 to 2	4 x arrays	None
Vertical Seismic Profiling	Calibrate seismic with known geology	3-8	1 ship, ~30 m	1,280 line km	100s to 1,000s of m	3-4 days	1	None	Single airgun	
High-Resolution Seismic Survey	Shallow hazards assessment and archaeological determinations	10-20	1 ship, ~30 m	175,465 line km	10s to 100s of m	3 days – 1 week	1	None	• 1-2 airguns • Boomer or chirp subbottom profiler • Side-scan sonar • Multi-beam depth sounder	None
3D Controlled Source Electromagnetic	Optimize reservoir production	0-2	1 ship, ~20-100 m	119,760 km	3-5 km	1-6 months	0 to 1	0 to 1	None	Anchors with bottom receivers, <1 OCS block
Magnetotelluric Survey	Optimize reservoir production	0-2	1 ship, ~20-100 m	100s to 1,000s of line kms; or ≤9 OCS blocks	3-5 km	1-6 months	0 to 1	0 to 1	None	Anchors with bottom receivers, <1 OCS block
Gravity and Magnetic	Passive measurement, gravity and magnetic fields	0-5	Acquisition with seismic typical	100s to 1,000s of line kms	kms to 10s of kms	4-12 months	0 to 1	0 to 1	None	None
Aeromagnetic	Passive measurement, magnetic fields	1-2	1 aircraft	100s to 1,000s of line kms	kms to 10s of kms	1-3 months	0 to 1	0	None	None
COST Well	Test drilling outside of lease program	0-3 well	Platform or drillship, ~100 m	<1/16 OCS block	≥150 m	5-30 days	0 to 1	0 to 2	None	≤2 ha per well
Shallow Test Drilling	Test drilling outside of lease program	0-5 wells	Platform or drillship, ~100 m	<1/16 OCS block	<150 m	5-30 days	0 to 1	0 to 2	None	≤2 ha per well
Bottom Sampling	Extract sediment core	50-300	1 barge or ship, ~20 m	<1/16 OCS block	<300 m	<3 days	0 to 1	None	None	~10 m^2, per sample

Table 3-9. Scenario Elements for Proposed G&G Activities in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020 (continued)

Activity Type	Purpose	Number of Events or Level of Effort	Primary Platform and Size	Scale of Activity	Penetration Depth	Approximate Duration/ Event	Shore Base[a]	Service Vessel	High-Energy Sound Source(s)	Bottom Area Disturbed
Renewable Energy										
High-Resolution Geophysical Survey	Shallow hazards assessment and archaeological determinations	1 or more surveys per state	1 ship, ~20-30 m	Each survey ≥1/16 OCS block[b] plus cable route to shore; Total 211,585 line km (about 220 OCS blocks)	Surficial to 10s to 100s of meters	3 days – 1 weeks	1	None	• Boomer or chirp subbottom profiler • Side-scan sonar • Multi-beam depth sounder	None
Cone Penetrometer Test	Measure sediment engineering properties	2,712-8,374	1 barge or ship, ~20 m	≥1/16 OCS block or along cable route to shore	<10 m	<3 days	1	None	None	~10 m^2 per sample
Geologic Coring	Extract sediment core	2,712-8,374	1 barge or ship, ~20 m	≥1/16 OCS block or along cable route to shore	<300 m	<3 days	1	None	None	~10 m^2 per sample
Grab Sampling	Collect sediment and benthic fauna	2,712-8,374	1 barge or ship, ~20 m	≥1/16 OCS lock or along cable route to shore	<1 m	<3 days	1	None	None	~10 m^2 per sample
Bottom-Founded Monitoring Buoy	Measure ocean and meteorological conditions	7-38	1 barge or ship, ~20 m	≥1/16 OCS block	Surficial	<3 days	1	None	None	~1 m^2 per buoy
2D or 3D Deep Penetration Seismic	Evaluate formation for carbon sequestration	0 to 1 survey	1 ship, ~100 m	<1 OCS block	km to 10s of km	1 - 30 days	1	0-2	Airgun array or dual array	None
Marine Minerals										
High-Resolution Geophysical Survey	Shallow hazards assessment and archaeological determinations	10-40 surveys, 9-21 wks	1 ship, ~30 m	~1,904-12,090 line kms; or 1-4.5 OCS blocks	10s to 100s of m	3 days - 1 weeks	1	None	• Boomer or chirp subbottom profiler • Side-scan sonar • Multi-beam depth sounder	None
Vibracoring	Extract sediment core	6-24 events (90-600 cores)	1 barge or ship, ~20 m	≥1/16 OCS block	10-15 m	3-5 days	1	None	None	~10 m^2 per sample
Geologic Coring	Extract sediment core	1-4 events (1-8 cores)	1 barge or ship, ~20 m	≥1/16 OCS block	<300 m	<3 days	1	None	None	~10 m^2 per sample

Table 3-9. Scenario Elements for Proposed G&G Activities in the Mid-Atlantic and South Atlantic Planning Areas, 2012-2020 (continued)

Activity Type	Purpose	Number of Events or Level of Effort	Primary Platform and Size	Scale of Activity	Penetration Depth	Approximate Duration/ Event	Shore Base[a]	Service Vessel	High-Energy Sound Source(s)	Bottom Area Disturbed
Grab Sampling	Collect sediment and benthic fauna	2-8 events (60-320 grabs)	1 barge or ship, ~20 m	≥1/16 OCS block	<1 m	<3 days	1	None	None	~10 m^2 per sample

Abbreviations: COST = Continental Offshore Stratigraphic Test; FAZ = Full Azimith Survey; NA = Not applicable; OCS = Outer Continental Shelf; WAZ = Wide Azimith Survey.

[a] Shore base is the point of deployment to return berth.

[b] 1/16 of an OCS block (256 ac) is the smallest area considered for renewable energy leasing. All full-build out renewable energy projects in the Mid-Atlantic and South Atlantic Planning Areas are wind park facilities that would be considerably larger than 1/16 of an OCS block. The average OCS wind park would be ≤10 OCS blocks in size.

Table 3-10

Impact-Producing Factors

Impact-Producing Factor	Program Area			Survey Type(s)	Brief Description
	OG	RE	MM		
Active Acoustic Sound Sources					
Airguns	X	--	--	Deep penetration seismic surveys and HRG surveys	Underwater noise from compressed air release
Electromechanical Sources	X	X	X	HRG surveys of renewable energy and marine mineral sites	Underwater noise from subbottom profilers, side-scan sonar, and multi-beam depth sounders
Vessel and Equipment Noise	X	X	X	All vessel surveys; drilling of COST wells and shallow test wells	Underwater noise from vessel engines and equipment, and from drilling activities
Vessel Traffic	X	X	X	All vessel surveys	Vessel movements including survey lines and round trips to onshore base
Aircraft Traffic and Noise	X	--	--	Aeromagnetic surveys	Aircraft traffic, and noise from engines and propellers
Vessel Exclusion Zones	X	--	--	Deep penetration seismic surveys with towed streamers	Temporary exclusion zone around streamer arrays to avoid entanglement
Vessel Waste Discharges	X	X	X	All vessel surveys	Bilge, ballast, sanitary and domestic waste discharges
Trash and Debris	X	X	X	All vessel surveys	Accidental release of trash or debris into the ocean
Seafloor Disturbance					
Bottom Sampling	X	X	X	Geotechnical sampling and testing	Collection of vibracore, geologic core, and grab samples; CPT testing
Cables, Nodes, Anchors	X	--	--	Certain deep penetration seismic surveys and CSEM and MT surveys	Temporary placement of cables, nodes, sensors, or anchors on or in seafloor
COST Wells and Shallow Test Drilling	X	--	--	Drilling of COST wells and shallow test wells	Seafloor disturbance due to placement of well template, jetting of well, and anchoring of drilling rig
Meteorological Buoys	--	X	--	Site characterization for renewable energy areas	Temporary anchoring of meteorological buoys
Drilling Discharges	X	--	--	Drilling of COST wells and shallow test wells	Release of drilling fluids and cuttings at seafloor and from drilling rig
Onshore Support Activities	X	X	X	All vessel surveys	Routine use of existing shorebase facilities, including purchase of fuel, supplies and services
Accidental Fuel Spills	X	X	X	All vessel surveys	Potential for release of diesel or fuel oil from a vessel accident

Abbreviations: CSEM = controlled source electromagnetic; COST = Continental Offshore Stratigraphic Test; CPT = cone penetrometer test; HRG = high-resolution geophysical; MM = marine minerals; MT = magnetotelluric; OG = oil and gas exploration; RE = renewable energy.

Table 3-11

Characteristics of Active Acoustic Sound Sources Included in the Proposed Action

Source	Usage	Operating Frequencies	Broadband Source Level (dB re 1 μPa at 1 m)
Large Airgun Array (5,400 in^2)	Deep penetration seismic surveys, oil and gas exploration (2D, 3D, WAZ, VSP, 4D, etc.)	10-2,000 Hz (most energy at <200 Hz)	230.7
Small Airgun Array (90 in^2)	HRG surveys, oil and gas exploration	10-2,000 Hz (most energy at <200 Hz)	210.3
Side-scan Sonar	HRG surveys, all program areas	100 kHz, 400 kHz	226
Boomer Subbottom Profiler	HRG surveys, all program areas	200-16,000 Hz	212
Chirp Subbottom Profiler	HRG surveys, all program areas	3.5 kHz, 12 kHz, 200 kHz	222
Multi-beam Depth Sounder	HRG surveys, all program areas	240 kHz	213

Source: **Appendix D**.

Table 4-1

Impact-Producing Factors for G&G Activities

Survey Type	OG	RE	MM	Active Acoustic Sound Sources	Vessel and Equipment Noise	Vessel Traffic	Aircraft Traffic and Noise	Exclusion Zones	Vessel Wastes	Trash and Debris	Seafloor Disturbance	Drilling Discharges	Onshore Support	Accidental Fuel Spills
Deep-Penetration Seismic Surveys														
2D Seismic Exploration Surveys	X	--	--	X	X	X	--	X	X	X	--	--	X	X
3D Seismic Exploration Surveys	X	--	--	X	X	X	--	X	X	X	--	--	X	X
Wide Azimuth Surveys	X	--	--	X	X	X	--	X	X	X	--	--	X	X
Nodes and Bottom Cable Surveys	X	--	--	X	X	X	--	X	X	X	X	--	X	X
Vertical Cable Surveys	X	--	--	X	X	X	--	X	X	X	X	--	X	X
4D (Time-Lapse) Surveys	X	--	--	X	X	X	--	X	X	X	X	--	X	X
Vertical Seismic Profile Surveys	X	--	--	X	X	X	--	X	X	X	X	--	X	X
High-Resolution Geophysical Surveys														
For oil and gas exploration (airgun as seismic source)	X	--	--	X	X	X	--	--	X	X	--	--	X	X
For renewable energy or marine minerals (boomer or chirp subbottom profiler as seismic source)	--	X	X	--	X	X	--	--	X	X	--	--	X	X
Electromagnetic Surveys														
Controlled Source Electromagnetic Surveys	X	--	--	--	X	X	--	--	X	X	--	--	X	X
Magnetotelluric Surveys	X	--	--	--	X	X	--	--	X	X	--	--	X	X
Deep Stratigraphic and Shallow Test Drilling														
Continental Offshore Stratigraphic Test Wells	X	--	--	--	X	X	--	--	X	X	X	X	X	X
Shallow Test Drilling	X	--	--	--	X	X	--	--	X	X	X	X	X	X
Bottom Sampling														
Cone Penetrometer Tests	X	X	X	--	X	X	--	--	X	X	X	--	X	X
Vibracoring	X	X	X	--	X	X	--	--	X	X	X	--	X	X
Geologic Coring	X	X	X	--	X	X	--	--	X	X	X	--	X	X
Grab Sampling	X	X	X	--	X	X	--	--	X	X	X	--	X	X
Remote Sensing														
Gravity Surveys	X	--	--	--	X	X	--	--	X	X	--	--	X	X
Gravity Gradiometry	X	--	--	--	X	X	--	--	X	X	--	--	X	X
Marine Magnetic Surveys	X	--	--	--	X	X	--	--	X	X	--	--	X	X
Radar Imaging	X	--	--	--	--	--	--	--	--	--	--	--	--	--
Aeromagnetic Surveys	X	--	--	--	--	--	X	--	--	--	--	--	X	--

Abbreviations: OG = oil and gas; RE = renewable energy; MM = marine minerals.

Table 4-2

Preliminary Screening of Potential Impacts (Leopold Matrix)

Resource	Impact-Producing Factor										
	Active Acoustic Sound Sources	Vessel and Equipment Noise	Vessel Traffic	Aircraft Traffic and Noise	Exclusion Zones	Vessel Wastes	Trash and Debris	Seafloor Disturbance	Drilling Discharges	Onshore Support	Accidental Fuel Spills
Benthic Communities											
• Soft Bottom	X	--	--	--	--	--	X	X	X	--	X
• Hard/Live Bottom/Coral/ Chemosynthetic	X	--	--	--	--	--	X	X	X	--	X
Marine Mammals	X	X	X	X	--	--	X	--	--	--	X
Sea Turtles	X	X	X	X	--	--	X	--	--	--	X
Marine and Coastal Birds	X	X	X	X	--	--	X	--	--	--	X
Fisheries Resources and Essential Fish Habitat	X	X	--	--	--	--		X	X	--	X
Threatened and Endangered Fishes	X	X	--	--	--	--	X	X	X	--	X
Commercial Fisheries	X	--	X	--	X	--	--	X	--	--	X
Recreational Fisheries	X	--	X	--	X	--	--	--	--	--	X
Recreational Resources	--	--	--	--	X	--	X	--	--	--	X
Archaeological Resources	--	--	--	--	--	--	--	X	X	--	X
Marine Protected Areas	X	--	--	--	--	--	X	X	X	--	X
Other Marine Uses	--	--	X	X	X	--	--	X	--	--	X
Human Resources and Land Use	--	--	--	--	--	--	--	--	--	X	X
Geology/Sediments	--	--	--	--	--	--	--	--	--	--	--
Air and Water Quality	--	--	--	--	--	--	--	--	--	--	--

X = potential impact for analysis. - = no impact expected.

Table 4-3

Sources for G&G Impact-Producing Factors

Impact Producing Factors	Program Area			Sources Included in Proposed Action
	OG	RE	MM	
Active Acoustic Sound Sources				
Airguns	X	--	--	Seismic airgun surveys
Electromechanical sources	X	X	X	HRG surveys
Vessel and Equipment Noise	X	X	X	All shipboard surveys
Vessel Traffic	X	X	X	All shipboard surveys
Aircraft Traffic and Noise	X	--	--	Aeromagnetic surveys
Exclusion Zones	X	--	--	Seismic airgun surveys using towed streamers
Trash and Debris	X	X	X	All shipboard surveys
Seafloor Disturbance	X	X	X	Bottom-founded activities – coring, equipment emplacement
Drilling Discharges	X	--	--	Drilling of COST wells and shallow test wells
Onshore Support	X	X	X	All surveys
Accidental Fuel Spills	X	X	X	All shipboard surveys

Abbreviations: OG = oil and gas; RE = renewable energy; MM = marine minerals.

Table 4-4

Marine Mammals Potentially Occurring in the Area of Interest

Common Name	Species	Stock	ESA/ Stock Status[1]	Occurrence	Best Pop. Estimate[2]	Critical Habitat in Area of Interest	Functional Hearing Group[3]			
							L	M	H	P
ORDER CETACEA										
Suborder Mysticeti (Baleen Whales)										
Common Minke Whale	*Balaenoptera acutorostrata acutorostrata*	Canadian East Coast		Rare	8,987	--	L			
Sei Whale	*Balaenoptera borealis*	Nova Scotia	E/S	Rare	386	--	L			
Bryde's Whale	*Balaenoptera brydei*	N/A		Rare	N/A	--	L			
Blue Whale	*Balaenoptera musculus*	Western North Atlantic	E/S	Rare	unknown	--	L			
Fin Whale	*Balaenoptera physalus*	Western North Atlantic	E/S	Regular	3,985	--	L			
North Atlantic Right Whale	*Eubalaena glacialis*	Western Atlantic	E/S	Regular	361	Yes	L			
Humpback Whale	*Megaptera novaeangliae*	Gulf of Maine	E/S	Regular	847	--	L			
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)										
Short-beaked Common Dolphin	*Delphinus delphis*	Western North Atlantic		Regular	120,743	--				
Pygmy Killer Whale	*Feresa attenuata*	Western North Atlantic		Rare	unknown	--		M		
Short-Finned Pilot Whale	*Globicephala macrorhynchus*	Western North Atlantic		Regular	24,674	--		M		
Long-Finned Pilot Whale	*Globicephala melas*	Western North Atlantic		Regular	12,619	--		M		
Risso's Dolphin	*Grampus griseus*	Western North Atlantic		Regular	20,479	--		M		
Northern Bottlenose Whale	*Hyperoodon ampullatus*	Western North Atlantic		Rare	unknown	--		M		
Pygmy Sperm Whale	*Kogia breviceps*	Western North Atlantic		Regular	395	--			H	
Dwarf Sperm Whale	*Kogia sima*	Western North Atlantic		Regular	395	--			H	
Atlantic White-sided Dolphin	*Lagenodelphis acutus*	Western North Atlantic		Rare	63,368	--		M		
Fraser's Dolphin	*Lagenodelphis hosei*	North Atlantic		Rare	unknown	--		M		
Sowerby's Beaked Whale	*Mesoplodon bidens*	Western North Atlantic		Regular	3,513	--		M		
Blainville's Beaked Whale	*Mesoplodon densirostris*	Western North Atlantic		Regular	3,513	--		M		
Gervais' Beaked Whale	*Mesoplodon europaeus*	Western North Atlantic		Regular	3,513	--		M		
True's Beaked Whale	*Mesoplodon mirus*	Western North Atlantic		Regular	3,513	--		M		
Killer Whale	*Orcinus orca*	Western North Atlantic		Rare	unknown	--		M		
Melon-Headed Whale	*Peponocephala electra*	Western North Atlantic		Rare	unknown	--		M		
Harbor Porpoise	*Phocoena phocoena*	Gulf of Maine/Bay of Fundy		Rare	89,054	--			H	
Sperm Whale	*Physeter macrocephalus*	North Atlantic	E/S	Regular	4,804	--		M		
False Killer Whale	*Pseudorca crassidens*	N/A		N/A	unknown	--		M		
Pantropical Spotted Dolphin	*Stenella attenuata*	Western North Atlantic		Regular	4,439	--		M		

Table 4-4 Marine Mammals Potentially Occurring in the Area of Interest (continued)

Common Name	Species	Stock	ESA/ Stock Status[1]	Occurrence	Best Pop. Estimate[2]	Critical Habitat in Area of Interest	Functional Hearing Group[3]			
							L	M	H	P
Clymene Dolphin	*Stenella clymene*	Western North Atlantic		Rare	unknown	--		M		
Striped Dolphin	*Stenella coeruleoalba*	North Atlantic		Regular	94,462	--		M		
Atlantic Spotted Dolphin	*Stenella frontalis*	Western North Atlantic		Regular	50,978	--		M		
Spinner Dolphin	*Stenella longirostris*	Western North Atlantic		Rare	unknown	--		M		
Rough-Toothed Dolphin	*Steno bredanensis*	Western North Atlantic		Rare	unknown	--		M		
Bottlenose Dolphin	*Tursiops truncatus*	Western North Atlantic Offshore		Regular	81,588	--		M		
		Coastal and estuarine stocks (12 stocks; see text)	S	Regular	varies	--		M		
Cuvier's Beaked Whale	*Ziphius cavirostris*	Western North Atlantic		Regular	3,513	--		M		
ORDER SIRENIA										
West Indian Manatee (Florida subspecies)	*Trichechus manatus latirostris*	Florida	E/S	Rare	3,802	Nearby (FL inland waters)				P[4]
ORDER CARNIVORA										
Suborder Pinnipedia										
Hooded Seal	*Cystophora cristata*	Western North Atlantic		Rare	unknown	--				P
Gray Seal	*Halichoerus grypus*	Western North Atlantic		Rare	unknown	--				P
Harbor Seal	*Phoca vitulina*	Western North Atlantic		Rare	unknown	--				P

N/A = Not available.

[1] ESA = Endangered Species Act; E = endangered; S = strategic stock.

[2] Best population estimate "NBest" from Table 1 of the Waring et al. (2010) stock assessment report.

[3] Functional marine mammal hearing groups and specific auditory ranges (Adapted from Southall et al., 2007). L = Low-Frequency Cetacean (7 Hz-22 kHz); M = Mid-Frequency Cetacean (150 Hz-160 kHz); H = High-Frequency Cetacean (200 Hz-180) kHz; P = Pinniped In Water (75 Hz-75 kHz).

[4] Manatee hearing is not addressed by Southall et al. (2007). Based on review of marine mammal hearing capabilities for this Programmatic EIS (**Appendix H**), manatee hearing is generally similar to that of phocid pinnipeds except at the lowest frequencies.

Source: Waring et al. (2010).

Table 4-5

Designated U.S. and Canadian Seasonal Management Areas for the North Atlantic Right Whale

Regional Area	Individual Areas	Concerns	Period of Activity
Northeast U.S. Seasonal Management Areas	Cape Cod Bay	Feeding Area	January 1–May 15
	Off Race Point	Feeding Area	March 1–April 30
	Great South Channel	Feeding Area	April 1–July 31
Mid-Atlantic U.S. Seasonal Management Areas	Block Island Sound	Migratory Route and Calving Grounds	November 1–April 30
	Ports of New York/ New Jersey		
	Entrance to Delaware Bay		
	Entrance to Chesapeake Bay		
	Ports of Morehead City and Beaufort, NC		
	Wilmington, NC to Brunswick, GA		
Southeast U.S. Seasonal Management Area	Central GA to northeast FL	Calving and Nursery Grounds	November 15–April 15
Grand Manan Basin Critical Habitat Area	New Brunswick and Nova Scotia, Canada	Feeding Area	
Roseway Basin Critical Habitat Area	South of Nova Scotia, Canada	Feeding Area	June–December

Table 4-6

Existing and Proposed Injury and Behavior Exposure Criteria for Cetaceans and Pinnipeds Exposed to Pulsed Sounds

Group	Level A (Injury)			Level B (Behavior)
	NMFS Criteria (*Federal Register*, 2000): Sound Pressure Level (dB re 1 µPa rms)	Southall et al. (2007) Criteria: Sound Exposure Level (dB re 1 µPa^2 s)	Southall et al. (2007) Criteria: Single Pulse, Sound Pressure Level (dB re 1 µPa rms)	NMFS Criteria (*Federal Register*, 2000): Sound Pressure Level (dB re 1 µPa rms)
Cetaceans	180	198	230	160
Pinnipeds	190	186	218	160

Note: Current regulatory thresholds are shaded.

Table 4-7

Functional Marine Mammal Hearing Groups, Associated Auditory Bandwidths, and Marine Mammal Species Present in the Area of Interest

Functional Hearing Group	Estimated Auditory Bandwidth	Marine Mammal Species Present in the AOI
Low-frequency cetaceans	7 Hz-22 kHz	North Atlantic right whale; blue whale; fin whale; humpback whale; sei whale; Bryde's whale; common minke whale
Mid-frequency cetaceans	150 Hz-160 kHz	Sperm whale; beaked whales; *Stenella* dolphins; bottlenose dolphin; killer whale; pygmy killer whale; false killer whale; Risso's dolphin; short-finned and long-finned pilot whales; common dolphin; melon-headed whale; Atlantic white-sided dolphin; Fraser's dolphin; rough-toothed dolphin
High-frequency cetaceans	200 Hz-180 kHz	Pygmy and dwarf sperm whales; harbor porpoise
Pinnipeds in water	75 Hz-75 kHz	Harbor, gray, and hooded seals
Pinnipeds in air	75 Hz-30 kHz	Harbor, gray, and hooded seals

Abbreviaton: AOI = Area of Interest; Hz = hertz; kHz = kilohertz.
Source: Southall et al., 2007.

Table 4-8

Summary of Radial Distances to the 160-dB and 180-dB (rms) Isopleths from a Single Pulse for Various Equipment

Equipment	Number of Scenarios Modeled	Pulse Duration	Adjustment (dB) for Short Pulse Duration[a]	180-dB Radius (m)		160-dB Radius (m)	
				Calculated using Nominal Source Level[b]	Recalculated for Short Pulse Duration[a]	Calculated using Nominal Source Level[b]	Recalculated for Short Pulse Duration[a]
Large Airgun Array (5,400 in^3), 2D and 3D Surveys	35	>100 ms	--	799-2,109	--	5,184-15,305	--
Small Airgun Array (90 in^3), Oil and Gas HRG Surveys	35	>100 ms	--	76-186	--	1,294-3,056	--
Boomer	14	180 µs	-27.3	38-45	<5	1,054-2,138	16
Side-Scan Sonar	14	20 ms	-7.0	128-192	65-96	500-655	337-450
Chirp Subbottom Profiler	14	64 ms	-1.9	32-42	26-35	359-971	240-689
Multibeam Depth Sounder	7	225 µs	-26.5	27	<5	147-156	12

[a] For sources with a pulse duration <100 ms, the nominal source level was adjusted by the amount indicated to produce a second, "recalculated" radius for both the 180-dB and 160-dB criteria. See **Appendix D**.

[b] The value is the radius (Rmax) for the maximum received sound pressure level. See **Appendix D**.

Source: **Appendix D**.

Table 4-9

Annual Level A Take Estimates from Seismic Airgun Sources Using Southall et al. (2007) Criteria for Marine Mammal Species during the Project Period (2012-2020)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common minke whale	0.000	0.083	0.161	0.013	0.069	0.044	0.021	0.022	0.009
Sei whale	0.000	0.208	0.402	0.032	0.176	0.113	0.057	0.060	0.030
Bryde's whale	0.000	0.632	1.237	0.128	0.721	0.526	0.359	0.166	0.040
Blue whale	0.000	0.831	1.622	0.164	0.915	0.663	0.439	0.208	0.043
Fin whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
North Atlantic right whale	0.000	0.036	0.071	0.008	0.045	0.034	0.024	0.009	0.001
Humpback whale	0.000	3.046	5.931	0.567	3.153	2.226	1.402	0.779	0.235
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked common dolphin	0.000	116.584	225.454	18.848	96.111	64.095	28.714	23.101	1.241
Pygmy killer whale	0.000	0.161	0.312	0.027	0.175	0.113	0.081	0.067	0.060
Short-finned pilot whale	0.000	11.616	22.498	1.939	82.495	51.938	90.208	122.188	151.359
Long-finned pilot whale	0.000	59.577	117.528	13.877	79.694	61.037	45.681	14.788	1.264
Risso's dolphin	0.000	370.550	731.439	87.140	501.580	385.115	290.103	92.466	7.868
Northern bottlenose whale	0.000	0.004	0.007	0.001	0.003	0.002	0.001	0.001	0.000
Pygmy sperm whale	0.000	0.000	0.000	0.000	0.081	0.041	0.080	0.083	0.138
Dwarf sperm whale	0.000	2.819	5.564	0.662	4.474	3.315	2.953	1.670	1.367
Atlantic white-sided dolphin	0.000	1.347	2.659	0.319	2.039	1.540	1.315	0.685	0.460
Fraser's dolphin	0.000	0.208	0.402	0.032	0.161	0.105	0.041	0.040	0.002
Sowerby's beaked whale	0.000	0.000	0.000	0.000	0.006	0.004	0.007	0.009	0.012
Blainville's beaked whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
Gervais' beaked whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
True's beaked whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
Killer whale	0.000	0.052	0.100	0.008	0.065	0.040	0.036	0.040	0.046
Melon-headed whale	0.000	0.161	0.312	0.027	0.175	0.113	0.081	0.067	0.060
Harbor porpoise	0.000	2.064	3.995	0.338	2.051	1.344	0.886	0.834	0.623
Sperm whale	0.000	0.095	0.184	0.015	0.076	0.050	0.021	0.019	0.001
False killer whale	0.000	0.155	0.300	0.026	0.236	0.151	0.158	0.170	0.194
Pantropical spotted dolphin	0.000	135.938	263.432	22.986	131.727	89.279	55.904	48.705	27.790
Clymene dolphin	0.000	64.945	125.855	10.982	62.933	42.653	26.708	23.269	13.277
Striped dolphin	0.000	527.416	1020.455	86.220	513.371	341.562	223.973	227.070	157.357
Atlantic spotted dolphin	0.000	771.308	1496.301	133.348	766.414	524.822	336.201	275.338	154.015
Spinner dolphin	0.000	0.611	1.184	0.103	0.592	0.401	0.251	0.219	0.125
Rough-toothed dolphin	0.000	0.000	0.000	0.000	0.036	0.023	0.043	0.061	0.075
Bottlenose dolphin	0.000	14.775	28.936	3.056	35.612	24.127	30.763	33.955	38.977
Cuvier's beaked whale	0.000	10.213	19.709	1.577	7.883	5.119	1.972	1.972	0.098
ORDER SIRENIA									
West Indian manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4-10

Annual Level A Takes Estimates from Seismic Airgun Sources Using 180-dB Criteria for Marine Mammal Species during the Project Period (2012-2020)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common minke whale	0.000	0.342	0.666	0.064	0.380	0.266	0.187	0.124	0.075
Sei whale	0.000	1.965	3.855	0.417	2.564	1.880	1.476	0.818	0.502
Bryde's whale	0.000	1.948	3.820	0.412	2.535	1.857	1.457	0.812	0.499
Blue whale	0.000	2.182	4.274	0.451	2.753	2.000	1.539	0.882	0.537
Fin whale	0.000	4.400	8.638	0.949	5.896	4.342	3.474	1.924	1.223
North Atlantic right whale	0.000	1.162	2.290	0.269	1.883	1.395	1.294	0.874	0.595
Humpback whale	0.000	5.897	11.542	1.207	7.332	5.314	4.043	2.319	1.385
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked common dolphin	0.000	3121.383	6146.553	706.842	4436.718	3316.557	2733.398	1434.611	913.703
Pygmy killer whale	0.000	2.253	4.410	0.462	2.807	2.037	1.549	0.879	0.520
Short-finned pilot whale	0.000	2354.300	4631.133	524.156	3290.543	2446.116	2004.600	1084.354	703.430
Long-finned pilot whale	0.000	297.400	582.360	61.349	376.210	273.181	211.129	122.524	76.692
Risso’s dolphin	0.000	1619.672	3180.466	350.367	2173.422	1603.231	1282.343	705.289	444.065
Northern bottlenose whale	0.000	0.127	0.250	0.029	0.179	0.134	0.110	0.055	0.033
Pygmy sperm whale	0.000	2.371	4.592	0.397	2.216	1.482	0.851	0.666	0.318
Dwarf sperm whale	0.000	14.844	29.005	2.947	17.492	12.581	9.146	5.268	2.852
Atlantic white-sided dolphin	0.000	4.668	9.152	0.985	5.987	4.389	3.388	1.830	1.060
Fraser's dolphin	0.000	0.242	0.468	0.039	0.218	0.143	0.078	0.066	0.031
Sowerby's beaked whale	0.000	0.203	0.397	0.040	0.242	0.174	0.128	0.075	0.042
Blainville's beaked whale	0.000	39.568	77.313	7.855	47.099	33.810	24.904	14.699	8.511
Gervais' beaked whale	0.000	39.568	77.313	7.855	47.099	33.810	24.904	14.699	8.511
True's beaked whale	0.000	39.568	77.313	7.855	47.099	33.810	24.904	14.699	8.511
Killer whale	0.000	1.965	3.843	0.396	2.393	1.727	1.293	0.748	0.440
Melon-headed whale	0.000	2.523	4.942	0.525	3.215	2.342	1.814	1.030	0.630
Harbor porpoise	0.000	7.054	13.798	1.428	8.705	6.283	4.777	2.831	1.753
Sperm whale	0.000	158.828	309.723	30.401	179.051	126.956	89.342	54.729	29.855
False killer whale	0.000	2.801	5.491	0.590	3.635	2.658	2.085	1.179	0.733
Pantropical spotted dolphin	0.000	446.741	876.082	94.513	580.242	425.213	332.719	184.322	111.974
Clymene dolphin	0.000	207.184	406.191	43.634	267.556	195.783	152.671	85.007	51.562
Striped dolphin	0.000	2038.848	3993.224	422.056	2575.257	1873.787	1441.135	817.898	495.292
Atlantic spotted dolphin	0.000	2978.964	5847.582	640.637	3949.211	2909.316	2303.489	1252.888	759.259
Spinner dolphin	0.000	1.949	3.821	0.410	2.517	1.842	1.436	0.800	0.485
Rough-toothed dolphin	0.000	13.755	26.888	2.752	16.672	11.986	8.985	5.358	3.240
Bottlenose dolphin	0.000	5977.039	11748.210	1313.855	8207.035	6079.369	4930.570	2684.179	1708.610
Cuvier's beaked whale	0.000	276.973	541.189	54.986	329.696	236.673	174.331	102.893	59.574
ORDER SIRENIA									
West Indian manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4-11

Annual Level B Take Estimates (160-dB criteria) from Airgun Surveys for Marine Mammal Species during the Project Period (2012-2020)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common minke whale	0.000	33.522	65.282	6.257	37.268	26.060	18.319	12.111	7.365
Sei whale	0.000	192.625	377.801	40.850	251.322	184.255	144.677	80.219	49.182
Bryde's whale	0.000	190.896	374.359	40.389	248.492	182.040	142.818	79.602	48.897
Blue whale	0.000	213.901	418.875	44.161	269.778	196.066	150.850	86.408	52.620
Fin whale	0.000	431.204	846.583	93.001	577.905	425.583	340.531	188.601	119.857
North Atlantic right whale	0.000	240.877	475.584	56.846	361.004	272.896	230.884	117.752	61.087
Humpback whale	0.000	577.964	1131.230	118.264	718.609	520.862	396.288	227.280	135.768
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked common dolphin	0.000	305926.755	602423.698	69277.598	434842.769	325055.721	267900.300	140606.264	89552.017
Pygmy killer whale	0.000	220.776	432.193	45.316	275.090	199.618	151.862	86.104	50.974
Short-finned pilot whale	0.000	230744.930	453897.344	51372.535	322506.126	239743.839	196470.811	106277.564	68943.198
Long-finned pilot whale	0.000	29148.152	57077.138	6012.771	36872.388	26774.497	20692.778	12008.551	7516.617
Risso’s dolphin	0.000	158744.009	311717.478	34339.430	213017.091	157132.663	125682.450	69125.392	43522.784
Northern bottlenose whale	0.000	12.462	24.544	2.829	17.568	13.169	10.733	5.418	3.214
Pygmy sperm whale	0.000	232.353	450.073	38.920	217.178	145.240	83.426	65.321	31.130
Dwarf sperm whale	0.000	1454.885	2842.740	288.795	1714.399	1233.034	896.367	516.331	279.556
Atlantic white-sided dolphin	0.000	457.481	896.987	96.497	586.754	430.117	332.072	179.330	103.897
Fraser's dolphin	0.000	23.717	45.882	3.865	21.337	14.063	7.641	6.436	3.006
Sowerby's beaked whale	0.000	19.910	38.905	3.957	23.674	17.008	12.499	7.317	4.143
Blainville's beaked whale	0.000	3878.016	7577.415	769.884	4616.211	3313.759	2440.889	1440.645	834.120
Gervais' beaked whale	0.000	3878.016	7577.415	769.884	4616.211	3313.759	2440.889	1440.645	834.120
True's beaked whale	0.000	3878.016	7577.415	769.884	4616.211	3313.759	2440.889	1440.645	834.120
Killer whale	0.000	192.589	376.649	38.861	234.535	169.229	126.733	73.295	43.147
Melon-headed whale	0.000	247.240	484.381	51.446	315.137	229.581	177.832	100.945	61.720
Harbor porpoise	0.000	691.367	1352.385	139.995	853.177	615.792	468.191	277.456	171.788
Sperm whale	0.000	15566.706	30355.996	2979.611	17548.740	12442.986	8756.403	5363.975	2926.098
False killer whale	0.000	274.527	538.213	57.806	356.282	260.465	204.367	115.520	71.815
Pantropical spotted dolphin	0.000	43785.058	85864.840	9263.266	56869.492	41675.091	32609.770	18065.447	10974.596
Clymene dolphin	0.000	20306.091	39810.739	4276.589	26223.212	19188.734	14963.300	8331.541	5053.608
Striped dolphin	0.000	199827.536	391375.882	41365.683	252400.939	183649.880	141245.653	80162.157	48543.554
Atlantic spotted dolphin	0.000	291968.246	573121.475	62788.875	387062.188	285142.042	225764.925	122795.508	74414.994
Spinner dolphin	0.000	191.026	374.513	40.231	246.691	180.515	140.765	78.378	47.541
Rough-toothed dolphin	0.000	1348.103	2635.268	269.746	1633.987	1174.707	880.655	525.176	317.548
Bottlenose dolphin	0.000	585809.587	1151442.029	128770.944	804371.539	595838.922	483245.127	263076.392	167460.910
Cuvier's beaked whale	0.000	27146.110	53041.902	5389.186	32313.477	23196.314	17086.222	10084.514	5838.840
ORDER SIRENIA									
West Indian manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4-12

Annual Level A Take Estimates from All Non-Airgun High-Resolution Geophysical Surveys Using Southall et al. (2007) Criteria for Marine Mammal Species during the Project Period (2012-2020)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common minke whale	0.0003	0.0004	0.0004	0.0004	0.0004	0.0003	0.0000	0.0000	0.0000
Sei whale	0.0020	0.0024	0.0024	0.0024	0.0024	0.0021	0.0004	0.0000	0.0000
Bryde's whale	0.0023	0.0030	0.0030	0.0030	0.0030	0.0027	0.0007	0.0000	0.0000
Blue whale	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0003	0.0000	0.0000
Fin whale	0.0155	0.0208	0.0208	0.0208	0.0208	0.0185	0.0053	0.0000	0.0000
North Atlantic right whale	0.0021	0.0026	0.0026	0.0026	0.0026	0.0022	0.0005	0.0000	0.0000
Humpback whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked common dolphin	4.0936	5.2235	5.2235	5.2235	5.2235	4.5460	1.1299	0.0000	0.0000
Pygmy killer whale	0.0004	0.0010	0.0010	0.0010	0.0010	0.0009	0.0006	0.0000	0.0000
Short-finned pilot whale	0.0053	0.0106	0.0106	0.0106	0.0106	0.0106	0.0053	0.0000	0.0000
Long-finned pilot whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Risso’s dolphin	1.8630	2.2287	2.2287	2.2287	2.2287	2.0205	0.3658	0.0000	0.0000
Northern bottlenose whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pygmy sperm whale	0.0048	0.0064	0.0064	0.0064	0.0064	0.0059	0.0016	0.0000	0.0000
Dwarf sperm whale	0.0145	0.0192	0.0192	0.0192	0.0192	0.0178	0.0047	0.0000	0.0000
Atlantic white-sided dolphin	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fraser's dolphin	0.0001	0.0003	0.0004	0.0004	0.0004	0.0003	0.0003	0.0000	0.0000
Sowerby's beaked whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
Blainville's beaked whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
Gervais' beaked whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
True's beaked whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
Killer whale	0.0025	0.0061	0.0061	0.0061	0.0061	0.0058	0.0036	0.0000	0.0000
Melon-headed whale	0.0001	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0000	0.0000
Harbor porpoise	0.0005	0.0007	0.0007	0.0007	0.0007	0.0006	0.0002	0.0000	0.0000
Sperm whale	0.0008	0.0009	0.0009	0.0009	0.0009	0.0008	0.0001	0.0000	0.0000
False killer whale	0.0001	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0000	0.0000
Pantropical spotted dolphin	0.4477	0.5868	0.6200	0.6200	0.6200	0.5432	0.1677	0.0287	0.0287
Clymene dolphin	0.2139	0.2803	0.2962	0.2962	0.2962	0.2595	0.0801	0.0137	0.0137
Striped dolphin	0.5954	0.7674	0.8121	0.8121	0.8121	0.7114	0.2107	0.0386	0.0386
Atlantic spotted dolphin	5.3991	6.9574	7.3614	7.3614	7.3614	6.4414	1.8980	0.3397	0.3397
Spinner dolphin	0.0020	0.0026	0.0028	0.0028	0.0028	0.0024	0.0008	0.0001	0.0001
Rough-toothed dolphin	0.0099	0.0145	0.0145	0.0145	0.0145	0.0134	0.0047	26.1283	0.0000
Bottlenose dolphin	1.2977	2.1422	2.3608	2.3608	2.3608	1.9922	1.0400	0.1955	0.1955
Cuvier's beaked whale	0.0013	0.0015	0.0015	0.0015	0.0015	0.0013	0.0003	0.0000	0.0000
ORDER SIRENIA									
West Indian manatee	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gray seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Harbor seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 4-13

Annual Level A Take Estimates from All Non-Airgun High-Resolution Geophysical Surveys Using 180-dB Criteria for Marine Mammal Species during the Project Period (2012-2020)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common minke whale	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0001	0.0004
Sei whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0012	0.0008	0.0024
Bryde's whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0012	0.0008	0.0024
Blue whale	0.0007	0.0010	0.0011	0.0011	0.0011	0.0011	0.0015	0.0009	0.0026
Fin whale	0.0012	0.0016	0.0017	0.0017	0.0017	0.0018	0.0031	0.0019	0.0055
North Atlantic right whale	0.0020	0.0025	0.0025	0.0025	0.0025	0.0027	0.0051	0.0031	0.0089
Humpback whale	0.0025	0.0034	0.0035	0.0035	0.0035	0.0034	0.0037	0.0022	0.0066
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked common dolphin	1.2187	1.4589	1.4946	1.4946	1.4946	1.5087	2.0876	1.3143	3.8682
Pygmy killer whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0011	0.0008	0.0024
Short-finned pilot whale	0.0132	0.0166	0.0171	0.0171	0.0171	0.1358	1.2475	0.8050	2.3163
Long-finned pilot whale	0.0027	0.0033	0.0033	0.0033	0.0033	0.0153	0.1295	0.0932	0.2808
Risso’s dolphin	0.0913	0.1118	0.1118	0.1118	0.1118	0.1826	0.8666	0.5861	1.7367
Northern bottlenose whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
Pygmy sperm whale	0.0011	0.0015	0.0015	0.0015	0.0015	0.0014	0.0007	0.0005	0.0017
Dwarf sperm whale	0.0034	0.0046	0.0046	0.0046	0.0046	0.0046	0.0057	0.0038	0.0119
Atlantic white-sided dolphin	0.0000	0.0001	0.0001	0.0001	0.0001	0.0002	0.0017	0.0014	0.0044
Fraser's dolphin	0.0004	0.0006	0.0007	0.0007	0.0007	0.0006	0.0003	0.0001	0.0002
Sowerby's beaked whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002
Blainville's beaked whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0134	0.0104	0.0320
Gervais' beaked whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0134	0.0104	0.0320
True's beaked whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0134	0.0104	0.0320
Killer whale	0.0005	0.0007	0.0007	0.0007	0.0007	0.0007	0.0010	0.0007	0.0021
Melon-headed whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0014	0.0009	0.0029
Harbor porpoise	0.0016	0.0018	0.0018	0.0018	0.0018	0.0019	0.0031	0.0023	0.0068
Sperm whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0041	0.0430	0.0377	0.1213
False killer whale	0.0004	0.0006	0.0006	0.0006	0.0006	0.0007	0.0016	0.0010	0.0029
Pantropical spotted dolphin	0.3036	0.4453	0.4509	0.4509	0.4509	0.4381	0.3559	0.1610	0.4798
Clymene dolphin	0.1450	0.2127	0.2154	0.2154	0.2154	0.2088	0.1643	0.0729	0.2170
Striped dolphin	0.3964	0.5755	0.5831	0.5831	0.5831	0.6088	0.9086	0.5299	1.5825
Atlantic spotted dolphin	3.4607	4.9269	4.9955	4.9955	4.9955	4.7511	3.0827	1.2151	3.5657
Spinner dolphin	0.0013	0.0019	0.0020	0.0020	0.0020	0.0019	0.0015	0.0007	0.0020
Rough-toothed dolphin	0.0057	0.0074	0.0075	0.0075	0.0075	0.0073	0.0080	0.0052	0.0164
Bottlenose dolphin	0.9382	1.4056	1.4650	1.4650	1.4650	1.6672	3.8323	2.2521	6.4434
Cuvier's beaked whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0090	0.0939	0.0726	0.2243
ORDER SIRENIA									
West Indian manatee	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gray seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Harbor seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 4-14

Annual Level B Take Estimates from All Non-Airgun High-Resolution Geophysical Surveys Using 160-dB Criteria for Marine Mammal Species during the Project Period (2012-2020)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common minke whale	0.0225	0.0287	0.0300	0.0300	0.0300	0.0282	0.0200	0.0135	0.0419
Sei whale	0.0358	0.0476	0.0511	0.0511	0.0511	0.0557	0.1152	0.0784	0.2328
Bryde's whale	0.0355	0.0470	0.0505	0.0505	0.0505	0.0553	0.1169	0.0790	0.2338
Blue whale	0.0659	0.0980	0.1037	0.1037	0.1037	0.1048	0.1448	0.0871	0.2568
Fin whale	0.1153	0.1598	0.1665	0.1665	0.1665	0.1722	0.3083	0.1847	0.5384
North Atlantic right whale	0.1945	0.2461	0.2491	0.2491	0.2491	0.2690	0.5016	0.3002	0.8702
Humpback whale	0.2454	0.3285	0.3444	0.3444	0.3444	0.3313	0.3597	0.2189	0.6492
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked common dolphin	119.4440	142.9833	146.4839	146.4839	146.4839	147.8699	204.6009	128.8144	379.1270
Pygmy killer whale	0.0345	0.0494	0.0494	0.0494	0.0494	0.0549	0.1097	0.0759	0.2370
Short-finned pilot whale	1.2920	1.6287	1.6711	1.6711	1.6711	13.3054	122.2637	78.8942	227.0254
Long-finned pilot whale	0.2621	0.3201	0.3267	0.3267	0.3267	1.4975	12.6893	9.1359	27.5252
Risso’s dolphin	8.9444	10.9577	10.9577	10.9577	10.9577	17.8981	84.9354	57.4417	170.2112
Northern bottlenose whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0063	0.0041	0.0118
Pygmy sperm whale	0.1119	0.1503	0.1503	0.1503	0.1503	0.1410	0.0732	0.0472	0.1675
Dwarf sperm whale	0.3358	0.4508	0.4508	0.4508	0.4508	0.4557	0.5592	0.3686	1.1655
Atlantic white-sided dolphin	0.0027	0.0055	0.0055	0.0055	0.0055	0.0208	0.1680	0.1357	0.4275
Fraser's dolphin	0.0345	0.0568	0.0637	0.0637	0.0637	0.0575	0.0304	0.0098	0.0183
Sowerby's beaked whale	0.0023	0.0026	0.0026	0.0026	0.0026	0.0030	0.0073	0.0056	0.0175
Blainville's beaked whale	0.0023	0.0026	0.0026	0.0026	0.0026	0.1259	1.3153	1.0167	3.1400
Gervais' beaked whale	0.0023	0.0026	0.0026	0.0026	0.0026	0.1259	1.3153	1.0167	3.1400
True's beaked whale	0.0026	0.0032	0.0032	0.0032	0.0032	0.1265	1.3156	1.0167	3.1400
Killer whale	0.0509	0.0642	0.0678	0.0678	0.0678	0.0680	0.0952	0.0667	0.2021
Melon-headed whale	0.0361	0.0525	0.0525	0.0525	0.0525	0.0604	0.1362	0.0921	0.2839
Harbor porpoise	0.1543	0.1717	0.1812	0.1812	0.1812	0.1894	0.2990	0.2206	0.6643
Sperm whale	0.0182	0.0215	0.0215	0.0215	0.0215	0.4051	4.2127	3.6965	11.8913
False killer whale	0.0389	0.0582	0.0582	0.0582	0.0582	0.0674	0.1524	0.0959	0.2885
Pantropical spotted dolphin	29.7529	43.6445	44.1968	44.1968	44.1968	42.9366	34.8805	15.7818	47.0220
Clymene dolphin	14.2145	20.8513	21.1152	21.1152	21.1152	20.4600	16.1068	7.1416	21.2706
Striped dolphin	38.8529	56.4013	57.1529	57.1529	57.1529	59.6638	89.0555	51.9312	155.0979
Atlantic spotted dolphin	339.1818	482.8880	489.6133	489.6133	489.6133	465.6510	302.1377	119.0890	349.4761
Spinner dolphin	0.1306	0.1899	0.1924	0.1924	0.1924	0.1862	0.1484	0.0672	0.2001
Rough-toothed dolphin	0.5554	0.7281	0.7355	0.7355	0.7355	0.7138	0.7853	0.5128	1.6114
Bottlenose dolphin	91.9501	137.7600	143.5851	143.5851	143.5851	163.3981	375.6071	220.7238	631.5169
Cuvier's beaked whale	0.0158	0.0181	0.0181	0.0181	0.0181	0.8810	9.2072	7.1172	21.9798
ORDER SIRENIA									
West Indian manatee	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gray seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Harbor seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 4-15

Sea Turtles Occurring in the Area of Interest

Scientific Name	Common Name	Status[1]	Occurrence in Area of Interest	Life Stage	Primary Nesting Sites	States with Nesting Reported in Area of Interest	ESA-Designated Critical Habitat
Caretta caretta	Loggerhead turtle	T[2]	DE–FL	All	Florida beaches: Brevard, Indian River, St. Lucie, Martin, Palm Beach, and Broward Counties	VA, NC, SC, GA, FL	Pending
Chelonia mydas	Green turtle	E, T[3]	DE–FL	All	Florida beaches: Brevard, Indian River, St. Lucie, Martin, Palm Beach, and Broward Counties	NC, SC, GA, FL	Culebra Island, Puerto Rico
Eretmochelys imbricata	Hawksbill turtle	E	DE–FL (uncommon north of FL)	All	Mexican beaches: Yucatán Peninsula; Caribbean Beaches: Puerto Rico [Culebra, Mona, and Vieques Islands], Barbados	--	Mona, Culebrita, and Culebra Islands, Puerto Rico; specific beaches on Culebra Island (Playa Resaca, Playa Brava, and Playa Larga), and the waters surrounding the islands of Mona and Monito
Lepidochelys kempii	Kemp's ridley turtle	E	DE–FL	Juveniles and Adults	Mexican beaches: Tamaulipas and Veracruz	NC, SC, FL	Pending
Dermochelys coriacea	Leatherback turtle	E	DE–FL	All	Florida beaches (southeast coast)	NC, SC, GA, FL	U.S. Virgin Islands: a strip of land 0.2-mi wide at Sandy Point Beach, St. Croix and the waters adjacent to the site

[1] Status: E = endangered (E); T = threatened.

[2] The loggerhead turtle is currently classified as threatened throughout its range. In March 2010, NMFS and USFWS proposed to list the Northwest Atlantic Ocean population of loggerhead turtles as endangered (*Federal Register*, 2010g).

[3] The green turtle is threatened, except for the Florida breeding population, which is endangered (USDOC, NMFS, 2011g).

Table 4-16

Families of Seabirds, Waterfowl, and Shorebirds Occurring in the Area of Interest

Order	Family	General Ecology	General Distribution/Migration
SEABIRDS			
Charadriiformes	Laridae (Gulls and terns)	Primarily inhabit coastal or inshore waters. Conspicuous and gregarious in nature. Nest colonially on the ground. Most feed on small fishes with some foraging on insects and crabs. Terns typically forage by hovering above the water's surface and plunge-diving head-first into the water from flight. Gulls seldom dive and prefer open areas. Highly adaptable.	Found predominantly along the coast but also inland in both populated and open areas. Found in the Arctic, northern Canada, and northern U.S., with some species migrating south to Mexico and South America.
	Rhyncopidae (Skimmers)	Primarily inhabit coastal and inshore waters. Nest colonially on sandy beaches. Forages for small fishes mainly at night, flying over shallow water with their elongated lower mandible below the water surface.	Year-round coastal distribution throughout the AOI.
	Stercorariidae (Skuas and jaegers)	Primarily oceanic, generally coming to land only to nest. Commonly acquire food by kleptoparasitism of other seabird species. Predatory when on nesting grounds.	Migratory species, wintering within the southern portion of the AOI and moving to arctic habitats to nest during the summer.
	Alcidae (Puffins, murres, murrelets, and auklets)	Oceanic species that come to land only to nest. Most nest colonially in crevices or burrows. All use their wings for underwater propulsion to pursue prey. Specialized bill shapes relate to feeding habits and prey types.	Occur year-round in arctic and subarctic marine habitats. In summer months, they occur at sea and at coastal nesting locations. In winter, they generally occur in oceanic waters, and individuals may move southward into temperate waters.
Gaviiformes	Gaviidae (Loons)	Medium to large birds that capture prey (fishes, crustaceans, and other aquatic organisms) by diving and pursuing underwater. Habitat includes tundra lakes and ponds in summer and coastal waters in winter. Nest on banks of ponds or lakes and winter on the open water.	Holarctic in the summer in freshwater areas. Highly migratory to more marine areas in northern Mexico for winter.
Pelicaniformes	Pelicanidae (Pelicans)	Very large, social water birds that swim buoyantly and feed predominantly on fishes and crustaceans in primarily shallow estuarine waters, occasionally up to 40 miles from shore. Plunges bill-first into the water while fishing and often flies just above the water surface looking for prey. Nesting occurs usually on coastal islands, on the ground, or in small bushes and trees.	Found in freshwater and marine coastal waters. Breeding range extends along the along Atlantic coast from Maryland south to Florida. The primary winter range includes Florida and the Gulf coast. Breeding activities extremely sensitive to human activity.
	Phaethontidae (Tropicbirds)	A mainly pelagic, highly aerial, solitary seabird found far offshore over and resting on warm water. Feed by plunge-diving. Nests in small to large colonies on tropical islands in rocky crevices, holes, or caves.	Distributed in tropical and subtropical waters. Occasionally found within the Gulfstream offshore of the south Atlantic coast. Breeds in Bermuda.
	Phalacrocoracidae (Cormorants)	Large, gregarious water birds found in coastal bays, marine islands, and seacoasts usually within sight of land. Some species are found along rocky shores, while other are found in open water. Eats mostly schooling fishes by diving.	Migratory and dispersive. Found along temperate and tropical marine coasts. Cosmopolitan. Northern coastal populations migrate southward for nonbreeding season and usually follow coastlines.
	Sulidae (Gannets and boobies)	Gregarious and colonial breeders in marine environment. Fish by plunging from air for fishes and squids. Boobies land-roost and gannets rest on open ocean. Nests in colonies on islands and rock stacks.	Tropical, subtropical, and temperate oceans. Oceanic, with some found well offshore while others stay close to shore.
	Fregatidae (Frigatebirds)	Found in offshore and coastal waters. Feeding habits are pelagic and include snatching prey from the sea surface or beach, or in some cases	One species (magnificent frigatebird [*Fregatta magnificens*]) occurs within the AOI. It is widespread

Table 4-16 Families of Seabirds, Waterfowl, and Shorebirds Occurring in the Area of Interest (continued)

Order	Family	General Ecology	General Distribution/Migration
		by robbing other seabirds of their catch (kleptoparasitism).	in the tropical Atlantic.
Podicipediformes	Podicipedidae (Grebes)	Found in ponds, lakes, salt bays, and nearshore habitats. Feed by diving. Spend virtually all their time in the water and are clumsy on land.	Cosmopolitan. Migrate from inland breeding areas to temperate nearshore areas. Breed on fresh water.
Procellariiformes	Hydrobatidae (Storm-petrels)	Medium to large seabirds found over the open ocean and come to land only for nesting. Colonial breeders. Feed on plankton, crustaceans, and small fishes. Nest on sea islands.	Breed November–May in the Antarctic and are transequatorial migrants offshore at higher latitudes of Atlantic.
	Procellariidae (Petrels and shearwaters)	Highly pelagic and return to land only for breeding. Feed on fishes, squids, and crustaceans. Colonial breeders on marine islands.	Transequatorial. Most breed in the northern Atlantic and migrate south in summer as far as South America. One species breeds in New Zealand and migrates north to northern Atlantic.
WATERFOWL			
Anseriformes	Anatidae (Aythyinae) (Diving Ducks)	Mainly in freshwater and estuarine environments, but species such as the greater scaup become marine during the winter. Breed in marshes. All dive for food including aquatic vegetation, mollusks, and crustaceans.	Arctic, circumpolar during nesting season. Migrate into temperate areas in winter. Frequent inland waters, estuaries and bays, and nearshore waters.
	Anatidae (Merginae) (Sea Ducks)	Found in marine environment along seacoast. Breed in marshes. All dive for food including mollusks and crustaceans.	Arctic, circumpolar during nesting season. Most migrate into subarctic and northern temperate areas in winter. Frequent coastal waters and open water near pack ice.
SHOREBIRDS			
Charadriiformes	Charadriidae (Plovers)	Wading birds found along mud flats, shores, and beaches that feed on small marine life, insects, and some vegetable matter. Nest singly or in loose colonies.	Arctic, circumpolar. Winter along coastal U.S. to South America, migrating along the coast.
	Haematopodidae (Oystercatchers)	Large wading birds found along the coastal shores and tidal flats. Feed on mollusks, crabs, and marine worms.	Distribution from Cape Cod south to Chile and Argentina.
	Recurvirostridae (Stilts and avocets)	Slim wading birds found along beaches and mud flats. Feed on insects, crustaceans, and other aquatic organisms. Typically nest on open flats or areas with scattered tufts of grass on islands.	Breed in southwest Canada and make seasonal migration to southern U.S. to Guatemala.
	Scolopacidae (Sandpipers, snipes, phalaropes, and allies)	Small to medium sized wading birds found along mud flats, tidal flats, shores, beaches, and salt marshes. Red and red-necked phalaropes occur in small groups along weed lines on the open ocean. Feed on insects, crustaceans, mollusks, and worms.	Cosmopolitan. Migrate along coast from northern North America south as far as southern South America.

Sources: Peterson, 1980; Harrison, 1983, 1987; Sibley, 2000; Morrison et al., 2001a; NatureServe, InfoNatura, 2010.

Table 4-17

Important Bird Areas within Offshore, Nearshore, and Coastal Habitats Within and Adjacent to the Area of Interest

IBA Site	State	Latitude	Longitude	Habitat	Resources of Concern
Assateague Island	MD	38.62°	75.94°	Barrier Island	Shorebirds, Seabirds
Chesapeake Bay Islands	VA	37.84°	75.99°	Coastal	Waterfowl, Seabirds
Barrier Island/Lagoon System	VA	37.53°	75.68°	Barrier Island/Coastal	Shorebirds, Seabirds
Back Bay	VA	36.62°	75.94°	Coastal	Shorebirds
Outer Banks Inshore Ocean	NC	35.90°	75.58°	Offshore	Seabirds, Waterfowl
Outer Continental Shelf	NC	35.30°	75.33°	Offshore	Seabirds
Cape Hatteras National Seashore	NC	35.20°	75.53°	Barrier Island	Shorebirds, Seabirds
Cape Lookout National Seashore	NC	34.60°	76.53°	Barrier Island	Shorebirds
Onslow Bay	NC	34.20°	77.78°	Offshore/Coastal	Seabirds, Waterfowl
Bald Head-Smith Island	NC	33.87°	77.97°	Coastal	Shorebirds, Waterfowl
Cape Romain National Wildlife Refuge	SC	33.02°	79,50°	Barrier Island/Coastal	Shorebirds, Waterfowl, Seabirds
Crab Bank	SC	32.98°	79.98°	Coastal	Seabirds
Bird Key Stono	SC	32.63°	79.98°	Barrier Island	Seabirds, Shorebirds
Little Tybee Island State Heritage Preserve	GA	31.97°	80.90°	Barrier Island	Shorebirds, Waterfowl, Seabirds
St. Catherines Island	GA	31.63°	81.15°	Barrier Island	Shorebirds, Waterfowl,
Wassaw National Wildlife Refuge	GA	31.55°	80.96°	Coastal	Shorebirds, Waterfowl
Altamaha River Delta	GA	31.30°	81.31°	Coastal	Shorebirds, Waterfowl, Seabirds
Jekyll Island	GA	31.05°	81.42°	Barrier Island	Shorebirds, Seabirds
Cumberland Island National Seashore	GA	30.83°	81.42°	Barrier Island	Seabirds, Waterfowl, Shorebirds
Huguenot Park-Nassau Sound	FL	30.51°	81.45°	Coastal	Shorebirds, Seabirds
Duval and Nassau Tidal Marshes	FL	30.48°	81.44°	Barrier Island/Coastal	Shorebirds
Fort George and Talbot Islands	FL	30.45°	81.42°	Coastal	Shorebirds, Seabirds
Northern Atlantic Migrant Stopover	FL	29.86°	81.27°	Coastal	Shorebirds, Seabirds
Matanzas Inlet and River	FL	29.71°	81.23°	Coastal	Shorebirds
Cape Canaveral – Merritt Island	FL	28.54°	80.67°	Barrier Island/Coastal	Shorebirds, Waterfowl, Seabirds

Abbreviation: IBA = Important Bird Area.
Source: National Audubon Society, Inc. (http://web4.audubon.org/bird/iba/index.html).

Table 4-18

Plant, Invertebrate, and Fish Species and Species Groups Broadly Associated with Demersal and Pelagic Habitats in the Area of Interest Managed by the South Atlantic Fishery Management Council, Mid-Atlantic Fishery Management Council, New England Fishery Management Council, and/or Highly Migratory Species Office of the National Marine Fisheries Service

Species or Species Groups	SAFMC	MAFMC	NEFMC	NMFS
Demersal				
Coral, coral reefs, and live/hard bottom	■	--	--	--
Spiny lobster (*Panulirus argus*)	■	--	--	--
Snapper-grouper complex (73 species)	■	--	--	--
Tilefish (*Lopholatilus chamaeleonticeps*)	■	■	--	--
Black sea bass (*Centropristis striata*)	■	■	--	--
Scup (*Stenotomus chrysops*)	■	■	--	--
Surfclam (*Spisula solidissima*)	--	■	--	--
Ocean quahog (*Arctica islandica*)	--	■	--	--
Sea scallop (*Placopecten magellanicus*)	--	--	■	--
Calico scallop (*Argopecten gibbus*)	--	--	--	--
Golden crab (*Chaceon fenneri*)	■	--	--	--
Red crab (*Chaceon quinquedens*)	--	--	■	--
Shrimps (Penaeidae and Sicyonidae)	■	--	--	--
Red drum (*Sciaenops ocellata*)	■	--	--	--
Monkfish (*Lophius americanus*)	--	■	--	--
Spiny dogfish (*Squalus acanthias*)	--	■	■	--
Offshore hake (*Merluccius albidus*)	--	■	■	--
Silver hake (*Merluccius bilinearis*)	--	--	■	--
Red hake (*Urophycis chuss*)	--	--	■	--
Witch flounder (*Glyptocephalus cynoglossus*)	--	--	■	--
Summer flounder (*Paralichthys dentatus*)	--	--	■	--
Windowpane flounder (*Scophthalmus aquosus*)	--	--	■	--
Pelagic				
Sargassum	■	--	--	--
Long-finned squid (*Loligo pealei*)	--	■	--	--
Short-finned squid (*Illix illecebrosus*)	--	■	--	--
Cobia (*Rachycentron canadum*)	■	--	--	--
King mackerel (*Scomberomorus cavalla*)	■	--	--	--
Spanish mackerel (*Scomberomorus maculatus*)	■	--	--	--
Little tunny (*Euthynnus alletteratus*)	■	--	--	--
Bluefish (*Pomatomus saltatrix*)	--	■	--	--
Atlantic mackerel (*Scomber scombrus*)	--	■	--	--
Butterfish (*Peprilus triacanthus*)	--	■	--	--
Atlantic herring (*Clupea harengus*)	--	--	■	--
Small coastal sharks (5 species)	--	--	--	■
Large coastal sharks (17 species)	--	--	--	■
Pelagic sharks (6 species)	--	--	--	--
Wahoo (*Acanthocybium solandri*)	■	--	--	--
Dolphin (*Coryphaena hippurus*)	■	--	--	--
Tunas and billfishes (Scombridae, Istiophoridae, Xiphiidae)	--	--	--	■

Abbreviations: MAFMC = Mid-Atlantic Fishery Management Council; NEFMC = New England Fishery Management Council; NMFC = Highly Migratory Species Office of the National Marine Fisheries Service; SAFMC = South Atlantic Fishery Management Council.

Table 4-19

Hard Bottom Species with Essential Fish Habitat Identified within the Area of Interest

Species	Eggs and Larvae	Juveniles	Adults
Spiny lobster (*Panulirus argus*)	Surface waters of the SAB and Gulf Stream	Not in AOI	Live/hard bottom and artificial reefs with medium- to high-profile outcroppings from nearshore to at least 100-m water depths from Cape Hatteras, NC, to Cape Canaveral, FL
Black sea bass (*Centropristis striata*)	Surface waters of the AOI shelf from May-October	Demersal soft and hard bottom habitats of the AOI shelf where water temperatures are greater than 6 °C and salinity greater than 18 ppt	Demersal soft and hard bottom habitats of the AOI shelf where water temperatures are greater than 6 °C and salinity greater than 18 ppt
Warsaw grouper (*Epinephelus nigritus*)	Surface waters of the SAB and Gulf Stream including pelagic *Sargassum*	Live/hard bottom and artificial reefs with medium to high profile outcroppings from inner shelf to at least 200-m water depths	Live/hard bottom and artificial reefs with medium to high profile outcroppings from 50- to at least 200-m water depths. Spawning occurs in the same area
Snowy grouper (*Epinephelus niveatus*)	Surface waters of the SAB and Gulf Stream including pelagic *Sargassum*	Live/hard bottom and artificial reefs with medium to high profile outcroppings from inner shelf to at least 200-m water depths	Live/hard bottom and artificial reefs with medium to high profile outcroppings from 50- to at least 200-m water depths. Spawning occurs in the same area
Gag grouper (*Mycteroperca microlepis*)	Surface waters of the SAB and Gulf Stream including pelagic *Sargassum*	Not in AOI	Live/hard bottom and artificial reefs with medium to high profile outcroppings from nearshore to at least 100-m water depths from Cape Hatteras, NC, to Cape Canaveral, FL. Spawning occurs in winter months in 30-100 m depths
Scamp (*Mycteroperca phenax*)	Surface waters of the SAB and Gulf Stream including pelagic *Sargassum*	Hard bottom areas on the shelf to the shelf edge from Cape Hatteras, NC, to Cape Canaveral, FL	Hard bottom areas from Cape Hatteras, NC, to Cape Canaveral, FL
Wreckfish (*Polyprion americanus*)	Gulf Stream waters including pelagic *Sargassum*	Not enough information	Live/hard bottom and artificial reefs with medium to high profile outcroppings in 800-1,200-m water depths
Gray snapper (*Lutjanus griseus*)	Surface waters of the SAB and Gulf Stream	Hard bottom and soft bottom areas on the shelf from Cape Hatteras, NC, to Cape Canaveral, FL	Hard bottom areas from Cape Hatteras, NC, to Cape Canaveral, FL

Table 4-19 Hard Bottom Species with Essential Fish Habitat Identified within the Area of Interest (AOI) (continued)

Species	Eggs and Larvae	Juveniles	Adults
Red snapper (*Lutjanus campechanus*)	Surface waters of the SAB and Gulf Stream	Not in AOI	Hard bottom areas from Cape Hatteras, NC, to Cape Canaveral, FL
Lane snapper (*Lutjanus synagris*)	Surface waters of the SAB and Gulf Stream	Not in AOI	Hard bottom areas from Cape Hatteras, NC, to Cape Canaveral, FL
Vermilion snapper (*Rhomboplites aurorubens*)	Surface waters of the SAB and Gulf Stream	Hard bottom areas on the shelf to the shelf edge from Cape Hatteras, NC, to Cape Canaveral, FL	Hard bottom areas from Cape Hatteras, NC, to Cape Canaveral, FL
Scup (*Stenotomus chrysops*)	Not in AOI	Not in AOI	Demersal waters of the continental shelf off the middle Atlantic south to Cape Hatteras, NC
Blueline tilefish (*Caulolatilus microps*)	Gulf Stream waters including pelagic *Sargassum*	Not enough information	Soft or rough bottom in water depths between 100 and 400 m
Tilefish (*Lopholatilus chamaeleonticeps*)	Water column on the outer continental shelf and slope throughout the AOI boundary in temperatures between 7.5 and 17.5 °C	Semi-lithified clay substrate on the outer continental shelf and slope throughout the AOI in bottom water temperatures which range from 9-14 °C, in depths between 100 and 300 m	Semi-lithified clay substrate on the outer continental shelf and slope throughout the AOI in bottom water temperatures ranging from 9-14 °C, in depths between 100 and 300 m

AOI = Area of Interest.
Sources: SAFMC, 1998; MAFMC, 1998a, 2008a.

Table 4-20

Soft Bottom Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest

Species	Eggs and Larvae	Juveniles	Adults
Surfclam (*Spisula solidissima*)	Not enough information	In substrate, to a depth of 3 ft below the water/sediment surface throughout the MAB from the shoreline out to 70 m	In substrate, to a depth of 3 ft below the water/sediment surface throughout the MAB from the shoreline out to 70 m
Ocean quahog (*Arctica islandica*)	Not enough information	In substrate, to a depth of 3 ft below the water/sediment surface throughout the MAB in water depths from 10-244 m	In substrate, to a depth of 3 ft below the water/sediment surface throughout the MAB from the shoreline out to 10-244 m
Sea scallop (*Placopecten magellanicus*)	Bottom habitats in the middle Atlantic south to the VA-NC border; Eggs are heavier than seawater and remain on the seafloor until they develop into the first free-swimming larval stage. Generally, eggs are thought to occur where water temperatures are below 17 °C. Larvae occur in pelagic waters and bottom habitats with a substrate of gravelly sand, shell fragments, and pebbles, or on various red algae, hydroids, amphipod tubes, and bryozoans in the MAB south to the VA-NC border where sea surface temperatures are below 18 °C and salinities are between 16.9 and 30 ppt	Bottom habitats with a substrate of cobble, shells, and silt in the middle Atlantic south to the VA-NC border where water temperatures are below 15 °C and water depths range from 18-110 m	Bottom habitats with a substrate of cobble, shells, coarse/gravelly sand, and sand in the middle Atlantic south to the VA-NC border where water temperatures are below 21 °C, water depths range from 18 to 110 m, and salinities are above 16.5 ppt. Spawning occurs from May through October, with peaks in May and June
Calico scallop (*Argopecten gibbus*)	Not enough information	Unconsolidated sediments including hard sand bottoms, sand and shell hash, quartz sand, smooth sand-shell-gravel, and sand and dead shell in 13-94 m, with concentrations occurring off Cape Canaveral, FL (Stuart to St. Augustine) and sporadically off Cape Lookout, NC, in 19-31 m, and offshore of the SC/GA border in 37-45 m	Unconsolidated sediments including hard sand bottoms, sand and shell hash, quartz sand, smooth sand-shell-gravel, and sand and dead shell in 13-94 m, with concentrations occurring off Cape Canaveral, FL (Stuart to St. Augustine), and sporadically off Cape Lookout, NC, in 19-31 m, and offshore of the SC/GA border in 37-45 m

Table 4-20 Soft Bottom Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest (continued)

Species	Eggs and Larvae	Juveniles	Adults
Golden crab (*Chaceon fenneri*)	Eggs are brooded attached to the underside of the female crab until they hatch into larvae and are released into the water column. Egg-bearing females are most commonly found on the shallow continental slope between 300 and 600 m; larvae occur in pelagic waters of the Gulf Stream	Soft bottom including foraminiferal ooze, dead coral mounds, dunes, and black pebble habitat in water depths of 367-549 m	Soft bottom including foraminiferal ooze, dead coral mounds, dunes, and black pebble habitat in water depths of 367-549 m
Red crab (*Chaceon quinquedens*)	Eggs are brooded attached to the underside of the female crab until they hatch into larvae and are released into the water column. Egg-bearing females are most commonly found on the shallow continental slope between 200 and 400 m where temperatures are typically between 4 and 10 °C and water depths range from 200-400 m to Cape Hatteras, NC. Larvae occur in the water column from the surface to the seafloor across the 200 to 1,800 m along the MAB south to Cape Hatteras, NC where water temperatures range between 4 and 25 °C, salinities between 29 and 36 ppt, and dissolved oxygen between 5 and 8 ml/L; larvae appear to be most common during January through June	Bottom habitats of the continental slope with a substrate of silts, clays, and all silt-clay-sand composites within the depths of 700-1,800 m along the southern flank of Georges Bank and south to Cape Hatteras, NC, where water temperatures are between 4 and 10 °C, and salinities are approximately 35 ppt, and dissolved oxygen range between 3 and 7 mg/L	Bottom habitats of the continental slope with a substrate of silts, clays, and all silt-clay-sand composites within the depths of 200 to 1,300 m along the southern flank of Georges Bank and south to Cape Hatteras, NC where water temperatures are between 5 and 14 °C, salinities average 35 ppt, and dissolved oxygen range between 3 and 8 mg/L
Royal red shrimp (*Pleoticus robustus*)	Pelagic Gulf Stream waters	Soft bottom including blue/black mud, sand, muddy sand, and white calcareous mud on the upper continental slope in water depths of 180-475 m	Soft bottom including blue/black mud, sand, muddy sand, and white calcareous mud on the upper continental slope in water depths of 180-475 m

Table 4-20 Soft Bottom Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest (continued)

Species	Eggs and Larvae	Juveniles	Adults
Rock shrimp (*Syconia* spp.)	Eggs and larvae in high salinity coastal waters of the SAB	Terrigenous and biogenic sand bottom habitats from 18-182 m in depth with highest concentrations occurring between 34 and 55 m in all areas from NC to Cape Canaveral, FL	Terrigenous and biogenic sand bottom habitats from 18-182 m in depth with highest concentrations occurring between 34 and 55 m. areas from NC to Cape Canaveral, FL. Spawning occurs in the same area
Brown shrimp (*Farfantepenaeus aztecus*)	Eggs and larvae in high salinity coastal waters of the SAB	Not in AOI (primarily in inshore waters)	Nearshore SAB shelf with medium to fine grained sediment. Spawning occurs offshore
Pink shrimp (*Farfantepenaeus duorarum*)	Eggs and larvae in high salinity coastal waters of the SAB	Not in AOI (primarily in inshore waters)	Coarse and particularly calcareous bottom sediments in SAB from mid- to outer shelf depths. Spawning occurs offshore
White shrimp (*Litopenaeus setiferus*)	Eggs and larvae in high salinity coastal waters of the SAB	Not in AOI (primarily in inshore waters)	Nearshore SAB shelf with medium to fine grained sediment
Red drum (*Sciaenops ocellata*)	Eggs in high salinity coastal waters; larvae not in AOI (primarily in inshore waters)	Not in AOI (primarily in inshore waters)	High salinity coastal waters of the AOI from VA to Cape Canaveral, FL
Monkfish (*Lophius americanus*)	MAB shelf areas south to Cape Hatteras, NC, with water temperatures below 15 °C and depths from 15-1,000 m for eggs and 25-1,000 m for larvae; egg veils and larvae are most often observed from March to September	MAB shelf areas with water temperatures below 13 °C, depths from 25 to 200 m, and a salinity range from 29.9 to 36.7 ppt	Bottom habitats with substrates of a sand-shell mix, algae covered rocks, hard sand, pebbly gravel, or mud along the outer MAB shelf
Offshore hake (*Merluccius albidus*)	MAB shelf to Cape Hatteras, NC where water temperatures less than 20 °C and water depths less than 1,250 m all year at depths from 110-270 m (eggs) and 70-130 m (larvae)	Bottom habitats along the outer MAB shelf south to Cape Hatteras, NC, generally where water temperatures are below 12 °C and depths range from 170-350 m	Bottom habitats along the outer MAB shelf south to Cape Hatteras, NC, where water temperatures are below 12 °C and depths range from 150-380 m. Spawning occurs throughout the year at depths from 330-550 m
Silver hake (*Merluccius bilinearis*)	Surface waters of the MAB south to Cape Hatteras where sea surface temperatures are below 20 °C and water depths are 50-130 m; larvae are observed all year, with peaks from July through September	Bottom habitats of all substrate types on the MAB shelf south to Cape Hatteras, NC, where water temperatures are below 21 °C, water depths 20-270 m, and salinities are greater than 20 ppt	Bottom habitats of all substrate types on the MAB shelf south to Cape Hatteras, NC, where water temperatures are below 22 °C and depths between 30 and 325 m. Spawning occurs in the same area where water temperatures are below 13 °C

Table 4-20 Soft Bottom Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest (continued)

Red hake (*Urophycis chuss*)	Continental shelf off the MAB south to Cape Hatteras, NC, where sea surface temperatures are below 10 °C along the inner shelf (eggs) or 19 °C in water depths less than 200 m (larvae), in a salinity greater than 0.5 ppt; May through November (eggs) to December (larvae), with peaks in June and July (eggs) and September-October (larvae)	Bottom habitats with a substrate of shell fragments, including areas with an abundance of live scallops on the shelf off the middle Atlantic south to Cape Hatteras, NC, where water temperatures are below 16 °C, depths are less than 100 m, and salinity ranges from 31-33 ppt	Bottom habitats in depressions with a substrate of sand and mud on the continental shelf off the middle Atlantic south to Cape Hatteras, NC, where water temperatures are below 12 °C, water depths range from 10-130 m, and salinity ranges from 33-34 ppt. Spawning occurs in water depths less than 100 m and salinity less than 25 ppt from May-November, with peaks in June and July
Witch flounder (*Glyptocephalus cynoglossus*)	Surface waters to 250 m on the MAB shelf off the middle Atlantic south to Cape Hatteras, NC, where sea surface temperatures are below 13 °C over deep water with high salinities; larvae are most often observed from March through November, with peaks in May-July	Bottom habitats with a fine-grained substrate along the outer MAB shelf south to Cape Hatteras, NC, where witch water temperatures are below 13 °C, depths range from 50-450 m, and salinity ranges from 34-36 ppt	Bottom habitats with a fine-grained substrate along the outer MAB continental shelf south to Chesapeake Bay, where water temperatures are below 13 °C, depths range from 25-300 m, and salinity ranges from 32-36 ppt. Spawning occurs from March through November, with peaks in May-August
Summer flounder (*Paralichthys dentatus*)	Surface waters of the MAB shelf south to Cape Canaveral, FL; in water depths from shore to 98 m (eggs) and from 10-70 m (larvae)	Demersal waters of the MAB shelf south to Cape Canaveral, FL, to water depths of 152 m	Demersal waters of the MAB shelf south to Cape Canaveral, FL, to water depths of 152 m. Spawning occurs between October and May
Windowpane (*Scophthalmus aquosus*)	Pelagic waters of the MAB south to Cape Hatteras, NC where sea surface temperatures are less than 20 °C and water depths less than 70 m; eggs and larvae are often observed from February-November with peaks in May and October	Bottom habitats with a substrate of mud or fine-grained sand on the MAB shelf south to Cape Hatteras, NC, where water temperatures are below 25 °C, depths range from 1-100 m, and salinities range between 5.5 and 36 ppt	Bottom habitats with a substrate of mud or fine-grained sand on the MAB shelf south to the VA-NC border where water temperatures are below 26.8 °C, depths range from 1-75 m, and salinities range between 5.5 and 36 ppt. Spawning occurs from February-December with a peak in May

Abbreviations: AOI = Area of Interest; MAB = Mid-Atlantic Bight; SAB = South Atlantic Bight.
Sources: MAFMC, 1998b, 2008a; SAFMC, 1998; NEFMC, 1998a,b,c; 2002.

Table 4-21

Coastal Pelagic Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest

Species	Eggs and Larvae	Juveniles	Adults
Longfin squid (*Loligo pealei*)	Coastal and offshore bottom habitats from Georges Bank southward to Cape Hatteras, NC egg masses are found attached to rocks and boulders on sand or mud bottom, as well as attached to aquatic vegetation where bottom water temperatures range between 10and 23 °C, salinities range from 30-32 ppt, and depths are less than 50 m	Pelagic waters of the continental shelf from the Gulf of Maine through Cape Hatteras, NC, from shore to 213 m water depths in temperatures ranging from 3.8-27 °C	Pelagic waters of the continental shelf from the Gulf of Maine through Cape Hatteras, NC, from shore to 305 m water depths in temperatures ranging from 3.8-27 °C
Shortfin squid (*Illex illecebrosus*)		Pelagic waters of the continental shelf from the Gulf of Maine through Cape Hatteras, NC, from shore to 183 m water depths in temperatures ranging from 2.2-22.8 °C	Pelagic waters of the continental shelf from the Gulf of Maine through Cape Hatteras, NC, from shore to 183 m water depths in temperatures ranging from 3.8-19 °C
Atlantic herring (*Clupea harengus*)	Not in AOI	Pelagic waters and bottom habitats in the MAB south to Cape Hatteras, NC. Generally, the following conditions exist where Atlantic herring juveniles are found: water temperatures below 10 °C, water depths from 15-135 m, and a salinity range from 26-32 ppt	Pelagic waters and bottom habitats in the MAB south to Cape Hatteras, NC. Generally, the following conditions exist where Atlantic herring adults are found: water temperatures below 10 °C, water depths from 20-130 m, and salinity above from 28 ppt
Cobia (*Rachycentron canadum*)	Pelagic waters of SAB and MAB from shore to the shelf edge	Shelf waters of SAB and MAB; artificial and natural hard bottom; associates with larger nekton (i.e., sharks, rays, sea turtles)	Shelf waters of SAB and MAB; artificial and natural hard bottom structures; associates with larger nekton (i.e., sharks, rays, sea turtles)
King mackerel (*Scomberomorus cavalla*)	Pelagic waters of SAB and MAB from shore to the shelf edge	Shelf waters of SAB and MAB; associates with artificial and natural hard bottom	Shelf waters of SAB and MAB; associates with artificial and natural hard bottom
Spanish mackerel (*Scomberomorus maculatus*)	Pelagic waters of SAB and MAB from shore to the shelf edge	Shelf and inshore waters of SAB and MAB; associates with artificial and natural hard bottom	Shelf and inshore waters of SAB and MAB; associates with artificial and natural hard bottom
Little tunny (*Euthynnus alletteratus*)	Pelagic waters of SAB and MAB from shore to beyond the shelf edge	Shelf waters of MAB and SAB; associates with artificial and natural hard bottom	Shelf waters of MAB and SAB; associates with artificial and natural hard bottom
Atlantic mackerel (*Scomber scomber*)	Shelf waters of MAB from Maine to Cape Hatteras, NC	Shelf waters of MAB from Maine to Cape Hatteras, NC to 320 m	Shelf waters from Maine to Cape Hatteras, NC (from shore to 320 m
Bluefish (*Pomatomus saltatrix*)	Shelf waters of MAB from Maine to Cape Hatteras, NC	Estuaries and coastal waters of the AOI	Shelf and inshore waters of SAB and MAB

Table 4-21 Coastal Pelagic Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest (AOI) (continued)

Species	Eggs and Larvae	Juveniles	Adults
Butterfish (*Peprilus triacanthus*)	Pelagic waters of MAB from shore to beyond the shelf edge where temperatures range from 11-17 °C	Pelagic waters of MAB from shore to beyond the shelf edge where temperatures are 11-20 °C and water depths range from 10-366 m	Pelagic waters of MAB from shore to beyond the shelf edge where temperatures are 3-28 °C and water depths range from 10-366 m
Spiny dogfish (*Squalus acanthias*)	Does not apply	Shelf waters of the entire AOI to water depths of 390 m (1,280 ft) where temperatures range from 3-28 ºC	Shelf waters of the entire AOI to water depths of 450 m (1,476 ft) where temperatures range from 3-28 ºC

Abbreviations: AOI = Area of Interest; MAB = Mid-Atlantic Bight; SAB = South Atlantic Bight.
Adapted from SAFMC, 1998; MAFMC, 1998c, 2008b.

Table 4-22

Small Coastal Shark Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest

Species	Neonate/Early Juveniles	Late Juveniles/Subadults	Adults
Angel shark (*Squatina dumerili*)	Off the coast of southern NJ, DE, and MD from 39°-38° N in shallow coastal waters out to the 25-m isobath, including the mouth of Delaware Bay	Off the coast of southern NJ, DE, and MD from 39°-38° N in shallow coastal waters out to the 25-m isobath, including the mouth of Delaware Bay	Off the coast of southern NJ, DE, and MD from 39°-38° N in shallow coastal waters out to the 25-m isobath, including the mouth of Delaware Bay
Bonnethead shark (*Sphyrna tiburo*)	Shallow coastal waters, inlets, and estuaries less than 25 m deep from Jekyll Island, GA, to just north of Cape Canaveral, FL	Shallow coastal waters, inlets, and estuaries less than 25 m deep from Cape Fear, NC, to West Palm Beach, FL	Shallow coastal waters, inlets and estuaries from Cape Fear, NC, to Cape Canaveral, FL
Atlantic sharpnose shark (*Rhizoprionodon terraenovae*)	Shallow coastal areas including bays and estuaries out to the 25-m isobath from Daytona Beach, FL north to Cape Hatteras, NC	From Daytona Beach, FL, north to Cumberland Island, GA; Hilton Head Island, SC, north to Cape Hatteras, NC, out to the 25-m isobath (slightly deeper – to the 50 m isobath – off NC)	From Cape May, NJ, south to the NC/SC border; shallow coastal areas north of Cape Hatteras, NC, to the 25-m isobath; south of Cape Hatteras between the 25- and 100-m isobaths; offshore St. Augustine, FL, to Cape Canaveral, FL, from inshore to the 100-m isobath
Blacknose shark (*Carcharhinus acronotus*)	Shallow coastal waters less than 25 m deep from the GA/FL border to Cape Canaveral, FL	Shallow coastal waters less than 25 m deep from the GA/FL border to Cape Canaveral, FL	Shallow coastal waters to the 25-m isobath from St. Augustine, FL south to Cape Canaveral, FL
Finetooth shark (*Carcharhinus isodon*)	Shallow coastal waters of SC, GA, and FL out to the 25-m isobath from 33°-30° N	Shallow coastal waters of SC, GA, and FL out to the 25-m isobath from 33°-30° N	Shallow coastal waters of SC, GA, and FL out to the 25-m isobath from 33°-30° N

Source: USDOC, NMFS, 2009a.

Table 4-23

Large Coastal Shark Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest

Species	Neonate/Early Juveniles	Late Juveniles/Subadults	Adults
Basking shark (*Cetorhinus maximus*)	Insufficient information	Offshore the mid-Atlantic U.S. south of Nantucket Shoals at 70°W to the northern edge of Cape Hatteras, NC, at 35.5° N in waters from 50-200 m deep	Not in AOI
Scalloped hammerhead (*Sphyrna lewini*)	Not in AOI	Pelagic waters of the U.S. Atlantic seaboard from the shoreline out to the 200-m isobath from 39° N south to the Florida Keys	Pelagic waters of the South from 36.5°-33° N between the 25 and 200-m isobaths
Great hammerhead (*Sphyrna mokarran*)	Insufficient information	Off the FL coast, all shallow coastal waters out to the 100-m isobath from 30° N south around peninsular FL to 82.5° W, including Florida Bay and adjacent waters east of 81.5° W (north of 25°N), and east of 82.5° W	Off the entire east coast of FL, all shallow coastal waters out to the 100-m isobath, south of 30° N, including the west coast of FL to 85.5° W
Bigeye thresher shark (*Alopias superciliosus*)	Insufficient information	Offshore NC from 36.5°-34°N, between the 200- and 2,000-m isobaths	Offshore NC from 35.5°-35°N, between the 200- and 2,000-m isobaths
White shark (*Carcharodon carcharias*)	Insufficient information	Offshore northern NJ and Long Island, NY, in pelagic waters from the 25- to 100-m isobaths in the New York Bight area, bounded to the east at 71.5° W and to the south at 39.5° N; also, offshore Cape Canaveral, FL, between the 25- and 100-m isobaths from 29.5° N south to 28° N	Insufficient information
Nurse shark (*Ginglymostoma cirtatum*)	Not in AOI	Shallow coastal waters from the shoreline to the 25-m isobath off the east coast of FL from south of Cumberland Island, GA (at 30.5° N)	Shallow coastal waters from the shoreline to the 25-m isobath off the east coast of FL from south of Cumberland Island, GA (at 30.5° N)
Bignose shark (*Carcharhinus altimus*)	From offshore Delmarva Peninsula (38° N) to Bull's Bay, SC (32° N), between the 100- and 200-m isobaths	From offshore Delmarva Peninsula (38° N) to Bull's Bay, SC (32° N), between the 100- and 500-m isobaths	Insufficient information
Blacktip shark (*Carcharhinus limbatus*)	Shallow coastal waters to the 25-m isobath from Bull's Bay, SC, at 33.5° N, south to Cape Canaveral, FL, at 28.5° N	Shallow coastal waters from the shoreline to the 25-m isobath from Cape Hatteras, NC, at 35.25° N to 29° N at Ponce de Leon Inlet, St. Augustine, FL	Shallow coastal waters of the Outer Banks, NC, from the shoreline to the 200-m isobath between 36° N and 34.5° N; shallow coastal waters offshore to the 50-m isobath from St. Augustine, FL (30° N), to offshore Cape Canaveral, FL (28.5° N)

Table 4-23 Large Coastal Shark Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest (continued)

Species	Neonate/Early Juveniles	Late Juveniles/Subadults	Adults
Bull shark (*Carcharhinus leucas*)	In shallow coastal waters, inlets, and estuaries in waters less than 25 m deep from just north of Cape Canaveral, FL, at 29° N to just south of Cape Canaveral, FL, at 28° N	In shallow coastal waters, inlets and estuaries in waters less than 25 m deep from Savannah Beach, GA, at 32°N	Not in AOI
Dusky shark (*Carcharhinus obscurus*)	Shallow coastal waters, inlets, and estuaries to the 25-m isobath from the eastern end of Long Island, NY, at 72° W south to Cape Lookout, NC, at 34.5° N; from Cape Lookout south to West Palm Beach, FL (27.5° N), shallow coastal waters, inlets, and estuaries and offshore areas to the 90-m isobath	Pelagic waters from VA/NC border to Jacksonville, FL, between the 25- and 200-m isobaths	Pelagic waters from VA/NC border south to Ft. Lauderdale, FL, between the 25- and 200-m isobaths
Night shark (*Carcharhinus signatus*)	Insufficient information	Pelagic waters from offshore Assateague Island, MD (38° N), south to offshore of Cape Fear, NC (33.5° N), from the 100- to 2,000-m isobaths	Pelagic waters of the South Atlantic Bight from the 100-m isobath to either the 2,000-m isobath or 100 mi from shore
Sandbar shark (*Carcharhinus plumbeus*)	Shallow coastal waters, inlets, and estuaries in waters less than 25 m deep from Montauk, NY, to Cape Canaveral, FL (27.5° N)	Shallow coastal waters, inlets, and estuaries in waters less than 25 m deep from Montauk, NY, to Cape Canaveral, FL (27.5° N)	Areas on the east coast of the U.S., shallow coastal areas from the coast to the 50-m isobath from Nantucket, MA, south to Miami, FL
Silky shark (*Carcharhinus falciformis*)	Waters off Cape Hatteras, NC, between the 100- and 2,000-m isobaths, plus shallow coastal waters just north and immediately west of Cape Hatteras; waters off St. Augustine, FL, south to off Miami in depths of 25-1,000 m (likely along the west edge of the Gulf Stream)	From offshore Chesapeake Bay, MD, south to offshore of NC/SC border from the 50- to 2,000-m isobaths	Insufficient information
Spinner shark (*Carcharhinus brevipinna*)	Shallow coastal waters less than 25 m deep from Cape Hatteras, NC, to around FL	Shallow coastal waters less than 200 m deep from GA/FL border south to Cape Canaveral, FL (28.5° N)	Shallow coastal waters less than 100 m deep from GA/FL border south to Cape Canaveral, FL (28.5° N)
Lemon shark (*Negaprion brevirostris*)	Shallow coastal waters, inlets, and estuaries out to the 25-m isobath from Savannah, GA, at 32° N, south to Indian River Inlet, FL at 29° N	Shallow coastal waters, inlets, and estuaries offshore to the 25-m isobath, west of 79.75° W from Bull's Bay, SC, to south of Cape Canaveral (West Palm Beach), FL, at 28° N	Shallow coastal waters, inlets, and estuaries offshore to the 25-m isobath from Cumberland Island, GA, at 31° N to St. Augustine, FL, at 31° N

Table 4-23 Large Coastal Shark Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest (continued)

Species	Neonate/Early Juveniles	Late Juveniles/Subadults	Adults
Tiger shark (*Gaelocerdo cuvier*)	Shallow coastal waters to the 200-m isobath from Canaveral, FL (27.5° N) to Montauk, NY	Around the peninsula of FL to the 100-m isobath to the FL/GA border; north to Cape Lookout, NC, from the 25- 100-m isobaths; from Cape Lookout north to just south of the Chesapeake Bay, MD, from inshore to the 100-m isobath	Offshore from Chesapeake Bay, MD, south to Ft. Lauderdale, FL, to the western edge of the Gulf Stream
Sand tiger shark (*Carcharias taurus*)	Shallow coastal waters less than 25 m deep from Barnegat Inlet, NJ, to Cape Canaveral, FL (27.5° N)	Insufficient information	Shallow coastal waters less than 25 m deep from Barnegat Inlet, NJ, to Cape Canaveral, FL (27.5° N)

Abbreviation: AOI = Area of Interest.
Source: USDOC, NMFS, 2009a.

Table 4-24

Highly Migratory Fishes and Life Stages with Essential Fish Habitat Identified within the Area of Interest

Species	Eggs, and Larvae	Juveniles/Subadults	Adults
Dolphin (*Coryphaena hippurus*)	Pelagic waters of the Gulf Stream including the "Point" offshore NC	Pelagic waters of the Gulf Stream including the "Point" offshore NC	Pelagic waters of the Gulf Stream including the "Point" offshore NC
Wahoo (*Acanthocybium solandri*)	Pelagic waters of the Gulf Stream including the "Point" offshore NC	Pelagic waters of the Gulf Stream including the "Point" offshore NC	Pelagic waters of the Gulf Stream including the "Point" offshore NC
Albacore (*Thunnus alalunga*)	Insufficient information	In pelagic waters with temperatures between 15.6 and 19.4 °C, offshore the U.S. east coast in the Mid-Atlantic Bight from the 50-m isobath to the 2,000-m isobath from 71° W (northeast boundary) to 38° N (southwest boundary)	In surface waters with temperatures between 13.5 and 25.2 °C, offshore the U.S. eastern seaboard between the 100- and 2,000-m isobaths from southeastern Georges Bank at 41.25° N, south to 36.5° N, offshore the VA/NC border; also, in the Blake Plateau and Spur region, from 79° W east to the Exclusive Economic Zone (EEZ) boundary and 29° N south to the EEZ boundary
Bigeye tuna (*Thunnus obesus*)	Insufficient information	In surface waters from southeastern Georges Bank to the boundary of the EEZ to Cape Hatteras, NC, at 35° N from the 200-m isobath to the EEZ boundary; also, in the Blake Plateau region off Cape Canaveral, FL, from 29° N south to the EEZ boundary (28.25° N) and from 79° W east to the EEZ boundary (approximately 76.75° W)	In pelagic waters from the surface to a depth of 250 m; from southeastern Georges Bank at the EEZ boundary to offshore Delaware Bay at 38° N, from the 100-m isobath to the EEZ boundary; from offshore Delaware Bay south to Cape Lookout, NC (approximately the region off Cape Canaveral, FL), from 29° N south to the EEZ boundary (28.25° N), and from 79° W east to the EEZ boundary (76.75° W)
Bluefin tuna (*Thunnus thynnus*)	In pelagic and near-coastal surface waters from the NC/SC border at 33.5° N, south to Cape Canaveral, FL, from 15 mi from shore to the 200-m isobath; all waters from offshore Cape Canaveral at 28.25° N	All inshore and pelagic surface waters warmer than 12 °C of the Gulf of Maine and Cape Cod Bay, MA, from Cape Ann, MA (~42.75° N), east to 69.75° W (including waters of the Great South Channel west of 69.75° W), continuing south to and including Nantucket Shoals at 70.5° W to off Cape Hatteras, NC (approximately 35.5° N)	South of 39° N, from the 50-m isobath to the 2,000-m isobath to offshore Cape Lookout, NC, at 34.5°N. In pelagic waters from offshore Daytona Beach, FL (29.5°N) south to Key West (82° W) from the 100-m isobath to the EEZ boundary

Table 4-24 Highly Migratory Fishes and Life Stages with Essential Fish Habitat Identified within the Area of Interest (AOI) (continued)

Species	Eggs, and Larvae	Juveniles/Subadults	Adults
Skipjack tuna (*Katsuwonus pelamis*)	Not in AOI	Not in AOI	In pelagic surface waters from 20-31 °C in the Mid-Atlantic Bight, from the 25-m isobath to the 200-m isobath from 71° W off the coast of Martha's Vineyard, MA, south and west to 35.5° N, offshore Oregon Inlet, NC
Yellowfin tuna (*Thunnus albacares*)	Not in AOI	Pelagic waters from the surface to 100 m deep between 18C and 31 °C from offshore Cape Cod, MA (70° W), southward to Jekyll Island, GA (31° N), between 200 and 2,000 m	Pelagic waters from the surface to 100 m deep between 18 and 31 ºC from offshore Cape Cod, MA (70°W), southward to Jekyll Island, GA (31°N), between 200 and 2,000 m
Swordfish (*Xiphias gladius*)	From Cape Hatteras, NC (35° N) extending south around peninsular FL through the Gulf of Mexico to the U.S./Mexico border from the 200-m isobath to the EEZ	Pelagic waters warmer than 18 °C from the surface to a depth of 500 m from Manasquan Inlet, NJ, at 40° N, east to 73° W, south to GA at 31.5° N	Pelagic waters warmer than 13 °C from the surface to 500 m deep from Cape Cod, MA, to Biscayne Bay, FL
Blue marlin (*Makaira nigricans*)	Offshore FL, identical to adult EFH in that area: from offshore Ponce de Leon Inlet (29.5° N) south to offshore Melbourne, FL, from the 100-m isobath to 50 mi seaward (79.25° W); from offshore Melbourne, FL	Pelagic waters warmer than 24 °C from offshore Delaware Bay (38.5° N) south to Cape Lookout, NC, between the 200- and 2,000-m isobaths	Pelagic waters warmer than 24 °C from offshore Delaware Bay (38.5° N) south to Wilmington, NC (33.5° N), between 200 and 2,000 m isobath
White marlin (*Tetrapterus albidus*)	Insufficient information	Pelagic waters warmer than 22 °C from offshore Georges Bank (41° N) south to Miami, FL (25.25° N), between the 50- and 2,000-m isobaths	Pelagic waters warmer than 22 °C from offshore the northeast U.S. east coast from 33.75°to 39.25° N between the 50- and 2,000-m isobaths
Sailfish (*Istiophorus platypterus*)	Not in AOI	Not in AOI	Pelagic and coastal waters between 21 and 28 °C offshore of the U.S. southeast coast from 5 mi off the coast to 200 m water depths from 36°-34° N, then from 5 mi offshore to 125 mi offshore or the EEZ boundary, whichever is closer to shore
Longbill spearfish (*Tetrapterus pfluegeri*)	Insufficient information	Offshore NC from 36.5°-35° N from the 200-m isobath to the EEZ boundary	Offshore of NC from 37°-31° N, including the Charleston Bump

Sources: SAFMC, 2003; USDOC, NMFS, 2009a.

Table 4-25

Pelagic Shark Species and Life Stages with Essential Fish Habitat Identified within the Area of Interest

Species	Neonate/Early Juveniles	Late Juveniles/Subadults	Adults
Longfin mako (*Isurus paucus*)	Pelagic waters of the northeast U.S. coast from the 100-m isobath out to the Exclusive Economic Zone (EEZ) boundary from Georges Bank to Cape Hatteras (35° N)	Pelagic waters of northeast U.S. coast from the 100-m isobath out to the EEZ boundary from Georges Bank to Cape Hatteras (35° N)	Pelagic waters of northeast U.S. coast from the 100-m isobath out to the EEZ boundary from Georges Bank to Cape Hatteras (35° N)
Shortfin mako (*Isurus oxyrinchus*)	Between the 50- and 2,000-m isobaths from Cape Lookout, NC (35° N) north to just east of Georges Bank (42° N and 66° W) to the EEZ boundary; and between the 25- and 50-m isobaths from the VA/NC border to southwest of Georges Bank	Between the 25- and 2,000-m isobaths from offshore Onslow Bay, NC, north to Cape Cod, MA, and extending west between 38° and 41.5° N to the EEZ boundary	Between the 25- and 2,000-m isobaths from offshore Cape Lookout, NC, north to Long Island, NY; and extending west between 38.5° N and 41.5° N to the EEZ boundary
Blue shark (*Prionace galauca*)	Not in AOI	Pelagic waters from offshore Cape Hatteras, NC (35° N), north to the EEZ boundary off Georges Bank, from the 25-m isobath to the EEZ	Pelagic waters from offshore Cape Hatteras, NC (35° N), north to the EEZ offshore off Georges Bank from the 25-m isobath to the EEZ
Oceanic whitetip shark (*Carcharhinus longimanus*)	In the vicinity of the Charleston Bump, from the 200-m isobath to the 2,000-m isobath, between 32.5° and 31° N	Offshore the southeast U.S. coast from 32°-26° N, from the 200-m isobath to the EEZ boundary, or 75° W, whichever is nearer	Pelagic waters offshore the U.S. east coast from the 200-m isobath out to the EEZ boundary, from 36°-30° N
Thresher shark (*Alopias vulpinus*)	Offshore Long Island, NY, and southern New England in the northeastern U.S., in pelagic waters deeper than 50 m, between 70° and 73.5° W, south to 40° N	Offshore Long Island, NY, and southern New England in the northeastern U.S., in pelagic waters deeper than 50 m, between 70° and 73.5° W, south to 40° N	Offshore Long Island, NY, and southern New England in the northeastern U.S., in pelagic waters deeper than 50 m, between 70° and 73.5° W, south to 40° N
Bigeye thresher shark (*Alopias superciliosus*)	Insufficient information	Offshore NC from 36.5°-34° N, between the 200- and 2,000-m isobaths	Offshore NC from 35.5°-35° N, between the 200- and 2,000-m isobaths

Source: USDOC, NMFS (2009a).

Table 4-26

Summary of Marine Fish Hearing Sensitivity

Family	Common Name of Taxa	Highest Frequency Detected (Hz)[1]	Hearing Category[2]	Reference	Notes
Asceripensidae	Sturgeon	800	2	Lovell et al., 2005; Meyer et al., 2010	Several different species tested. Relatively poor sensitivity
Anguillidae	Eels	300	2	Jerkø et al., 1989	Poor sensitivity
Batrachoididae	Toadfishes	400	2	Fish and Offutt, 1972; Vasconcelos and Ladich, 2008	--
Clupeidae	Shad, menhden	>120,000	4	Mann et al., 1997, 2001	Ultrasound detecting, but sensitivity relatively poor
	Anchovy, sardines, herrings	4,000	4	Mann et al., 2001	Not detect ultrasound, and relativley poor sensitivitiy
Chondrichthyes [Class]	Rays, sharks, skates	1,000	1	Casper et al., 2003	Low frequency hearing, not very sensitive to sound
Gadidae	Atlantic cod, haddock, pollack, hake	500	2	Chapman and Hawkins, 1973; Sand and Karlsen, 1986	Probably detect infrasound (below 40 Hz). Best hearing 100-300 Hz.
	Grenadiers	--	3?	Deng et al., 2011	Deep sea, highly specialized ear structures suggesting good hearing, but no measures of hearing
Gobidae	Gobies	400	1 or 2	Lu and Xu, 2009	--
Labridae	Wrasses	1,300	2	Tavolga and Wodinksy, 1963	--
Lutjanidae	Snappers	1,000	2	Tavolga and Wodinksy, 1963	--
Malacanthidae	Tilefish		2	--	No data
Moronidae	Striped bass	1,000	2	Ramcharitar unpublished	--
Pomacentridae	Damselfish	1,500 – 2,000	2	Myrberg and Spires, 1980	--
Pomadasyidae	Grunts	1,000	2	Tavolga and Wodinsky, 1963	--
Polyprionidae	Wreckfish	--	2	--	No data
Sciaenidae	Drums, weakfish, croakers	1,000	2	Ramcharitar et al., 2006	Hear poorly
	Silver perch	3,000	3	Ramcharitar et al., 2004, 2006	--
Serranidae	Groupers	--	2	--	No data
Scombridae	Yellowfin tuna	1,100	2	Iversen, 1967	With swim bladder
	Tuna	1,000	1	Iversen, 1969	Without swim bladder
	Bluefin tuna	1,000	2	Song et al., 2006	Based only on ear anatomy

Notes: See text for important caveats.
For taxa shaded gray, hearing capabilities can only be surmised from morphological data.

[1] Lower frequency of hearing is not given since, in most studies, the lower end of the hearing bandwidth is more a function of the equipment used than determination of actual lowest hearing threshold. In all cases, fish hear below 100 Hz, and there are some species studied, such as Atlantic cod, Atlantic salmon, and plaice, where fish have been shown to detect infrasound, or sounds below 40 Hz.

[2] See **Chapter 4.2.5.1.4** for an explanation.

Source: **Appendix J** (data compiled from Fay [1988] and Nedwell et al. [2004]). Scientific names marked with an asterisk have a different name in the literature (updated names are from www.fishbase.org).

Table 4-27

Commercial Landings within the Area of Interest during 2006-2009

State	Commercial Landings (metric tons)			
	2006	2007	2008	2009
Virginia	193,339.00	220,110.70	189,383.10	193,346.80
North Carolina	31,182.10	28,541.60	32,300.40	31,281.10
Maryland	23,235.90	28,038.30	28,889.80	30,986.60
Florida (East Coast)	12,256.60	11,428.90	11,932.50	12,474.30
South Carolina	4,804.10	4,223.10	4,572.40	4,252.70
Georgia	3,762.00	3,586.90	4,057.20	3,369.50
Delaware	1,981.60	2,213.80	1,982.50	2,272.60
Total	270,561.30	298,143.30	273,117.90	277,983.60

Source: USDOC, NMFS, 2011k.

Table 4-28

Primary Commercial Species Landed with the Most Economic Value for Each State within the Area of Interest during 2006-2009

State	Commercial Species
Delaware	Blue crab, Eastern oyster, and striped bass. Other important commercial species included snails (conch), knobbed whelk, American eel, and black sea bass.
Maryland	Blue crab, striped bass, and clams. Other important commercial species were sea scallops, oysters, and softshell blue crab.
Virginia	Sea scallops, menhaden, and blue crab. Other important commercial species were quahog clam, Atlantic croaker, and striped bass.
North Carolina	Blue crab, white shrimp, and summer flounder. Other important commercial species were brown shrimp, Atlantic croaker, and quahog clam.
South Carolina	White shrimp, blue crab, and Eastern oyster. Other important commercial species were gag grouper, scamp, and vermilion snapper.
Georgia	White shrimp, blue crab, shrimp (Dendrobranchiata), and finfish (unclassified). Other economically important species were quahog clam, brown shrimp, and shellfish (unclassified).
Florida (East Coast)	White shrimp, king mackerel, blue crab, and rock shrimp. Other important commercial species were spiny lobster, swordfish, and Spanish mackerel.

Source: USDOC, NMFS, 2011k.

Table 4-29

Commercial Fishing Landings and Value for Each State within the Area of Interest during 2009

State	Distance from Shore					
	Landings 0-4.8 km		Landings 4.8-322 km		Landings >322 km	
	Thousands of kg	Thousands of Dollars	Thousands of kg	Thousands of Dollars	Thousands of kg	Thousands of Dollars
Delaware	1,864	6,106	118	445	--	--
Maryland	20,614	55,633	4,735	11,719	--	--
Virginia	35,390	63,015	153,962	91,360	--	--
North Carolina	23,066	53,908	8,143	25,560	--	--
South Carolina	2,191	6,599	2,090	10,317	--	--
Georgia	2,209	6,556	1,131	5,110	--	--
Florida (East Coast)	4,364	13,831	8,020	26,784	--	--

Source: USDOC, NMFS, 2011k (The NMFS indicates that these are preliminary annual landings and are subject to change; the numbers differ somewhat from the annual State totals reported in **Table 4-23**).

Table 4-30

Seasonal and/or Area Closures to Commercial Fishing in Federal Waters Offshore the Mid-Atlantic and South Atlantic States

Closed or Restricted Area	Location	Season	Gear Restrictions or Protection Measures	Reason/Purpose
Deepwater MPAs: Snowy Grouper Wreck; Northern South Carolina; Edisto; Charleston Deep Artificial Reef; Georgia; and North Florida	Cape Fear, NC to Jacksonville, FL (two others offshore south FL are outside the Area of Interest)	Year-round	No bottom longline gear	Protect snapper-grouper complex species
Proposed deepwater *Lophelia* coral HAPCs: Cape Lookout, Cape Fear, Blake Ridge Diapir, and Stetson-Miami Terrace	South Atlantic Bight	Year-round	No anchors or chains; bottom longline, trawl (mid-water and bottom), dredge, pot, or trap gear prohibited	Protect deepwater corals
Oculina Bank HAPC and Experimental Closed Area	Offshore FL	Year-round	In HAPC, no bottom longline, bottom trawl, dredge, or trap/pot gear; in experimental closed area, no fishing for snapper-grouper species	Protect deepwater corals; protect snapper-grouper complex species
SMZs (51 sites)	Offshore SC, GA, and FL	Year-round	Restrictions vary; examples include prohibitions on powerhead, bottom longline, fish traps or pots, and hydraulic or electric reels	Protect snapper-grouper complex species
Allowable octocoral closed area	Atlantic EEZ north of 28°35.1’ N	Year-round	No harvest or possession of octocoral	Protect deepwater corals
Pelagic *Sargassum* area	All EEZ waters south of 34° N and waters within 100 nmi of the coast from 34° N to the NC/SC border	July 1-October 31	All *Sargassum* harvest prohibited in the closed area; elsewhere prohibited July-October, with catch limits and restrictions on mesh and frame size of nets	Protect *Sargassum* as habitat for sea turtles and essential fish habitat for snappers, groupers, and coastal migratory pelagic fishes
Longline closed areas	All waters south of 27°10’ N, and waters north of 27°10’ N where depth is <91 m (300 ft)	Year-round	No longline gear for snapper-grouper	Protect snapper-grouper complex species
Charleston Bump Area	Offshore NC and SC and Jekyll Island, GA	February 1-April 30	No pelagic or bottom longline gear	Protect juvenile swordfish and reduce bycatch
East Florida Coast Area	Offshore Jekyll Island, GA; FL east coast; Key West, FL	Year-round	No pelagic or bottom longline gear	Protect juvenile swordfish and billfishes

Table 4-30 Seasonal and/or Area Closures to Commercial Fishing in Federal Waters Offshore the Mid-Atlantic and South Atlantic States (continued)

Closed or Restricted Area	Location	Season	Gear Restrictions or Protection Measures	Reason/Purpose
Mid-Atlantic Shark Area	Offshore Oregon Inlet, NC and Cape Fear, NC	January 1-July 31	No bottom longline and shark gillnet gear	Protect juvenile sharks and prohibited sharks
Carl N. Schuster Jr. Horseshoe Crab Reserve	Offshore DE, MD, and VA	Year-round	No trawl nets, pound nets, gillnets, or fyke nets	Protect horseshoe crab spawning population and maintain crab eggs for migratory shorebirds
South Atlantic shrimp cold weather closure	Offshore NC, SC, GA, and FL	In winter during severe cold weather, when adjacent South Atlantic states close all or part of their waters to shrimp trawling	No trawling for brown, pink, or white shrimps	Protect shrimp populations depleted by severe cold weather
Golden crab trap closed areas	Southeastern U.S. (divided into Northern, Middle, and Southern zones)	Year-round	Vessel size restrictions; permits limit a vessel to a particular zone	Protect golden crab from overfishing
Atlantic Large Whale Take Reduction Plan	Entire U.S. east coast (divided into several subareas)	September 1-May 31 from 32° N to northern edge of Area of Interest; November 15-April 15 from 29°-32° N; December 1-March 31 from 29° N to southern edge of Area of Interest	Restrictions on trap/pot and gillnet use	Protect large whales from entanglement

Abbreviations: EEZ = Economic Exclusion Zone; HAPCs = Habitat Areas of Particular Concern; MPA = Marine Protected Areas; SMZs = Special Management Zones.
Adapted from USDOC, NMFS, 2010d; 50 CFR 622.35.

Table 4-31

Partial List of Recreational Fishing Tournaments within the Area of Interest

State	Fishing Tournament	Tournament Dates
Delaware	Delaware Sport Fishing Tournament	1 January–31 December
	Annual Delaware Black Drum Tournament	22 April–1 June
	Annual Summer Flounder Tournament	1 June –1 September
	Annual Rocktober Fishing Tournament and Festival	19-21 October
	Turkey Week Striper Tournament	20-26 November
Maryland	Annual Opening Day Rockfish Tournament	16 April
	Flounder Frenzy	18-19 May
	Mako Mania Tournament	3-5 June
	World's Largest Fishing Tournament: Maryland Fishing Challenge (1 Year Challenge)	7 September– 6 September
	Harbor Tackle Annual Red Drum Tournament	23-25 September
	Annual Surf Fishing Tournament	20-22 October
	Harbor Tackle Annual Assateague Striper Tournament	19-20 November
Virginia	Virginia Saltwater Fishing Tournament	1 January −31 December
	Virginia Beach Rockfish Frostbite Challenge	15-18 January
	Triple Threat Tournament	14 April–30 August
	Croaker Fishing Tournament	4 June
	Virginia Beach Tuna Tournament	11-14 July
	The Annual Colonial Beach Rockfish Tournament	31 October – 2 November
North Carolina	Annual Hatteras Village Offshore Open	12-15 May
	Guiseppe Giaimo Scholarship Tournament	17 May
	Big Rock Blue Marlin	10-18 June
	Cape Fear Blue Marlin Fishing Tournament	1-4 July
	Bay Creek Classic	September 26
	U.S. Open King Mackerel Tournament	30 September–2 October
	The Wahoo Challenge	13-16 October
	Annual Davis Island Fishing Foundation Surf Fishing Tournament	14-16 October
	Manteo Rotary Rockfish Rodeo	3-4 December
South Carolina	Charleston Trident Fishing Tournament	1 January
	Bohicket Marina Invitational Billfish Tournament	11-14 May
	Annual Spring King Mackerel Tournament	11-12 June
	Carolina Billfish Classic	22-25 May
	Annual Fall King Mackerel Tournament	16-18 September
	Charleston Trident Fishing Tournament	1 December
Georgia	Annual King Mackerel Tournament	13-16 May
	Blue Water Tournament	17-20 June
	Kingfish/General Tournament	7 August
	General Tournament	18 September
	General Tournament	16 October
Florida	Jacksonville Offshore Sport Fishing Club's Tournament	26 February
	IFA Redfish Tour	5-6 March
	The Halifax Sport Fishing Club's Annual Offshore Challenge	8-10 April
	Metro PCS Saltwater Classic	6-7 May
	Invitational Bluewater Tournament	16-21 May
	Fountain Mercury Kingbuster	10-13 June
	AT&T Greater Jacksonville Kingfish Tournament and Festival	22-24 July
	El Pescado Billfish Tournament	30 September–2 October
	The Halifax Sport Fishing Club's Surf Fishing Tournament	13 November

Sources: Caught the Skunk.com, 2011; Florida Sportsman, 2011; World Fishing Network, 2011.

Table 4-32

Selected Parks, Seashores, Recreation Areas, and Wildlife Refuges
along the Mid-Atlantic and South Atlantic Coasts

State	Recreational Area
Delaware	Cape Henlopen State Park Delaware Seashore State Park Fenwick Island State Park
Maryland	Assateague State Park Assateague Island National Seashore
Virginia	Assateague Island National Seashore Chincoteague National Wildlife Refuge Fisherman Island National Wildlife Refuge Seashore State Park False Cape State Park
North Carolina	Wright Brothers National Memorial Park Cape Hatteras National Seashore Pea Island National Wildlife Refuge Cape Lookout National Seashore Fort Macon State Park Theodore Roosevelt Natural Area Hammocks Beach State Park Masonboro Island Coastal Reserve Freeman Park Fort Fisher State Recreation Area
South Carolina	Myrtle Beach State Park Huntingdon Beach State Park Baruch-North Island Preserve Edisto Beach State Park Hunting Island State Park Cape Roman National Wildlife Refuge
Georgia	Wassaw National Wildlife Refuge Blackbeard Island National Wildlife Refuge Wolf Island National Wildlife Refuge Wassaw National Wildlife Refuge Jekyll Island State Park Cumberland Island National Seashore
Florida	Fort Clinch State Park Amelia Island State Park Little Talbot Island State Park Anastasia State Park Washington Oaks Gardens State Park Gamble Rogers Memorial State Recreation Area North Peninsula State Park Canaveral National Seashore Jetty Park

Table 4-33

Types of Recreational Activities by Location in the Area of Interest
and along the Mid-Atlantic and South Atlantic Coasts

Location	Recreational Activities
Offshore waters (depths >30 m)	Fishing Diving (very limited – e.g., Monitor National Marine Sanctuary) Wildlife viewing (e.g., whale watching, pelagic birdwatching)
Nearshore waters (depths <30 m)	Fishing Boating Diving (artificial reefs and wrecks; Gray's Reef National Marine Sanctuary) Wildlife viewing (e.g., whale watching, pelagic birdwatching)
Beaches	Swimming, snorkeling, surfing, etc. Sunbathing Fishing Boating Wildlife viewing Camping (e.g., state parks and national seashores)
Lagoons and embayments	Swimming Fishing Boating Wildlife viewing Camping
Other coastal areas	Sightseeing Golf Bicycling Hiking Hunting

Table 4-34

Economic Contribution of Marine-Based Tourism and Recreation to State Economies in 2004

State	Employment	Wages
Marine Based Tourism and Recreation Sectors[1]		
Delaware	12,997	$188,532,229
Maryland	35,014	$566,771,344
Virginia	46,827	$669,121,385
North Carolina	31,933	$387,164,508
South Carolina	38,301	$614,585,607
Georgia	19,739	$299,828,309
Florida	262,643	$4,668,917,536
Share of State Economy[2]		
Delaware	3.16%	1.08%
Maryland	1.42%	0.54%
Virginia	1.34%	0.47%
North Carolina	0.85%	0.29%
South Carolina	2.14%	1.08%
Georgia	0.51%	0.21%
Florida	3.52%	1.78%

[1] National Ocean Economics Program, 2004.

[2] Total employment and wages for States from the U.S. Department of Labor, Bureau of Labor Statistics, 2004.

Table 4-35

Economic Contribution of Leisure and Hospitality to Coastal Economies[1] in 2008

State	Employment	Wages
Leisure and Hospitality		
Delaware	40,869	$758,460,245
Maryland	125,220	$2,465,284,222
Virginia	116,989	$2,038,305,323
North Carolina	43,518	$600,529,156
South Carolina	83,648	$1,454,839,518
Georgia	32,196	$531,105,248
Florida	661,930	$14,042,229,011
Share of Coastal County Economy		
Delaware	9.90%	3.86%
Maryland	9.98%	4.17%
Virginia	10.56%	3.81%
North Carolina	14.58%	6.31%
South Carolina	19.31%	9.83%
Georgia	14.92%	6.66%
Florida	11.81%	6.10%

[1] Economies of shoreline adjacent counties.

Source: National Ocean Economics Program, 2008.

Table 4-36

Summary of Federal, Partnership, Federal Fishery Management, and State Designated Marine Protected Areas Listed in the National System of Marine Protected Areas

Site	State	Managing Agency	Type of Site[1]	Protection Focus[2]	Primary Conservation Focus	Fishing Restrictions[3]	Area (km^2)
NEARSHORE/OFFSHORE SITES							
National Marine Sanctuaries							
NOAA's Monitor National Marine Sanctuary	NC	NMSP	NMS	Focal Resource	Cultural Heritage	A	2.21
Gray's Reef National Marine Sanctuary	GA	NMSP	NMS	Ecosystem	Natural Heritage	A	57.42
Deepwater Marine Protected Areas (MPAs)							
Snowy Grouper Wreck MPA	NC	NMFS	MPA	Focal Resource	Sustainable Production	H	501.30
Northern South Carolina MPA	SC	NMFS	MPA	Focal Resource	Sustainable Production	H	177.89
Edisto MPA	SC	NMFS	MPA	Focal Resource	Sustainable Production	H	200.08
Charleston Deep Reef MPA	SC	NMFS	MPA	Focal Resource	Sustainable Production	H	69.54
Georgia MPA	GA	NMFS	MPA	Focal Resource	Sustainable Production	H	264.91
North Florida MPA	FL	NMFS	MPA	Focal Resource	Sustainable Production	H	356.62
Other Federal Fishery Management Areas							
Waters off New Jersey Closure	DE	NMFS	FFMZ	Focal Resource	Natural Heritage	H	34,826.90
Elephant Trunk Sea Scallop Closed Area	DE/MD	NMFS	FFMZ	Focal Resource	Sustainable Production	H	5,387.01
Carl N. Shuster, Jr. Horseshoe Crab Reserve	DE/MD	NMFS	FFMZ	Focal Resource	Sustainable Production	C	4,135.64
Other Northeast Gillnet Waters Area	DE/MD/VA	NMFS	FFMZ	Focal Resource	Natural Heritage	H	280,599.00
Offshore Trap/Pot Waters	DE/MD/VA/NC	NMFS	FFMZ	Focal Resource	Natural Heritage	H	336,101.00
Southern Nearshore Trap/Pot Waters	DE/MD/VA/NC	NMFS	FFMZ	Focal Resource	Natural Heritage	H	74,209.40
Mid-Atlantic Coastal Waters Area	DE/MD/VA/NC	NMFS	FFMZ	Focal Resource	Natural Heritage	H	228,708.00
Southern Mid-Atlantic Waters Closure Area	DE/MD/VA/NC	NMFS	FFMZ	Focal Resource	Natural Heritage	H	171,705.00
Mid-Atlantic Shark Area	NC	NMFS	FFMZ	Focal Resource	Sustainable Production	H	18,748.50
Flynet Closure	NC	NMFS	FFMZ	Focal Resource	Sustainable Production	C	15,689.70
Charleston Bump Closed Area	NC/SC/GA	NMFS	FFMZ	Focal Resource	Sustainable Production	H	125,760.00
Southeast U.S. Restricted Area	GA/FL	NMFS	FFMZ	Focal Resource	Natural Heritage	H	64,498.40
Oculina Bank Habitat Area of Particular Concern	FL	NMFS	HAPC	Ecosystem	Sustainable Production	C	1,054.18
East Florida Coast Closed Area	FL	NMFS	FFMZ	Focal Resource	Sustainable Production	H	103,669.00

Table 4-36 Summary of Federal, Partnership, Federal Fishery Management, and State Designated Marine Protected Areas Listed in the National System of Marine Protected Areas (continued)

Site	State	Managing Agency	Type of Site[1]	Protection Focus[2]	Primary Conservation Focus	Fishing Restrictions[3]	Area (km^2)
COASTAL SITES							
National Park System							
Assateague Island National Seashore	VA	NPS	NS	Ecosystem	Natural Heritage	C	197.54
Cape Hatteras National Seashore	NC	NPS	NS	Ecosystem	Natural Heritage	C	126.10
Cape Lookout National Seashore	NC	NPS	NS	Ecosystem	Natural Heritage	C	113.35
Cumberland Island National Seashore	GA	NPS	NS	Ecosystem	Natural Heritage	C	147.90
Canaveral National Seashore	FL	NPS	NS	Ecosystem	Natural Heritage	C	237.43
National Wildlife Refuges							
Chincoteague National Wildlife Refuge	VA	USFWS	NWR	Ecosystem	Natural Heritage	D	73.52
Fisherman Island National Wildlife Refuge	VA	USFWS	NWR	Ecosystem	Natural Heritage	E	8.83
Back Bay National Wildlife Refuge	VA	USFWS	NWR	Ecosystem	Natural Heritage	D	65.90
Currituck National Wildlife Refuge	NC	USFWS	NWR	Ecosystem	Natural Heritage	E	81.04
Pea Island National Wildlife Refuge	NC	USFWS	NWR	Ecosystem	Natural Heritage	D	18.85
Cape Roman National Wildlife Refuge	SC	USFWS	NWR	Ecosystem	Natural Heritage	B	268.17
Blackbeard Island National Wildlife Refuge	GA	USFWS	NWR	Ecosystem	Natural Heritage	A	32.73
Wassaw National Wildlife Refuge	GA	USFWS	NWR	Ecosystem	Natural Heritage	B	40.68
Merritt Island National Wildlife Refuge	FL	USFWS	NWR	Focal Resource	Natural Heritage	C	562.10
Archie Carr National Wildlife Refuge	FL	USFWS	NWR	Focal Resource	Natural Heritage	F	3.64
National Estuarine Research Reserves							
Guana Tolomato Matanzas National Estuarine Research Reserve	FL	FDEP/ NOAA	NERR	Ecosystem	Natural Heritage	F	313.35
State Designated MPAs							
Cape Henlopen State Park	DE	DDNREC	SP	Ecosystem	Natural Heritage	G	21.76
Blue Crab Sanctuary	VA	VMRC	Sanctuary	Focal Resource	Sustainable Production	A	2,448.33
Wreck Island Natural Area Preserve	VA	VDCR	NA	Ecosystem	Natural Heritage	D	2.90
Sea Turtle Sanctuary	NC	NCDENR	Sanctuary	Focal Resource	Natural Heritage	C	24.15
Oregon Inlet Crab Spawning Sanctuary	NC	NCDENR	Sanctuary	Focal Resource	Natural Heritage	C	24.79
Hatteras Inlet Crab Spawning Sanctuary	NC	NCDENR	Sanctuary	Focal Resource	Natural Heritage	C	18.58
Ocracoke Inlet Crab Spawning Sanctuary	NC	NCDENR	Sanctuary	Focal Resource	Natural Heritage	C	38.45
Drum Inlet Crab Spawning Sanctuary	NC	NCDENR	Sanctuary	Focal Resource	Natural Heritage	C	20.99
Bardens Inlet Crab Spawning Sanctuary	NC	NCDENR	Sanctuary	Focal Resource	Natural Heritage	C	20.11
Fort Macon State Park	NC	NCDENR	SP	Ecosystem	Cultural Heritage	F	2.18

Table 4-36 Summary of Federal, Partnership, Federal Fishery Management, and State Designated Marine Protected Areas Listed in the National System of Marine Protected Areas (continued)

Site	State	Managing Agency	Type of Site1	Protection Focus2	Primary Conservation Focus	Fishing Restrictions 3	Area (km2)
Fort Macon State Park Dedicated Nature Preserve	NC	NCDENR	DNP	Ecosystem	Natural Heritage	B	1.94
Masonboro Island Estuarine Reserve Dedicated Nature Preserve	NC	NCDENR	DNP	Ecosystem	Natural Heritage	B	22.37
Currituck Banks Estuarine Reserve Dedicated Nature Preserve	NC	NCDENR	DNP	Ecosystem	Natural Heritage	A	1.40
Currituck Outer Banks Preserve Dedicated Nature Preserve	NC	NCDENR	DNP	Ecosystem	Natural Heritage	A	0.26
Zekes Island Estuarine Reserve Dedicated Nature Preserve	NC	NCDENR	DNP	Ecosystem	Natural Heritage	B	9.47
Neuse-Southeast Pamlico Sound Area Outstanding Resource Water	NC	NCDENR	ORW	Ecosystem	Natural Heritage	B	174.43
Core Sound, Neuse River Basin Outstanding Resource Water	NC	NCDENR	ORW	Ecosystem	Natural Heritage	B	106.67
Topsail Sound and Middle Sound Area Outstanding Resource Water	NC	NCDENR	ORW	Ecosystem	Natural Heritage	B	21.47
Pamlico Sound Mechanical Harvesting of Oysters Prohibited Area	NC	NCDENR	PA	Focal Resource	Natural Heritage	C	692.74
Trawl Nets Prohibited Areas	NC	NCDENR	PAs	Focal Resource	Natural Heritage	C	819.56
Core Sound Mechanical Harvesting of Oysters Prohibited Area	NC	NCDENR	PA	Focal Resource	Natural Heritage	C	265.28
South of Onslow County Mechanical Harvesting of Oysters Prohibited Area	NC	NCDENR	PA	Focal Resource	Natural Heritage	C	143.26
Queen Anne's Revenge	NC	NCDCR	Historic Site	Focal Resource	Cultural Heritage	D	0.24
USS Huron Historic Shipwreck Preserve	NC	NCDCR	Historic Site	Focal Resource	Cultural Heritage	D	0.03
False Cape State Park	SC	SCDCR	SP	Ecosystem	Natural Heritage	A	15.68
Tom Yawkee Wildlife Center	SC	SCDNR	Wildlife Center	Focal Resource	Natural Heritage	B	80.26
Pelican Spit Natural Area	GA	GDNR	NA	Ecosystem	Natural Heritage	A	0.58
St. Catherines Bar Natural Area	GA	GDNR	NA	Ecosystem	Natural Heritage	E	1.15
Egg Island Bar Natural Area	GA	GDNR	NA	Ecosystem	Natural Heritage	E	0.92
Ossabaw Island Wildlife Management Area	GA	GDNR	WMA	Ecosystem	Natural Heritage	A	114.46

Table 4-36 Summary of Federal, Partnership, Federal Fishery Management, and State Designated Marine Protected Areas Listed in the National System of Marine Protected Areas (continued)

Big Talbot Island State Park	FL	FDEP	SP	Ecosystem	Natural Heritage	C	6.95
Anastasia State Park	FL	FDEP	SP	Ecosystem	Natural Heritage	C	6.53
Fort Clinch State Park Aquatic Preserve	FL	FDEP	AP	Ecosystem	Cultural Heritage	B	30.58
Guana River Marsh Aquatic Preserve	FL	FDEP	AP	Ecosystem	Natural Heritage	B	166.18
Nassau River - St. Johns River Marshes Aquatic Preserve	FL	FDEP	AP	Ecosystem	Natural Heritage	B	286.16
Anastasia State Park Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	6.80
Big Talbot Island State Park Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	7.29
Canaveral National Seashore Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	238.66
Fort Clinch State Park Aquatic Preserve Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	30.58
Guana River Marsh Aquatic Preserve Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	120.13
Little Talbot Island State Park Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	7.74
Merritt Island National Wildlife Refuge Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	490.90
Nassau River-St. Johns River Marshes Aquatic Preserve Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	286.03
Timucuan Ecological and Historic Preserve Outstanding Florida Water	FL	FDEP	OFW	Ecosystem	Natural Heritage	B	148.76

Abbreviations: DDNREC = Delaware Department of Natural Resources and Environmental Control; FDEP = Florida Department of Environmental Protection; FFMZ = Federal Fishery Management Zone; FT/ESPA = Federal Threatened/Endangered Species Protected Area; GDNR = Georgia Department of Natural Resources; NCDCR = North Carolina Department of Cultural Resources; NCDENR = North Carolina Department of Environment and Natural Resources; NERR = National Estuarine Research Reserve; NM = National Monument; NMFS = National Marine Fisheries Service; NMS = National Marine Sanctuary; NOAA = National Oceanic and Atmospheric Administration; NP = National Park; NPS = National Park Service; NS = National Seashore; NWR = National Wildlife Refuge; SCDNR = South Carolina Department of Natural Resources; SFWS = U.S. Fish and Wildlife Service; USDOI = U.S. Department of the Interior; VDCR = Virginia Department of Conservation and Recreation; VMRC =Virginia Marine Resource Commission.

[1] Type of Site: AP = Aquatic Preserve; DNP = Dedicated Nature Preserve; FFMZ = Federal Fishery Management Areas; MPA = Marine Protected Area; NA = Natural Area; NERR = National Estuarine Research Reserve; NMS = National Marine Sanctuary; NS = National Seashore; NWR = National Wildlife Refuge; OFW = Outstanding Florida Water; ORW = Outstanding Resource Water; PA = Prohibited Areas; SP = State Park; WMA = Wildlife Management Area.

Table 4-36 Summary of Federal, Partnership, Federal Fishery Management, and State Designated Marine Protected Areas Listed in the National System of Marine Protected Areas (continued)

[2] Protection Focus:

Ecosystem: MPAs or zones whose legal authorities and management measures are intended to protect all of the components and processes of the ecosystem within its boundaries. Examples: Ecosystem-scale MPAs include most marine sanctuaries, national parks and national monuments.

Focal Resource: MPAs or zones whose legal authorities and management measures specifically target a particular habitat, species complex, or single resource (either natural or cultural). Examples: Focal-resource MPAs include many fisheries and cultural resource sites, including some national wildlife refuges and marine sanctuaries.

[3] Fishing Restrictions: A = Restrictions Unknown; B = No Site Restrictions; C = Commercial and Recreational Fishing Restricted; D = Commercial Fishing Prohibited and Recreational Fishing Restricted; E = Commercial and Recreational Fishing Prohibited; F = Commercial Fishing Prohibited; G = Recreational Fishing Restricted; H = Commercial Fishing Restricted.

Source: USDOC, NOAA, National Marine Protected Areas Center (http://www.mpa.gov).

Table 4-37

Population of the Metropolitan Statistical Areas Associated with Five Atlantic Coast Ports in 2000 and 2010

Port	Metropolitan Statistical Area	Population 2000	Population 2010	Growth (%)
Virginia	Virginia Beach-Norfolk-Newport News	1,569,541	1,671,683	6.51
Wilmington	Wilmington	233,450	362,315	55.20
Charleston	Charleston-North Charleston-Summerville	549,033	664,607	21.05
Savannah	Savannah	293,000	347,611	18.64
Jacksonville	Jacksonville	1,100,491	1,345,596	22.27

Source: U.S. Census Bureau, 2011.

Table 4-38

Gross Domestic Product (GDP) of the Metropolitan Statistical Areas Associated with Five Atlantic Coast Ports in 2009

Port	Metropolitan Statistical Area	GDP ($ millions)	GDP per Capita ($)[1]	Real GDP per Capita Growth, 2001-2009[2] (%)
Virginia	Virginia Beach-Norfolk-Newport News	79,600	47,617	12.02
Wilmington	Wilmington	13,170	36,350	-13.40
Charleston	Charleston-North Charleston-Summerville	26,691	40,161	2.64
Savannah	Savannah	12,921	37,171	-1.65
Jacksonville	Jacksonville	58,303	43,329	1.44

[1] Calculated by dividing GDP by the population shown in **Table 4-33**.
[2] In 2005 dollars.
Source: USDOC, Bureau of Economic Analysis, 2011.

Table 4-39

Labor Force and Unemployment in the Metropolitan Statistical Areas Associated with Five Atlantic Coast Ports in January 2011

Port	Metropolitan Statistical Area	Labor Force (thousands)	Unemployment Rate (%)	Unemployed (thousands)
Virginia	Virginia Beach-Norfolk-Newport News	813.5	7.6	61.8
Wilmington	Wilmington	172.3	10.6	18.3
Charleston	Charleston-North Charleston-Summerville	317.9	8.3	26.3
Savannah	Savannah	174.7	9.2	16.1
Jacksonville	Jacksonville	679.9	11.5	78.4

Source: U.S. Department of Labor, Bureau of Labor Statistics, 2011.

Table 4-40

Minority Presence in Metropolitan Statistical Areas Associated with Five Atlantic Coast Ports in 2010, Compared with State and National Averages

Location	Total Population	Percent of Total Population								
		White	Black or African American	Alaska Native or American Indian	Asian	Native Hawaiian and Other Pacific Islander	Some Other Race Alone	Two or More Races	Hispanic or Latino[1]	Total Minority Population[2]
United States	308,745,538	72.41	12.61	0.95	4.75	0.17	6.19	2.92	16.35	36.25
Virginia (statewide)	8,001,024	68.58	19.39	0.37	5.50	0.07	3.18	2.92	7.90	35.18
Virginia Beach-Norfolk-Newport News, VA-NC MSA	1,671,683	59.65	31.25	0.41	3.47	0.12	1.67	3.43	5.36	42.82
North Carolina (statewide)	9,535,483	68.47	21.48	1.28	2.19	0.07	4.34	2.16	8.39	34.73
Wilmington, NC MSA	362,315	79.83	14.21	0.57	0.88	0.05	2.55	1.91	5.37	22.44
South Carolina (statewide)	4,625,364	66.16	27.90	0.42	1.28	0.06	2.45	1.73	5.10	35.95
Charleston-North Charleston-Summerville, SC MSA	664,607	65.57	27.69	0.46	1.63	0.09	2.47	2.09	5.37	36.77
Georgia (statewide)	9,687,653	59.74	30.46	0.33	3.25	0.07	4.01	2.14	8.81	44.12
Savannah, GA MSA	347,611	59.68	33.87	0.27	2.08	0.09	1.88	2.14	4.95	42.68
Florida (statewide)	18,801,310	75.04	15.96	0.38	2.42	0.07	3.62	2.51	22.47	42.11
Jacksonville, FL MSA	1,345,596	69.89	21.77	0.39	3.43	0.09	1.82	2.62	6.90	34.23

[1] Individuals who identify themselves as Hispanic, Latino, or Spanish might be of any race; the sum of the other percentages under the "Percent of Total Population" columns plus the "Hispanic or Latino" column therefore does not equal 100%.

[2] The total minority population, for the purposes of this analysis, is the total population minus the non-Latino/Spanish/Hispanic white population.

Source: U.S. Census Bureau, 2011.

Table 4-41

Low-Income Presence in Metropolitan Statistical Areas Associated with Five Atlantic Coast Ports in 2009, Compared with State and National Averages

Location	Total Population[1]	Low-Income Population	Share (%)
United States	299,026,555	42,868,163	14.34
Virginia (statewide)	7,623,736	802,578	10.53
Virginia Beach-Norfolk-Newport News, VA-NC MSA	1,621,837	167,507	10.33
North Carolina (statewide)	9,095,948	1,478,214	16.25
Wilmington, NC MSA	346,425	56,481	16.30
South Carolina (statewide)	4,416,859	753,739	17.07
Charleston-North Charleston-Summerville, SC MSA	642,921	100,217	15.59
Georgia (statewide)	9,535,714	1,574,649	16.51
Savannah, GA MSA	334,330	47,805	14.30
Florida (statewide)	18,124,789	2,707,925	14.94
Jacksonville, FL MSA	1,305,970	176,188	13.49

[1] Population for whom poverty status is determined.

Source: U.S. Census Bureau, 2009.

Table 4-42

Minority Presence in Fishing Communities in 2000 in States Adjacent to the Area of Interest

Location	Total Population	Percent of Total Population							
		White	Black or African American	Alaska Native or American Indian	Asian	Native Hawaiian and Other Pacific Islander	Some Other Race Alone	Two or More Races	Hispanic or Latino[1]
Delaware (statewide)	783,600	74.6	19.2	0.3	2.1	0.0	2.0	1.7	4.8
DE Fishing Communities	13,008	86.9	9.2	0.2	0.8	0.0	1.3	1.5	0.7
Maryland (statewide)	5,296,486	64.0	27.9	0.3	4.0	0.0	1.8	2.0	4.3
MD Fishing Communities	38,556	79.1	18.5	0.3	0.4	0.0	0.3	1.4	0.3
Virginia (statewide)	7,078,515	72.3	19.6	0.3	3.7	0.1	2.0	2.0	4.7
VA Fishing Communities	972,008	74.5	21.3	0.3	1.3	0.0	1.0	1.5	0.9
North Carolina (statewide)	8,049,313	72.1	21.6	1.2	1.4	0.0	2.3	1.3	4.7
NC Fishing Communities	21,930	79.5	17.3	0.3	0.6	0.0	1.3	1.0	2.2
South Carolina (statewide)	4,012,012	67.2	29.5	0.3	0.9	0.0	1.0	1.0	2.4
SC Fishing Communities	207,762	62.9	30.6	4.1	0.6	0.1	0.7	1.0	1.8
Georgia (statewide)	8,186,453	65.1	28.7	0.3	2.1	0.1	2.4	1.4	5.3
GA Fishing Communities	172,358	68.8	28.6	0.3	0.7	0.1	0.6	1.0	1.0
Florida (statewide)	15,982,378	78.0	14.6	0.3	1.7	0.1	3.0	2.4	16.8
FL Fishing Communities	1,331,618	78.9	15.5	0.3	1.3	0.1	1.9	2.1	2.2

[1] Individuals who identify themselves as Hispanic, Latino, or Spanish might be of any race; the sum of the other percentages under the "Percent of Total Population" columns plus the "Hispanic or Latino" column therefore does not equal 100%.

Source: USDOC, NMFS, 2009c.

Table 4-43

Low-Income Presence in Fishing Communities in States Adjacent to the Area of Interest in 2000

Location	Percent of Family Households Below Poverty Level
Delaware (statewide)	6.5
Delaware Fishing Communities	1.7–10.6
Maryland (statewide)	6.1
Maryland Fishing Communities	1.9–30.5
Virginia (statewide)	7.0
Virginia Fishing Communities	1.1–17.1
North Carolina (statewide)	9.0
North Carolina Fishing Communities	0.0–27.9
South Carolina (statewide)	10.7
South Carolina Fishing Communities	3.2–19.9
Georgia (statewide)	9.9
Georgia Fishing Communities	0.0–25.2
Florida (statewide)	9.0
Florida Fishing Communities	2.3–25.4

Note: Poverty rates vary considerably among fishing communities identified in each state. The ranges shown indicate the lowest and highest poverty rates among the identified fishing communities in each state.

Source: USDOC, NMFS, 2009c.

Table 5-1

EFH Consultation Requirements and the Applicable Programmatic EIS Chapters

EFH Assessment Critical Elements	Chapters	Chapter Titles
Description of the action	Chapter 2	Alternatives Including the Proposed Action
	Chapter 3	G&G Activities and Proposed Action Scenario
	Chapter 3.2	Oil and Gas Development Surveys
	Chapter 3.3	Renewable Energy Resource Assessment and Site Characterization Surveys
	Chapter 3.4	Marine Minerals Surveys
An analysis of potential adverse effects on EFH and managed species	Chapter 2	Alternatives Including the Proposed Action
	Chapter 4.2.5.1	Fish Resources and Essential Fish Habitat Description
	Chapter 4.2.5.2	Fish Resources and Essential Fish Habitat Impacts of Routine Events
	Chapter 4.2.5.3	Fish Resources and Essential Fish Habitat Impacts of Accidental Events
	Chapter 4.2.5.4	Fish Resources and Essential Fish Habitat Impacts of Cumulative Events
	Appendix A (to be provided under separate cover)	Biological Assessment (for ESA)
Federal agency conclusions regarding the identified effects	Chapter 4.2.5.1	Fish Resources and Essential Fish Habitat Description
	Chapter 4.2.5.2	Fish Resources and Essential Fish Habitat Impacts of Routine Events
	Chapter 4.2.5.3	Fish Resources and Essential Fish Habitat Impacts of Accidental Events
	Chapter 4.2.5.4	Fish Resources and Essential Fish Habitat Impacts of Cumulative Events
	Appendix A (to be provided under separate cover)	Biological Assessment (for ESA)
Mitigations plans (if applicable)	Appendix A (to be provided under separate cover)	Biological Assessment (for ESA)
	Appendix C	Existing Regulations, Protective Measures, and Mitigation
Additional information	Chapter 2	Alternatives Including the Proposed Action
	Appendix A (to be provided under separate cover)	Biological Assessment (for ESA)
	Appendix J	Fish Hearing and Sensitivity to Acoustic Impacts

Table 5-2

NMSA Consultation Requirements and the Applicable Programmatic EIS Chapters

NMSA Discussion of Critical Elements	Chapters	Chapter Titles
Description of the action	Chapter 2	Alternatives Including the Proposed Action
	Chapter 3	G&G Activities and Proposed Action Scenario
	Chapter 3.2	Oil and Gas Development Surveys
	Chapter 3.3	Renewable Energy Resource Assessment and Site Characterization Surveys
	Chapter 3.4	Marine Mineral Surveys
An analysis of potential adverse effects on NMSA	Chapter 2	Alternatives Including the Proposed Action
	Chapter 4.2.1	Benthic Communities
	Chapter 4.2.11.1	Marine Protected Areas Description
	Chapter 4.2.11.2	Marine Protected Areas Routine Events
	Chapter 4.2.11.4	Marine Protected Areas Cumulative Events
Federal agency conclusions regarding the identified effects	Chapter 4.2.11.1	Marine Protected Areas Description
	Chapter 4.2.11.2	Marine Protected Areas Routine Events
	Chapter 4.2.11.4	Marine Protected Areas Cumulative Events
Mitigations plans (if applicable)	Appendix C	Existing Regulations, Protective Measures, and Mitigation
Additional information	Chapter 2	Alternatives Including the Proposed Action

APPENDIX A

BIOLOGICAL ASSESSMENT

(TO BE INCLUDED IN FINAL PROGRAMMATIC EIS)

APPENDIX B

STATE COASTAL ZONE MANAGEMENT PROGRAMS

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The Coastal Zone Management Act (CZMA) was established to develop comprehensive programs to manage and balance competing uses of and impacts to coastal resources. The CZMA emphasizes the primacy of State decision-making regarding the coastal zone preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations; and to encourage and assist the States to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone, giving full consideration to ecological, cultural, historic, and esthetic values as well as the needs for compatible economic development. In order to implement CZMA, each State has a Coastal Zone Management Program (CZMP) that is federally approved by National Oceanic and Atmospheric Administration (NOAA). These CZMPs are a comprehensive statement setting forth objectives, enforceable policies, and standards for public and private use of land and water resources and uses in that State's coastal zone.

Federal consistency is the CZMA requirement where Federal agency activities that have reasonably foreseeable effects on any land or water use or natural resource of the coastal zone must be consistent to the maximum extent practicable with the enforceable policies of a coastal State’s federally approved coastal management program. The State requirements for Federal consistency review are based on the requirements of State statutes, CZMA regulations at 15 Code of Federal Regulations (CFR) 930, and U.S. Department of the Interior (USDOI) regulations at 30 CFR 250, 30 CFR 254, and 30 CFR 256. There are currently changes undertaken within the CZMA program regulations, and NOAA intends to replace the CZMA program change regulations, 15 CFR 923, subpart H, and the Office of Ocean and Coastal Resource Management’s (OCRM’s) Program Change Guidance (July 1996) with new regulations at 15 CFR 923, Subpart H (U.S. Department of Commerce [USDOC], NOAA, 2008).

Each coastal State’s official coastal boundary can be identified from NOAA’s website (USDOC, NOAA, 2011). Federal agencies provide feedback to the States through each Section 312 evaluation conducted by NOAA.

A State’s approved CZMP may also provide for the State’s review of permits and license activities to determine whether they will be conducted in a manner consistent with the State’s CZMP. This review authority is applicable to activities conducted in any area that has been leased under the Outer Continental Shelf Lands Act (OCSLA) and that affect any land or water use or natural resource within the State’s coastal zone (16 United States Code [U.S.C.] 1456(c)(3)(B)).

This section provides an overview of the CZMP within each state within the area of interest (AOI).

1. STATE OF DELAWARE’S COASTAL MANAGEMENT PROGRAM

Delaware’s Coastal Zone Act was passed in 1971 and provides to the Secretary of the Department of Natural Resources and Environmental Control (DNREC) and the Coastal Zone Industrial Control Board the authority to promulgate regulations to carry out the requirements contained within the Act. Delaware has defined its Coastal Management Area as the entire state for the purposes of the federally approved coastal management program. The management of Delaware’s coastal resources is shared by a number of entities within DNREC including the Delaware Coastal Management Program (DCMP) and the Delaware National Estuarine Research Reserve (DNERR). These programs help to preserve, protect, develop and enhance the state’s coastal resources and resolve conflicts related to coastal zone issues. Functions of the DCMP include management of coastal resources through research projects, education and grant programs, and policy development; administration of the Coastal Zone Federal Consistency Certification program; special area management planning; and providing technical assistance to State and local governments for local land use planning. The function of DNERR is to preserve and manage the natural resources within the Reserve and to promote informed coastal decision-making.

In 2004, the DCP was responsible for the State’s Coastal and Estuarine Land Conservation Program (CELCP) development. The CELCP is a land acquisition program funded by NOAA that provides grants to eligible State agencies and local governments to acquire property or conservation easements from willing sellers within a State's coastal zone or coastal watershed boundary.

The State of Delaware requires a detailed description and the coastal zone effects, objective, and schedule for all activities associated with a project; an analysis of the project’s likely coastal zone effects and a description of how it will comply with applicable Coastal Zone Management Policies; and an evaluation of the relevant enforceable policies of the DCMP. Supporting information can include copies of Federal permit applications, construction plans, environmental assessments or environmental impact statements, monitoring data, modeling data and verification of other permits received. A guide to the Delaware's coastal consistency process can be found at DNREC's website (DNREC, 2004).

2. STATE OF MARYLAND'S COASTAL PROGRAM

Maryland's Coastal Program, established by executive order and approved in 1978, is a network of State laws and policies designed to protect coastal and marine resources. Maryland's coastal zone includes 16 counties (Anne Arundel, Baltimore, Calvert, Caroline, Charles, Cecil, Dorchester, Harford, Kent, Prince George's, Queene Anne's, Somerset, St. Mary's, Talbot, Wicomico, Worcester), Baltimore City, the Chesapeake Bay, other coastal bays, and the boundary extends to the limit of Maryland's three-mile jurisdiction in the Atlantic Ocean. Through partnerships and funding to local governments, State agencies, non-profit organizations, and universities, the Coastal Program addresses a variety of coastal issues including provision of public access, nonpoint source pollution reduction, coastal hazards mitigation, habitat and living resources protection and growth management.

The Department of Natural Resources (DNR) is the lead agency for the State's CZMP. Within DNR, the Coastal Zone Management Division of the Watershed Services Unit is the lead agency for the CZMP. The Federal consistency requirements are carried out by the Coastal Zone Consistency Division in the Wetlands and Waterways Program of the Water Management Administration (WMA) in the Maryland Department of the Environment (MDE). WMA is responsible for coordinating the Federal consistency review with appropriate State agencies, consolidating the State's comments, and forwarding the State's response and decision to the appropriate applicant. Maryland does not require a separate CZM application for, but requires that applicants for actions including Outer Continental Shelf (OCS)-related permits or approvals must certify that their proposed activity will be conducted in a manner consistent with the State's CZMP. Typically either the Federal permits and licenses or the Joint Federal/State Permit Application will be reviewed for consistency with the CZMP. The State's permit authorization for permitted activities will include the required Federal consistency decision. A guide to Maryland's coastal consistency program (Ghigiarelli, 2004) can be found at Maryland's DNR website.

3. COMMONWEALTH OF VIRGINIA'S COASTAL ZONE MANAGEMENT PROGRAM

The Virginia CZMP was established in 1986 through an Executive Order to protect and manage Virginia's "coastal zone." The Program is a network of State agencies and local governments through which the coastal resources of Virginia are managed. The network consists of 13 State agencies and local governments including the Marine Resources Commission; Department of Environmental Quality Lead coordinating agency; Department of Game and Inland Fisheries; Department of Conservation and Recreation; Department of Health; Tidewater Cities and Counties; Department of Agriculture and Consumer Affairs; Department of Forestry; Department of Historic Resources; Department of Mines, Minerals and Energy; Department of Transportation; Economic Development Partnership; and the Virginia Institute of Marine Science.

Virginia's coastal zone encompasses 29 counties, 15 cities, and 42 incorporated towns and all of the waters therein, and out to, the three nautical mile Territorial Sea boundary, including all of Virginia's Atlantic coast watershed as well as parts of the Chesapeake Bay and Albemarle - Pamlico Sound watersheds.

The Department of Environmental Quality (DEQ) serves as the lead agency for Virginia's networked coastal zone management program and helps agencies and localities to develop and implement coordinated coastal policies and solve coastal management problems while Coastal Policy Teams (CPTs) facilitate cooperation among the State agencies and local governments. The CPTs members represent all of Virginia's key CZM partners and provide a forum for discussion and resolution of cross-cutting coastal resource management issues. Virginia's eight coastal planning district commissions (PDCs) also participate in the implementation of the Virginia CZMP by providing a link between the State agencies and 87 localities that constitute Virginia's network of coastal resource managers. A representative from each PDC serves on the Virginia CZMP's Coastal Policy Team. Virginia's eight PDCs are Accomack-Northampton Planning District Commission, Crater Planning District Commission, Hampton Roads

Planning District Commission, Middle Peninsula Planning District Commission, Northern Neck Planning District Commission, Northern Virginia Regional Commission, George Washington Regional Commission, and Richmond Regional Planning District Commission.

For Federal consistency review, Virginia requires an adequate description including aspects of the project that may cause direct or indirect environmental impacts, objective, and schedule for all activities associated with a project; an evaluation that includes a set of findings relating to the probable coastal effects of the proposed project and its associated facilities to the relevant enforceable policies of the Virginia CZMP. Further information on the Virginia consistency determination process may be found at DEQ’s website (DEQ, 2011).

4. STATE OF NORTH CAROLINA’S COASTAL MANAGEMENT PROGRAM

The North Carolina Coastal Area Management Act (CAMA) was created in 1974. The CAMA established the Coastal Resources Commission (CRC), required local land use planning in 20 coastal counties, and provided for a program for regulating development. The North Carolina Coastal Management Program was federally approved in 1978. The CRC administers the CAMA, establishes policies for the North Carolina Coastal Management Program, and adopts implementing rules for both CAMA and the North Carolina Dredge and Fill Act. The commission also designates areas of environmental concern, adopts rules and policies for coastal development within those areas, and certifies local land-use plans. As a part of this program, the CRC designated "Areas of Environmental Concern" within the 20 coastal counties and set rules for managing development within these areas.

The Division of Coastal Management (DCM), in the Department of Environment and Natural Resources, provides staffing services to the CRC, implements CRC rules, and issues CAMA permits. DCM is the lead agency of the North Carolina Coastal Management Program and implements and supervises all the various CZMPs in the state. North Carolina's coastal zone includes 20 coastal counties (Beaufort, Hertford, Bertie, Hyde, Brunswick, New Hanover, Camden, Onslow, Carteret, Pamlico, Chowan, Pasquotank, Craven, Pender, Currituck, Perquimans, Dare, Tyrrell, Gates, Washington) that in whole or in part are adjacent to, adjoining, intersected or bounded by the Atlantic Ocean.

The consistency review process can be divided into two classifications, one for Federal activities and the other for non-Federal projects that require a Federal permit and/or license. For non-Federal projects, a Consistency Certification document must be submitted that demonstrates how the proposed project would be considered consistent with the State’s Coastal program. The procedures for making this submission are contained in Subpart “D” of 15 CFR 930 and further information on the North Carolina CZM process can be found at the North Carolina Department of Environment and Natural Resources website (NCDENR, 2010).

For Federal consistency, any project must comply with the key elements of North Carolina's Coastal Management Program such as the CAMA, the State's Dredge and Fill Law, Chapter 7 of Title 15A of North Carolina's Administrative Code, regulations passed by the CRC, and local land use plans certified by the CRC.

5. STATE OF SOUTH CAROLINA’S COASTAL ZONE MANAGEMENT PROGRAM

The South Carolina CZMP was established under the guidelines of the national Coastal Zone Management Act (1972) as a State-Federal partnership to comprehensively manage coastal resources. It was authorized in 1977 under South Carolina’s Coastal Tidelands and Wetlands Act (CTWA) (S.C. Code Ann. Section 48-39-10 et seq.) with the goal of achieving balance between the appropriate use, development, and conservation of coastal resources in the best interest of all citizens of the state.

The South Carolina Coastal Program established a permanent South Carolina Coastal Council (SCCC); provided for the development and administration of a comprehensive Coastal Management Program; set up a permitting process for activities occurring in the four "critical areas" of the coastal zone (tidelands, coastal waters, beaches and. primary ocean-front sand dunes); and provided a mechanism for State and local agency consistency with the State's approved Coastal Management Program throughout the coastal zone.

The South Carolina Department of Health and Environmental Control Office of Ocean and Coastal Resource Management (DHEC-OCRM) is the designated State coastal management agency and is responsible for implementing the approved South Carolina CZMP through the authorities specified in the Coastal Tidelands and Wetlands Act (SC Code ann. §48-39-110 et. seq.); the DHEC Coastal Division Regulations and the enforceable policies of the South Carolina Coastal Program Document.

The DHEC-OCRM has direct permitting authority for proposed activities within the "critical areas" of the coast. The DHEC-OCRM also has broader management authority over activities within the eight-county Coastal Zone (Beaufort, Berkeley, Charleston, Colleton, Dorchester, Horry, Jasper, and Georgetown) through consistency certification of both Federal and State permits, Federal licenses, and requests for funding assistance. The "critical areas" receive more intensive attention through a direct permitting system while the remainder of the coastal zone is managed through cooperation with other State and local agencies.

The burden of implementing the South Carolina Coastal Management Program rests not only with the Coastal Council but also with all other State and local agencies and commissions. Seventeen State agencies, including the Archeology Institute; South Carolina Department of Health and Environmental Control; South Carolina Department of Parks, Recreation, and Tourism; South Carolina Forestry Commission; South Carolina Land Resources Conservation Commission; South Carolina State Ports Authority; South Carolina Water Resources Commission; and the South Carolina Wildlife &Marine Resources Department, exercise authority over the use of coastal resources, specific areas in the coastal zone, or activities in the coastal zone. Memoranda of Agreement are used to effectively coordinate all State agency activities with the Coastal Management Program.

South Carolina requires an detailed description of the proposed activities and their associated facilities, objective, and schedule for all activities associated with a project; a brief assessment relating the probable coastal zone effects of the activities; and specific information on onshore support base, support vessels, shallow hazards, oil-spill response, wastes and discharges, transportation activities, and air emissions; and all relevant State and/or local government permits.

6. STATE OF GEORGIA'S COASTAL MANAGEMENT PROGRAM

In 1992, the State of Georgia initiated the development of the Georgia Coastal Management Program (GCMP). The Georgia General Assembly authorized the GCMP with the passage of the Georgia Coastal Management Act (O.C.G.A.12-5-320 et. seq.) in April 1997, and designated the Georgia Department of Natural Resources (DNR), Coastal Resources Division as the lead agency for administering the GCMP. NOAA subsequently approved the Program in January 1998, at which time Georgia became the 32nd state participating in the National CZMP.

In 1992 the GCMP was advised by a 25-member Coastal Zone Advisory Committee appointed by the Governor of Georgia. The Committee was made up of a diverse cross-section of the coastal Georgia citizenry with the goal of providing public input throughout the development of the GCMP. In 1994, a new Coastal Advisory Committee was appointed by the Commissioner of the Department of Natural Resources to review the draft Program Document, to assist with public education throughout the program development process, and to provide technical assistance. In 1997, the committee was expanded to increase participation from interested local governments. Finally, in 2003, the Committee was revamped and reauthorized by the Commissioner of DNR as the Coastal Advisory Council with by-laws and an appointed membership. The Council is charged with developing annual themes and funding criteria for the Coastal Incentive Grant Program, and providing a communication loop between the CZMP and coastal citizens.

The GCMP consists of 33 State codes, which constitute the enforceable policies and is administered by the Department of Natural Resources, Coastal Resources Division. The Program works with coastal local governments and other State and Federal agencies to enhance service to the public, increase coordination and communication, provide assistance with the Program, among its many other activities. The Program also implements the Georgia Coastal Marshlands Protection Act (O.C.G.A.12-5-280), Shore Protection Act (O.C.G.A.12-5-230), and Revocable License Program (O.C.G.A. 50-16-61).

For effective coastal management, the GCMP encompasses all tidally influenced water bodies and all areas economically tied to coastal resources including such industries as shrimping, crabbing, recreational fishing, tourism, shipping, and manufacturing. The GCMP's service area includes the following

11 counties: Brantley, Bryan, Camden, Charlton, Chatham, Effingham, Glynn, Liberty, Long, McIntosh, and Wayne. Within the 11 counties, all waters of the state including the coastal ocean to the limit of the state jurisdiction (3 nautical miles), and all submerged lands are part of the coastal area.

As lead agency for the GCMP, the Coastal Resources Division (CRD) conducts several functions including resource management, ecological monitoring, permitting, technical assistance (such as Best Management Practices), and Federal consistency review. Additional activities covered by the program include Outreach and Education, Coastal Nonpoint Source (6217) Program, and Coastal Incentive Grants. Local, State, and Federal agencies perform their respective functions in accordance with the GCMP and coordinated with the DNR. In addition, research institutes and other organizations assist in information gathering and analysis with coastal resource issues.

Activities implemented through the Coastal Management Network are divided into Local Governments, State Agencies, and Federal Agencies. Local governments assist in long-term planning, economic development, and natural resource protection through preparation and implementation of their respective comprehensive plans, local laws, and zoning regulations, as well as through their chambers of commerce and economic development authorities. State agencies continue to administer their respective coastal management efforts as defined by existing Georgia State law. Memoranda of Agreement between the CRD and other State agencies with regulatory authority in the coastal area help ensure that all agencies act in accordance with the policies of the GCMP. State agencies involved in the GCMP include the CRD; Department of Community Affairs; Department of Human Resources; Environmental Protection Division; Georgia Department of Transportation; Georgia Forestry Commission; Georgia Ports Authority; Historic Preservation Division; Jekyll Island Authority; Office of the Secretary of State, Parks, Recreation; and Historic Sites Division; Public Service Commission, and Wildlife Resources Division. Federal agencies continue to administer their respective programs as they are renewed for consistency with the GCMP. The following Federal agencies are involved in the GCMP: Army Corps of Engineers; Bureau of Lands Management; Coast Guard; Department of Agriculture; Department of Defense; Environmental Protection Agency; Federal Aviation Administration; Federal Emergency Management Agency; Federal Energy Regulatory Commission; Federal Highway Administration; Federal Law Enforcement Training Center; Fish and Wildlife Service; General Services Administration; General Services Administration; Bureau of Ocean Energy Management (BOEM); National Park Service; and Nuclear Regulatory Commission.

For Federal consistency review, the State of Georgia requires a detailed description of the proposed activity, its expected effects upon the land or water uses or natural resources of Georgia's coastal zone, and an evaluation of the proposed activity in light of applicable enforceable policies.

7. STATE OF FLORIDA’S COASTAL MANAGEMENT PROGRAM

For purposes of the CZMA, the State of Florida’s coastal zone includes the area encompassed by the State’s 67 counties and its territorial seas. Lands owned by the Federal Government and the Seminole and Miccosukee Indian tribes are not included in the State’s coastal zone; however, Federal activities in or outside the coastal zone, including those on Federal or tribal lands, that affect any land or water or natural resource of the State’s coastal zone are subject to review by Florida under the CZMA. The Florida Coastal Management Act, codified as Chapter 380, Part II, Florida Statutes, authorized the development of a coastal management program. In 1981 the Florida Coastal Management Program (FCMP) was approved by NOAA.

The policies identified by the State of Florida as being enforceable in the FCMP are the 23 chapters that NOAA approved for incorporation in the State’s program. The 2005 Florida Statutes are the most recent version approved by NOAA and include the listing of OCSLA permits under Subpart E; and the addition of draft Environmental Assessments and Environmental Impact Statements as necessary data and information for Federal consistency review.

A network of eight State agencies and five regional water management districts implement the FCMP’s 24 statutes. The water management districts are responsible for water quantity and quality throughout the State’s watersheds. The State agencies include the Department of Environmental Protection (DEP), the lead agency for the FCMP and the State’s chief environmental regulatory agency and steward of its natural resources; the Florida Department of Agriculture and Consumer Affairs (DACS), which is responsible for hydrologic restoration and development of best management practices for water quality and water conservation among other responsibilities; Florida Department of Community Affairs (DCA), which serves as the State's land planning and emergency management agency; the Department of Health (DOH), which, among other responsibilities, regulates on-site sewage disposal; the Department of State (DOS), Division of Historical Resources, which protects historic and archaeological resources; the Fish and Wildlife Conservation Commission (FWCC), which protects and regulates fresh and saltwater fisheries, marine mammals, and birds and upland species, including protected species and the habitat used by these species; the Department of Transportation (DOT), which is charged with the development, maintenance, and protection of the transportation system; Florida Division of Emergency Management (DEM), which ensures that Florida is prepared to respond to emergencies caused by a wide variety of threats, recover from disasters, mitigate disaster impacts, and reduce or eliminate long-term risk to human life and property; and the Governor's Office of Planning and Budget, which plays a role in the comprehensive planning process. Some of these agencies are currently being reorganized and will be combined or modified, including the DCA and DEM, which will cease to exist. Instead, the DCA responsibilities will become part of the new Department of Economic Opportunity and the DEM will move to the Executive Office of the Governor.

The DEP is designated as the lead agency for the FCMP pursuant to the CZMA 14. The DEP's Office of Intergovernmental Programs, is charged with overseeing the State's coastal management program and coordinates the review of OCS plans with FCMP member agencies to ensure that the plan is consistent with applicable State enforceable policies and the Governor's responsibilities under the Act. The OCS is a jurisdictional term used to describe those submerged lands (sea bed and subsoil) that lie seaward of State water boundaries (3 nautical miles off the east coast). An OCS plan is any plan for offshore exploration; development of oil, natural gas, and other mineral resources; or production activity that is conducted in any area leased under the OCSLA. The Federal government manages natural resources on the OCS, while the States manage the resources directly off their coasts.

The State of Florida requires an adequate description, objective, and schedule for all activities associated with a project; specific information on the natural resources potentially affected by the proposed activities; and specific information on onshore support base, support vessels, shallow hazards, oil-spill response, wastes and discharges, transportation activities, and air emissions; and a Federal consistency certification, assessment, and findings. As identified by the State of Florida, the State-enforceable policies that must be addressed for OCS activities are found at the BOEM website (USDOI, BOEM, 2011).

8. REFERENCES CITED

Delaware Department of Natural Resources and Environmental Control. 2004. Delaware Coastal Management Program. Available at: http://www.dnrec.delaware.gov/swc/SiteCollectionDocuments/Soil/Coastal/2004%20Policy%20Document.pdf. Accessed October 5, 2011.

Ghigiarelli, E. 2004. A guide to Maryland's Coastal Zone Management Program Federal consistency process. Available at: http://www.dnr.state.md.us/bay/czm/fed_consistency_guide.pdf. Accessed October 5, 2011.

North Carolina Department of Environment and Natural Resources. 2010. CAMA Permits: Federal consistency. Available at: http://dcm2.enr.state.nc.us/Permits/consist.htm. Accessed October 5, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Ocean & Coastal Resource Management. 2008. CZMA Program change rulemaking. Available at: http://coastalmanagement.noaa.gov/consistency/programchange.html. Accessed October 5, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. 2011. State coastal zone boundaries. Available at: http://coastalmanagement.noaa.gov/mystate/docs/StateCZBoundaries.pdf. Accessed September 26, 2011.

U.S. Dept. of the Interior, Bureau of Ocean Energy Management. 2011. Coastal Zone Management Program policies for the Gulf of Mexico States applicable to Outer Continental Shelf (OCS) plan filings. Available at: http://www.gomr.boemre.gov/homepg/regulate/regs/ntls/enforpols.pdf. Accessed October 5, 2011.

Virginia Department of Environmental Quality. 2011. Federal consistency information package. Available at: http://www.deq.virginia.gov/eir/federal.html#determine. Accessed October 5, 2011.

APPENDIX C

EXISTING REGULATIONS, PROTECTIVE MEASURES, AND MITIGATION

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LIST OF ACRONYMS AND ABBREVIATIONS

1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
4D	four-dimensional
AAM	active acoustic monitoring
ACNWR	Archie Carr National Wildlife Refuge
AN(SW)T	ambient-noise (surface-wave) tomography
AOI	area of interest
AUV	autonomous underwater vehicle
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulations
DLI	daylight imaging
DTAGS	deep-towed acoustics/geophysics system
EEZ	Exclusive Economic Zone
ESA	Endangered Species Act
FAA	Federal Aviation Administration
FAZ	full azimuth
G&G	geological and geophysical
HAPC	Habitat Areas of Particular Concern
HRG	high-resolution geophysical
HyMAS	hydrocarbon microtremor analysis
IAGC	International Association of Geophysical Contractors
ITA	Incidental Take Authorization
IVI	Industrial Vehicles International, Inc.
LACS	low level acoustic combustion source
LET	local earthquake tomography
LISA	low impact seismic array
LFS	low-frequency spectroscopy
LFPS	low frequency passive seismic
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MPA	Marine Protected Area
NASA	National Aeronautics and Space Administration
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NMSA	National Marine Sanctuaries Act
NMS	National Marine Sanctuary
NOAA	National Oceanic and Atmospheric Administration
NTL	Notice to Lessees and Operators
OBS	ocean bottom seismometer
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
PAM	passive acoustic monitoring
Programmatic EIS	Programmatic Environmental Impact Statement
PGS	Petroleum Geo-Services
SEL	sound exposure level
SMA	Seasonal Management Area
SWA	surface-wave amplitude
TTS	temporary threshold shift
UAS	unmanned aircraft system
U.S.C.	United States Code
USDOI	U.S. Dept. of the Interior
WAZ	wide azimuth

1. INTRODUCTION

The Bureau of Ocean Energy Management (BOEM) is proposing to authorize geological and geophysical (G&G) activities in support of its oil and gas, renewable energy, and marine minerals programs in Federal waters of the Mid- and South Atlantic Outer Continental Shelf (OCS) and adjacent State waters. The area of interest (AOI) for the proposed action includes the Mid- and South Atlantic OCS Planning Areas, as well as adjacent State waters (outside of estuaries) and waters beyond the Exclusive Economic Zone (EEZ) extending to 648 km (350 nmi) from shore (**Figure C-1**).

All G&G activities authorized by BOEM must comply with existing laws and regulations as described in **Chapter 1.0** of the Programmatic Environmental Impact Statement (Programmatic EIS). These include measures to avoid or reduce potential impacts of G&G activities. Compliance with existing laws and regulations – by BOEM as well as individual operators, when required – may result in additional measures or changes to the measures described here. In addition, a suite of protective measures is included in the proposed action as described in **Chapter 2.0** of the Programmatic EIS. This appendix describes and discusses the rationale for the measures selected for this program. It also describes measures that were considered but not selected, including measures and technologies identified for possible future use when proven effective and feasible. Additional mitigation measures may be incorporated into the proposed action through the public review process for the Programmatic EIS.

2. EXISTING REGULATIONS

This section identifies mitigation or protective measures already in place as a result of current G&G permit requirements, including G&G operator compliance with lease stipulations and other protective measures, as well as applicable guidance documents. Permit requirements and existing mitigation or protective measures are included in the proposed action.

2.1. G&G PERMIT REQUIREMENTS

Pursuant to 30 Code of Federal Regulations (CFR) 551.4, a permit must be obtained to conduct prelease geological or geophysical exploration for oil, gas, and sulphur resources. Permits for exploration for other minerals in support of competitive leasing are granted pursuant to requirements outlined in 30 CFR 580.3. Permit applications must be submitted to BOEM in accordance with the requirements outlined in 30 CFR 551.5 and 30 CFR 551.6 and explained further in applicable Letters to Permittees. The Letter to Permittees dated 20 January 1989 specifies forms and maps, stipulations, and special provisions applicable to most permit activity. The 30 CFR 551 regulations do not apply to G&G activities conducted by, or on behalf of, a lessee on a leased block. Such G&G activities are governed by 30 CFR 550.201 regulations and by applicable Notices to Lessees and Operators. **Table C-1** identifies the appropriate Federal regulations and their applicability to select mineral resources and activity phase.

Table C-1

Federal Regulations Applicable to Prelease and Postlease Activities by Mineral Resource of Interest

Regulatory Citation	Mineral Resource	Activity Phase
30 CFR 550	Oil, gas, and sulphur	Postlease (i.e., on-lease)
30 CFR 551	Oil, gas, and sulphur	Prelease or off-lease exploration or scientific research
30 CFR 580[a]	All minerals exclusive of oil, gas, and sulphur	Prelease (prospecting)
30 CFR 585	Renewable energy	Prelease and postlease

[a] 30 CFR 580 regulations apply only to G&G activities in support of competitive leasing. For noncompetitive leasing for public works, authorizations are issued pursuant to Section 11 of the OCSLA.

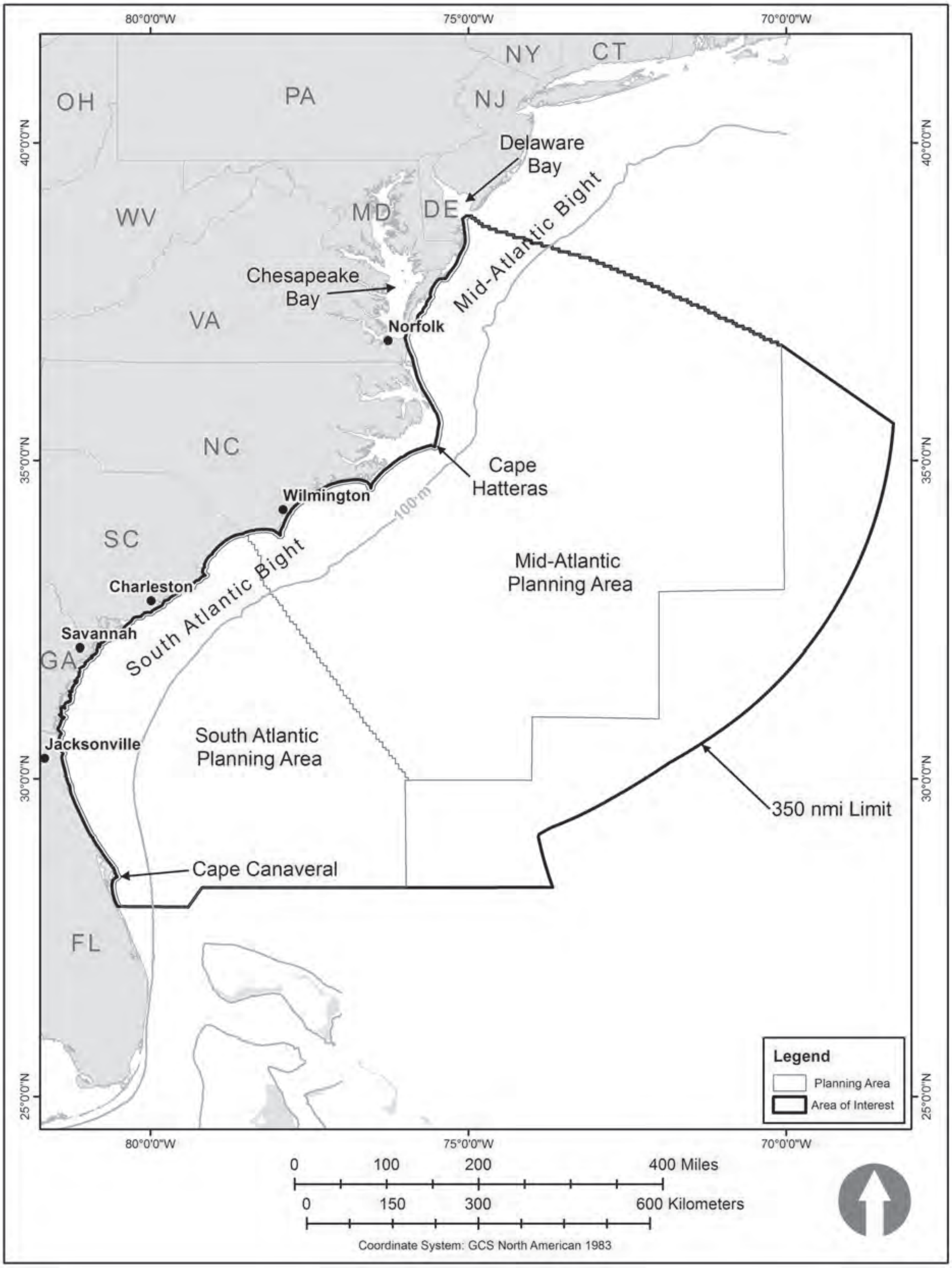


Figure C-1. Area of Interest for the Proposed Action.

Geological and geophysical explorations for mineral resources may not be conducted in the OCS without an approved permit unless such activities are being conducted pursuant to a lease issued or maintained under the Outer Continental Shelf Lands Act (OCSLA). Separate permits must be obtained for either geological or geophysical explorations for mineral resources.

The OCSLA directs BOEM to ensure G&G data are obtained in a technically safe and environmentally sound manner. Regulations at 30 CFR 551.6 state that permit holders for G&G activities must not

- interfere with or endanger operations under any lease, right-of-way, easement, right-of-use, notice, or permit issued or maintained under the Act;
- cause harm or damage to life (including fishes and other aquatic life), property, or to the marine, coastal, or human environment;
- cause harm or damage to any mineral resource (in areas leased or not leased);
- cause pollution;
- disturb archaeological resources;
- create hazardous or unsafe conditions; or
- unreasonably interfere with or cause harm to other uses of the area.

Geological and Geophysical operators conducting activities under 30 CFR 551 must immediately report to the Director, BOEM, when

- hydrocarbon occurrences are detected;
- environmental hazards are encountered that constitute an imminent threat to human life or property; or
- activities occur that adversely affect the environment, aquatic life, archaeological resources, or other uses of the area in which the exploration or scientific research activities are conducted.

The Energy Policy Act of 2005 (Public Law 109-58) added Section 8(p)(1)(C) to the OCSLA, which mandated that the Secretary of the Interior issue leases, easements, or rights-of-way on the OCS for the purpose of renewable energy development. The Secretary delegated this authority to the former Minerals Management Service (MMS), now BOEM. In addition to providing the authority to issue leases, easements, and rights-of-way, the Energy Policy Act included a requirement that any activity permitted under this authority be carried out in a manner that provides for various factors including

- safety;
- protection of the environment;
- prevention of waste;
- conservation of the natural resources of the OCS;
- prevention of interference with reasonable uses of the exclusive economic zone, the high seas, and the territorial seas;
- consideration of any other use of the sea or seabed, including use for a fishery, a sea lane, a potential site of a deepwater port, or navigation;
- public notice and comment on any proposal submitted for a lease, easement, or right-of-way under this subsection; and
- oversight, inspection, research, monitoring, and enforcement relating to a lease, easement, or right-of-way under this subsection."

On April 22, 2009, BOEM promulgated final regulations implementing this authority at 30 CFR 585 (*Federal Register*, 2009). Under the renewable energy regulations, after a lease is issued, the lessee may not commence construction of meteorological or other site assessment facilities until a Site Assessment Plan and the site characterization survey reports are submitted to and reviewed by BOEM (30 CFR 585.605 – 585.618). The lessee's Site Assessment Plan must contain a description of environmental protection features or measures that the lessee will use. Similarly, when a grant is made for a right of way, or right of use and easement, the grantee may not commence construction or perform other site assessment activities until a General Activities Plan and site characterization survey reports are submitted to and reviewed by BOEM (30 CFR 285.645-648).

The BOEM has developed guidelines for providing G&G, hazards, and archaeological information pursuant to 30 CFR 585 (U.S. Dept. of the Interior [USDOI], BOEM, 2011). The guidelines specify that BOEM recommends avoidance as a primary mitigation strategy. Avoidance strategies seek to ensure that harm or damage to objects of historical or archaeological significance will be less likely. The applicant has the option to demonstrate through additional investigations that an archaeological resource either does not exist or would not be adversely affected by the seafloor/bottom-disturbing activities. If an applicant, while conducting activities, discovers a potential archaeological resource such as the presence of a shipwreck (e.g., a sonar image or visual confirmation of an iron, steel, or wooden hull, wooden timbers, anchors, concentrations of historic objects, piles of ballast rock), prehistoric artifacts, and/or relict landforms, etc. within the project area, the applicant is to:

- immediately halt seafloor/bottom-disturbing activities within the area of discovery;
- notify the appropriate BOEM/Office of Offshore Alternative Energy Programs Environmental Branch Chief within 72 hr of its discovery; and
- keep the location of the discovery confidential and take no action that may adversely affect the archaeological resource until BOEM has made an evaluation and instructs the applicant on how to proceed.

The BOEM may require the applicant to conduct additional investigations to determine if the resource is eligible for listing in the National Register of Historic Places.

2.2. BOEM STIPULATIONS AND PROTECTIVE MEASURES

The BOEM currently requires oil and gas operators to comply with a series of stipulations and protective measures during G&G activities. These requirements effectively represent mitigation measures designed to reduce or eliminate impacts to sensitive resources. Such measures are implemented through regulations governing prelease and postlease G&G activities. Key points consist of the following:

- *Explosives Prohibition*: Explosives cannot be used for G&G activities except under written authorization from the Regional Supervisor. Further protective measures (including Endangered Species Act [ESA] Section 7 consultation with the National Marine Fisheries Service [NMFS]) and a Marine Mammal Protection Act [MMPA] authorization apply in the event that explosives are proposed for use.
- *Archaeological Resources*: The permittee must report discovery of any archaeological resource (i.e., shipwreck/prehistoric site) to BOEM and take precautions to protect the resource from operational activities.
- *Seismic Safety*: All pipes, buoys, and other markers used in connection with seismic work must be properly flagged and lighted according to the navigation rules of the U.S. Army Corps of Engineers and the U.S. Coast Guard.

There are no active oil and gas leases in the Atlantic OCS. In the event that leasing occurs during the period of the proposed action, BOEM may add measures to mitigate the impacts of lease-specific activities in the form of lease stipulations. In addition, BOEM provides additional guidance to lessees and operators through Notices to Lessees and Operators (NTLs).

At a programmatic level, there are no mitigation measures that apply to G&G activities conducted in support of renewable energy development; however, best management practices were documented in the Programmatic EIS for the renewable energy program (USDOI, MMS, 2007, pp. 2-20). A NEPA evaluation is part of the approval process for OCS plans, without exception, under the renewable energy program. A proposed action at a specific location, tool type, and intensity of G&G activity are subjected to evaluation, which may be an Environmental Assessment or an EIS. The consultations required under environmental law for protected species are part of the NEPA evaluation. Through the NEPA process, BOEM may identify mitigation measures to avoid/minimize environmental impacts during G&G surveys.

Mitigation measures may be implemented as a condition for OCS plan approval. Additional mitigation measures may be required as a result of consultations under the ESA or MMPA.

Similarly, at a programmatic level, there are no mitigation measures that apply to G&G activities under the marine minerals program. Under Section 11 of the OCSLA, BOEM may authorize G&G prospecting for non-energy marine minerals, except in the case that another Federal agency is performing the survey on the OCS. Before authorizing any proposed prospecting, BOEM undertakes the necessary environmental review, including preparation of a NEPA document and consultations for protected species. Through the NEPA process, BOEM may identify mitigation measures to avoid/minimize environmental impacts during G&G surveys. Mitigation measures may be implemented as a condition for survey authorization.

3. PROTECTIVE MEASURES INCLUDED IN THE PROPOSED ACTION

The following protective measures are included in the proposed action:

- a time-area closure for North Atlantic right whales;
- a seismic airgun survey protocol;
- a high-resolution geophysical (HRG) survey protocol (for renewable energy and marine minerals sites);
- guidance for vessel strike avoidance;
- guidance for marine debris awareness;
- avoidance and reporting of historic and prehistoric sites;
- avoidance of sensitive benthic communities;
- guidance for activities in or near National Marine Sanctuaries; and
- guidance for military and NASA coordination.

3.1. TIME-AREA CLOSURE FOR NORTH ATLANTIC RIGHT WHALES

Alternative A includes a time-area closure intended to avoid most impacts from vessel strikes or ensonification of the water column on North Atlantic right whales. It is estimated that this closure would avoid about two-thirds of the incidental takes of North Atlantic right whales by active acoustic sound sources over the period of the Programmatic EIS. Although right whales could occur anywhere within the AOI, they are most likely to be found in the calving/nursery areas offshore the southeastern U.S. coast during the winter months and near the South Atlantic and Mid-Atlantic coast during their seasonal migrations (Knowlton et al., 2002).

The locations and timing of the closure are shown in **Figure C-2**. The total closure area under Alternative A would be 7,589,594 ac (30,714 km^2) or approximately 4 percent of the AOI. No G&G surveys using airguns would be authorized within the designated right whale critical habitat area from November 15 through April 15 nor within the Mid-Atlantic and Southeast U.S. Seasonal Management Areas (SMAs) during the times when vessel speed restrictions are in effect under the Right Whale Ship Strike Reduction Rule (50 CFR 224.105). However, HRG surveys proposed in critical habitat area and SMAs may be considered on a case-by-case basis only if: (1) they are proposed for renewable energy or marine minerals operations; and (2) they use acoustic sources other than air guns. The coincidence is necessary because of other biological use windows or project monitoring requirements. Any such authorization may include additional mitigation and monitoring requirements to avoid or significantly reduce impacts on right whales. Other supporting surveys (e.g., biological surveys) would not be affected by this restriction.

The Southeast U.S. SMA, with seasonal restrictions in effect from November 15 to April 15, is a continuous area that extends from St. Augustine, Florida, to Brunswick, Georgia, extending 37 km (20 nmi) from shore (**Figure C-3**). The Mid-Atlantic U.S. SMA, with seasonal restrictions from November 1 through April 30, is a combination of both continuous areas and half circles drawn with 37-km (20-nmi) radii around the entrances to certain bays and ports. Within the AOI, the Mid-Atlantic U.S. SMA includes a continuous zone extending between Wilmington, North Carolina, and Brunswick, Georgia, as well as the entrance to Delaware Bay (Ports of Wilmington [Delaware] and Philadelphia), the

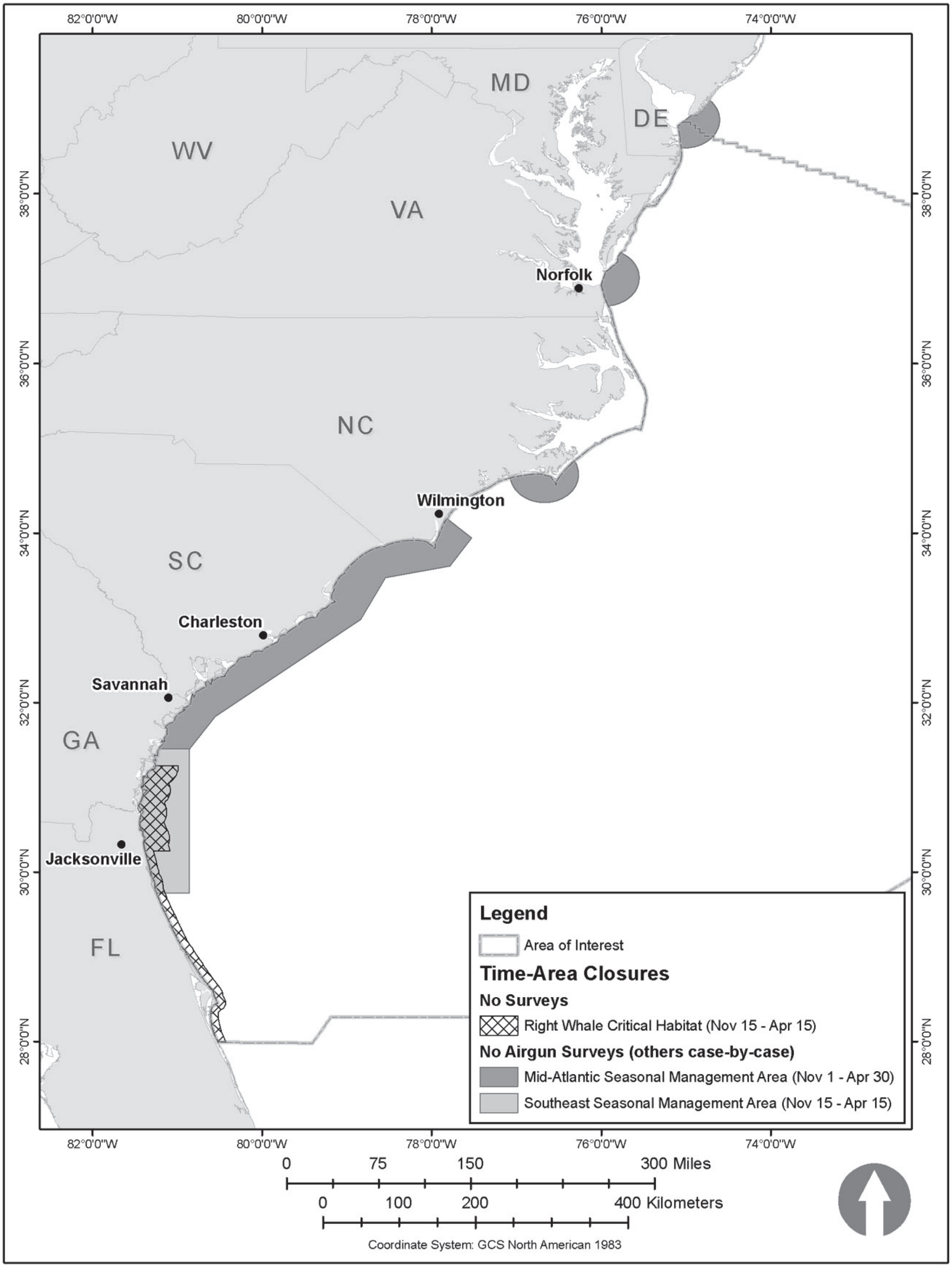
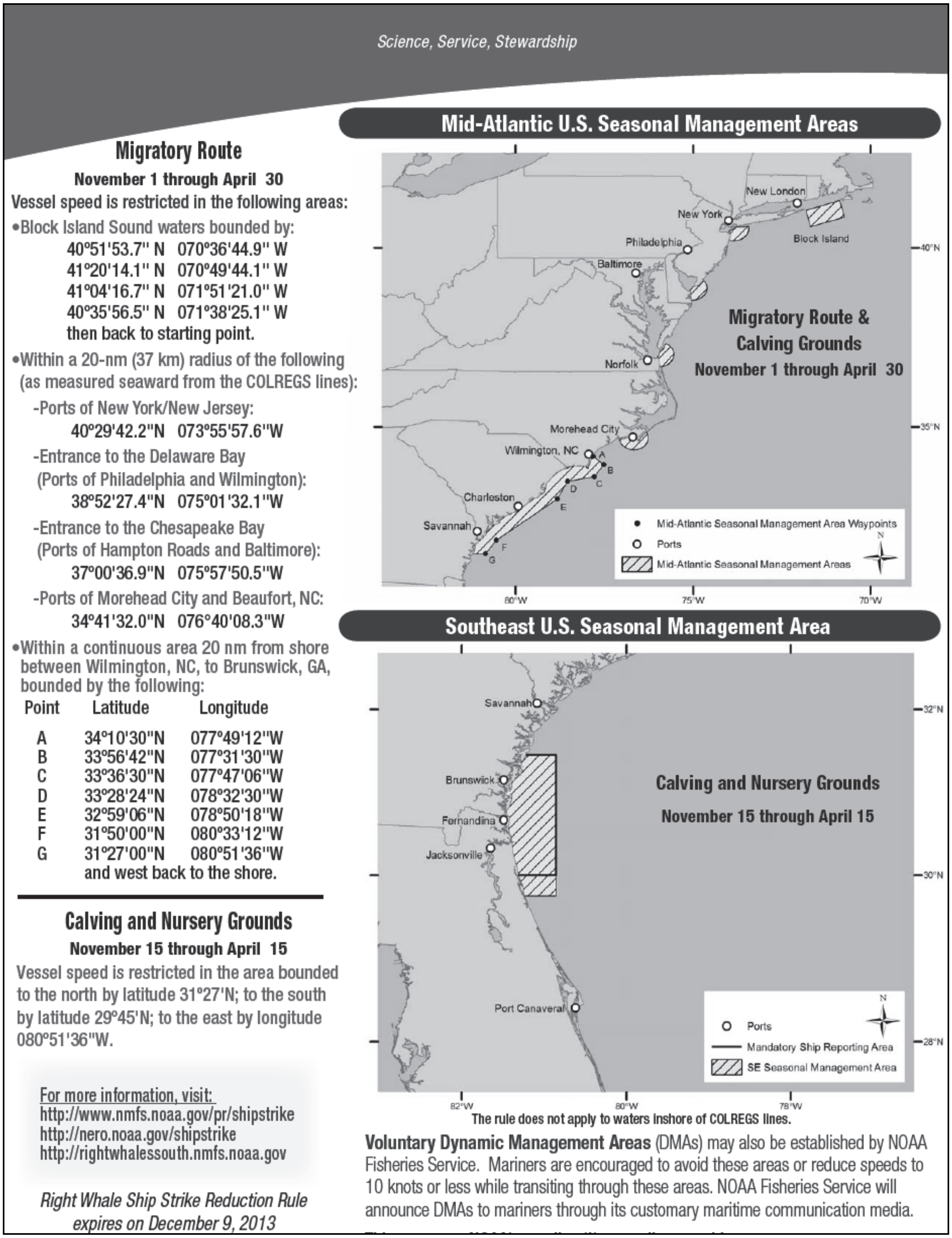


Figure C-2. Time-Area Closures Included in Alternative A.



Science, Service, Stewardship

Migratory Route

November 1 through April 30

Vessel speed is restricted in the following areas:

- Block Island Sound waters bounded by:

40°51'53.7" N	070°36'44.9" W
41°20'14.1" N	070°49'44.1" W
41°04'16.7" N	071°51'21.0" W
40°35'56.5" N	071°38'25.1" W

then back to starting point.

- Within a 20-nm (37 km) radius of the following (as measured seaward from the COLREGS lines):
  - -Ports of New York/New Jersey:
    40°29'42.2"N 073°55'57.6"W
  - -Entrance to the Delaware Bay (Ports of Philadelphia and Wilmington):
    38°52'27.4"N 075°01'32.1"W
  - -Entrance to the Chesapeake Bay (Ports of Hampton Roads and Baltimore):
    37°00'36.9"N 075°57'50.5"W
  - -Ports of Morehead City and Beaufort, NC:
    34°41'32.0"N 076°40'08.3"W
- Within a continuous area 20 nm from shore between Wilmington, NC, to Brunswick, GA, bounded by the following:

Point	Latitude	Longitude
A	34°10'30"N	077°49'12"W
B	33°56'42"N	077°31'30"W
C	33°36'30"N	077°47'06"W
D	33°28'24"N	078°32'30"W
E	32°59'06"N	078°50'18"W
F	31°50'00"N	080°33'12"W
G	31°27'00"N	080°51'36"W

and west back to the shore.

Calving and Nursery Grounds

November 15 through April 15

Vessel speed is restricted in the area bounded to the north by latitude 31°27'N; to the south by latitude 29°45'N; to the east by longitude 080°51'36"W.

For more information, visit:
http://www.nmfs.noaa.gov/pr/shipstrike
http://nero.noaa.gov/shipstrike
http://rightwhalessouth.nmfs.noaa.gov

Right Whale Ship Strike Reduction Rule expires on December 9, 2013

The rule does not apply to waters inshore of COLREGS lines.

Voluntary Dynamic Management Areas (DMAs) may also be established by NOAA Fisheries Service. Mariners are encouraged to avoid these areas or reduce speeds to 10 knots or less while transiting through these areas. NOAA Fisheries Service will announce DMAs to mariners through its customary maritime communication media.

Figure C-3. Summary of Speed Restrictions and Locations for Vessel Operators to Comply with the Right Whale Strike Reduction Rule (50 CFR 224.105) (Source: USDOC, NOAA, 2011).

entrance to Chesapeake Bay (Ports of Hampton Roads and Baltimore), and the Ports of Morehead City and Beaufort, North Carolina (**Figure C-3**).

Exceptions to the right whale time-area closure could occur if a survey was needed to serve important operational or monitoring requirements for a particular project. For example, monitoring surveys for renewable energy (e.g., scour, cable burial) might need to take place at fixed intervals to capture seasonal changes or safety-related conditions. Another example would be a marine minerals project in which dredging is not seasonally restricted and real-time bathymetry data must be collected to track dredging operations or pre- and post-bathymetric surveys must be collected immediately before or after dredging to establish volumes borrowed.

3.2. SEISMIC AIRGUN SURVEY PROTOCOL

All authorizations for seismic airgun surveys (those involving airguns as an acoustic source) would include a survey protocol that specifies mitigation measures for protected species, including an exclusion zone, ramp-up requirements, visual monitoring by protected species observers prior to and during seismic airgun surveys, and array shutdown requirements. The protocol specifies the conditions under which airgun arrays can be started and those under which they must be shut down. It also includes the recommended but optional use of passive acoustic monitoring (PAM) to help detect vocalizing marine mammals. The protocol requirements apply specifically to airguns, not electromechanical sources such as side-scan sonars, boomer and chirp subbottom profilers, and single beam or multibeam depth sounders that may be operating concurrently during seismic airgun surveys.

A draft seismic airgun survey protocol is provided as the **Attachment** to this appendix. The draft protocol is based on Joint BOEM-BSEE NTL 2012-G02 ("Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program") (USDOI, BOEM and BSEE, 2012a), with key exceptions as noted in the protocol.

3.2.1. Rationale

The purpose of the operational measures included in the seismic airgun survey protocol is to prevent injury to marine mammals and sea turtles and to avoid most Level A harassment of marine mammals.

There are 38 species of marine mammals potentially occurring in the Area of Interest (AOI), as described in **Chapter 4.2.2** of the Programmatic EIS. They include 34 species of cetaceans, 3 species of pinnipeds, and one sirenian (the Florida manatee). The pinnipeds (harbor seal, gray seal, and hooded seal) are considered to be extralimital in the AOI and are unlikely to be exposed to underwater sound from seismic airgun surveys under the proposed action. Manatees are present only in inland and near-coastal waters along the southeast coast and are unlikely to be exposed to underwater sound from seismic airgun surveys under the proposed action. Incidental take calculations in **Appendix E** based on abundance data for the AOI predict zero incidental takes of pinnipeds or manatees, even without considering operational mitigation measures included in the seismic airgun survey protocol.

For the analysis in the Programmatic EIS, two sizes of airgun arrays were modeled, based on current usage in the Gulf of Mexico, and considered representative for potential Atlantic G&G seismic surveys:

- large airgun array (5,400 in^3) – this array was used to represent sound sources for deep penetration seismic surveys, including 2D, 3D, WAZ, and other variations; and
- small airgun array (90 in^3) – this array was used to represent sound sources for HRG surveys for oil and gas exploration sites.

Detailed acoustic characteristics of airguns are discussed in **Appendix D**. Broadband source levels are 230.7 dB re 1 µPa for the large airgun array and 210.3 dB re 1 µPa for the small array (**Table C-2**). Although airguns have a frequency range from about 10 to 2,000 Hz, most of the acoustic energy is radiated at frequencies below 200 Hz.

Table C-2

Acoustic Characteristics of Airgun Arrays Included in the Proposed Action

Source	Usage	Operating Frequencies	Broadband Source Level (dB re 1 µPa at 1 m)
Large Airgun Array ($5,400$ in^2)	Deep penetration seismic surveys, oil and gas exploration (2D, 3D, WAZ, VSP, 4D, etc.)	10-2,000 Hz (most energy at <200 Hz)	230.7
Small Airgun Array (90 in^2)	HRG surveys, oil and gas exploration	10-2,000 Hz (most energy at <200 Hz)	210.3

Abbreviations: 2D = two-dimensional; 3D = three-dimensional; 4D = four-dimensional; HRG = high-resolution geophysical; VSP = vertical seismic profile; WAZ = wide azimuth.

Source: **Appendix D**.

Acoustic pulses from airguns are within the hearing range of all marine mammals in the AOI (**Appendix H**). All of the mysticetes occurring in the AOI are low-frequency cetaceans (7 Hz-22 kHz), and most of the odontocetes are mid-frequency cetaceans (150 Hz-160 kHz), with the exception of the harbor porpoise (a high-frequency cetacean, 200 Hz-180 kHz). Manatees have hearing capabilities that are generally similar to phocid pinnipeds, with functional hearing between about 250 Hz and ~90 kHz. Airgun pulses are also within the hearing range of sea turtles, whose best hearing is mainly below 1,000 Hz (**Appendix I**).

To reduce the risk of injury and Level A harassment, the seismic airgun survey protocol would establish an exclusion zone based on the predicted range at which animals could be exposed to a received sound pressure level of 180 dB re 1 µPa, which is the current NMFS criterion for Level A harassment of cetaceans. The radius of the exclusion zone would be calculated on a survey-specific basis, but would not be less than 500 m (1,640 ft). This exclusion zone applies specifically to airguns, not electromechanical sources such as side-scan sonars, boomer and chirp subbottom profilers, and single beam or multibeam depth sounders that may be operating concurrently during seismic airgun surveys. Although there are no NMFS noise exposure criteria for sea turtles, the mitigation measures are expected to similarly reduce the risk of temporary or permanent hearing loss in sea turtles. The operational mitigation measures would reduce the extent of, but not prevent, behavioral responses including Level B harassment of marine mammals. Other measures such as the time-area closure for North Atlantic right whales (**Chapter 3.1**) would help to reduce the risk of those impacts. Key elements of the protocol are discussed in the following sections.

3.2.2. Ramp-Up

Ramp-up (also known as “soft start”) entails the gradual increase in intensity of an airgun array over a period of 20 min or more, until maximum source levels are reached. The intent of ramp-up is to either avoid or reduce the potential for instantaneous hearing damage to an animal (from the sudden initiation of an acoustic source at full power) that might be located in close proximity to an airgun array. Increasing sound levels are designed to warn animals of pending seismic operations, and to allow sufficient time for those animals to leave the immediate area. Increasing sound levels (e.g., from an airgun array) are thought to be annoying or aversive to marine mammals. Under optimal conditions, sensitive individuals are expected to move out of the area, beyond the range where hearing damage might occur.

Ramp-up has become a standard mitigation measure in the U.S. and worldwide. The International Association of Geophysical Contractors (IAGC) recommends ramp-up in its seismic survey guidelines (IAGC, 2011). In the Gulf of Mexico, BOEM requires ramp-up for operators working in water depths >200 m throughout the Gulf and all OCS waters of the Eastern Gulf of Mexico Planning Area under Joint BOEM-BSEE NTL 2012-G02 (USDOI, BOEM and BSEE, 2012a).

Although ramp-up is widely used, it is used mainly as a “common sense” procedure, and there is little information on its effectiveness (Weir and Dolman, 2007; Parsons et al., 2009).

3.2.3. Exclusion Zone

The seismic airgun survey protocol includes an exclusion zone to prevent injury to marine mammals and sea turtles and to avoid Level A harassment of marine mammals to the maximum extent practicable.

The radius of the exclusion zone would be based on the predicted range at which animals could be exposed to a received sound pressure level of 180 dB re 1 μPa, which is the current NMFS criterion for Level A harassment of cetaceans. The radius of the exclusion zone would be calculated on a survey-specific basis, but would not be less than 500 m (1,640 ft). This exclusion zone applies specifically to airguns, not electromechanical sources such as side-scan sonars, boomer and chirp subbottom profilers, and single beam or multibeam depth sounders that may be operating concurrently during seismic airgun surveys.

Although the NMFS also uses a criterion of 190 dB re 1 μPa for Level A harassment of pinnipeds, based on the rare occurrence of pinnipeds in the AOI it is unlikely that a smaller exclusion zone based on the 190-dB criterion would be appropriate for any seismic airgun survey there. There are no noise exposure criteria for sea turtles, but a 180-dB exclusion zone is expected to prevent mortalities, injuries, and most auditory impacts on sea turtles as well.

Based on calculations in **Appendix D** and summarized in **Table C-3**, the 180-dB zone for a large airgun array (5,400 in^3) ranges from 799 to 2,109 m (2,622 to 6,920 ft), with a mean of 1,086 m (3,563 ft). Marine mammals can be detected at distances of up to several kilometers, depending on sea state and the animal's size and behavior. Sea turtles are not likely to be detected beyond 500 m (1,640 ft).

For oil and gas HRG surveys using a small airgun array (90 in^3), the 180-dB zone ranges from 76 to 186 m (249 to 610 ft), with a mean of 128 m (420 ft) (**Table C-3**). A 500-m (1,640-ft) radius exclusion zone can be effectively monitored and would encompass the zone where Level A harassment could occur.

Table C-3

Estimated Ranges (m) for Level A Harassment of Cetaceans by Airgun Arrays
Based on the NMFS Level A Criterion

Equipment	Usage	Number of Scenarios Modeled	Statistics	NMFS Level A Criterion 180 dB re 1 μPa (rms)	
				R_{max}	$R_{95\%}$
5,400 in^3 Airgun Array	Deep penetration seismic surveys, oil and gas exploration (2D, 3D, WAZ, VSP, 4D, etc.)	21	Min (m)	799	737
			Max (m)	2,109	1,677
			Mean (m)	**1,086**	**930**
90 in^3 Airgun Array	HRG surveys, oil and gas exploration	21	Min (m)	76	74
			Max (m)	186	177
			Mean (m)	**128**	**124**

R_{max} is the maximum received sound pressure level. $R_{95\%}$ is the received level over 95% of the energy of the pulse.

Source: **Appendix D.**

3.2.4. Visual Monitoring by Protected Species Observers

The seismic airgun survey protocol includes visual monitoring of the exclusion zone by trained protected species observers. At least two protected species observers will be required on watch aboard seismic vessels at all times during daylight hours (dawn to dusk – i.e., from about 30 min before sunrise to 30 min after sunset) when seismic operations are being conducted, unless conditions (fog, rain, darkness) make sea surface observations impossible. If conditions deteriorate during daylight hours such that the sea surface observations are halted, visual observations must resume as soon as conditions permit. Ongoing activities may continue but may not be initiated under such conditions (i.e., without appropriate pre-activity monitoring). Operators may engage trained third party observers, utilize crew members after training as observers, or use a combination of both third party and crew observers.

The main tasks of protected species observers are to monitor the exclusion zone for protected species and to observe and document their presence and behavior. Observers search the area around the vessel using high-powered, pedestal-mounted, "Big Eye" binoculars, hand-held binoculars, and the unaided eye. For larger monitoring programs with a specified visual observation platform, two observers survey for protected species generally using the high-powered binoculars, while a third observer searches with the unaided eye and occasionally hand-held binoculars, and serves as data recorder. If the vessel is utilizing a passive acoustic monitoring (PAM) system, a fourth observer will be assigned to monitor that station and communicate with the third observer on the visual observing platform. Data are recorded on paper sheets and/or a laptop computer that has direct input from the vessel's global positioning system navigation system. Observers rotate among the duty stations at regular intervals, and alternate work and rest periods based upon a pre-determined schedule. In the event a marine mammal is sighted or otherwise detected within the impact zone, seismic operations are suspended until the animal leaves the area (see **Attachment**).

Visual, shipboard monitoring is affected by limitations on sightability of individuals due to poor visibility (fog, elevated Beaufort sea state, nighttime operations), species detectability (cryptic species), and/or observer fatigue. Routine activities of marine mammals (e.g., diving duration patterns, pod size, overt behaviors) show considerable variability between species, thereby affecting whether or not animals are sighted (i.e., availability bias). During nighttime operations or during periods of reduced visibility, several options are available to allow for continual monitoring of the impact zone (e.g., shipboard lighting of waters around the vessel, use of enhanced vision equipment, night-vision equipment, and acoustic monitoring [both active and passive]). However, the efficiency of visual monitoring during nighttime hours, using shipboard lighting or enhanced vision equipment, is limited when compared with visual monitoring during daylight hours.

3.2.5. Shutdown Requirements

The seismic airgun survey protocol requires shutdown of the airgun array any time a marine mammal or sea turtle is observed within the exclusion zone, whether due to the animal's movement, the vessel's movement, or because the animal surfaced inside the exclusion zone. In the event of a shutdown, seismic operations and ramp-up of airguns would recommence only when the sighted animal has cleared the exclusion zone and no other marine mammals or sea turtles have been sighted within the exclusion zone for at least 30 min. However, shutdown would not be required for dolphins approaching the vessel or towed equipment at a speed and vector that indicates voluntary approach to bow-ride or chase towed equipment. If a dolphin voluntarily moves into the exclusion zone after the airguns are operating, it is reasoned that the sound pressure level is not negatively affecting that particular animal.

3.3. HRG SURVEY PROTOCOL (RENEWABLE ENERGY AND MARINE MINERALS SITES)

The HRG surveys of renewable energy and marine minerals sites would use only electromechanical sources such as side-scan sonar, boomer and chirp subbottom profilers, and single beam and multibeam depth sounders. The BOEM does not expect that airguns would be used for these surveys. All authorizations for non-airgun HRG surveys would include requirements for visual monitoring of an exclusion zone by protected species observers and startup and shutdown requirements.

The HRG surveys for oil and gas exploration and development sites typically use the electromechanical acoustic sources operating concurrently with airgun arrays. These surveys would be subject to the seismic airgun survey protocol described in **Chapter 3.2**.

3.3.1. Rationale

Important considerations in defining an exclusion zone (or "safe" range) include the source level, operating frequencies, pulse duration, and directivity of the source as well as the hearing capabilities of the receiving animals. Acoustic characteristics of electromechanical sources are discussed in detail in **Appendix D** and summarized in **Table C-4**.

Table C-4

Acoustic Characteristics of Representative Electromechanical Sound Sources Included in the Programmatic EIS

Source	Broadband Source Level (dB re 1 µPa at 1 m)	Operating Frequencies	Within Hearing Range	
			Cetaceans	Sea Turtles
Boomer	212	200 Hz–16 kHz	Yes	Yes
Side-Scan Sonar	226	100 kHz	Yes	No
		400 kHz	No	No
Chirp Subbottom Profiler	222	3.5 kHz	Yes	No
		12 kHz	Yes	No
		200 kHz	No	No
Multibeam Depth Sounder[a]	213	240 kHz	No	No

[a] Single beam depth sounders may also be used for seafloor mapping, and the frequencies and source levels may differ. The multibeam depth sounder was selected as a representative source and is conservative from the standpoint of acoustic impacts.

▨ = no auditory impacts expected because frequency is beyond hearing range.

Source: **Appendix D**.

Based on a review of marine mammal hearing, **Appendix H** recognizes three cetacean groups: low-frequency cetaceans (7 Hz to 22 kHz), mid-frequency cetaceans (150 Hz to 160 kHz) and high-frequency cetaceans (200 Hz to 180 kHz). Boomer pulses are within the hearing range of all three cetacean groups. However, the operating frequency of the representative multibeam system (240 kHz) is above the hearing range of all three groups. For side-scan sonar, the 100 kHz operating frequency is within the hearing range of mid- and high-frequency cetaceans, but the 400 kHz frequency is above the range of all groups. For the chirp subbottom profiler, the 3.5 kHz and 12 kHz frequencies are within the hearing range of all three cetacean groups, but the 200 kHz is above the range of all groups. Frequencies emitted by individual equipment may differ from these representative systems selected for programmatic analysis.

Sea turtles are low-frequency specialists whose best hearing is mainly below 1,000 Hz (**Appendix I**). Acoustic signals from electromechanical sources other than the boomer are not likely to be detectable by sea turtles. Because of the relatively low source level of the boomer as discussed below, sea turtles are unlikely to hear boomer pulses unless they are very near the source.

3.3.1.1. Injury Ranges Calculated Using the 180-dB NMFS Criterion

To reduce the risk of injury and Level A harassment of marine mammals, the HRG survey protocol would establish an exclusion zone based on the predicted range at which animals could be exposed to a received sound pressure level of 180 dB re 1 µPa, which is the current NMFS criterion for Level A harassment of cetaceans. The operational mitigation measures would not prevent all Level A harassment and would reduce the extent of, but not prevent, behavioral responses including Level B harassment.

Table C-5 lists the maximum 180-dB range calculated for electromechanical sources, based on acoustic modeling in **Appendix D**. The range of values reflects the various geographic and seasonal scenarios modeled. The 180-dB radius ranged from 38 to 45 m (125 to 148 ft) for the boomer and from 32 to 42 m (105 to 138 ft) for the chirp subbottom profiler. The 180-dB radius was 27 m (89 ft) for the multibeam depth sounder under all scenarios. The side-scan sonar had the largest 180-dB radius, ranging from 128 to 192 m (420 to 630 ft).

The initial 180-dB calculations in **Table C-5** are based on nominal source levels and do not take into account the pulse duration. As indicated in the table, the pulses produced by all of the electromechanical sources are much shorter than 1 s. As summarized by Au and Hastings (2008), when receiving tone pulses, the mammalian ear behaves like an integrator with an "integration time constant." Energy is summed over the duration of a pulse until the pulse is longer than the integration time constant. Studies of bottlenose dolphins by Johnson (1968) indicate an integration time constant of approximately 100 ms. A 10-ms pulse with a received SPL of 180 dB would be integrated over a 100-ms period, resulting in a 10-fold (10 dB) reduction. Using the assumption of a 100-ms integration time, the 180-dB radii for side-scan sonar and multibeam depth sounder were recalculated to account for short pulse duration as shown in **Table C-5**. For the boomer and multibeam depth sounder, the recalculated 180-dB radius was

<5 m under all scenarios. The recalculated 180-dB radius ranged from 65 to 96 m (213 to 315 ft) for the side-scan sonar and from 26 to 35 m (85 to 115 ft) for chirp subbottom profiler. Specific considerations for each source are discussed below.

Table C-5

Estimated Ranges for Level A and B Harassment of Cetaceans byElectromechanical Sources Based on the NMFS 180-dB and 160-dB Criteria

Equipment	Number of Scenarios Modeled	Pulse Duration	Adjustment (dB) for Short Pulse Duration[a]	180-dB Radius (m)		160-dB Radius (m)	
				Calculated using Nominal Source Level[b]	Recalculated for Short Pulse Duration[a]	Calculated using Nominal Source Level[b]	Recalculated for Short Pulse Duration[a]
Boomer	14	180 µs	-27.3	38-45	<5	1,054-2,138	16
Side-Scan Sonar	14	20 ms	-7.0	128-192	65-96	500-655	337-450
Chirp Subbottom Profiler	14	64 ms	-1.9	32-42	26-35	359-971	240-689
Multibeam Depth Sounder	7	225 µs	-26.5	27	<5	147-156	12

[a] The nominal source level was adjusted by the amount indicated to recalculate the 180-dB radius in the last column.

[b] The value is the radius (Rmax) for the maximum received sound pressure level (**Appendix D)**.

Source: **Appendix D**.

3.3.1.1.1. Boomer

The frequency range of the representative boomer (200 Hz to 16 kHz) is entirely within the hearing range of all cetacean groups and is also within the expected hearing range of sea turtles. Based on a source level of 212 dB re 1 µPa, the 180-dB radius is estimated to range from 38 to 45 m (125 to 148 ft) for the various geographic and seasonal scenarios modeled. However, taking into account the short pulse duration (180 µs), the recalculated 180-dB radius is <5 m (16 ft) in all modeled scenarios (**Table C-5**).

3.3.1.1.2. Side-Scan Sonar

For the representative side-scan sonar, the 100 kHz operating frequency is within the hearing range of mid- and high-frequency cetaceans, but the 400 kHz frequency is above the range of all groups. Sea turtles are not expected to hear this source. Based on a source level of 226 dB re 1 µPa, the 180-dB radius is estimated to range from 128 to 192 m (420 to 630 ft) for the various geographic and seasonal scenarios modeled. Taking into account the short pulse length of 20 ms, the recalculated 180-dB radius ranges from 65 to 96 m (213 to 315 ft) (**Table C-5**).

3.3.1.1.3. Chirp Subbottom Profiler

The representative chirp subbottom profiler operates at three frequencies: 3.5 kHz, 12 kHz, and 200 kHz. The highest frequency (200 kHz) is above the hearing range for all cetaceans. Sea turtles are not expected to hear this source. Based on a source level of 222 dB re 1 µPa, the 180-dB radius ranges from 32 to 42 m (105 to 138 ft) for the various geographic and seasonal scenarios modeled. Because the pulse length of 64 ms is relatively close to the 100 ms integration time assumed for the cetacean ear, the correction for pulse length reduces the ranges only slightly to 26-35 m (85-115 ft) (**Table C-5**).

3.3.1.1.4. Multibeam Depth Sounder

Based on a source level of 213 dB re 1 µPa, the 180-dB radius calculated for the multibeam depth sounder is 27 m (89 ft) for all of the geographic and seasonal scenarios modeled. Taking into account the short pulse duration (225 µs), the radius is further reduced to <5 m (16 ft) for all modeled scenarios. More importantly, because the operating frequency of the representative multibeam system (240 kHz) is above the hearing range of all three cetacean groups, no auditory impacts are expected. Similarly, sea turtles are not expected to hear this source.

The relatively low risk of auditory impacts on marine mammals from multibeam depth sounders is consistent with a recent analysis by Lurton and DeRuiter (2011) taking into account both the short pulse duration and high directivity of these sources.

3.3.1.2. Injury Ranges Calculated Using the Southall Criteria

Based on data for onset of temporary threshold shift (TTS), Southall et al. (2007) proposed dual injury criteria for cetaceans exposed to non-pulse sources. In the Southall et al. (2007) terminology, all of the electromechanical sources evaluated here would be considered non-pulse sources. The first injury criterion is a sound exposure level (SEL) of 215 dB re 1 μPa^2 s and the second is a flat-weighted peak pressure exceeding 230 dB re 1 μPa. Injury is assumed to occur if either criterion is exceeded (or both).

For all of the representative electromechanical sources in this Programmatic EIS, the source level is less than 230 dB re 1 μPa and therefore the pressure criterion would not be exceeded and the injury radius is zero. Calculation of the injury radius using the SEL criterion is complicated because exposure depends on the ping rate and the number of pulses an animal receives; however, in general, predicted injury radii are expected to be less than 10 m (33 ft) for all of the sources.

3.3.1.3. Level B Harassment Ranges Calculated Using the 160-dB NMFS Criterion

Table C-5 also lists the maximum 160-dB range calculated for electromechanical sources, based on acoustic modeling in **Appendix D**. The range of values reflects the various geographic and seasonal scenarios modeled. The boomer had the largest 160-dB radius, ranging from 1,054 to 2,138 m (3,458 to 7,015 ft), followed by the chirp subbottom profiler (359-971 m or 1,178-3,186 ft), the side-scan sonar (500-655 m or 1,640-2,149 ft) and the multibeam depth sounder (147-156 m or 482-512 ft).

Values taking into account pulse duration are shown in the last column of **Table C-5**. Due to the very short pulse duration, the boomer and multibeam depth sounder have radii of 16 m (52 ft) and 12 m (39 ft), respectively. The recalculated 160-dB radius ranged from 240 to 689 m (787 to 2,261 ft) for the chirp subbottom profiler and from 337 to 450 m (1,106 to 1,476 ft) for side-scan sonar.

3.3.1.4. Discussion and Conclusions

Among the representative electromechanical sources, boomers and multibeam depth sounders pose the smallest risk of auditory impacts to marine mammals. Under all scenarios modeled, the 180-dB radius for both sources is estimated to be <50 m (160 ft) for the nominal source level and <5 m (16 ft) when pulse duration is taken into account. Based on the Southall criteria, the predicted injury radius would be zero for both sources. In addition, the operating frequency of the representative multibeam depth sounder is beyond the range of all three cetacean groups. (Some multibeam depth sounders use different frequencies that are within the cetacean hearing range, but the system modeled here is considered representative of the equipment likely to be used during HRG surveys for renewable energy and marine minerals sites.)

Both the representative side-scan sonar and chirp subbottom profiler could be detectable by cetaceans, depending on the operating frequencies selected. The side-scan sonar operating at 100 kHz would be detectable and the 180-dB radius is estimated to be 128-192 m (420-630 ft) based on the nominal source level and 65-96 m (213-315 ft) when the short pulse length is taken into account. The chirp subbottom profiler operating at either 3.5 kHz or 12 kHz would be detectable and the 180-dB radius is estimated to be 32-42 m (105-138 ft) based on the nominal source level and 26-35 m (85-115 ft) when the short pulse length is taken into account. Based on the Southall criteria, predicted injury ranges are less than 10 m (33 ft) for both sources.

Depending on the suite of equipment selected and the operating frequencies selected, there may be no Level A or B harassment of marine mammals. For example, if a survey uses side-scan sonar at 400 kHz, chirp subbottom at 200 kHz, multibeam depth sounder at 240 kHz, and no boomer, then no acoustic harassment of marine mammals would be expected.

For surveys with one or more sources operating at frequencies within the cetacean hearing range, if source levels are low enough, it may be feasible to monitor the entire 160-dB radius. In that case, both Level A and B harassment would be prevented and it would be reasonable to assume that no Incidental

Take Authorization (ITA) may be needed. For example, a source level of 206 dB re 1µPa would have a 160-dB radius of 200 m (656 ft) (based on the simplistic assumption of spherical spreading).

Sea turtles are unlikely to hear the electromechanical sources except perhaps the boomer at very close range (e.g., the 180-dB radius is 38-45 m). Vessel strike avoidance measures already included in the Programmatic EIS include a recommended separation distance of 45 m (150 ft) for sea turtles. Therefore, the protocol does not include an exclusion zone or shutdown requirements for sea turtles. However, the exclusion zone would be initially clear of sea turtles prior to startup.

3.3.1.5. Practical Considerations

The BOEM expects that a 200-m (656-ft) radius exclusion zone can be effectively monitored from the types of coastal survey vessels expected to be used for HRG surveys of renewable energy and marine minerals sites. The operational ranges for these HRG surveys would be approximately <25 mi from shore and in water <30 m (98 ft) deep. Unlike the large, dedicated vessels used for oil and gas seismic surveys, coastal survey vessels may not have a bridge or elevated viewing platform, and their capability for effectively monitoring a radius larger than a few hundred meters would depend on vessel size and configuration. An exclusion zone radius of 200 m (656 ft) would encompass the 180-dB Level A harassment radius calculated for all of the representative electromechanical sources included in this Programmatic EIS as summarized above. Depending on the source levels of the equipment used on particular surveys, this radius may also encompass the 160 dB Level B harassment zone. The BOEM anticipates that if an operator can effectively monitor the 160-dB zone to prevent both Level A and B harassment of marine mammals, it would be reasonable to assume that an ITA under the MMPA may not be necessary for that particular survey. Therefore, the protocol would allow an operator to monitor a radius larger than 200 m (656 ft) if the operator demonstrates that it can be effectively monitored.

Ramp-up is not expected to be an effective mitigation measure for HRG surveys because electromechanical sources typically are either on or off and are not powered up gradually.

Geophysical operators report that dolphins frequently approach and chase the side-scan sonar towfish. Therefore, requiring a shutdown for dolphins could significantly increase survey duration or even make it impossible to complete some HRG surveys. The protocol requires that the exclusion zone be initially clear of all marine mammals and specifies shutdown for any marine mammal entering the exclusion zone. However, the protocol includes an exception for dolphins that approach the vessel or towed equipment at a speed and vector that indicates voluntary approach to bow-ride or chase towed equipment. If a dolphin voluntarily moves into the exclusion zone after the active acoustic sound sources are operating, it is reasoned that the sound pressure level is not negatively affecting that particular animal.

3.3.2. Protocol Requirements

1. All HRG surveys must comply with requirements for vessel strike avoidance as detailed in separate guidance in **Chapter 3.4**. The recommended separation distance for North Atlantic right whales of 457 m (1,500 ft) would remain in effect during HRG surveys since it exceeds the exclusion zone radius specified below. Recommended separation distances for other whales and small cetaceans are less than, and would be superseded by, the exclusion zone radius. The exclusion zone must be initially clear of sea turtles as indicated below, but thereafter the vessel strike separation distance of 45 m (150 ft) for sea turtles would be maintained.
2. One protected species observer would be required on watch aboard HRG survey vessels at all times during daylight hours (dawn to dusk – i.e., from about 30 min before sunrise to 30 min after sunset) when survey operations are being conducted, unless conditions (fog, rain, darkness) make sea surface observations impossible. If conditions deteriorate during daylight hours such that the sea surface observations are halted, visual observations must resume as soon as conditions permit. Ongoing activities may continue but may not be initiated under such conditions (i.e., without appropriate pre-activity monitoring). Operators may engage trained third party observers, utilize crew members after training as observers, or use a combination of both third party and crew observers.

3. The following additional requirements apply only to HRG surveys in which one or more active acoustic sound sources will be operating at frequencies less than 200 kHz.
    a. A 200-m (656-ft) radius exclusion zone will be monitored around the survey vessel. If the exclusion zone does not encompass the 160-dB Level B harassment radius calculated for the acoustic source having the highest source level, BOEM will consult with NMFS about additional requirements. On a case-by-case basis, BOEM may authorize surveys having an exclusion zone larger than 200 m (656 ft) to encompass the 160-dB radius if the applicant demonstrates that it can be effectively monitored.
    b. Active acoustic sound sources must not be activated until the protected species observer has reported the exclusion zone clear of all marine mammals and sea turtles for 30 min.
    c. Except as noted in (d) below, if any marine mammal is sighted within or transiting towards the exclusion zone, an immediate shutdown of the equipment will be required. Subsequent restart of the equipment may only occur following clearance of the exclusion zone for 30 min.
    d. Shutdown would not be required for dolphins approaching the vessel or towed equipment at a speed and vector that indicates voluntary approach to bow-ride or chase towed equipment. If a dolphin voluntarily moves into the exclusion zone after the active acoustic sound sources are operating, it is reasoned that the sound pressure level is not negatively affecting that particular animal.

The HRG surveys of renewable energy and marine minerals sites in the SMAs for the North Atlantic right whale would be reviewed on a case-by-case basis, and authorizations may include additional mitigation and monitoring requirements to avoid or reduce impacts on right whales.

3.4. GUIDANCE FOR VESSEL STRIKE AVOIDANCE

All authorizations for shipboard surveys would include guidance for vessel strike avoidance. The guidance would be similar to Joint BOEM-BSEE NTL 2012-G01 ("Vessel Strike Avoidance and Injured/Dead Protected Species Reporting") (USDOI, BOEM and BSEE, 2012b) which incorporates the NMFS "Vessel Strike Avoidance Measures and Reporting for Mariners" addressing protected species identification, vessel strike avoidance, and injured/dead protected species reporting. Key elements of the guidance are as follows:

1. Vessel operators and crews must maintain a vigilant watch for marine mammals and sea turtles and slow down or stop their vessel to avoid striking protected species.
2. When whales are sighted, maintain a distance of 91 m (300 ft) or greater from the whale. If the whale is believed to be a North Atlantic right whale, the vessel must maintain a minimum distance of 457 m (1,500 ft) from the animal (50 CFR 224.103).
3. When sea turtles or small cetaceans are sighted, the vessel must maintain a distance of 45 m (150 ft) or greater whenever possible.
4. When cetaceans are sighted while a vessel is underway, the vessel must remain parallel to the animal's course whenever possible. The vessel must avoid excessive speed or abrupt changes in direction until the cetacean has left the area.
5. Reduce vessel speed to 10 kn (18.5 km/h) or less when mother/calf pairs, pods, or large assemblages of cetaceans are observed near an underway vessel when safety permits. A single cetacean at the surface may indicate the presence of submerged animals in the vicinity of the vessel; therefore, precautionary measures should always be exercised.
6. Whales may surface in unpredictable locations or approach slowly moving vessels. When animals are sighted in the vessel's path or in close proximity to a moving vessel, the vessel must reduce speed and shift the engine to neutral. The engines must not be engaged until the animals are clear of the area.

7. Vessel crews would be required to report sightings of any injured or dead marine mammals or sea turtles to BOEM and NMFS within 24 hr, regardless of whether the injury or death was caused by their vessel.

In addition, vessel operators would be to required to comply with the NMFS marine mammal and sea turtle viewing guidelines for the Northeast Region (USDOC, NMFS [2011a] for surveys offshore Delaware, Maryland, or Virginia) or the Southeast Region (USDOC, NMFS [2011b] for surveys offshore North Carolina, South Carolina, Georgia, or Florida) or combined guidance if recommended by NMFS. These measures are meant to reduce the potential for vessel harassment or collision with marine mammals or sea turtles regardless of what activity a vessel is engaged in.

The guidance will also incorporate the NMFS Compliance Guide for the Right Whale Ship Strike Reduction Rule (50 CFR 224.105), which limits vessel speed to 18.5 km/h (10 kn) in the Mid-Atlantic and Southeast U.S. SMAs for North Atlantic right whales during migration (**Figure C-3**). Vessel speed restrictions in these areas are in effect between November 1 and April 30 in the Mid-Atlantic and between November 15 and April 15 in the southeast U.S.

3.5. GUIDANCE FOR MARINE DEBRIS AWARENESS

All authorizations for shipboard surveys would include guidance for marine debris awareness. The guidance would be similar to BSEE's NTL 2012-G01 ("Marine Trash and Debris Awareness and Elimination") (USDOI, BSEE, 2012). All vessel operators, employees, and contractors actively engaged in G&G surveys must be briefed on marine trash and debris awareness elimination as described in this NTL except that BSEE will not require applicants to undergo formal training or post placards. The applicant will be required to ensure that its employees and contractors are made aware of the environmental and socioeconomic impacts associated with marine trash and debris and their responsibilities for ensuring that trash and debris are not intentionally or accidentally discharged into the marine environment where it could affect protected species. The above-referenced NTL provides information that applicants may use for this awareness training.

3.6. AVOIDANCE OF SENSITIVE SEAFLOOR RESOURCES

A basic mitigation philosophy for BOEM is to mitigate by avoidance. That is, this Agency must know enough about the nature of the seafloor area where activities are proposed so that the activities can be moved or offset to another area if sensitive resources are already there. This principle applies to sensitive cultural resources such as shipwrecks and prehistoric archaeological resources as well as sensitive benthic communities, and it applies to G&G activities in all three program areas.

3.6.1. Avoidance and Reporting of Historic and Prehistoric Sites

The BOEM and BSEE would require site-specific information regarding potential archaeological resources prior to approving any G&G activities involving seafloor-disturbing activities or placement of bottom-founded equipment or structures in the AOI. The BOEM and BSEE would use this information to ensure that physical impacts to archaeological resources do not take place.

All authorizations for G&G activities that involve seafloor-disturbing activities would include requirements for operators to report suspected historic and prehistoric archaeological resources to BOEM and BSEE and take precautions to protect the resource. The requirements are expected to be similar to NTL 2005-G07 ("Archaeological Resource Surveys and Reports") (USDOI, MMS, 2005), the enforcement for which is shared between BOEM and BSEE. The BOEM and BSEE also require reporting and avoidance for any previously undiscovered suspected archaeological resource and precautions to protect the resource from operational activities while appropriate mitigation measures are developed. Regulations have been promulgated based on the National Historic Preservation Act (NHPA) (16 U.S.C. 470 et seq.), especially Sections 106 and 110; the Archaeological Resources Protection Act (ARPA) of 1979 (16 U.S.C. 470), which prohibits the excavation and removal of items of archaeological interest from Federal lands without a permit; and the Antiquities Act of 1906 (16 U.S.C. 431). Under the oil and gas regulations, archaeological resource surveys are required as by 550.203(o), 550.204(s), and 550.1007(a)(5), and an archaeological resource report is required by 550.203(b)(15), 550.204(b)(8)(v)(A), and 550.1007(a)(5). These existing regulations are applicable to all G&G operations that involve seafloor-disturbing activities, including coring, grab sampling, and placement of bottom cables or nodes. Equivalent information needs to be provided for renewable energy and marine minerals programs, although equivalent regulations do not expressly exist for renewable energy or for marine minerals. The equivalent is provided through guidance, supported by regulation and/or statutory authority (see NHPA Section 106, OCSLA, and 30 CFR 585 and 580).

If an operator discovers any archaeological resource while conducting operations authorized under a lease or pipeline right-of-way, operations within or that may affect the discovery must be immediately halted the discovery reported to BOEM and BSEE. If BOEM determines that the resource is significant, based on criteria under the NHPA, BSEE, in consultation with BOEM, will direct how the resource is to be protected during operations and activities. If BOEM determines that the resource is not significant, BOEM will so advise BSEE. The BSEE informs the operator when operations may resume (30 CFR 250.194).

3.6.2. Avoidance of Sensitive Benthic Communities

The BOEM will require site-specific information regarding sensitive benthic communities (including hard/live bottom areas, deepwater coral communities, and chemosynthetic communities) prior to approving any G&G activities involving seafloor-disturbing activities or placement of bottom-founded equipment or structures in the AOI. All authorizations for seafloor-disturbing activities will be subject to restrictions to protect corals and hard/live bottom resources, including requirements for mapping and avoidance, as well as pre-deployment photographic surveys of areas where bottom-founded instrumentation and appurtenances are to be deployed.

The BOEM has not designated specific benthic locations for avoidance in the AOI. However, likely areas for avoidance would include known hard/live bottom areas; known deepwater coral locations including *Lophelia* and *Oculina* coral sites; deepwater coral Habitat Areas of Particular Concern (HAPCs); deepwater Marine Protected Areas (MPAs); Gray’s Reef National Marine Sanctuary (NMS); the Charleston Bump area; and the walls of submarine canyons. These benthic features are discussed in **Chapter 4.2.1.1.2** of the Programmatic EIS. All authorizations for G&G surveys proposed within or near these areas would be subject to the review noted above to facilitate avoidance.

The BOEM has not developed specific buffer zones for sensitive benthic communities in the Atlantic, but it is expected that they would be similar to those that BOEM uses in the Gulf of Mexico, where the locations of many sensitive bottom communities are known and there is a long history of bottom surveying in association with oil and gas exploration and production. In the Gulf of Mexico, sensitive benthic features in water depths less than 300 m (~1,000 ft) are protected by NTL 2009-G39 (“Biologically-Sensitive Underwater Features and Areas”) (USDOI, MMS, 2009a) and features in greater water depths are protected by NTL 2009-G40 (“Deepwater Benthic Communities”) (USDOI, MMS, 2009b). Large topographic features, such as the Flower Garden Banks and similar offshore “banks” are defined by “No Activity Zones” where no bottom-disturbing activity may take place within 152 m (500 ft). No seafloor-disturbing activities can occur within 30 m (100 ft) of “pinnacle trend” hard/live bottom features that have vertical relief of 2.4 m (8 ft) or more. Avoidance of low-relief hard/live bottom features is required but no buffer distance is specified; plans proposing activities near these areas must include survey coverage extending to 1,000 m (3,280 ft) from the location of proposed bottom-disturbing activity. For high-density deepwater benthic communities (including chemosynthetic and deepwater coral communities), setbacks of 610 m (2,000 ft) are required for drilling discharge locations and 76 m (250 ft) from the location of all other proposed seafloor disturbances. The application of similar setbacks as default buffer zones would be expected when G&G activities take place in the AOI.

3.7. GUIDANCE FOR ACTIVITIES IN OR NEAR NATIONAL MARINE SANCTUARIES

There are two NMSs within the AOI: Monitor and Gray’s Reef (see **Chapter 4.2.11.1.1** of the Programmatic EIS for brief descriptions). The BOEM would not authorize seafloor-disturbing activities within the boundaries of an NMS. Seafloor-disturbing activities proposed near the boundaries of an NMS would be assigned a setback distance as a condition of permit approval to be determined at the time the action is before BOEM and in consultation with the Sanctuary Manager. Setbacks of 152 m (500 ft) for seafloor-disturbing activities would be expected that could be modified by consultations with NOAA under the NMSA for specific activities in proximity to an NMS. **Chapter 1.6.15** of the Programmatic EIS provides information about the NMSA consultation process.

All BOEM authorizations for G&G activities would include instructions to minimize impacts on NMS resources. Operators proposing to conduct activities within or near the boundaries of Monitor NMS or Gray's Reef NMS would be instructed to exercise caution to ensure that such activities do not endanger any other users of the Sanctuary. Additionally, if proposed activities involve seafloor-disturbing activities near an NMS or moving the surface marker buoys for the Sanctuary, the operator would be required to contact the Sanctuary Manager for instructions.

Existing Federal regulations for Monitor NMS (15 CFR 922.61) prohibit certain activities including (but not limited to) anchoring, stopping, remaining, or drifting without power at any time; any type of subsurface salvage or recovery operation; diving of any type, whether by an individual or by a submersible; lowering below the surface of the water any grappling, suction, conveyor, dredging or wrecking device; detonating below the surface of the water any explosive or explosive mechanism; drilling or coring the seabed; lowering, laying, positioning or raising any type of seabed cable or cable-laying device; trawling; or discharging waste material into the water in violation of any Federal statute or regulation.

Existing Federal regulations for Gray's Reef NMS (15 CFR 922.92) prohibit certain activities including (but not limited to) anchoring; dredging; drilling; using explosives; breaking, damaging, or removing any bottom formation; constructing structures; constructing, placing, or abandoning any structure, material, or other matter on the submerged lands of the Sanctuary; and discharging or depositing any material or other matter except fish or fish parts, bait, or chumming materials, effluent from marine sanitation devices, and vessel cooling water. Under a new regulation that went into effect December 4, 2011, the southern third of the NMS is now a research area where fishing and diving is prohibited but vessels are allowed to travel across the area as long as they don't stop (*Federal Register*, 2011; Office of National Marine Sanctuaries, 2011).

3.8. GUIDANCE FOR MILITARY AND NASA COORDINATION

All authorizations for permitted activities would include guidance for military and National Aeronautics and Space Administration (NASA) coordination. The guidance would be similar to NTL 2009-G06 ("Military Warning and Water Test Areas") (USDOI, MMS, 2009c). All vessel operators and contractors actively engaged in G&G surveys and permitted activities would be required to establish and maintain early contact and coordination with the appropriate military command headquarters or NASA point of contact (POC), in order to avoid or minimize the effects of conflicts with potentially hazardous military operations. In addition, the placement, location, and planned periods of operation of any surface structures would be subject to BOEM approval. When command headquarters determines it is necessary the vessel operator would be required to enter into a formal Operating Agreement that delineates the specific requirements and parameters for the operator's activities.

4. ADDITIONAL PROTECTIVE MEASURES INCLUDED IN ALTERNATIVE B

The following protective measures in Alternative B would be identical to those previously described for the Proposed Action (Alternative A):

- HRG survey protocol (renewable energy and marine minerals sites);
- guidance for vessel strike avoidance guidance;
- guidance for marine debris awareness;
- avoidance and reporting of historic and prehistoric sites;
- avoidance of sensitive benthic communities;
- guidance for activities in or near National Marine Sanctuaries; and
- guidance for military and NASA coordination.

Alternative B would include the additional or revised measures listed below and described in the following subsections:

- an expanded time-area closure for North Atlantic right whales;
- a time-area closure for nesting sea turtles offshore Brevard County, Florida;
- limitations on concurrent seismic surveys; and
- a seismic airgun survey protocol with required use of PAM.

4.1. EXPANDED TIME-AREA CLOSURE FOR NORTH ATLANTIC RIGHT WHALES

Under Alternative B, the time-area closure for North Atlantic right whales would be expanded to a continuous 37-km (20-nmi) wide zone extending from Delaware Bay to the southern limit of the AOI (**Figure C-4**). The expanded closure zone would fill gaps in coverage between Delaware Bay and Wilmington, North Carolina where the Mid-Atlantic SMA is discontinuous. It would also cover areas offshore Florida adjacent to the right whale critical habitat between the Southeast SMA and the southern boundary of the AOI. The expanded closure area would add 6,823,753 ac (27,615 km^2) to the SMA closure areas described under Alternative A, totaling 14,413,356 ac (58,329 km^2) and representing 7 percent of the total AOI (vs. approximately 4 percent under Alternative A).

The purpose of the expanded time area closure is to prevent impacts to right whales along their entire migration route and calving and nursery grounds. The SMAs do not provide continuous coverage of the right whale migratory route along the Mid-Atlantic coast because they focus on areas of heavy ship traffic (including entrances to certain bays and ports). Sightings data reviewed by NMFS in developing the ship strike rule indicate that approximately 83 percent of right whale sightings occur within 37 km (20 nmi) of the coast. The expanded time-area closure under Alternative B would form a continuous zone of the same width along the coast of the AOI (**Figure C-4**).

Under the expanded time-area closure, no G&G surveys using air guns would be authorized within the right whale critical habitat area from November 15 through April 15 nor within the Mid-Atlantic and Southeast U.S. Seasonal Management Areas (SMAs) and the expanded closure areas during the times when vessel speed restrictions are in effect under the Right Whale Ship Strike Reduction Rule (50 CFR 224.105). However, HRG surveys proposed in the critical habitat area, SMAs, and the expanded areas may be considered on a case-by-case basis only if: (1) they are proposed for renewable energy or marine minerals operations; and (2) they use acoustic sources other than air guns. The coincidence is necessary because of other biological use windows or project monitoring requirements. Any such authorization may include additional mitigation and monitoring requirements to avoid or significantly reduce impacts on right whales. Other supporting surveys (e.g., biological surveys) would not be affected by this restriction.

Exceptions to the right whale time-area closure could occur if a survey was needed to serve important operational or monitoring requirements for a particular project. For example, monitoring surveys for renewable energy (e.g., scour, cable burial) might need to take place at fixed intervals to capture seasonal changes or safety-related conditions. Another example would be a marine minerals project in which dredging is not seasonally restricted and real-time bathymetry data must be collected to track dredging operations or pre- and post-bathymetric surveys must be collected immediately before or after dredging to establish volumes borrowed.

4.2. TIME-AREA CLOSURE FOR NESTING SEA TURTLES OFFSHORE BREVARD COUNTY, FLORIDA

Alternative B would include a time-area closure in near-coastal waters offshore Brevard County, Florida during the sea turtle nesting season (May 1 to October 31) (**Figure C-4**). No airgun surveys would be authorized within the closure area during this time. Other non-airgun surveys in the closure area, including HRG surveys of renewable energy and marine minerals sites, would be reviewed on a case-by-case basis, and authorizations may include additional mitigation and monitoring requirements to avoid or reduce impacts on sea turtles.

The Brevard County time-area closure would include the portion of Brevard County that is within the AOI and would extend 11 km (5.9 nmi) offshore (**Figure C-5**). The southern border of Brevard County is beyond the southern boundary of the AOI. The closure would also extend radially from the northern county boundary at the shoreline. The extent is based on acoustic modeling of distances that could receive sound pressure levels of 160 dB re 1 µPa from a large airgun array in this area.

The purpose of the closure would be to avoid disturbing the large numbers of loggerhead turtles (and hatchlings) that are likely to be present in nearshore waters of Brevard County during turtle nesting and hatching season. Brevard County includes some of the world's most important nesting beaches for sea turtles. During the 2010 nesting season, there were over 31,000 loggerhead nests in Brevard County. The Archie Carr National Wildlife Refuge (ACNWR), located mainly within Brevard County, has been identified as the most important nesting area for loggerhead turtles in the western hemisphere. The ACNWR is critical to the recovery and survival of loggerhead turtles; it has been estimated that 25 percent of all loggerhead nesting in the U.S. occurs in the ACNWR. Nesting densities have been estimated at 625 nests per km (1,000 nests per mile) within the ACNWR.

The sea turtle time-area closure would overlap with the right whale time-area closure (**Figure C-5**). The overlapping area would be under closure most of the year (November 15 – April 15 for right whales and May 1 – October 31 for sea turtles). The right whale critical habitat area, the SMAs and expanded right whale closure areas, and the sea turtle closure area would be closed only to surveys deploying airguns, such as seismic surveys for oil and gas exploration and HRG surveys for oil and gas leases. Other activities such as HRG surveys for renewable energy or marine minerals programs could occur; as noted previously, applications would be reviewed on a case-by-case basis, and authorizations may include additional mitigation and monitoring requirements.

4.3. SEPARATION BETWEEN SIMULTANEOUS SEISMIC AIRGUN SURVEYS

Alternative B would establish a 40 km (25 mi) separation distance between simultaneously operating deep-penetration seismic surveys. This is in contrast to Alternative A, which does not require any geographic separation of concurrent seismic surveys. However, in practice, operators typically maintain a separation of about 17.5 km (9.5 nmi) between concurrent surveys to avoid interference (i.e., overlapping reflections received from multiple source arrays). The separation distance under Alternative B was created by rounding up this typical "operational" separation distance to 20 km (10.8 nmi), then doubling it.

The purpose of this measure is to limit ensonification of large areas of the AOI at the same time by specifying a conservative separation distance between simultaneous surveys. The largest exposure radii estimated for the 160 dB threshold for a large airgun array is approximately 15 km (8 nmi) (**Appendix D**). This operational separation requirement would be included as part of OCSLA authorizations (i.e., through lease stipulations, permits, conditions for plan approvals [for example, a renewable energy Construction and Operations Plan], and NTLs for existing leases).

4.4. SEISMIC AIRGUN SURVEY PROTOCOL WITH REQUIRED USE OF PASSIVE ACOUSTIC MONITORING

Under Alternative B, the use of PAM would be required as part of the seismic airgun survey protocol (rather than optional or "encouraged" as in Alternative A). The purpose would be to improve detection of marine mammals prior to and during seismic airgun surveys so that impacts can be avoided by shutting down or delaying startup of airgun arrays until the animals are outside the exclusion zone.

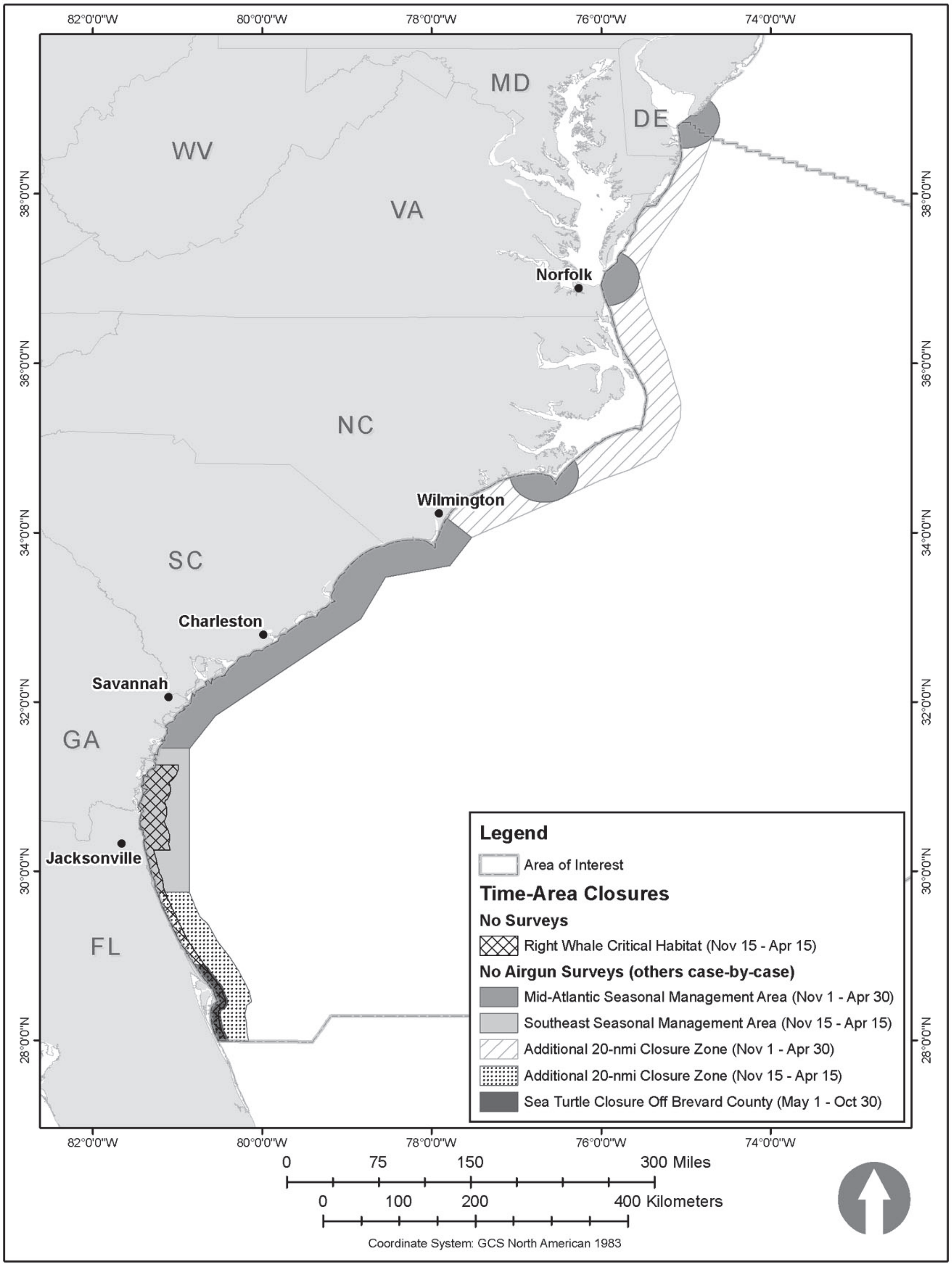


Figure C-4. Time-Area Closures under Alternative B.

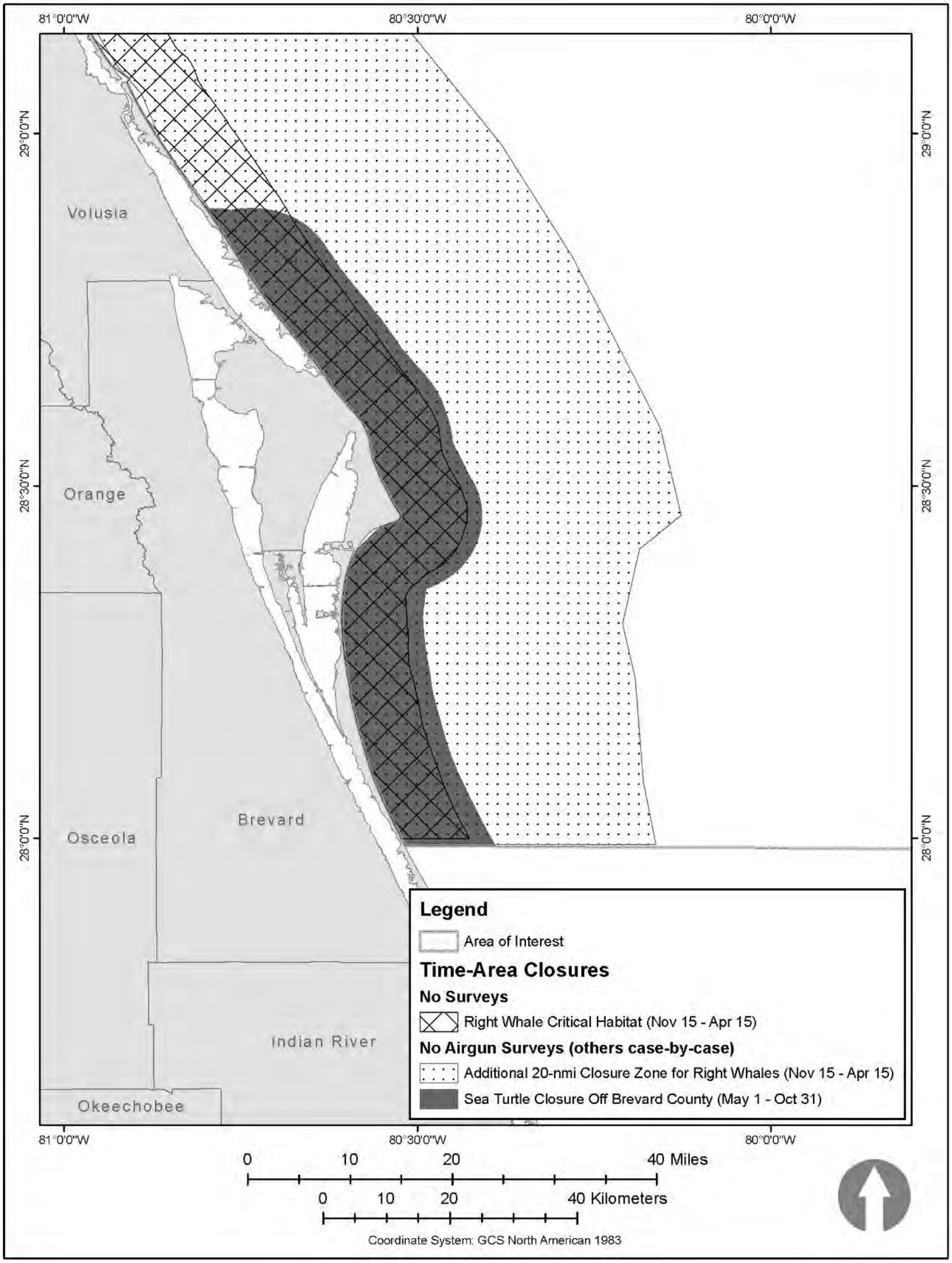


Figure C-5. Close-Up View of Time-Area Closures Offshore Brevard County under Alternative B.

5. OTHER MITIGATION AND MONITORING MEASURES CONSIDERED BUT NOT SELECTED

5.1. EXPANDED EXCLUSION ZONE (160 DB)

The seismic airgun survey protocol (see **Attachment**) includes an exclusion zone based on the range at which animals could be exposed to a received sound pressure level of 180 dB re 1 µPa, which is the current NMFS criterion for Level A harassment of cetaceans. The BOEM also considered establishing an exclusion zone based on a received sound pressure level of 160 dB re 1 µPa, which is the current NMFS criterion for Level B harassment of cetaceans. The purpose of this larger zone would be to avoid most Level B harassment of marine mammals. Based on calculations in **Appendix D** as summarized in **Table C-6**, this zone could extend up to 15 km (9.3 mi) from a large airgun array (5,400 in^3) and up to 3 km (1.9 mi) from a small airgun array (90 in^3) depending on the geographic location and season modeled. The mean distances were 8.5 km (5.3 mi) for a large airgun array and 1.9 km (1.2 mi) for a small airgun array.

Table C-6

Estimated Ranges (m) for Level B Harassment of Cetaceans by Airgun Arrays
Based on the NMFS 160-dB Criterion

Equipment	Number of Scenarios Modeled	Statistics	Current NMFS Level B Criterion 160 dB re 1 µPa (rms)	
			R_{max}	$R_{95\%}$
5,400 in^3 Airgun Array	21	Min (m)	5,184	4,959
		Max (m)	15,305	9,122
		Mean (m)	**8,679**	**6,856**
90 in^3 Airgun Array	35	Min (m)	1,294	1,100
		Max (m)	3,056	2,519
		Mean (m)	**1,919**	**1,684**

R_{max} is the maximum received sound pressure level. $R_{95\%}$ is the received level over 95% of the energy of the pulse.

Source: **Appendix D**.

The BOEM has determined that it is not feasible to routinely require monitoring of a 160-dB exclusion zone for seismic surveys using shipboard protected species observers. Effective monitoring of a larger, 160-dB exclusion zone may be feasible for some surveys if the 160-dB radius is small enough, but in many cases it would require a combination of techniques in addition to shipboard protected species observers. These could include aerial monitoring using manned or unmanned aircraft. As explained in **Chapter 4.4**, in current practice those techniques have significant limitations and disadvantages, given the geographic scope of the proposed action. The BOEM has determined that it is not currently feasible to require a combination of shipboard and aerial surveys on a routine basis to effectively monitor a 160-dB exclusion zone.

Although 160 dB is the current criterion for Level B harassment of cetaceans by impulsive sources, there is much variability and ongoing research about the levels of received sound that can cause behavioral responses in marine mammals, as well as the biological significance of those responses (National Research Council, 2005; Southall et al., 2007; Ellison et al., 2011). Also, although the exclusion zone included in the proposed action would not prevent Level B harassment of marine mammals, other measures such as the time-area closure for North Atlantic right whales (**Chapter 3.1**) would help to reduce the risk of those impacts.

5.2. PASSIVE ACOUSTIC MONITORING

The seismic airgun survey protocol based on encourages, but does not require, the use of PAM to supplement visual observations during monitoring of the exclusion zone (see **Attachment**).

There are two types of PAM systems in current use: fixed PAM and towed systems. Fixed systems have the capability to monitor underwater sounds over a wide range of spatial and temporal scales. There are three categories of fixed systems: autonomous recorders, radio-linked hydrophones, and fixed cable hydrophones. Autonomous recorders acquire and store acoustic data internally and are deployed semi-permanently underwater via a mooring or buoy and must be retrieved to access the data. They are capable of continuous recording, automatic detection/classification of sounds, and collection of non-acoustic data. Radio-linked hydrophone systems consist of hydrophones that are moored or fixed to the bottom and transmit the audio signal via radio waves to a receiving station on shore. The acoustic data can be monitored and processed in real or near-real time, or post-processed; however, these data are limited by bandwidth, range of transmission, and data transfer rates. Fixed cable hydrophone systems are typically located on the seafloor in a permanent configuration and can continuously send data to a receiving station. Fixed PAM systems are typically used for monitoring of marine mammals prior to a noise-generating activity (i.e., pile driving, offshore liquefied natural gas facility operation) at a fixed location (Bingham, 2011). For example, the Navy uses a fixed PAM system to monitor their test ranges.

Towed PAM systems were an early configuration applied to monitoring of marine mammals and are used with seismic airgun surveys and for close-range mitigation of the effects of other mobile activities. Towed arrays have the advantage of mobility and large spatial coverage, and therefore can be used for monitoring when the active source is mobile or covering a large spatial area. However, these systems have limited directional capabilities and challenges from both sound sources and the receivers being mobile. In addition, the towed systems have short time coverage, limited detection range, and are prone to masking problems from vessel noise, flow noise, and seismic source noise, including reverberation in shallow water. They also have limitations from ship availability, can be readily damaged, have difficulties localizing whale calls, and are difficult for use for detection in front of the vessel. Some of these limitations can be overcome, and new technology is being developed (e.g., vector sensors that can measure angles from a single point and assist with determining a more precise bearing of the animal) (Bingham, 2011). Every installation must be designed on a case-by-case basis given the requirements, environment, and resources available, and will need to consider the technological limitations to determine the best method for PAM, which will still need to be used in conjunction with visual observers, as PAM can be conducted at night when visual observations are not possible.

The software and hardware technologies for PAM currently exists that can perform many marine mammal monitoring and mitigation requirements under a wide range of operational conditions. However, these existing systems were not designed specifically for monitoring and mitigation for the offshore industrial application. No single technical approach has the ability to satisfy all or even most of the marine mammal monitoring and mitigation requirements of the offshore industry, and most likely an integrated approach is necessary. In addition, one of the limitations of PAM is that it works only if the animals produce sound that can be detected by the system; there are cryptic species of marine mammals that do not vocalize much or at all. Also, PAM is unable to simultaneously listen to all species in an area due to the wide range of frequencies of vocalizations. The PAM operators must be trained and experienced in order to successfully operate the systems. Fixed PAM technologies are more mature than towed PAM for mitigation and monitoring of marine mammals for the offshore industry. However, towed PAM has been used with some success to supplement visual monitoring of exclusion zones (Bingham, 2011). Towed arrays have been used primarily for sperm whale work, although they have the disadvantage of not being able to see straight ahead or through the ship unless the array is towed deeper than the bottom of the vessel.

Although the technology for detecting and locating underwater sounds and their sources in general is well developed, integrated hardware and software systems using acoustics specifically designed to locate and track marine mammals as mitigation for seismic airgun surveys are relatively new and have only been commercially available in recent years.

Currently, BOEM strongly encourages but does not require the use of PAM for seismic airgun surveys in the Gulf of Mexico (USDOI, BOEM and BSEE, 2012b). Under Joint BOEM-BSEE NTL 2012-G02 ("Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program"), PAM can be used to allow ramp-up during low visibility conditions when ramp-up would otherwise not be allowed. Canada and New Zealand have similar provisions, but no country requires routine use of PAM (Blue Planet Marine, 2010).

5.3. ACTIVE ACOUSTIC MONITORING

Active acoustic monitoring (AAM) is a method of determining the presence of marine mammals that use sonar. The AAM can potentially detect non-vocalizing marine mammals, whereas PAM can detect only vocalizing animals. However, there a number of significant issues with AAM, including that AAM systems transmit acoustic energy that may disturb marine mammals by influencing their behavior, and a separate permit may be necessary for its use (Bingham, 2011).

Active sonar produces a short sound pulse (energy) from a high power source (transducer) that travels through the water, reflects off objects, and travels back to a hydrophone receiver. The time it takes for the sound to travel to and from the target is easily computed from the difference in time that the source "ping" was sent and the time the reflected returning sound is measured. This travel time multiplied by the speed of sound in water divided by two is the approximate distance to the target. Bearing and range from the ship (or some other platform) can be converted to an absolute position on a map, given the ship position and some simple geometry. This is used, for example, to map seabed features, or to discriminate among different objects on the seafloor and in the water.

Potential problems with the use of AAM include standard sonar problems of reverberations and propagation in high-clutter shallow water environments, false alarms, species classification, methods of deployment, and cost (Stein, 2011). In addition, while AAM can identify animals swimming at right angle to the sound source, it is difficult to detect animals that are directly facing toward or away from the AAM sound source. It is also difficult to detect animals swimming at depth or animals swimming close to the surface with AAM. Another operational challenge with AAM is that it does not penetrate beneath thermoclines or haloclines, so animals swimming below them would also not be detected by AAM systems that are hull-mounted. In these situations, towed AAM systems would be required. In addition, AAM is not very useful in very shallow water, especially in rough seas. Currently the use of AAM technology for mitigation and monitoring of marine mammals during offshore industry activities is less advanced than either fixed or towed PAM systems. However, recent testing of the technology indicates that it can be useful in certain circumstances (Bingham, 2011).

There have also been some studies performed using high frequency fisheries sonar for locating marine mammals, killer whales in Norway in particular (Knudsen et al., 2007). These fisheries sonars operate at 20-30 kHz, with some operating at frequencies above 100 kHz. Most whales can detect frequencies in the 20-30 kHz range, but only smaller whales and dolphins can detect frequencies above 100 kHz (Knudsen et al., 2007). One study compared results using two sonars with different operating ranges, one operated at 20-30 kHz and the other operated at 110-122 kHz, and determined that the lower frequency sonar detected killer whales up to at least a 1,500-m (4,921-ft) range, whereas the higher frequency sonar did not give reliable detection at ranges greater than 400 m (1,312 ft) (Knudsen et al., 2007). However, most fish-finding sonars operate at around 30 kHz and would be good for detecting whales out to about 2 km (1.2 mi) and dolphins out to about 1 km (0.6 mi), but due to the frequency they also would be audible to all the small marine mammals and some of the larger whales. If the whale detection sonar is operated at frequencies that the animals might hear, the detection sonar also would need to be assessed as a source of disturbance, and the signal processing for species discrimination and potential cumulative effects would need to be addressed.

Development of an effective active sonar system will require consideration of the behavioral differences among various types of marine mammals. It may be difficult to develop a single approach that will work well with all species.

The BOEM has determined that it is not currently feasible to require AAM on a routine basis.

5.4. AERIAL SURVEYS

As a mitigation measure, aerial surveys with protected species observers provide the ability to observe and monitor large exclusion zones that cannot be adequately monitored from a vessel. As a mitigation measure, aerial surveys can monitor seismic exclusion zones, and if marine mammals are seen from the aircraft within the appropriate exclusion zone around the seismic source vessel or heading toward that zone, the aerial protected species observer could notify the seismic vessel on-board personnel in order for the sighting to be monitored, tracked, and appropriate mitigation measures initiated as necessary.

Aerial surveys are performed by two primary observers sitting at bubble windows on opposite sides of a small aircraft flying typically at 305-457 m (1,000-1,500 ft) above the surface. The observers search the sea surface visible through the bubble windows with the unaided eye. When a marine mammal is sighted, the observers record the species, number of individuals, size/sex/and age class when possible, activity, heading, and swimming speed category (if traveling). In addition, the observer will recorded the time, sightability (subjectively classified as excellent, good, moderately impaired, seriously impaired, or impossible), sea conditions, and sun glare (none, little, moderate, or severe) at intervals along the transect and at the end of each transect.

Aerial monitoring programs have significant limitations. Practically, they are limited to nearshore waters where there is an airport nearby to allow for adequate survey duration to allow for less transit time to and from the seismic survey vessel location. They also require additional logistical coordination, are sensitive to weather-related interruptions, and carry safety risks to survey personnel. For example, in May 2008 a small aircraft conducting marine mammal surveys for a renewable energy site offshore the Mid-Atlantic coast crashed in New Jersey, killing two people and injuring two others (Spoto, 2008).

Because of the significant limitations for manned aerial surveys in offshore waters due to the long transit times, unmanned aircraft systems (UASs) are a possibility for future use. The UASs have been emerging as a potential monitoring resource for detecting the presence of marine mammals during research as well as to meet mitigation and monitoring requirements during human activities, such as military sonar, seismic airgun surveys and geophysical research. A number of organizations, such as members of the offshore oil and gas industry, NMFS, BOEM, and the U.S. Navy, have been investigating the use of these surveys for a number of reasons, including but not limited to (1) unmanned surveys address safety concerns of putting human pilots and observers in potentially dangerous offshore areas; (2) unmanned aircraft can generally fly up to 20 hr, which is longer than manned surveys; (3) unmanned surveys can provide video data, even with high definition video cameras, which can be carefully reviewed post-flight rather than relying simply on visual observations during the flight; (4) unmanned surveys may provide for more frequent survey effort since securing personnel for flights is not necessary; and (5) aircraft can be launched from seismic ships. Preliminary scientific testing has been conducted by NMFS scientists at the National Marine Mammal Laboratory (NMML). However, NMFS has indicated that more testing is necessary before NMFS will give approval to its use as a mitigation or monitoring tool. In addition, the Federal Aviation Administration (FAA) currently prohibits use of UASs in U.S. airspace except under certain circumstances and with Federal sponsorship. The NMFS and BOEM are aware of ongoing efforts to gain FAA approval to deploy and test the UASs in order to assist in detecting marine mammals, but that approval is unlikely in the near future. Should the FAA grant UAS approval for use in offshore waters of the Atlantic Ocean, NMFS (and BOEM) would then make a final determination (informed by the results of additional UAS testing) on whether UASs are a practical tool to detect marine mammals in offshore waters in support of seismic survey monitoring programs.

5.5. AUTONOMOUS UNDERWATER VEHICLES

Autonomous underwater vehicles (AUVs) can be used to aid in PAM. The AUVs are capable of monitoring at vertical and horizontal scales similar to the diving and foraging movements of the whales themselves (Moore et al., 2007). Another advantage of deploying PAM from AUVs or towed platforms is that it provides a good means of detecting vocalizing marine mammals that is less affected by sea state, visibility, or presence of a survey vessel (USDOC, NOAA, 2007).

The Office of Naval Research is sponsoring studies involving five different AUVs using PAM on gliders. However, the results of these studies are not available at this time. One issue with using PAM on AUVs is that they are already slow vessels, and attaching a towed array system creates additional drag that slows them down further. The BOEM has determined that it is not currently feasible to use AUVs for monitoring seismic airgun surveys on a routine basis.

6. NON-AIRGUN ALTERNATIVES AND RELATED MEASURES CONSIDERED BUT NOT SELECTED

The impulsive airgun has been under scrutiny as a sound source for seismic exploration due to the potential impacts of underwater noise on marine life (Weilgart, 2010). Alternative acoustic source technologies generally put the same level of useable energy into the water as airguns, but over a longer period of time with a resulting lower peak sound level, i.e., they are quieter. One alternative, the low frequency passive seismic method, relies on naturally produced sounds and does not introduce any sound into the environment. These alternative acoustic sources are in various stages of development, and none of the systems with the potential to replace airguns as a seismic source are currently commercially available. However, they are discussed in detail in the technical write-up below along with technology-based mitigation measures that attempt to decrease the noise level of airguns.

6.1. MARINE VIBRATORS (VIBROSEIS)

6.1.1. Hydraulic

In 1981, Industrial Vehicles International, Inc. (IVI) signed an agreement with Britoil to develop a marine vibrator seismic source. In 1983, after scrapping the first design, IVI began developing a new system with the goal of producing a marine source able to emit a broad band, high amplitude, modulating frequency output. In 1985, the first commercial system was offered (IVI, 2003). The developed system consists of a marine vibrator, vibrator controller, and a power unit. The marine vibrator contains a piston within a housing with power supplied to the electrical, pneumatic and hydraulic systems by the power unit. An alternator, air compressor, and two pressure-driven hydraulic pumps are driven by an air-cooled diesel engine. The source is capable of generating modulated frequencies between 10 and 250 Hz and can be used in water depths as shallow as 1 m (3 ft). Signals are generated by conventional land vibrator controllers (IVI, 2010).

The system has been tested in various environments from transition zones to deepwater. Acoustic performance tests conducted at the Seneca Lake Facility of the Naval Underwater Systems Center in 1988 evaluated the system and determined that the marine vibrator was deficient in the low frequencies (Johnston, 1989; Walker et al., 1996). A comparison of marine vibrator, dynamite, and airgun sources in southern Louisiana concluded that the marine vibrator was a viable source for environmentally sensitive areas (Potter et al., 1997; Smith and Jenkerson, 1998). In transition zones, when coupled with the seafloor, marine vibrators operate like a land vibrator (Christensen, 1989). The best performance is on a seafloor which distributes the vibrator's forces.

Initial deepwater tests were conducted in the Gulf of Mexico by Geco-Prakla using a vibrator with an energy output approximately equivalent to a 1,000 in^3 airgun. Despite limitations of low frequency energy, good definition of reflectors down to 3 s indicated that the system was viable (Haldorsen et al., 1985). In 1996, a commercial field test comparing a six-marine-vibrator array with a single 4,258 in^3 airgun was undertaken in the North Sea by Geco-Prakla with the objectives of evaluating cost, reliability, production rate and quality of the geophysical data. After 2 weeks of data collection, a comparison between the marine vibrator and the airgun data indicated that the marine vibrator data contained more frequency content above 30 Hz and less frequency content below 10 Hz than the airgun data, but overall the data were comparable. Marine vibrator production rates were slightly lower than those of the airgun, but by the end of the survey, the technical downtime of the marine vibrator was similar to the airgun (Johnson et al., 1997).

Geco-Prakla, a subsidiary of Schlumberger, operated the marine vibrator program, conducting surveys and tests until 2000 when the exclusive-use agreement between IVI and Schlumberger expired (Bird, 2003). Industrial Vehicles International, Inc. continued to further develop the system into the early 2000's, but they are no longer actively marketing the product because there is no client base for the system. The significant expense to retrofit the marine exploration companies' ships to support marine vibrators is not offset by reduced operation costs or better data quality. Industrial Vehicles International, Inc. presently has marine vibrator systems that could be used for seismic data collection, but they would require renovation prior to deployment, which could take 3 months to a year (E. Christensen, Vice President IVI, pers. Comm. with J. Lage, BOEM, 2010).

6.1.2. Electric

Petroleum Geo-Services (PGS) began developing an electro-mechanical marine vibrator in the late 1990's. The original system consists of two transducers: the lower frequency (6-20 Hz) "Subtone" source and the higher frequency (20-100 Hz) "Triton" source (Tenghamn, 2005, 2006). Each vibrator is composed of a flextensional shell that surrounds an electrical coil, a magnetic circuit and a spring element. The sound in the water column is generated by a current in the coil, which causes the spring elements and shell to vibrate. Mechanical resonances from the shell and spring elements allow very efficient, high power generation (Tenghamn, 2005, 2006; Spence et al., 2007). The source tow-depth, generally between 5 and 25 m (16 and 82 ft) below the sea surface, is selected depending on the frequency and enhancement from the surface reflection which, to a certain degree, directs the acoustic signal downwards.

The reduction of the overall sound level and specifically the frequencies above 100 Hz, which are beyond the useful seismic range, is a major advantage of the system. Another is the reduction of acoustic power in comparison with conventional seismic sources, which occurs because the net source energy is spread over a long period of time (Tenghamn, 2005, 2006).

This system was compared to a 760 in^3 airgun along a 2D line in shallow water. A comparison of the data demonstrates that the marine vibrator equals the penetration of the airgun down to 5.5 s two-way travel time while emitting less acoustic energy into the water. A second test comparing dynamite to the vibrators was run in the transition zone (1.2-1.8 m [4-6 ft] of water). The transducers were mounted in a frame that was placed on the seabed. The vibrators lost the low frequency component due to attenuation of the signal, limiting the depth of penetration to approximately 2 s two-way travel time. However, in the shallower sections imaged by the vibrator, the two sources compared favorably (Tenghamn, 2005, 2006). Most of the trials have been conducted in shallow water (<100 m [<328 ft]); deeper water tests need to be run to determine performance depth range of the system (Tenghamn, 2010).

During the early period of development, the system proved the concept that it worked as a source for seismic data. However, unreliability prevented it from becoming a commercial system. Petroleum Geo-Services spent 2006 and 2007 conducting a feasibility study to improve reliability and testing a newly developed prototype. After that work, PGS developed three additional systems that are currently being tested. Petroleum Geo-Services does not have a commercial system available for data collection at this time. They project that, if funds were available, it would take 2-4 years to fully develop and test a system for commercial use (R. Tenghamn, VP Innovation and Business Development PGS, pers. comm. to J. Lage, BOEM, 2010).

6.2. LOW-FREQUENCY ACOUSTIC SOURCE (PATENTED) (LACS)

Originally designed as a ship sound simulator for the Norwegian navy, the low level acoustic combustion source (LACS) is being promoted as an alternative source for seismic acquisition (Weilgart, 2010). The LACS system is a combustion engine with a cylinder, spark plug, two pistons, two lids, and a shock absorber. It creates an acoustic pulse when two pistons push lids vertically in opposite directions; one wave reflects from the sea surface and combines with the downward moving wave. There is no bubble noise from this system as all air is vented and released at the surface, not into the underwater environment. The absence of bubble noise allows the system to produce long sequences of acoustic pulses at a rate of 11 shots per second; this allows the signal energy to be built up in time with a lower amount of energy put into the water (Askeland et al., 2007, 2009). The system design also controls the output signal waveform, which can reduce the amount of non-seismic (>100 Hz) frequencies produced (Spence et al., 2007). The transmitted pulses are recorded by a near-field hydrophone and seafloor and sediment reflections are recorded by a far-field streamer (Askeland et al., 2007, 2009).

Two LACS systems are being offered commercially. The LACS 4A has a diameter of 400 mm (15.7 in), a height of 600 mm (24 in), and a weight of approximately 100 kg (220 lb) in air. Pulse peak-peak pressure is 218 dB re 1µPa @ 1 m. Field test results of the LACS 4A system demonstrate that the system is capable of accurately imaging shallow sediments (~230 m [755 ft]) within a fjord environment (Askeland et al., 2008, 2009). This system is suitable for shallow penetration towed-streamer seismic surveys or vertical seismic profiling (Askeland et al., 2008).

The second system, the LACS 8A, theoretically has the potential to compete with a conventional deep penetration airgun seismic array. The LACS 8A system has pulse peak-peak pressure of 3 Bar meter or

230 dB re 1µPa @ 1 m. The weight is 400 kg (880 lb), and the diameter is 800 mm (31.5 in). Several LACS units may be operated together to provide an increased pulse pressure (Bjørge Naxys AS, 2010). This system currently does not exist, and the project is presently on hold. It would take at least 18 months to build and field test one of these systems if money came available to do so (J. Abrahamsen, Managing Director Bjørge Naxys, pers. comm. to J. Lage, BOEM, 2010).

6.3. DEEP-TOWED ACOUSTICS/GEOPHYSICS SYSTEM (DTAGS)

The Navy developed a deep-towed acoustics/geophysics system (DTAGS) to better characterize the geoacoustic properties of abyssal plain and other deepwater sediments. The system was tested and modified in the early 1990's and used in various locations around the world until it was lost at sea in 1997 (Gettrust et al., 1991; Wood et al., 2003).

The second generation DTAGS is based on the original design but with more modern electronics. It uses the same Helmholtz resonator source consisting of five concentric piezoelectric ceramic rings sealed in an oil-filled rubber sleeve to generate a broadband signal greater than 2 octaves. The optimum frequency performance range is between 220 and 1,000 Hz with a source level of 200 dB re 1 µPa @ 1 m, which is a major improvement over the original DTAGS. The source is extremely flexible, allowing for changes in waveform and decrease in sound level to produce a source amplitude, waveform, and frequency to suit specific requirements (Wood et al., 2003; Wood, 2010).

The DTAGS is towed behind a survey vessel usually at a level of 100 m (328 ft) above the seafloor and a vessel speed of 3.7 km/hr (2 kn); it can operate at full ocean depths (6,000 m [19,685 ft]). A 450-m (1,476 ft), 48-channel streamer array is towed behind the source to record the reflected signals. Seismic signals are digitized at each hydrophone and recorded in SEG Y format in a top-side unit (Wood et al., 2003; Wood, 2010). The DTAGS can also be configured with an aluminum landing plate, which transmits the acoustic energy directly into the seafloor. With this configuration, vertical bottom founded hydrophone arrays are used to receive reflections (Breland, 2010).

Proximity of the acoustic source to the seafloor is an advantage of the DTAGS. The system has a limit of 1 km (0.6 mi) penetration in most marine sediments (Wood et al., 2003). It has been used very successfully to map out gas hydrates in the Gulf of Mexico (Wood et al., 2008), Canadian Pacific (Wood and Gettrust, 2000; Wood et al., 2002), and Blake Ridge (Wood and Gettrust, 2000).

There is only one DTAGS in existence at this time. While it has imaged shallow sediments and gas hydrate environments extremely well, the current tool design could not replace a deep penetration airgun array for oil and gas exploration at this time; DTAGS was not designed for this purpose. However, there is no physical limitation to designing a resonant cavity source to simulate the frequency band of air guns.

6.4. LOW FREQUENCY PASSIVE SEISMIC METHODS FOR EXPLORATION

Low frequency passive seismic methods utilize microseisms, which are faint earth tremors caused by the natural sounds of the earth, to image the subsurface. A typical survey consists of highly sensitive receivers (usually broadband seismometers) placed in the area of interest to collect data over a period of time. Upon completion of the survey, the data are analyzed and filtered to remove all non-natural sounds, which is most efficiently completed using an automated process (Hanssen and Bussat, 2008).

All of the current methods use one of following three sources of natural sounds: natural seismicity, ocean waves, or microseism surface waves.

Natural seismicity uses the earth's own movements as a source of energy. Two techniques have been developed to utilize this energy source.

Daylight imaging (DLI) uses the local seismicity of an area to produce reflection seismic profiles, similar to those recorded in active seismic surveys (Claerbout, 1968). As in active reflection seismic operations, geophones are deployed; the target can be imaged using a regularly spaced 2D line geometry (Hohl and Mateeva, 2006; Draganov et al., 2009). The seismicity of the area, geologic complexity, and receiver sensitivity control the record length. The DLI can augment active seismic data, where it is difficult to collect data.

Local earthquake tomography (LET) also uses local seismicity of a region to map on the reservoir scale (Kapotas et al., 2003). However, it is used to calculate the velocity structure of the subsurface in 3D by analyzing each earthquake on multiple receivers and generating ray paths instead of cross-correlating the recorded signals. This method requires a longer period of data collection than the other methods to produce results.

Ocean waves are used as a sound source for the sea floor compliance technique. The method requires that ocean bottom seismometer (OBS) stations with highly-sensitive, broadband seismometers and differential or absolute pressure gauges be installed in water several hundred meters deep. In the right setting, a coarse one-dimensional (1D) S-wave velocity model of the subsurface down to the Moho can be generated using the measured water pressure and vertical movement of the seabed caused by large passing ocean waves (Crawford and Singh, 2008).

Ambient-noise (surface-wave) tomography [AN(SW)T] uses low frequency (between 0.1 and 1 Hz) ambient noise records to estimate shear wave velocities and structural information about the earth. The ambient noise used consists mainly of microseism surface waves (Rayleigh and Love waves) (Bussat and Kugler, 2009). This technique requires the use of broadband seismometers to record the low frequency surface waves, which can penetrate to depths of several kilometers (Bensen et al., 2007, 2008). Because the marine environment produces abundant, high-energy surface waves, a few hours or days of acquisition can produce good quality data. The AN(SW)T can be used in areas where seismic data are difficult to collect or in environmentally sensitive areas. While this technology is new and still in need of further testing, the lateral resolution at several kilometer depths may reach a few hundred meters, and the resolution may be better than gravimetric or magnetic data, which is promising for oil and gas exploration (Bussat and Kugler, 2009).

Surface-wave amplitudes (SWAs) is a 1D method that images the geological structure of the subsurface by analyzing passive acoustic data that have not been geophysically processed. The transformation of incoming micro-seismic surface waves, scattered at vertical discontinuities, into body waves may produce these data, but the process is not well understood (Gorbatikov et al., 2008).

Low-frequency spectroscopy (LFS), also known as low frequency passive seismic (LFPS) or hydrocarbon microtremor analysis (HyMAS), tests for an indication of subsurface hydrocarbon accumulation using spectral signatures gathered from the ambient seismic wave field recorded by broadband seismometers. The cause of the spectral anomalies, often called direct hydrocarbon indicators, is presently unknown, but the following reasons have been proposed: standing wave resonance, selective attenuation, resonant amplification (Graf et al., 2007), and pore fluid oscillations (Frehner et al., 2006; Holzner et al., 2009). Energy anomalies in the frequency range between 1 and 6 Hz have been observed in known hydrocarbon areas including Mexico (Saenger et al., 2009), Abu Dhabi (Birkelo et al., 2010), Brazil, Austria (Graf et al., 2007), and southern Asia (West et al., 2010). However, this methodology is highly dependent on the ability to process out all anthropogenic noise and topography (Hanssen and Bussat, 2008). This method is still in the early stage of development and has not been confirmed in the field during all studies (Ali et al., 2007; Al-Faraj, 2007).

The most successful use of low frequency passive micro-seismic data has been on land, where it is easier to isolate the extraneous noise from the natural signal. The technique is also promising in the marine environment. To ensure success of a marine survey: (1) it is imperative that the recording instruments are in proper contact with the substrate (the natural signal may not be accurately recorded in unconsolidated material) and (2) the increase in both anthropogenic and naturally produced noise in the marine environment is correctly filtered so that it does not mask the signal of interest.

Passive seismic surveys cannot replace active seismic acquisition. However, passive acoustic data have the potential to enhance oil recovery at a better resolution than magnetic or gravimetric methods (Bussat and Kugler, 2009), especially in areas that are environmentally sensitive or where active seismic operations are difficult.

6.5. LOW-IMPACT SEISMIC ARRAY (LISA)

Nedwell (2010) describes the concept of a low impact seismic array (LISA) based on the use of inexpensive but powerful and rugged electromagnetic projectors to replace airgun arrays. The prospective benefit was that since the signal could be well controlled, both in frequency content and in the direction in which the sound propagated, the possibility existed of undertaking seismic surveys in environmentally sensitive areas with little or no collateral environmental impact.

The LISA project embodies the idea of using a large array of small but powerful electromagnetic projectors to replace airgun arrays. Initial measurements were made on a small (n=4) array of existing electromagnetic transducers. It was found that a source level of about 142 dB re 1 μPa per volt @ 1 m was achieved, at a peak frequency of 25 Hz. The operating frequency could be reduced to below 10 Hz with reasonable modifications, allowing use of an array for seismic exploration. The results indicate that it would be possible to achieve an array source level of about 223 dB re 1 μPa @ 1 metre, which is adequate for seismic surveying.

6.6. FIBER OPTIC RECEIVERS

Short of replacing seismic airguns, improvements in fiber optic sensing and telemetering could allow use of smaller airguns and airgun arrays in the future (Nash and Strudley, 2010). Fiber optic receivers are receivers that incorporate optical fibers to transmit the received acoustic signal as light. They are most frequently used in the petroleum industry for seismic permanent reservoir monitoring, a four-dimensional (4D) reservoir evaluation application. The optical receivers are permanently placed on the seafloor, ensuring consistency and repeatability of the 4D surveys, better signal to noise ratios, and quality of subsequently collected data. Fiber optic systems are not new. Fiber optical components have been used by the military for years in similar applications for antisubmarine warfare and area surveillance, and they have proven to be highly reliable.

Fiber optic receivers are more sensitive than standard receivers, which allows for smaller airgun arrays to be used. While these receivers offer a benefit to the environment through a decrease in airgun noise, this technology is not presently available for towed-streamer surveys.

Fiber optic receivers typically are used in areas with large-scale oil and gas production requiring 4D monitoring. They would not be expected to be used in the Atlantic OCS during the time period of the Programmatic EIS because there are no active leases and only very limited exploration activities could occur between 2018-2020 if leasing is allowed (**Chapter 3** of the Programmatic EIS).

6.7. AIRGUN MODIFICATIONS TO LESSEN IMPACTS

In addition to alternative methods for seismic data collection, industry and the public sector have actively investigated the use of technology-based mitigation measures to lessen the impacts of airguns in the water.

6.7.1. Airgun Silencers

One such measure, an airgun silencer, which has acoustically absorptive foam rubber on metal plates mounted radially around the airgun, has demonstrated 0-6 dB reductions at frequencies above and 0-3 dB reductions below 700 Hz. This system has been tested only on low pressure airguns and is not a viable mitigation tool because it needs to be replaced after 100 shots (Spence et al., 2007).

6.7.2. Bubble Curtains

Bubble curtains generally consist of a rubber hose or metal pipe with holes to allow air passage and a connector hose attached to an air compressor. They have successfully been tested and used in conjunction with pile driving and at construction sites to frighten away fishes and decrease the noise level emitted into the surrounding water (Würsig et al., 2000; Sexton, 2007; Reyff, 2009). They have also been used as stand-alone units or with light and sound to deflect fishes away from dams or keep them out of specific areas (Pegg, 2005; Weiser, 2010).

The use of bubbles as a mitigation for seismic noise has also been pursued. During an initial test of the concept, the sound source was flanked by two bubble screens; it demonstrated that bubble curtains were capable of attenuating seismic energy up to 28 dB at 80 Hz while stationary in a lake. This two-bubble curtain configuration was field tested from a moving vessel in Venezuela and Aruba where a 12-dB suppression of low frequency sound and a decrease in the sound level of laterally projecting sound was documented (Sixma, 1996; Sixma and Stubbs, 1998). A different study in the Gulf of Mexico tested an "acoustic blanket" of bubbles as a method to suppress multiple reflections in the seismic data. The results of the acoustic blanket study determined that suppression of multiples was not practical using the current technology. However, the acoustic blanket measurably suppressed tube waves in boreholes and has the capability of blocking out thruster noises from a laying vessel during an ocean bottom cable survey, which would allow closer proximity of the shooting vessel and increase productivity (Ross et al., 2004, 2005).

A recent study "Methods to Reduce Lateral Noise Propagation from Seismic Exploration Vessels" was conducted by Stress Engineering Services Inc. under BOEM's Technology Assessment & Research Program (Ayers et al., 2009, 2010). The first phase of the project was spent researching, developing concepts for noise reduction, and evaluating the following three concepts: (1) an air bubble curtain; (2) focusing arrays to create a narrower footprint; and (3) decreasing noise by redesigning airguns. The air bubble curtain was selected as the most promising alternative, which led to more refined studies the second year (Ayers et al., 2009). A rigorous 3D acoustic analysis of the preferred bubble curtain design, including shallow-water seafloor effects and sound attenuation within the bubble curtain, was conducted during the second phase of the study. Results of the model indicated that the bubble curtains performed poorly at reducing sound levels and are not a viable option for mitigation of lateral noise propagation during seismic operations from a moving vessel (Ayers et al., 2010).

6.7.3. Reduction of Sound Source Levels

Reduction of sound source levels would lower the peak pressures from an airgun array and reduce the size of the impact zone, further reducing the potential for acoustic impacts. Reduction of sound source levels has been evaluated on a limited number of occasions in the Gulf of Mexico. Lowering the peak pressure reduces not only the peak frequency but also the entire spectrum of frequencies emitted from a typical airgun array. In general, the spectrum extends from a low frequency of 10 Hz, reaches a peak frequency at about 50 Hz, then falls off. However, frequencies above 50 Hz are extremely important as they provide data on the finer details of a hydrocarbon deposit.

G&G operators attempt to optimize their systems to use the broadest spectrum of energy, including higher frequencies. Reduction of source levels will reduce higher frequency output with the subsequent loss of these detailed data. The ability to interpret finer detail will be adversely affected should this mitigation measure be implemented. Therefore, G&G data acquired using lower sound source levels are considered unacceptable. Such data are extremely difficult to interpret. If data cannot be properly interpreted, there is also the possibility that areas would have to be re-surveyed, with the additional potential for impacts to marine mammals that might be present.

7. REFERENCES CITED

Al-Faraj, M. 2007. Workshop confirms promise of passive seismic for reservoir imaging and monitoring. First Break 25(7).

Ali, M.Y., K.A. Berteussen, J. Small, and B. Barkat. 2007. A low frequency, passive seismic experiment over a carbonate reservoir in Abu Dhabi. First Break 25:71–73

Askeland, B., H. Hobæk, and R. Mjelde. 2007. Marine seismics with a pulsed combustion source and Pseudo Noise codes. Marine Geophysical Research 28:109-117. Available at: https://bora.uib.no/bitstream/1956/2215/4/mgr%20article%20askeland.pdf. Accessed September 28, 2011.

Askeland, B., H. Hobæk, and R. Mjelde. 2008. Semiperiodic chirp sequences reduce autocorrelation side lobes of pulsed signals. Geophysics 73(3):Q19-Q27.

Askeland, B., B.O. Ruud, H. Hobæk, and R. Mjelde. 2009. A seismic field test with a Low-level Acoustic Combustion Source and Pseudo-Noise codes. Journal of Applied Geophysics 67:66-73.

Au, W.L. and M.C. Hastings. 2008. Hearing in marine animals, pp. 337-400. In: Principles of Marine Bioacoustics. Springer-Verlag, New York.

Ayers R.R., W.T. Jones, and D. Hannay. 2009. Methods to reduce lateral noise propagation from seismic exploration vessels. Report by Stress Engineering Services, Inc. for the U.S. Dept. of the Interior, Minerals Management Service. April 2009. Available at: http://www.boemre.gov/tarprojects/608/FinalMMSSEISMICREPORT.pdf. Accessed September 28, 2011.

Ayers R.R., W.T. Jones, and D. Hannay. 2010. Methods to reduce lateral noise propagation from seismic exploration vessels. Part 2: 3D acoustic analysis including attenuation of the effectiveness of the bubble curtain concept. Report by Stress Engineering Services, Inc. for the U.S. Dept. of the Interior, Minerals Management Service. July 2010. Available at: http://www.boemre.gov/tarprojects/608/AB.pdf. Accessed September 28, 2011.

Bensen, G.D., M.H. Ritzwoller, M.P. Barmin, A.L. Levshin, F. Lin, M.P. Moschetti, N.M. Shapio, and Y. Yang. 2007. Processing seismic ambient noise data to obtain reliable broad-band surface wave dispersion measurements. Geophys. J. Int. 169:1239-1260.

Bensen, G.D., M.H. Ritzwoller, and N.M Shapiro. 2008. Broad-band ambient noise surface wave tomography across the United States. J. Geophys. Res. 113:B05306.

Bingham, G. 2011. Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals: Workshop Proceedings; November 17-19, 2009, Boston, Massachusetts. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2011-002. 384 pp. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/5113.pdf. Accessed September 28, 2011.

Bird, J. 2003. The marine vibrator. The Leading Edge 22:368-370.

Birkelo, B., M. Duclos, B. Artman, B. Schechinger, B. Witten, A. Goertz, K. Weemstra, and M.T. Hadidi. 2010. A passive low-frequency seismic survey in Abu Dhabi – Shaheen project. SEG Expanded Abstracts 29:2207-2211.

Bjørge Naxys AS. 2010. LACS (patented) Low-frequency Acoustic Source.

Blue Planet Marine. 2010. Review of Seismic Guidelines and Reference Document. Discussion Paper prepared for Department of Conservation. Document Reference No. BPM-10-DOC-DP-v1.0. May 2010.

Breland, S. 2010. NRL-SSC Scientists Investigate Acoustics in Gulf of Mexico. NRL Press Release 59-10r. Available at: http://www.nrl.navy.mil/media/news-releases/59-10r/. Accessed September 28, 2011.

Bussat, S. and S. Kugler. 2009. Recording noise - estimating shear-wave velocities: Feasibility of offshore ambient-noise surfacewave tomography (answt) on a reservoir scale: SEG Technical Program Expanded Abstracts 28:1627–1631.

Christensen, E. 1989. Shallow water use of marine vibrators. SEG Abstracts 59(1):657-659.

Claerbout J.F. 1968. Synthesis of a layered medium from its acoustic transmission response. Geophysics 33:264-269.

Crawford, W.C. and S.C. Singh. 2008. Sediment shear velocities from seafloor compliance measurements: Faroes-Shetland Basin case study. Geophysical Prospecting 56:313-325.

Draganov D., X. Campman, J. Thorbecke, A. Verdel, and K. Wapenaar. 2009. Reflection images from ambient seismic noise. Geophysics 74(5):A63-A67.

Ellison, W.T., B.L. Southall, C.W. Clark, and A.S. Frankel. 2011. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conservation Biology, online version published December 19, 2011. DOI: 10.1111/j.1523-1739.2011.01803.x.

Federal Register. 2009. Renewable Energy and Alternate Uses of Existing Facilities on the Outer Continental Shelf. U.S. Dept. of the Interior, Minerals Management Service. April 29, 2009. 74 FR 81, pp. 19638-19871. Available at: http://www.boemre.gov/offshore/renewableenergy/PDF/FinalRenewableEnergyRule.pdf. Accessed January 13, 2012.

Federal Register. 2011. Research area within Grays' Reef National Marine Sanctuary. 76 FR 199, pp. 63824-63833. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. Available at: http://graysreef.noaa.gov/management/research/pdfs/fr_2011_26633_res_area.pdf. Accessed January 10, 2012.

Frehner, M., S.M. Schmalholz, R. Holzner, and Y. Podladchikov. 2006. Interpretation of hydrocarbon microtremors as pore fluid oscillations driven by ambient seismic noise: Presented at the Workshop on Passive Seismic, EAGE.

Gettrust, J.F., J.H. Ross, and M.M. Rowe. 1991. Development of a low frequency, deep tow geoacoustics system. Sea Technol. 32:23–32.

Gorbatikov, A.V., Stepanova, M. Yu., and G.E. Korablev. 2008. Microseisis Field Affected by Local Geological Heterogeneities and Microseismic Sounding of the Medium, Izvestiya, Physics of the Solid Earth 44(7):577-592. First Break 21(12).

Graf, R., S.M. Schmalholz, Y. Podladchikov, and E.H. Saenger. 2007. Passive low frequency spectral analysis: Exploring a new field in geophysics: World Oil 228:47–52.

Haldorsen, J., J.F. Desler, D. and Chu. 1985. Use of vibrators in a marine seismic source. SEG Abstracts 1:509-511.

Hanssen, P. and S. Bussat. 2008. Pitfalls in the analysis of low frequency passive seismic data. First Break 26:111-119.

Hohl, D. and A. Mateeva. 2006. Passive seismic reflectivity imaging with ocean-bottom cable data: 76th Annual International Meeting, SEG. Expanded Abstracts:1560–1564.

Holzner, R., P. Eschle, S. Dangel, M. Frehner, C. Narayanan, and D. Lakehal. 2009. Hydrocarbon microtremors interpreted as nonlinear oscillations driven by oceanic background waves. Communications in Nonlinear Science and Numerical Simulations 14:160-173.

International Association of Geophysical Contractors. 2011. Recommended mitigation measures for cetaceans during geophysical operations. Revision 02, June 2011. Available at: http://www.iagc.org/attachments/contentmanagers/7708/IAGC_doc_RevRecMitigationMeasuresCetaceans_VF_2011_06_03.pdf. Accessed September 28, 2011.

Industrial Vehicles International, Inc. 2003. The IVI Marine Vibrator Project. 8 pp.

Industrial Vehicles International, Inc. 2010. Marine Vibrator technical specifications.

Johnson, C. S. 1968. Relation between absolute threshold and duration-of-tone pulses in the bottlenosed porpoise. J. Acoust. Soc. Am. 43(4):757-763.

Johnston, R.C. 1989. Acoustic Tests of Industrial Vehicles International (IVI) Marine Vibrators. Naval Research Laboratory, Washington, D.C. NRL Memorandum Report No. 6399.

Johnson, G., S. Ronen, and T. Noss. 1997. Seismic data acquisition in deep water using a marine vibrator source. SEG Expanded Abstracts 16:63.

Kapotas, S., G-A. Tselentis, and N. Martakis. 2003. Case study in NW Greece of passive seismic tomography: a new tool for hydrocarbon exploration. First Break 21:37-42.

Knowlton, A.B., J.B. Ring, and B. Russell. 2002. Right Whale Sightings and Survey Effort in the Mid Atlantic Region: Migratory Corridor, Time Frame, and Proximity to Port Entrances. A report submitted to the NMFS Right Whale Ship Strike Working Group. July 2002.

Knudsen, F.R., O.B. Gammelasaeter, P.H. Kvadheim, and L. Nøttestad. 2007. Evaluation of fisheries sonars for whale detection in relation to seismic survey operations. Simrad AS, Norwegian Defense Research Establishment, Institute of Marine Research.

Lurton, X. and S. DeRuiter. 2011. Sound radiation of seafloor-mapping echosounders in the water column, in relation to the risks posed to marine mammals. Intl. Hydrographic Review, November 2011. Available at: http://www.iho.int/mtg_docs/IHReview/2011/IHR_Nov032011.pdf. Accessed January 24, 2012.

Moore, S.E, B.M. Howe, K.M. Stafford, and M.L. Boyd. 2007. Including whale call detection in standard ocean measurements: Application of acoustic seagliders. Marine Technology Society Journal 41:53-57.

Nash, P. and A.V. Strudley. 2010. Fibre optic receivers and their effects on source requirements, pp. 27-28. In: L.S. Weilgart (ed.), Report of the Workshop on Alternative Technologies to Seismic Airgun Surveys for Oil and Gas Exploration and their Potential for Reducing Impacts on Marine Mammals. Monterey, California, USA, 31st August - 1st September, 2009. Okeanos – Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 29 pp. Available at: http://www.sound-in-the-sea.org/download/AirgunAlt2010_en.pdf. Accessed September 28, 2011.

National Research Council. 2005. Marine mammal populations and ocean noise: Determining when noise causes biologically significant effects. The National Academies Press, Washington, DC. 99 pp. + apps. Available at: http://www.nap.edu/openbook.php?record_id=11147&page=1. Accessed September 6, 2011.

Nedwell, J. 2010. The dBht Method for Evaluating Impact, Airgun Silencers and LF Projector Arrays, pp. 26-27. In: L.S. Weilgart (ed.), Report of the Workshop on Alternative Technologies to Seismic Airgun Surveys for Oil and Gas Exploration and their Potential for Reducing Impacts on Marine Mammals. Monterey, California, USA, 31st August - 1st September, 2009. Okeanos – Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 29 pp. Available at: http://www.sound-in-the-sea.org/download/AirgunAlt2010_en.pdf. Accessed September 28, 2011.

Office of National Marine Sanctuaries. 2011. Gray's Reef National Marine Sanctuary Final Environmental Impact Statement Sanctuary Research Area Designation. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. Available at: http://graysreef.noaa.gov/management/research/pdfs/grnmsresearchareafeis.pdf. Accessed January 10, 2012.

Parsons, E.C.M., S.J. Dolman, M. Jasny, N.A. Rose, M.P. Simmonds, and A.J. Wright. 2009. A critique of the UK's JNCC seismic survey guidelines for minimising acoustic disturbance to marine mammals: Best practise? Mar. Poll. Bull. 58:643–651.

Pegg, M. 2005. Sound and Bubble Barrier Deters Asian Carp. ACES News. July 21, 2005.

Potter, G., A. Mann, M. Jenkerson, and J.M. Rodriguez. 1997. Comparison of marine vibrator, dynamite and airgun sources in the transition zone. Conference and Technical Exhibition - European Association of Geoscientists and Engineers 59:B018. Geneva, Switzerland, 26-30 May, 1997.

Reyff, J.A. 2009. Reducing Underwater Sounds with Air Bubble Curtains. Protecting Fish and Marine Mammals from Pile-Driving Noise. TR News 262:31-33. Available at: http://onlinepubs.trb.org/onlinepubs/trnews/trnews262rpo.pdf. Accessed September 28, 2011.

Ross W.S.,S.E. Heiney, E.N. Drake, R. Tenghamn, A. Stenzel. 2004. Mitigating Noise in Seismic Surveys with an "Acoustic Blanket. EAGE Research Workshop - Advances in Seismic Acquisition Technology, 20 September 2004.

Ross W.S., P.J. Lee, S.E. Heiney, and J.V. Young. 2005. Mitigating seismic noise with an acoustic blanket—the promise and the challenge. The Leading Edge 24(3):303-313.

Saenger, E.H., S. Schmalholz, S. Metzger, R. Habiger, T. Müller, and S. Rentsch. 2009. A passive seismic survey over a gas field: Analysis of low-frequency anomalies: Geophysics 74:029-040.

Sexton, T. 2007. Underwater Sound Levels Associated with Pile Driving during the Anacortes Ferry Terminal Dolphin Replacement Project, April 2007. 41 pp + appendix.

Sixma, E. 1996. Bubble Screen Acoustic Attenuation Test #1. Western Atlas/Western Geophysical Report. Conducted for Shell Venezuela. As cited in Ayers et al. (2009).

Sixma, E. and S. Stubbs. 1998. Air Bubble Screen Noise Suppression Tests in Lake Maracaibo. Sociedad Venezolana de Ingenieros Geofiscos, Congreso Venezolano de Geofisica.

Smith, J.G. and M.R. Jenkerson. 1998. Acquiring and processing marine vibrator data in the transition zone. Mobil Exploration and Producing Technical Centre.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4):411-521.

Spence, J. R. Fischer, M. Bahtiarian, L. Boroditsky, N. Jones, and R. Dempsey. 2007. Review of Existing and Future Potential Treatments for Reducing Underwater Sound from Oil and Gas Industry Activities. Prepared by Noise Control Engineering, Inc. for Joint Industry Programme on E&P Sound and Marine Life, London, U.K. NCE Report 07-001. 185 pp.

Spoto, M. 2008. Plane crash victims were conducting scientific survey. Available at: http://www.nj.com/news/index.ssf/2008/05/officials_plane_crash_victims.html. Accessed September 28, 2011.

Stein, P.J. 2011. Active Acoustic Monitoring Systems for Detecting, Localizing, tracking, and Classifying Marine Mammals and Fish. Journal of the Acoustical Society of America 129(4):2369.

Tenghamn, R. 2005. PGS Electrical Marine Vibrator. PGS Tech Link. 5(11):4

Tenghamn, R. 2006. An Electrical Marine Vibrator with Flextensional Shell. Exploration Geophysics. 37(4):286-291.

Tenghamn, R. 2010. Vibroseis Technology, pp. 23-24. In: L.S. Weilgart, (ed.), Report of the Workshop on Alternative Technologies to Seismic Airgun Surveys for Oil and Gas Exploration and their Potential for Reducing Impacts on Marine Mammals. Monterey, California, USA, 31st August – 1st September, 2009. Okeanos - Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 29+iii pp. Available at: http://www.sound-in-the-sea.org/download/AirgunAlt2010_en.pdf. Accessed September 28, 2011.

U.S. Dept. of Commerce, National Marine Fisheries Service. 2011a. Whalewatching guidelines for the northeast region including the Stellwagen Bank National Marine Sanctuary. Available at: http://www.nmfs.noaa.gov/pr/pdfs/education/viewing_northeast.pdf. No post date. Accessed October 24, 2011.

U.S. Dept. of Commerce, National Marine Fisheries Service. 2011b. Southeast region marine mammal and turtle viewing guidelines. Available at: http://www.nmfs.noaa.gov/pr/education/southeast/guidelines.htm. No post date. Accessed October 24, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. 2007. Report of the 2006 NOAA National Passive Acoustics Workshop. Developing a Strategic Program Plan for NOAA's Paassive Acoustic Ocean Observing System (PAOOS). NOAA Technical Memorandum NMFS-F/SPO-76. Woods Hole, MA, 11-13 April 2006. March 2007.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. 2011. Compliance Guide for Right Whale Ship Strike Reduction Rule (50 CFR 224.105). Available at: http://www.nero.noaa.gov/shipstrike/doc/compliance_guide.pdf. No Post Date. Accessed August 5, 2011.

U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement. 2011. Guidelines for Providing Geological and Geophysical, Hazards, and Archaeological Information Pursuant to 30 CFR 585. Available at: http://www.boemre.gov/offshore/RenewableEnergy/PDFs/GGARCH4-11-2011.pdf. Accessed September 2, 2011.

U.S. Dept. of the Interior, Bureau of Ocean Energy Management and Bureau of Safety and Environmental Enforcement. 2012a. Joint NTL 2012-G02. Notice to Lessees and Operators (NTL) of Federal oil, gas, and sulphur leases and pipeline right of-way holders in the OCS, Gulf of Mexico OCS Region. Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program. Available at: http://www.bsee.gov/Regulations-and-Guidance/Notices-to-Lessees/2012/2012-JOINT-G02-pdf.aspx. Accessed January 11, 2012.

U.S. Dept. of the Interior, Bureau of Ocean Energy Management and Bureau of Safety and Environmental Enforcement. 2012b. Joint NTL 2012-G01. Notice to Lessees and Operators (NTL) of Federal oil, gas, and sulphur leases and pipeline right of-way holders in the OCS, Gulf of Mexico OCS Region. Vessel Strike Avoidance and Injured/Dead Protected Species Reporting. Available at: http://www.boem.gov/Regulations/Notices-To-Lessees/2012/2012-JOINT-G01-pdf.aspx. Accessed January 11, 2012.

U.S. Dept. of the Interior, Bureau of Safety and Environmental Enforcement. 2012. BSEE NTL 2012-G01. Notice to Lessees and Operators (NTL) of Federal oil, gas, and sulphur leases and pipeline right of-way holders in the OCS, Gulf of Mexico OCS Region. Marine trash and debris awareness and elimination. Available at: http://www.bsee.gov/Regulations-and-Guidance/Notices-to-Lessees/2012/2012-BSEE-G01-pdf.aspx. Accessed January 11, 2012.

U.S. Dept. of the Interior, Minerals Management Service. 2005. NTL 2005-G07. Notice to Lessees and Operators (NTL) of Federal oil, gas, and sulphur leases and pipeline right of-way holders in the outer continental shelf, Gulf of Mexico OCS Region. Archaeology resource surveys and reports. Available at: http://www.gomr.boemre.gov/homepg/regulate/regs/ntls/2005%20NTLs/05-g07.html. Accessed November 2, 2011.

U.S. Dept. of the Interior, Minerals Management Service. 2007. Final Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf. U.S. Dept. of the Interior, Herndon, VA. OCS EIS/EA 2007-046. Available at: http://ocsenergy.anl.gov/eis/guide/index.cfm. No Post Date. Accessed August 4, 2011.

U.S. Dept. of the Interior, Minerals Management Service. 2009a. NTL 2009-G39. Notice to Lessees and Operators (NTL) of Federal oil, gas, and sulphur leases and pipeline right of-way holders in the outer continental shelf, Gulf of Mexico OCS Region. Biologically sensitive underwater features and areas. Available at: http://www.gomr.boemre.gov/homepg/regulate/regs/ntls/2009NTLs/09-G39.pdf. Accessed January 11, 2012.

U.S. Dept. of the Interior, Minerals Management Service. 2009b. NTL 2009-G40. Notice to Lessees and Operators (NTL) of Federal oil, gas, and sulphur leases and pipeline right of-way holders in the outer continental shelf, Gulf of Mexico OCS Region. Deepwater benthic communities. Available at: http://www.gomr.boemre.gov/homepg/regulate/regs/ntls/2009NTLs/09-G40.pdf. Accessed January 11, 2012.

U.S. Dept. of the Interior, Minerals Management Service. 2009c. NTL 2009-G06. Notice to Lessees and Operators (NTL) of Federal oil, gas, and sulphur leases and pipeline right of-way holders in the outer continental shelf, Gulf of Mexico OCS Region. Military Warning and Water Test Areas. Internet website: http://www.gomr.boemre.gov/homepg/regulate/regs/ntls/2009NTLs/09-G06.pdf. Accessed January 24, 2012.

Walker, L., G. Potter, M. Jenkerson, and J.M. Rodriguez. 1996. The acoustic output of a marine vibrator. SEG Annual Meeting Expanded Technical Program Abstracts with Biographies 66:17-20.

Weilgart, L.S. (ed.). 2010. Report of the Workshop on Alternative Technologies to Seismic Airgun Surveys for Oil and Gas Exploration and their Potential for Reducing Impacts on Marine Mammals. Monterey, California, USA, 31st August - 1st September, 2009. Okeanos – Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 29 pp. Available at: http://www.sound-in-the-sea.org/download/AirgunAlt2010_en.pdf. Accessed September 28, 2011.

Weir, C.R. and S.J. Dolman. 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. J. Intl. Wildlife Law & Policy 10:1-27.

Weiser, M. 2010. 'Bubble curtain' planned for slough to steer salmon to safety. The Sacramento Bee. December 7, 2010.

West, P., K. Cieślik, S. Haider, A. Aziz Muhamad, S.K.Chandola, A. Harun. 2010. Evaluating low frequency passive seismic data against an exploration well program. SEG Denver 2010 Annual Meeting.

Wood, W.T. 2010. A Deep Water Resonator Seismic Source, p. 21. A Deep Water Resonator Seismic Source in L.S. Weilgart, (ed.), Report of the Workshop on Alternative Technologies to Seismic Airgun Surveys for Oil and Gas Exploration and their Potential for Reducing Impacts on Marine Mammals. Monterey, California, USA, 31st August – 1st September, 2009. Okeanos - Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 29+iii pp. Available at: http://www.sound-in-the-sea.org/download/AirgunAlt2010_en.pdf. Accessed September 28, 2011.

Wood, W.T. and J.F. Gettrust. 2000. Deep-towed seismic investigations of methane hydrates, pp. 165-178. In: C.K. Paull and W.P. Dillon, (eds.), Natural Gas Hydrates: Occurrence, Distribution and Detection. AGU Monograph Series, No. 124. AGU, Washington, D.C.

Wood, W.T., J.F. Gettrust, N.R. Chapman, G.D. Spence, and R.D. Hyndman. 2002. Decreased stability of methane hydrates in marine sediments owing to phase-boundary roughness. Nature 420:656–660.

Wood, W.T., J.F. Gettrust, and S.E. Spychalski. 2003. A new deep-towed, multi-channel seismic system. Sea Technology 44:44-49.

Wood, W.T., P.E. Hart, D.R. Hutchinson, N. Dutta, F. Snyder, R.B. Coffin, and J.F. Getrrust. 2008. Gas and gas hydrate distribution around seafloor seeps in Mississippi Canyon, Northern Gulf of Mexico, using multi-resolution seismic imagery. Marine and Petroleum Geology 25(9):952-959.

Würsig, B., C.R. Greene, and T.A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Mar. Environ. Res. 49:79-93.

Attachment: Draft Seismic Airgun Survey Protocol

Note: The following draft protocol is based on Joint BOEM-BSEE NTL 2012-G02 (*Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program*) (USDOI, BOEM and BSEE, 2012b) with the following key exceptions:

- The protocol would apply to all seismic surveys in the AOI regardless of water depth. Joint NTL 2012-G02 does not apply to water depths less than 200 m (656 ft) in the Gulf of Mexico west of 88º W.
- The radius of the exclusion zone would be based on the predicted range at which animals could be exposed to a received sound pressure level of 180 dB re 1 µPa, which is the current NMFS criterion for Level A harassment of cetaceans. The radius would be calculated for each survey but would not be less than 500 m (1,640 ft). In contrast, Joint NTL 2012-G02 specifies a single, fixed radius of 500 m (1,640 ft).
- Shutdown of the airgun array would be required any time a marine mammal or sea turtle is observed within the exclusion zone, whether due to the animal's movement, the vessel's movement, or because the animal surfaced inside the exclusion zone. There would be an exception for dolphins approaching the vessel or towed equipment at a speed and vector that indicates voluntary approach to bow-ride or chase towed equipment. In contrast, Joint NTL 2012-G02 requires the exclusion zone to be clear of all marine mammals and sea turtles for startup, but shutdown is required only for whales entering the exclusion zone.

Background

The use of an airgun or airgun arrays while conducting seismic operations may have an impact on marine wildlife, including marine mammals and sea turtles. Some marine mammals, such as the North Atlantic right whale (*Eubalaena glacialis*), blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), sei whale (*Balaenoptera borealis*), humpback whale (*Megaptera novaeangliae*), sperm whale (*Physeter macrocephalus*), and Florida manatee (*Trichechus manatus latirostris*), that inhabit the AOI are protected under the ESA, and all marine mammals are protected under the MMPA. All five sea turtle species inhabiting the AOI are protected under the ESA. They are the loggerhead turtle (*Caretta caretta*), green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), Kemp's ridley turtle (*Lepidochelys kempii*), and leatherback turtle (*Dermochelys coriacea*).

In order to protect marine mammals and sea turtles during seismic operations, the NMFS requires seismic operators to use ramp-up and visual observation procedures when conducting seismic surveys. Procedures for ramp-up, protected species observer training, visual monitoring, and reporting are described in detail in this protocol. These mitigation measures apply to all seismic survey operations conducted regardless of water depth. Performance of these mitigation measures is also a condition of the approval of applications for geophysical permits. Permittees must demonstrate compliance with these mitigation measures by submitting to BOEM certain reports detailed in this protocol. The measures contained herein would apply to all on-lease surveys conducted under 30 CFR 550 and all off-lease surveys conducted under 30 CFR 551 in the AOI. In addition, the measures would apply to any deep penetration seismic surveys conducted to evaluate formation suitability for carbon sequestration in the renewable energy program.

Definitions

Terms used in this protocol have the following meanings:

1. Airgun means a device that releases compressed air into the water column, creating an acoustical energy pulse with the purpose of penetrating the seafloor.
2. Ramp-up means the gradual increase in emitted sound levels from an airgun array by systematically turning on the full complement of an array's airguns over a period of time.

3. Visual monitoring means the use of trained protected species observers to scan the ocean surface visually for the presence of marine mammals and sea turtles. These observers must have successfully completed a visual observer training program as described below. The area to be scanned visually includes, but is not limited to, the exclusion zone. Visual monitoring of an exclusion zone and adjacent waters is intended to establish and, when visual conditions allow, maintain a zone around the sound source and seismic vessel that is clear of marine mammals and sea turtles, thereby reducing or eliminating the potential for injury.
4. Exclusion zone means the area at and below the sea surface within a radius to be determined by calculating the maximum range at which animals could be exposed to a received sound pressure level of 180 dB re 1 µPa, which is the current NMFS criterion for Level A harassment of cetaceans. The distance is calculated from the center of an airgun array. Each survey vessel must maintain its own unique exclusion zone. The radius of the exclusion zone must be calculated independently for each survey based on the configuration of the airgun array and the ambient acoustic environment, but must not be less than 500 m (1,640 ft).
5. Dolphins mean all marine mammal species in the family Delphinidae. This includes, among others, killer whales, pilot whales, and all of the "dolphin" species.

Ramp-Up Procedures

The intent of ramp-up is to warn marine mammals and sea turtles of pending seismic operations and to allow sufficient time for those animals to leave the immediate vicinity. Under normal conditions, animals sensitive to these activities are expected to move out of the area. For all seismic surveys, including airgun testing, use the ramp-up procedures described below to allow marine mammals and sea turtles to depart the exclusion zone before seismic surveying begins.

Measures to conduct ramp-up procedures during all seismic survey operations, including airgun testing, are as follows:

1. Visually monitor the exclusion zone and adjacent waters for the absence of marine mammals and sea turtles for at least 30 min before initiating ramp-up procedures. If none are detected, you may initiate ramp-up procedures. <u>Do not initiate</u> ramp-up procedures at night or when you cannot visually monitor the exclusion zone for marine mammals and sea turtles if your minimum source level drops below 160 dB re 1 µPa-m (rms) (see measure 5).
2. Initiate ramp-up procedures by firing a single airgun. The preferred airgun to begin with should be the smallest airgun, in terms of energy output (dB) and volume (in^3).
3. Continue ramp-up by gradually activating additional airguns over a period of at least 20 min, but no longer than 40 min, until the desired operating level of the airgun array is obtained.
4. Immediately shut down all airguns, ceasing seismic operations at any time a marine mammal or sea turtle is detected entering or within the exclusion zone. However, shutdown would not be required for dolphins approaching the vessel or towed equipment at a speed and vector that indicates voluntary approach to bow-ride or chase towed equipment. After a shutdown, you may recommence seismic operations and ramp-up of airguns only when the exclusion zone has been visually inspected for at least 30 min to ensure the absence of marine mammals and sea turtles.
5. You may reduce the source level of the airgun array, using the same shot interval as the seismic survey, to maintain a minimum source level of 160 dB re 1 µPa-m (rms) for the duration of certain activities. By maintaining the minimum source level, you will not be required to conduct the 30-min visual clearance of the exclusion zone before ramping back up to full output. Activities that are appropriate for maintaining the minimum source level are (1) all turns between transect lines, when a survey using the full array is being conducted immediately prior to the turn and will be resumed immediately after the turn; and (2) unscheduled, unavoidable maintenance of the airgun array that requires the interruption of a survey to shut down the array.

> The survey should be resumed immediately after the repairs are completed. There may be other occasions when this practice is appropriate, but use of the minimum source level to avoid the 30-min visual clearance of the exclusion zone is only for events that occur during a survey using the full power array. The minimum sound source level is not to be used to allow a later ramp-up after dark or in conditions when ramp-up would not otherwise be allowed.

Protected Species Observer Program

Visual Observers

Visual observers who have completed a protected species observer training program as described below are required on all seismic vessels conducting operations in the AOI. at least two protected species visual observers will be required on watch aboard seismic vessels at all times during daylight hours (dawn to dusk) when seismic operations are being conducted, unless conditions (fog, rain, darkness) make sea surface observations impossible. If conditions deteriorate during daylight hours such that the sea surface observations are halted, visual observations must resume as soon as conditions permit. Operators may engage trained third party observers, utilize crew members after training as observers, or use a combination of both third party and crew observers. During these observations, the following guidelines shall be followed: (1) other than brief alerts to bridge personnel of maritime hazards, no additional duties may be assigned to the observer during his/her visual observation watch (if conditions warrant more vigilant look-outs when navigating around or near maritime hazards, additional personnel must be used to ensure that watching for protected species remains the primary focus of the on-watch observers); (2) no observer will be allowed more than 4 consecutive hours on watch as a visual observer; (3) a “break” time of no less than 2 hr must be allowed before an observer begins another visual monitoring watch rotation (break time means no assigned observational duties); and (4) no person (crew or third party) on watch as a visual observer will be assigned a combined watch schedule of more than 12 hr in a 24-hr period. Due to the concentration and diligence required during visual observation watches, operators who choose to use trained crew members in these positions may select only those crew members who demonstrate willingness as well as ability to perform these duties.

Training

All visual observers must have completed a protected species observer training course. The BOEM will not sanction particular trainers or training programs. However, basic training criteria have been established and must be adhered to by any entity that offers observer training. Operators may utilize observers trained by third parties, may send crew for training conducted by third parties, or may develop their own training program. All training programs offering to fulfill the observer training requirement must (1) furnish to BOEM a course information packet that includes the name and qualifications (i.e., experience, training completed, or educational background) of the instructor(s), the course outline or syllabus, and course reference material; (2) furnish each trainee with a document stating successful completion of the course; and (3) provide BOEM with names, affiliations, and dates of course completion of trainees.

The training course must include the following elements:

I. Brief overview of the MMPA and the ESA as they relate to seismic acquisition and protection of marine mammals and sea turtles in the Atlantic Ocean.
II. Brief overview of seismic acquisition operations.
III. Overview of seismic mitigation measures and the protected species observer program.
IV. Discussion of the role and responsibilities of the protected species observer, including
    a) Legal requirements (why you are here and what you do);
    b) Professional behavior (code of conduct);
    c) Integrity;
    d) Authority of protected species observer to call for shutdown of seismic acquisition operations;

- e) Assigned duties;
    - 1) What can be asked of the observer;
    - 2) What cannot be asked of the observer; and
- f) Reporting of violations and coercion;

V. Identification of Atlantic marine mammals and sea turtles.

VI. Cues and search methods for locating marine mammals and sea turtles.

VII. Data collection and reporting requirements:

- a) Forms and reports to BOEM via email on the 1st and 15th of each month; and
- b) Marine mammal or sea turtle in exclusion zone/shutdown report within 24 hr.

Visual Monitoring Methods

The observers on duty will look for marine mammals and sea turtles using the naked eye and hand-held binoculars provided by the seismic vessel operator. The observers will stand watch in a suitable location that will not interfere with navigation or operation of the vessel and that affords the observers an optimal view of the sea surface. The observers will provide 360º coverage surrounding the seismic vessel and adjust their positions appropriately to ensure adequate coverage of the entire area. These observations must be consistent, diligent, and free of distractions for the duration of the watch.

Visual monitoring will begin no less than 30 min prior to the beginning of ramp-up and continue until seismic operations cease or sighting conditions do not allow observation of the sea surface (e.g., fog, rain, darkness). If a marine mammal or sea turtle is observed, the observer should note and monitor the position (including latitude/longitude of the vessel and relative bearing and estimated distance to the animal) until the animal dives or moves out of visual range of the observer. Make sure you continue to observe for additional animals that may surface in the area, as often there are numerous animals that may surface at varying time intervals. At any time a marine mammal or sea turtle is observed within the exclusion zone, whether due to the animal's movement, the vessel's movement, or because the animal surfaced inside the exclusion zone, the observer will call for the immediate shutdown of the seismic operation, including airgun firing (the vessel may continue on its course but all airgun discharges must cease). However, shutdown would not be required for dolphins approaching the vessel or towed equipment at a speed and vector that indicates voluntary approach to bow-ride or chase towed equipment. The vessel operator must comply immediately with such a call by an on-watch visual observer. Any disagreement or discussion should occur only after shutdown. After a shutdown, when no marine mammals or sea turtles are sighted for at least a 30-min period, ramp-up of the source array may begin. Ramp-up cannot begin unless conditions allow the sea surface to be visually inspected for marine mammals and sea turtles for 30 min prior to commencement of ramp-up (unless the method described in the section entitled "Experimental Passive Acoustic Monitoring" is used). Thus, ramp-up cannot begin after dark or in conditions that prohibit visual inspection (fog, rain, etc.) of the exclusion zone. Any shutdown due to a marine mammal or sea turtle sighting within the exclusion zone must be followed by a 30-min all-clear period and then a standard, full ramp-up. Any shutdown for other reasons, including, but not limited to, mechanical or electronic failure, resulting in the cessation of the sound source for a period greater than 20 min, must also be followed by full ramp-up procedures. In recognition of occasional, short periods of the cessation of airgun firing for a variety of reasons, periods of airgun silence **not exceeding 20 min** in duration will not require ramp-up for the resumption of seismic operations if (1) visual surveys are continued diligently throughout the silent period (requiring daylight and reasonable sighting conditions), and (2) no marine mammals or sea turtles are observed in the exclusion zone. If marine mammals or sea turtles are observed in the exclusion zone during the short silent period, resumption of seismic survey operations must be preceded by ramp-up.

Reporting

The importance of accurate and complete reporting of the results of the mitigation measures cannot be overstated. Only through diligent and careful reporting can BOEM, and subsequently the NMFS, determine the need for and effectiveness of mitigation measures. Information on observer effort and seismic operations is as important as animal sighting and behavior data. In order to accommodate various vessels' bridge practices and preferences, vessel operators and observers may design data reporting forms in whatever format they deem convenient and appropriate. Alternatively, observers or vessel operators may adopt the United Kingdom's Joint Nature Conservation Committee forms (available at their website, www.jncc.gov.uk). At a minimum, the following items should be recorded and included in reports to BOEM:

Observer Effort Report: Prepared for each day during which seismic acquisition operations are conducted. Furnish an observer effort report to BOEM on the 1st and the 15th of each month that includes

- vessel name;
- observers' names and affiliations;
- survey type (e.g., site, 3D, 4D);
- BOEM Permit Number (for "off-lease seismic surveys") or OCS Lease Number (for "on-lease seismic surveys");
- date;
- time and latitude/longitude when daily visual survey began;
- time and latitude/longitude when daily visual survey ended; and
- average environmental conditions while on visual survey, including
  - wind speed and direction;
  - sea state (glassy, slight, choppy, rough, or Beaufort scale);
  - swell (low, medium, high, or swell height in meters); and
  - overall visibility (poor, moderate, good).

Survey Report: Prepared for each day during which seismic acquisition operations are conducted and the airguns are being discharged. Furnish a survey report to BOEM on the 1st and the 15th of each month during which operations are being conducted that includes

- vessel name;
- survey type (e.g., site, 3D, 4D);
- BOEM Permit Number (for "off-lease seismic surveys") or OCS Lease Number (for "on-lease seismic surveys");
- date;
- time pre-ramp-up survey begins;
- what marine mammals and sea turtles were seen during pre-ramp-up survey;
- time ramp-up begins;
- were marine mammals seen during ramp-up;
- time airgun array is operating at the desired intensity;
- what marine mammals and sea turtles were seen during survey;
- if marine mammals were seen, was any action taken (i.e., survey delayed, guns shut down);
- reason that marine mammals might not have been seen (e.g., swell, glare, fog); and
- time airgun array stops firing.

Sighting Report: Prepared for each sighting of a marine mammal or sea turtle made during seismic acquisition operations. Furnish a sighting report to BOEM on the 1st and the 15th of each month during which operations are being conducted that includes

- vessel name;
- survey type (e.g., site, 3D, 4D);
- BOEM Permit Number (for "off-lease seismic surveys") or OCS Lease Number (for "on-lease seismic surveys");
- date;
- time;
- watch status (Were you on watch or was this sighting made opportunistically by you or someone else?);

- observer or person who made the sighting;
- latitude/longitude of vessel;
- bearing of vessel;
- bearing and estimated range to animal(s) at first sighting;
- water depth (meters);
- species (or identification to lowest possible taxonomic level);
- certainty of identification (sure, most likely, best guess);
- total number of animals;
- number of juveniles;
- description (as many distinguishing features as possible of each individual seen, including length, shape, color and pattern, scars or marks, shape and size of dorsal fin, shape of head, and blow characteristics);
- direction of animal's travel – compass direction;
- direction of animal's travel – related to the vessel (drawing preferably);
- behavior (as explicit and detailed as possible; note any observed changes in behavior);
- activity of vessel;
- airguns firing (yes or no); and
- closest distance (meters) to animals from center of airgun or airgun array (whether firing or not).

Note: If this sighting was of a marine mammal or sea turtle within the exclusion zone that resulted in a shutdown of the airguns, include in the sighting report the observed behavior of the animal(s) before shutdown, the observed behavior following shutdown (specifically noting any change in behavior), and the length of time between shutdown and subsequent ramp-up to resume the seismic survey (note if seismic survey was not resumed as soon as possible following shutdown). Send this report to BOEM **within 24 hr of the shutdown**. These sightings should also be included in the first regular semi-monthly report following the incident.

Additional information, important points, and comments are encouraged. All reports will be submitted to BOEM on the 1st and the 15th of each month (with one exception noted above). Forms should be scanned (or data typed) and sent via email to BOEM.

Please note that these marine mammal and sea turtle reports are in addition to any reports required as a condition of the geophysical permit.

Borehole Seismic Surveys

Borehole seismic surveys differ from surface seismic surveys in a number of ways, including the use of much smaller airgun arrays, having an average survey time of 12-24 hr, utilizing a sound source that is not usually moving at 7.4-9.3 km/hr (4-5 kn), and requiring the capability of moving the receiver in the borehole between shots. Due to these differences, the following altered mitigations apply only to borehole seismic surveys:

- During daylight hours, when visual observations of the exclusion zone are being performed as required in this protocol, borehole seismic operations will not be required to ramp-up for shutdowns of 30 min or less in duration, as long as no marine mammals or sea turtles are observed in the exclusion zone during the shutdown. If a marine mammal or sea turtle is sighted in the exclusion zone, ramp-up is required and may begin only after visual surveys confirm that the exclusion zone has been clear for 30 min.
- During nighttime or when conditions prohibit visual observation of the exclusion zone, ramp-up will not be required for shutdowns of 20 min or less in duration. For borehole seismic surveys that utilize passive acoustics during nighttime and periods of poor visibility, ramp-up is not required for shutdowns of 30 min or less.

- Nighttime or poor visibility ramp-up is allowed only when passive acoustics are used to ensure that no marine mammals are present in the exclusion zone (as for all other seismic surveys). Operators are strongly encouraged to acquire the survey in daylight hours when possible.
- Protected species observers must be used during daylight hours, as required in this protocol, and may be stationed either on the source boat or on the associated drilling rig or platform if a clear view of the sea surface in the exclusion zone and adjacent waters is available.
- All other mitigations and provisions for seismic surveys as set forth in this protocol will apply to borehole seismic surveys.
- Reports should reference OCS Lease Number, Area/Block and Borehole Number.

Experimental Passive Acoustic Monitoring

Whales are very vocal marine mammals, and periods of silence are usually short and most often occur when these animals are at the surface and may be detected using visual observers. However, whales are at the greatest risk of potential injury from seismic airguns when they are submerged and under the airgun array. Passive acoustic monitoring appears to be very effective at detecting submerged and diving sperm whales, and some other marine mammal species, when they are not detectable by visual observation. The BOEM strongly encourages operators to participate in an experimental program by including passive acoustic monitoring as part of the protected species observer program. Inclusion of passive acoustic monitoring does **not** relieve an operator of any of the mitigations (including visual observations) in this protocol **with the following exception**: Monitoring for whales with a passive acoustic array by an observer proficient in its use will allow ramp-up and the subsequent start of a seismic survey during times of reduced visibility (darkness, fog, rain, etc.) when such ramp-up otherwise would not be permitted using only visual observers. If passive acoustic monitoring is used, an assessment must be included of the usefulness, effectiveness, and problems encountered with the use of that method of marine mammal detection in the reports described in this protocol. A description of the passive acoustic system, the software used, and the monitoring plan should also be reported to BOEM at the beginning of its use.

APPENDIX D

ACOUSTIC MODELING REPORT

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
AASM	Airgun Array Source Model
AIM	Acoustic Integration Model©
ANSI	American National Standard Institute
BOEM	Bureau of Ocean Energy Management
C	Celsius
cm	centimeter
CW	continuous wave
dB	decibel
G&G	geological and geophysical
GDEM	Generalized Digital Environmental Model
GI	generator-injector
HRG	high-resolution geophysical
Hz	hertz
in	inch
J	joule
kHz	kilohertz
kJ	kilojoule
km	kilometer
kV	kilovolt
kW	kilowatt
m	meter
MAI	Marine Acoustics, Inc.
mbsf	meters below seafloor
MMPA	Marine Mammal Protection Act
MONM	Marine Operations Noise Model
MOODS	Master Oceanographic Observational Data Set
NMFS	National Marine Fisheries Service
nmi	nautical mile
OCS	Outer Continental Shelf
ODP	Ocean Drilling Program
PE	parabolic equation
Programmatic EIS	Programmatic Environmental Impact Statement
ppt	parts per trillion
RAM	Range-dependent Acoustic Model
RL	received level
rms	root-mean-square
s	second
SEL	sound exposure level
SL	source level
SPL	sound pressure level
TL	transmission level
USGS	U.S. Geological Survey
VSP	vertical seismic profiling

1. INTRODUCTION

This report provides technical information in support of the Draft Programmatic Environmental Impact Statement (Programmatic EIS) prepared by the Bureau of Ocean Energy Management (BOEM) concerning the potential environmental effects of geological and geophysical (G&G) exploration activities on the Mid- and South Atlantic Outer Continental Shelf (OCS). Specifically, this document describes the procedures used to estimate the sound fields that would be generated by airgun arrays and electromechanical sources during said activities. Some background information on acoustic metrics and on the principal factors that affect sound propagation in the water is also provided as a preamble.

The proposed G&G exploration activities encompass a wide range of marine geotechnical studies using acoustic sources including seismic surveying (high-resolution, 2D, 3D, and vertical seismic profiling [VSP]), shallow sediment surveying, and shallow hazard assessment. The activities are to take place in different water depths (shallow water, shelf, slope, and deep ocean environments) and in different seasons of the year.

Six acoustic sources were considered for the modeling study to provide example acoustic fields for different types of G&G exploration activities. The sources are large and small airgun arrays, side-scan sonar, boomer, chirp subbottom profiler, and multibeam depth sounder.

Twenty-two modeling sites were defined throughout the Area of Interest (AOI). The water depth at the sites varied from 30 to 5,400 meters (m). Two types of bottom composition were considered: sand and clay, their selection depending on the water depth at the source. Twelve possible sound speed profiles for the water column were used to cover the variation of the sound velocity distribution in the water with location and season. Thirty-five distinct propagation scenarios resulted from considering different sound speed profiles at some of the modeling sites. Multiple sources were modeled for each scenario, yielding a total of 105 acoustic field estimates.

Two acoustic propagation models were employed to estimate the acoustic field radiated by the sound sources. A version of JASCO's Marine Operations Noise Model (MONM) based on the Range-dependent Acoustic Model (RAM) parabolic-equations model, MONM-RAM, was used to estimate the sound exposure levels (SELs) for low-frequency sources (below 2 kilohertz [kHz]) such as airgun arrays and boomer. A version based on the BELLHOP ray-trace model, MONM-BELLHOP, was used to model the sound propagation from mid- and high-frequency sources. Both models take into account the geoacoustic properties of the sea bottom, vertical sound speed profile in the water column, range-dependent bathymetry, and the directivity of the source.

The directional source levels (SLs) for the airgun arrays were modeled using the Airgun Array Source Model (AASM) based on the specifications of the source such as the arrangement and volume of the guns, firing pressure, and depth below the sea surface. The directivity function of the high-frequency sources was modeled numerically from technical specifications such as beam width, number of beams, and main beam axis direction; these were obtained from the manufacturer's product specification sheets or through direct contact with the manufacturer. The modeled directional SLs were used as the input for the acoustic propagation model.

2. BASICS OF UNDERWATER ACOUSTICS

2.1. ACOUSTIC METRICS

Various sound level metrics are commonly used to express the loudness of noise and estimate its effects on marine life. The three primary metrics of importance in this study are peak pressure, root-mean-square (rms) sound pressure level (SPL), and SEL. Some of the criteria used to assess potential bioacoustic impacts on marine species are expressed in terms of sound pressure; most relevantly, the safety and disturbance thresholds currently applied to marine seismic surveys by the U.S. National Marine Fisheries Service (NMFS) are based on the rms SPL metric as adapted for impulsive sound sources. Other criteria proposed in more recent studies, like Southall et al. (2007), place greater emphasis on sound exposure and define impact thresholds in terms of the SEL metric.

The peak pressure is defined as the maximum absolute value of the amplitude of a pressure time series $p(t)$.

The rms SPL (dB re 1 µPa, [American National Standard Institute] ANSI symbol L_p) is the rms of the pressure level, *p(t)*, received at a location over a time interval, *T*:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt\right) \tag{1}$$

The rms SPL can be thought of as a measure of the average pressure or as the "effective" pressure over the duration of an acoustic event, such as a single acoustic pulse. Because the time interval, *T*, is used as a divisor, pulses that are more spread out in time have a lower rms SPL for the same total acoustic energy. The time interval, *T*, is conventionally defined as the "90 percent energy pulse duration" rather than a fixed time window (Malme et al., 1986, Greene, 1997, McCauley et al., 1998).

For a pure sine wave the peak pressure (dB re 1 µPa, ANSI symbol L_{pk}) and rms SPL are related through a simple expression (Laughton and Warne, 2003):

$$L_{pk} = 10\log_{10}\left(\sqrt{2}\frac{1}{T}\int_T p^2(t)dt\right) = L_p + 3\text{dB} \tag{2}$$

Sound exposure level (dB re 1 µPa^2·s, ANSI symbol L_E) is the time-integral of the square pressure over a fixed time interval, *T*:

$$L_E = 10\log_{10}\left(\int_T p^2(t)dt\right) \tag{3}$$

Sound exposure level represents the total acoustic energy delivered over the duration of an acoustic event.

Because the rms SPL and SEL are both computed from the integral of square pressure, these metrics are related numerically by a simple expression which depends only on the duration of the integration time interval *T*:

$$L_p = L_E - 10\log_{10}(T) \tag{4}$$

For continuous sound sources, a time interval of one second is conventionally used, and the rms SPL is equal to the SEL. For impulsive sources, an objective definition of pulse duration is needed when defining the rms SPL. As previously mentioned, the pulse duration is conventionally taken to be the interval during which 90 percent of the pulse energy is received at a location from the source.

2.2. MAJOR FACTORS AFFECTING UNDERWATER SOUND PROPAGATION

The propagation of sound in the ocean environment is a complex phenomenon to model. Multiple factors can affect the response of the medium to an acoustic wave and the propagation loss of acoustic energy. Some factors, such as geometric spreading, refraction, and absorption are well understood and their influence can be fairly readily calculated. Others, such as scattering, can be difficult to quantify because of their dependence on fine-scale features of the local environment; it is possible, however, to estimate and predict their effect using more empirical approaches. In the sections that follow, the principal factors affecting sound propagation in the ocean are briefly discussed in terms of their numerical estimation.

2.2.1. Geometric Spreading

In a homogeneous free space the wave front moving away from a point-like source has the form of a sphere, whose area (A) increases proportionally to the square of the distance ($A \propto R^2$). In turn, the received pressure is inversely proportional to the square root of the area ($p \propto A^{-1/2}$). Therefore, in a free space the received pressure is inversely proportional to the distance from the source ($p \propto R^{-1}$). In terms of the sound level in decibel, this means that the transmission loss (TL) due to spherical spreading is equal to $20 \cdot \log_{10} R$.

Once the acoustic wave front reaches the seafloor, the spreading can no longer be considered spherical. In the water column, constrained by the sea surface and the sea bottom and at distances greater than the water depth, the acoustic wave front can be approximated more closely as a cylinder. The area of the side of a cylinder is proportional to the radius ($A \propto R$), and the received pressure is thus inversely proportional to the square root of the distance ($p \propto R^{-1/2}$). In decibel terms, the TL due to cylindrical spreading is therefore equal to $20 \cdot \log_{10} R^{1/2}$ or $10 \cdot \log_{10} R$.

In the oceanic environment, the TL due to geometric spreading of the acoustic wave front is generally calculated as spherical spreading for ranges from the source up to the water depth, and as cylindrical spreading beyond that distance.

2.2.2. Absorption

As sound waves propagate they interact at a molecular level with the constituents of sea water through a range of mechanisms, resulting in absorption of some of the sound energy (Thorp, 1965; Fisher and Simmons, 1977; Francois and Garrison, 1982a; Francois and Garrison, 1982b; Medwin, 2005). This occurs even in completely particulate-free waters and is in addition to energy losses from scattering by objects such as zooplankton or suspended sediments. The absorption coefficient depends on such factors as temperature, salinity, and pressure, and is different for acoustic waves of different frequencies.

The loss of sound energy by absorption is expressed as an attenuation coefficient in units of decibels per kilometer (dB/km). This coefficient is computed from empirical equations and increases generally with the square of frequency.

A representative curve of absorption loss as a function of frequency is shown in **Figure D-1**. The absorption of the acoustic wave energy is virtually nil in the low-frequency range (below 500 hertz [Hz]). It starts having a noticeable effect (at least 1 dB over ranges of 10-20 km) at frequencies above 1 kHz. The absorption loss increases markedly for higher frequencies; for a 100 kHz acoustic signal the absorption loss can exceed 30 dB over just 1 km kHz. In the context of this study the absorption loss is an important factor for the high-frequency electromechanical sources whereas it plays virtually no role in the attenuation of sound from airgun sources.

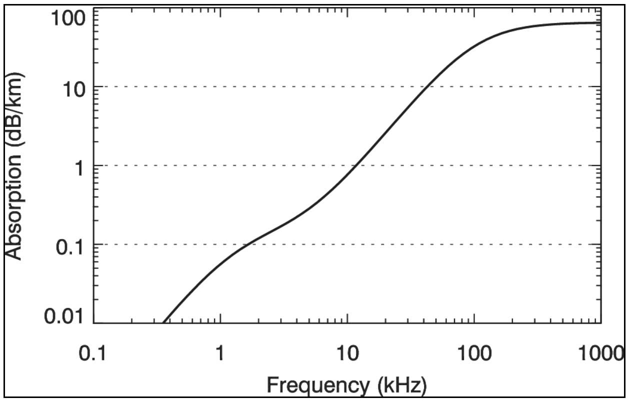

Figure D-1. Sample Plot of Absorption Loss Versus Frequency (T° = 15 °C, Salinity = 33 ppt, z = 50 m).

2.2.3. Refraction

Refraction is a change of direction in a propagating wave because of spatial variations in sound speed within the medium. As a wave travels across a sound speed interface or gradient, portions of the wave front travel at different speeds, resulting in bending of the ray path (Medwin, 2005). The ray path bends away from a region with a higher sound speed toward a region with a lower sound speed. By affecting travel paths within the medium, refraction can alter the angle of arrival of the sound at a receiver as well as the angle of incidence upon boundaries (e.g., the seafloor).

In order for refraction to occur, the medium must exhibit a spatial variation of the sound velocity over a scale comparable to the wavelength of the propagating wave. The major variables affecting the sound speed in sea water are the temperature, pressure, and salinity. The dependence is direct for all three variables; with an increase of the parameter, the sound speed also increases.

Both temperature and pressure in the ocean have significant variation with depth, resulting in a spread of the sound velocity in the water column that can exceed a 60 meters per second (m/s) differential between maximum and minimum. As the physical parameters of the water can vary with time over a daily or seasonal cycle, so does the sound speed. The longer the period of the variation, the deeper the water layers that can be affected by it. In general, seasonal variations of the sound speed can be observed to depths up to 300 m. Water depths of more than 1,200 m exhibit a uniform sound speed gradient on a global scale.

Figure D-2 presents an example of a sound speed profile that can be observed in the ocean. Seasonal variations occur in the mixed layer, which, depending on ambient conditions, can have either a positive or negative vertical sound speed gradient or none at all. During cold months of the year when temperature in the upper mixed layer increases with depth, upward refracting conditions can be induced by the positive sound speed gradient in the top water layer. In such conditions the sound tends to be channeled in the near-surface layer, referred to as a surface duct, as it is repeatedly reflected downward at the water surface and refracted upward by the positive sound speed gradient (Medwin, 2005). In the underlying thermocline region both temperature and sound speed decline, but below this, the temperature is constant and sound speed begins to increase again with depth. The sound velocity minimum results in acoustic refraction from both below and above toward the depth at which the minimum occurs, forming a propagation channel. This allows sound to travel without interaction with either the bottom or the sea surface, significantly reducing TL. The deep sound channel is an important stable channel for long-range propagation, allowing low-frequency sound to travel thousands of kilometers (Medwin, 2005). In shallow continental shelf regions, the water depth is not sufficient to form a deep sound channel. Sound propagation in such regions is, in general, strongly affected by seasonal and daily temperature changes.

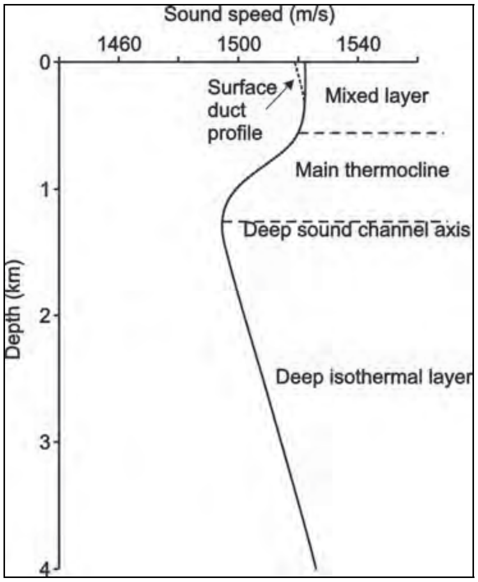

Figure D-2. Generic Sound Speed Profile with Some Common Features Defined.

In deep ocean areas, features of the acoustic field known as convergence zones can be formed because of strong refractive conditions in the deep isothermal layer. Rays emitted from the source at different angles can be focused by refraction in certain volumes, increasing the overall RLs compared with the surrounding areas. The increase can be as high as 20 dB; such convergence zones, however, are localized. An example of an acoustic field with convergence zones is shown in **Figure D-3**. In the figure, the convergence zone where the received acoustic level reaches a local maximum can be observed near the surface at 65 and 130 km from the source; in a cross section it would have the form of a ring with a width of several hundred meters and a height of several tens of meters.

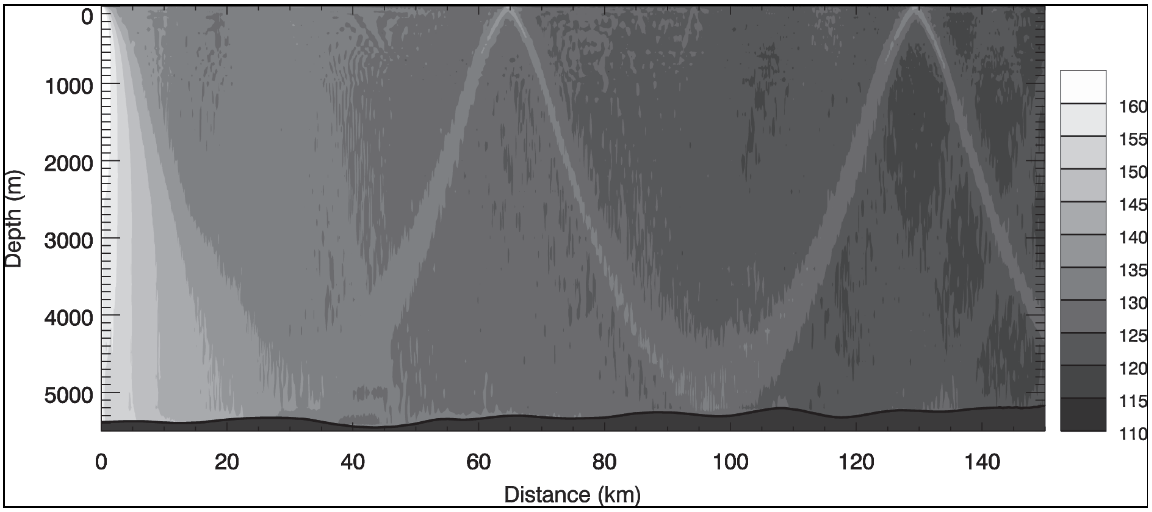

Figure D-3. Example of an Acoustic Field from an Airgun Array Source with Convergence Zones.

2.2.4. Scattering

Scattering is a general term that covers several types of dispersive phenomena arising from the interaction of a propagating wave front with inhomogeneities in the medium (e.g., suspended particulates, bubbles, buried objects, air-sea or sea-sediment interfaces). Sound energy arriving at an object may bend around it (diffraction) and/or be scattered back toward the source (backscattering) or in other directions. For complex objects (e.g., a rough seafloor), the nature of these interactions can be quite complicated, as individual portions of a wave front are scattered differently (Medwin, 2005). However, if the acoustic wavelength is much greater than the scale of the non-uniformities in the medium (as is most often the case for low-frequency sounds) the effect of scattering on propagation loss is negligible. As the source spectral maximum of airgun arrays is below 200 Hz, sound propagation from such sources is virtually unaffected by scattering. In contrast, scattering loss effects are noticeable for electromechanical sources operating at high frequencies – several kHz and higher.

2.2.5. Bathymetry

Water depth is very influential on sound propagation, particularly at frequencies below a few kHz. In shallow water (less than ~100 m depth) acoustic propagation loss is dominated by reflection, transmission, and scattering of sound at the seabed. In deep water (greater than ~1 km depth) sound propagation is largely driven by refraction in the water column. At intermediate water column depths, sound propagation is influenced by a combination of these factors.

Low-frequency acoustic waves may not be able to propagate through a shallow water column even in otherwise non-favourable conditions. If the wavelength of the sound is four times greater than the water depth, mode cut-off does occur (essentially the medium cannot support the oscillation) and the TL increases drastically compared to higher frequency waves (Clay and Medwin, 1977).

Also, as discussed in an earlier section, the type of geometric spreading of the acoustic wave front is dependent on the water depth, which defines at which range from the source spherical spreading switches to cylindrical spreading. The TL in the spherical spreading regime is twice as large as in the cylindrical one, so the bathymetry can be very influential on propagation loss for this reason alone.

2.2.6. Source Depth

The radiated power of an underwater sound emitter depends on the position of the source below the sea surface. The propagation model used is designed to fully account for the source depth. The effectiveness of the source at a specific frequency, defined as the ratio of radiated power to the nominal power of the source placed in a free space, increases with depth and depends on the ratio of the source depth to the acoustic wavelength (z_s/λ) (Brekhovskikh and Lysanov, 2003). The effectiveness increases approximately linearly from 0 at $z_s = 0$ reaching value of 1.0 at $z_s/\lambda = 1/4$ and 1.2 at $z_s/\lambda = 3/8$. For example, the effectiveness of a broadband source placed at 10 m depth with 1,500 m/s sound velocity will be 1.2 at 56 Hz and only about 0.27 at 10 Hz.

2.2.7. Bottom Loss

Bottom loss is the amount of the original acoustic wave energy that is lost at the water-sediment interface through coupling of the sound into the sediment. Bottom loss or TL is the complement of the reflection coefficient, to be defined below.

An acoustic wave travelling in a medium can be reflected from an interface at which abrupt change in media parameters is observed. Generally at the interface only a portion of the total acoustic energy is reflected back and the rest is transmitted past the interface. The reflection coefficient is the ratio of the amount of the reflected energy to the original energy of an incoming acoustic wave.

The reflection coefficient depends on the discrepancy of the acoustic impedances (defined as the product of density and sound velocity) of the media on each side of the interface. The greater the change of acoustic properties between the media, and hence the mismatch of the impedances, the closer to unity is the reflection coefficient. This coefficient also depends on the incident angle of the acoustic wave; it has its minimal value when the incident angle is 90° (normal to the interface) and can reach unity at sufficiently glancing angles for certain types of interface.

For the purpose of numerical modeling of sound propagation, the reflection coefficient or bottom loss can be calculated exactly given the properties of the media and the incident angle. In practice, however, there is often uncertainty associated with the estimation of these parameters. The spatial variation of sediment properties can also be significant, which further complicates the estimations. Certain rules of thumb apply to the approximate gauging of bottom loss: since the sound velocity and density of a sediment both increase with grain size, resulting in greater impedance mismatch relative to the water, the bottom loss for sediments with larger grain size is lower than for the sediments with smaller grain size. In general, a sand bottom is more reflective and thus less acoustically absorptive than a clay bottom.

2.3. ACOUSTIC IMPACT CRITERIA

2.3.1. M-Weighting

The potential for anthropogenic underwater noise to affect marine species depends on the species' ability to hear the sounds produced (Ireland et al., 2007). Noises are less likely to disturb animals if they are at frequencies that the animal cannot hear well. An exception is when the sound pressure is so high that it can cause physical injury. For non-injurious sound levels, frequency weighting curves based on audiograms may be applied to weight the importance of sound levels at particular frequencies in a manner reflective of the receiver's sensitivity to those frequencies (Nedwell and Turnpenny, 1998).

An NMFS-sponsored Noise Criteria Committee has proposed standard frequency weighting curves — referred to as M-weighting filters — for use with marine mammal species (Gentry et al., 2004). M-weighting filters are band-pass filter networks that are designed to reduce the importance of inaudible or less-audible frequencies for four marine mammal functional hearing groups:

1. Low-frequency cetaceans;
2. Mid-frequency cetaceans;
3. High-frequency cetaceans; and
4. Pinnipeds.

The amount of discount applied by M-weighting filters for less-audible frequencies is not as great as would be indicated by the corresponding audiograms for these groups of species. The rationale for applying a smaller discount than would be suggested by the audiogram is in part because of an observed characteristic of mammalian hearing that perceived equal loudness curves increasingly have less rapid roll-off outside the most sensitive hearing frequency range as sound levels increase. This is the reason that C-weighting curves for humans, used for assessing very loud sounds such as blasts, are flatter than A-weighting curves used for quiet to mid-level sounds. Additionally, out-of-band frequencies, though less audible, can still cause physical injury if pressure levels are very high. The M-weighting filters therefore are primarily intended to be applied at high sound levels where effects such as temporary or permanent hearing threshold shifts may occur. The use of M-weighting should be considered precautionary (in the sense of overestimating the potential for an effect) when applied to lower level effects such as onset of behavioral response. **Figure D-4** shows the decibel frequency weighting of the four standard underwater M-weighting filters.

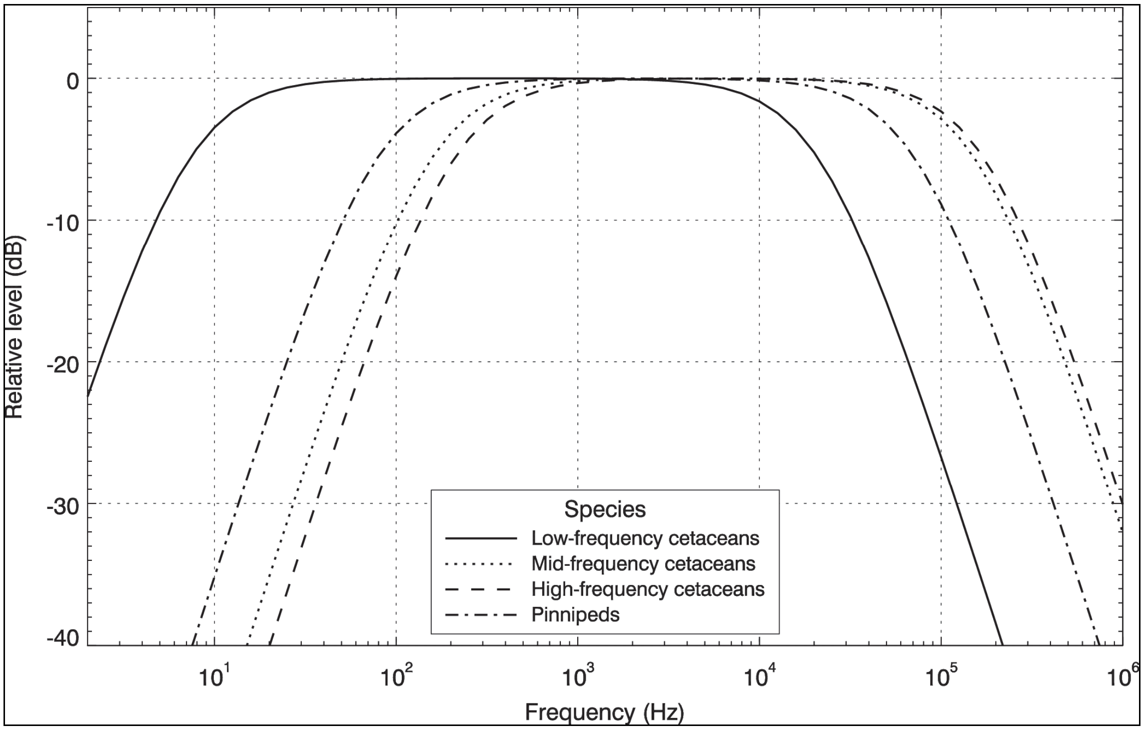

Figure D-4. Standard M-Weighting Curves for Low-, Mid-, and High-Frequency Cetaceans and Pinnipeds Underwater.

The M-weighting filters have unity gain (0 dB) through the pass band, and their high- and low-frequency roll offs are approximately –12 dB per octave. The amplitude response in the frequency domain of the M-weighting filters is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{f_{lo}^2}{f^2}\right)\left(1+\frac{f^2}{f_{hi}^2}\right)\right]\text{dB} \tag{5}$$

The roll off and pass band of these filters are defined by the parameters f_{lo} and f_{hi}. The parameter values of the standard M-weighting curves are presented in **Table D-1**.

Table D-1

Low-Frequency (flo) and High-Frequency (fhi) Cutoff Parameters
for Standard Marine Mammal M-Weighting Curves
(Southall et al., 2007)

M-Weighting Filter	f_{lo} (Hz)	f_{hi} (Hz)
Low-frequency cetaceans	7	22,000
Mid-frequency cetaceans	150	160,000
High-frequency cetaceans	200	180,000
Pinnipeds underwater	75	75,000

The amplitude response of the M-weighting filter is calculated separately for each modeled frequency and added to the received level at that specific frequency to obtain the M-weighted received level:

$$RL_{MW}(f) = RL(f) + G(f) \tag{6}$$

Since the amplitude response of the M-weighting filter calculated using Equation (5) is a negative value, the M-weighted received level is lower than the unweighted one.

2.3.2. Consideration of the Minimum Integration Time

The numerical models used for estimating the received levels assume that a virtual receiver does not have a limit on the minimum integration time and therefore the integration time used for the calculation of rms SPL (see Equation [2]) can be as small as the actual length of the pulse emitted by the source. When assessing the impact of the acoustic source on marine mammals it is important to take the specific properties of the marine mammal hearing apparatus into consideration.

As summarized by Au and Hastings (2008), when receiving tone pulses, the mammalian ear behaves like an integrator with an “integration time constant.” Energy is summed over the duration of a pulse until the pulse is longer than the integration time constant. Studies of bottlenose dolphins by Johnson (1968) indicate an integration time constant of approximately 100 ms. Richardson et al. (1995) (Chapter 8.2.4) summarized a number of studies that compared the effect of short signals (less than 100 ms) with the effect of prolonged signals on marine mammals. It was observed that the thresholds for pulses of 0.2 ms duration were ~10-20 dB poorer (i.e., higher). For even shorter pulses the thresholds can increase by as much as 40 dB.

It can be concluded that the increase in the thresholds with decreasing the signal duration exists because of minimum integration time limitation caused by the specifics of the hearing apparatus of some marine mammals. As such, when calculating the apparent received levels with Equation (2), the minimum integration time should be used for the time interval value T instead of the actual pulse duration. The adjustment for the minimum integration time can be calculated by the following formula:

$$\Delta_{RL} = RL_{app} - RL_{act} = 10\log_{10}\left(\frac{T_{pulse}}{T_{MIT}}\right), \tag{7}$$

where RL_{app} is the apparent received level that takes into consideration the minimum integration time, RL_{act} is the actual received level calculated using actual pulse duration, T_{pulse} is the pulse length, and T_{MIT} is the minimum integration time. The adjustment is a negative value and should be used only in case $T_{pulse} < T_{MIT}$.

2.3.3. National Marine Fisheries Service Criteria

The NMFS considers two levels of harassment to the marine mammals: Level A (injury) and Level B (disturbance). According to the 1994 Amendments to the Marine Mammal Protection Act (MMPA) of 1972, Level A Harassment is defined as “any act that injures or has the significant potential to injure a marine mammal or marine mammal stock in the wild.” Level B Harassment is defined as “any act that disturbs or is likely to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavioral patterns, including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering, to a point where such behavioral patterns are abandoned or significantly altered."

The NMFS (2005) specified that Level A Harassment for pulsed sources occurs when an animal is exposed to sound pressure levels of 180 dB re 1 µPa rms (for cetaceans) or 190 dB re 1 µPa rms (for pinnipeds). The criterion of 160 dB re 1 µPa rms SPL is considered as Level B Harassment for both mammal groups for pulsed sources.

The 180-160 dB criteria were thought to be well understood by public and easily calculated from standard propagation models (*Federal Register*, 2005). Being expressed in rms units, the criteria take into account not only the energy of the pulse, but also the length of the pulse (see Equation [1]). The exposure levels need to be calculated using the unweighted acoustic signal, i.e., they do not take into account different hearing ability of the animals at different frequencies. The disadvantage of such a criterion is that it does not take into account certain important attributes of the exposure such as duration, frequency, or repetition rate (*Federal Register*, 2005).

2.3.4. Southall Criteria

In order to address the shortcomings of the 180-160 dB rms SPL criteria, the Noise Criteria Group was established, which was sponsored by NMFS. The goal of the Noise Criteria Group was to develop updated noise exposure criteria based on solid scientific evidence. In 2007 the findings of the Group were published by an group of scientists led by Brandon Southall (Southall et al., 2007). In the publication new noise impact criteria were introduced, now commonly referred to as 'Southall criteria.'

The Southall criteria (**Table D-2**) are based on numerous data collected in the course of controlled and uncontrolled experiments during which different species were exposed to various levels of sound. The observations were made for the occurrence of permanent threshold shift (PTS) or temporary threshold shift (TTS) in animals' hearing. As a result, the criteria for injury were suggested. In terms of behavioral impacts, Southall et al. (2007) did not propose criteria for sources other than a single impulse (e.g., explosion) for the reasons of context-dependence and other complexities in the nature of behavioral responses and available literature.

Table D-2

Southall Criteria for Injury
(Southall et al., 2007)

Marine Mammal Group	Injury	
	Peak Pressure	Sound Exposure Level
Low-frequency cetaceans	230 dB re 1 µPa (flat)	198 dB re 1 $\mu Pa^2 \cdot s$ (M_{lf})
Mid-frequency cetaceans	230 dB re 1 µPa (flat)	198 dB re 1 $\mu Pa^2 \cdot s$ (M_{mf})
High-frequency cetaceans	230 dB re 1 µPa (flat)	198 dB re 1 $\mu Pa^2 \cdot s$ (M_{hf})
Pinnipeds underwater	218 dB re 1 µPa (flat)	186 dB re 1 $\mu Pa^2 \cdot s$ (M_{pw})

The injury criteria are based both on peak pressure of the acoustic wave, expressed in dB re 1 µPa, and the total SEL, expressed in dB re 1 $\mu Pa^2 \cdot s$. In order to comply with the criteria, the characteristics of the acoustic wave should not exceed either or both.

Two different levels were established for cetaceans and pinnipeds, with the levels for pinnipeds being lower. Prior to calculation of the sound exposure level appropriate M-weighting filter (see **Section 2.3.1**) would be applied to the acoustic signal to take into account hearing specifics of different mammal groups. During the calculations of the sound exposure level the length of the pulse is not considered, only the total energy released during the pulse event (see Equation [3]).

3. ACOUSTIC SOURCES

The acoustic sources covered in the programmatic modeling study can be subdivided into two major groups:

- airgun sources; and
- electromechanical sources.

An airgun source can consist of a single device, but most often it is made up of an array of airguns. It is considered a low-frequency source since most of its acoustic energy is radiated at frequencies below 200 Hz. Airgun arrays are broadband emitters, with source spectra spanning a number of third-octave bands. A single airgun is an omnidirectional source, i.e. the amplitude of the acoustic wave emitted from the source is uniform in all directions. An airgun array, on the other hand, does exhibit directionality because of the varying delays between signals from the spatially separated airguns in different directions. The main specification of an airgun, which defines its broadband SL and spectral content, is the volume of the air chamber.

Electromechanical sources are considered mid- or high-frequency emitters. They usually have one or two (sometimes three) main operating frequencies, which fall in the range from 2 to 900 kHz. The acoustic energy emitted outside the main operating frequency band in most of these devices is negligible; they can therefore usually be considered narrow band sources. High-frequency electromechanical sources are highly directive with beam widths as narrow as a few degrees. Electromechanical sources include side-scan sonars, subbottom profilers, single and multibeam depth sounders, boomers, etc.

The list of acoustic sources addressed in this study is presented in **Table D-3**. The operating frequencies and operational application are also provided.

Table D-3

List of Acoustic Source Types Modeled in This Study Indicating Representative Equipment Types, Operating Frequencies, and Survey Application

Type of Acoustic Source	Operating Frequencies	Modeled at Sites		
		Oil and Gas Exploration	Renewable Energy	Marine Minerals
Large airgun array (5,400 in^3)	10-2,000 Hz	●	--	--
Small airgun array (90 in^3)	10-2,000 Hz	●	--	--
Boomer	200-16,000 Hz	●	●	●
Side-scan sonar	100, 400 kHz	●	●	●
Chirp subbottom profiler	3.5, 12, 200 kHz	●	●	●
Multibeam depth sounder	240 kHz	●	●	●

3.1. AIRGUN SOURCES

3.1.1. Seismic Survey Overview

Marine seismic surveys using airgun sources are capable of producing high-resolution, 3D images of geological stratification down to several kilometers depth, and have thus become an essential tool for geophysicists studying the Earth's crust. Seismic airgun surveys can be divided into two types, 2D and 3D, according to the type of data that they acquire. Two-dimensional surveys are so called because they only provide a 2D cross-sectional image of the Earth's structure; they are characterized operationally by large spacing between survey lines, on the order of a kilometer or more. Three-dimensional surveys, on the other hand, rely on very dense line spacing, of the order of a few hundred meters or less, to provide a 3D volumetric image of the underlying geological structures.

The total volume of the airgun array source and the volume of individual airguns for a typical 2D survey are usually larger than for a typical 3D seismic survey. Two-dimensional surveys aim at deeper imaging of the geological structures at the expense of resolution.

A typical seismic survey, either 2D or 3D, is operated from a single survey ship that tows both the seismic source and the receiver apparatus. Up to tens of individual airguns in the source array are fired simultaneously in order to project a high-amplitude seismo-acoustic pulse into the ocean bottom. The receiver equipment usually consists of one or more streamers, often several kilometers in length, that contain hundreds of sensitive hydrophones for detecting echoes of the seismic pulse reflected from subbottom features. In some cases, the receiving equipment consists of cabled seismometers placed on the ocean floor. For other seismic surveys, both streamers and ocean-bottom seismometers are used.

The majority of the underwater sound generated by a seismic survey is attributable to the airgun array, the survey vessel itself contributing very little in relative terms to the overall sound field. Airgun arrays are broadband acoustic sources that project energy over a wide range of frequencies, from under 10 Hz to over 5 kHz. Most of the energy, however, is concentrated in the frequency range below 200 Hz. The constituent airguns in the array are geometrically arranged so as to project the maximum amount of seismic energy vertically into the seafloor. A significant portion of the sound energy from the array is, nonetheless, emitted at off-vertical angles and propagated into the surrounding environment. The frequency spectrum of the sound propagating near-horizontally can differ markedly from that of the sound directed downward. There can also be substantial differences in the intensity and frequency spectrum of sound projected in different horizontal directions.

3.1.2. Airgun Operating Principles

An airgun is a pneumatic sound source that creates predominantly low-frequency acoustic impulses by generating bubbles of compressed air in water. The rapid release of highly-compressed air (typically at pressures of ~2,000 psi) from the airgun chamber creates an oscillating air bubble in the water. The expansion and oscillation of this air bubble generates a strongly-peaked, high-amplitude acoustic impulse that is useful for seismic profiling. The main features of the pressure signal generated by an airgun, as shown in **Figure D-5**, are the strong initial peak and the subsequent bubble pulses. The amplitude of the initial peak depends primarily on the firing pressure and chamber volume of the airgun, whereas the period and amplitude of the bubble pulse depend on the chamber volume and firing depth.

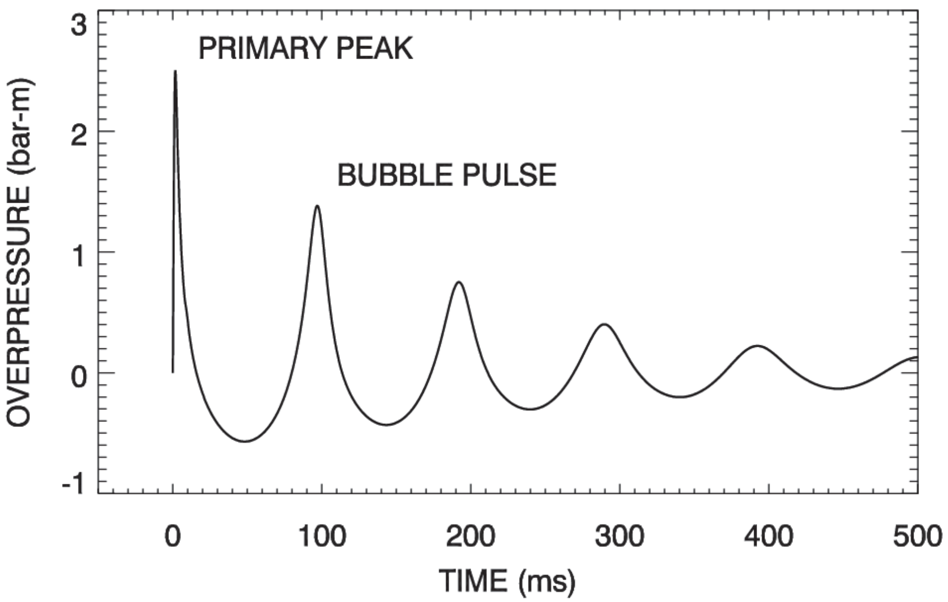

Figure D-5. Overpressure Signature for a Single Airgun, Showing the Primary Peak and the Bubble Pulse.

As mentioned earlier, airguns are designed to generate most of the acoustic energy at frequencies less than ~200 Hz, which are most useful for seismic penetration beneath surficial seabed sediment layers. Because of their impulsive nature, airgun sources inevitably generate sound energy above 200 Hz, although the energy output at those frequencies is substantially less than at low frequencies. In general, the predominant frequency output of an airgun is inversely dependent on its volume.

Zero-to-peak (0-p) SLs for individual airguns range typically between 220 and 235 dB re 1μPa at 1m (~1–6 bar•m), with larger airguns generating higher peak pressures than smaller ones. The peak pressure of an airgun pulse, however, only increases with the cubic root of the chamber volume. Furthermore, the amplitude of the subsequent bubble pulses also increases with the volume of the airgun and constitutes an undesirable feature of the airgun signal as it smears subbottom reflections. In order to increase the pulse amplitude (to "see" deeper into the earth), geophysicists generally combine multiple airguns together into arrays. Airgun arrays provide several advantages over single airguns for deep geophysical surveying:

- the far-field peak pressure of an airgun array in the vertical direction increases nearly linearly with the number of airguns;
- the geometric lay-out of airgun arrays can be optimized to project maximum peak levels toward the seabed (i.e., directly downward), whereas single airguns produce nearly omnidirectional sound; and
- by using airguns of several different volumes, airgun arrays can be "tuned" to increase the amplitude of the primary peak and simultaneously decrease the relative amplitude of the subsequent bubble pulses.

3.1.3. Airgun Array Source Levels

The far-field pressure generated by a seismic airgun array is substantially greater than that of an individual airgun, but is also strongly angle-dependent relative to the array axis. An array of thirty guns, for example, can have a zero-to-peak SL of 255 dB re 1 μPa at 1m (~56 bar•m) in the vertical direction. This apparently high value for the SL can lead to erroneous conclusions about the impact on the marine environment for the following reasons:

- peak SLs for seismic survey sources are usually quoted for the sound propagating vertically downward; because of the directional dependence of the radiated sound field, however, SLs for the sound propagating off to the sides of the array are generally lower; and
- far field SLs do not apply in the near field of the array because an airgun array is a distributed source in which the sound from the individual airguns does not add coherently; sound levels in the near field are, in fact, lower than would be expected from far-field estimates.

The acoustic SL of a seismic airgun array varies considerably in both the horizontal and vertical directions because of the complex interaction between the signals from the component airguns. One must account for this variability in order to correctly predict the sound field generated by an airgun array. If the source signatures and relative positions (in 3D) of the individual airguns are known, then it is possible to accurately compute the SL of an array in any direction by summing the contributions of the array elements with the appropriate time delays, according to their relative positions. This is the basis for the airgun array source model discussed in the next section.

3.1.4. Airgun Array Source Model

The current study makes use of a full-waveform AASM, developed by JASCO (MacGillivray, 2006), to compute the SL and directionality of the airgun array. The airgun model is based on the physics of the oscillation and radiation of airgun bubbles, as described by Ziolkowski (1970). The model solves in parallel, using a numerical integration scheme, a set of ordinary differential equations that define the airgun bubble oscillations.

In addition to the basic bubble physics, the source model also accounts for non-linear pressure interactions between airguns, port throttling, bubble damping, and generator-injector (GI) gun behavior, as described by such authors as Dragoset (1984), Laws et al. (1990), and Landro (1992). The source model includes four empirical parameters that are tuned so that the model output matches observed airgun behavior. These parameters were fitted to a large library of real airgun data using a “simulated annealing” global optimization algorithm. The airgun data were obtained from a systematic study (Racca and Scrimger, 1986) that measured the signatures of Bolt 600/B guns ranging in volume from 5 to 185 cubic inches (in^3).

The airgun array source model requires several inputs, including the array layout, volumes, towing depths, and firing pressure. The output of the source model is a set of “notional” signatures for the array elements; these are the pressure waveforms of the individual airguns, compensated for the interaction with other airguns in the array, at a standard reference distance of 1 m.

After the source model is executed, the resulting notional signatures are summed together with the appropriate phase delays to obtain the far-field source signature of the array. The far-field array signature, in turn, is filtered into third-octave pass bands to compute the SL of the array as a function of frequency band, f_c, and propagation azimuth, θ: $SL = SL(f_c, \theta)$.

The interaction between the signals from individual airguns creates a directionality pattern in the overall acoustic emission from the array. This directionality is particularly prominent at frequencies from several tens to several hundred Hz; at lower frequencies the array appears omnidirectional, whereas at higher frequencies the pattern of lobes becomes too finely spaced to resolve.

The propagation model, discussed in **Section 4.1**, calculates TL from an equivalent point-like acoustic source to receiver locations at various distances, depths, and bearings. As previously mentioned, however, the point-source assumption is not valid in the near field, where the output from the distinct array elements does not add coherently. The maximum extent of the near field of an array is given by the expression

$$R_{nf} < \frac{L^2}{4\lambda} \tag{8}$$

Here, λ is the sound wavelength and L is the longest dimension of the array (Lurton, 2002, §5.2.4). For example, along the diagonal of the 3-string (18-airgun) array discussed below, $L \approx 22$ m and so the maximum near field range is 80 m at 1 kHz (R_{nf} is less for lower frequencies). Beyond these ranges it is assumed that an array radiates like a directional point source and can be treated as such for the purpose of propagation modeling.

3.1.5. Large Airgun Array

A 5,400 in^3 airgun array was taken as a representative example of a large seismic source for oil and gas exploration. The configuration of the array and air gun volumes were suggested in the “MAI Discussion Points about Modeling Assumptions” document.

The array has dimensions of 16 × 15 m and consists of 18 air guns placed in three identical strings of six air guns each (**Figure D-6**). The volume of individual air guns ranges from 105 to 660 in^3. Firing pressure for all elements is 2,000 psi. The depth below the sea surface for the array was set at 6.5 m.

The array was modeled using the JASCO airgun array source model to compute notional source signatures and from them obtain third-octave band SLs as a function of azimuth angle. The resulting broadside and endfire (relative to the trackline) overpressure signatures and corresponding power spectrum levels are shown in **Figure D-7**. Horizontal third-octave band directionality plots are shown in **Figure D-8**. Specific characteristics of the 5,400 in^3 airgun array pressure signature are provided in **Table D-4**.

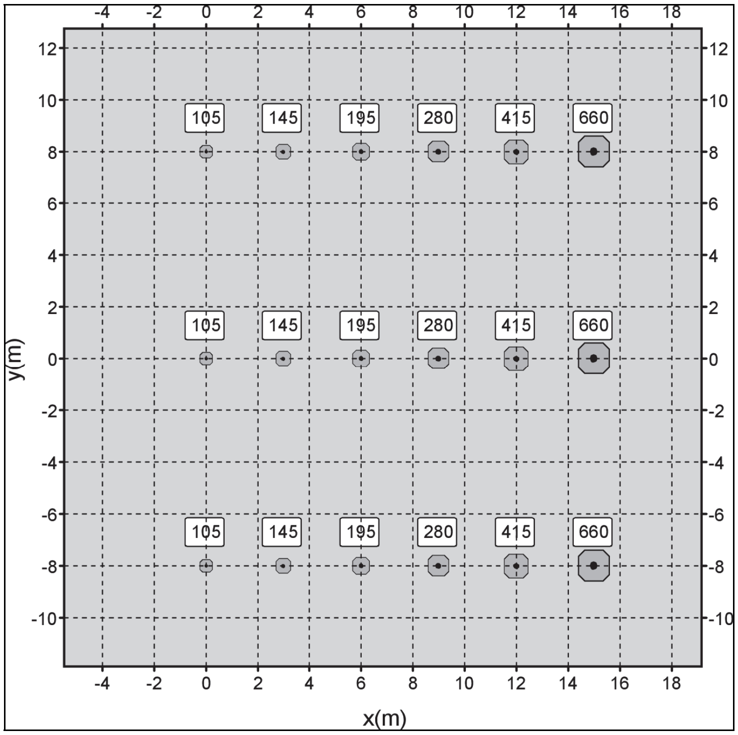

Figure D-6. Layout of the 5,400 in^3 Seismic Array (symbol sizes and labels indicate the volume of the airguns in cubic inches).

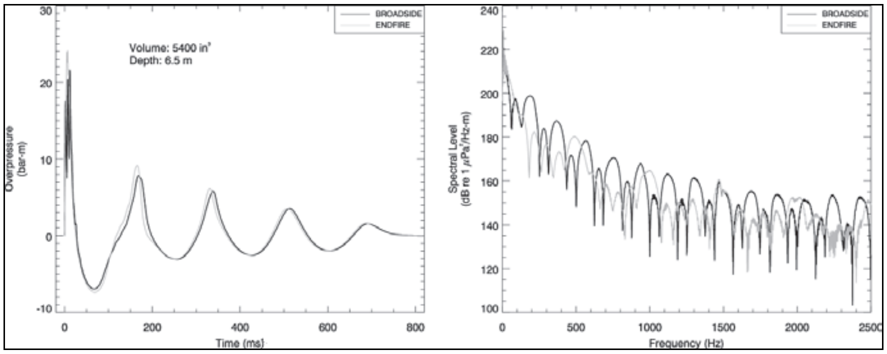

Figure D-7. Predicted Overpressure Signature (left) and Power Spectrum (right) for the 5,400-in^3 Airgun Array in the Broadside and Endfire Directions (surface ghosts [effects of the pulse reflection at the water surface] are not included in these signatures).

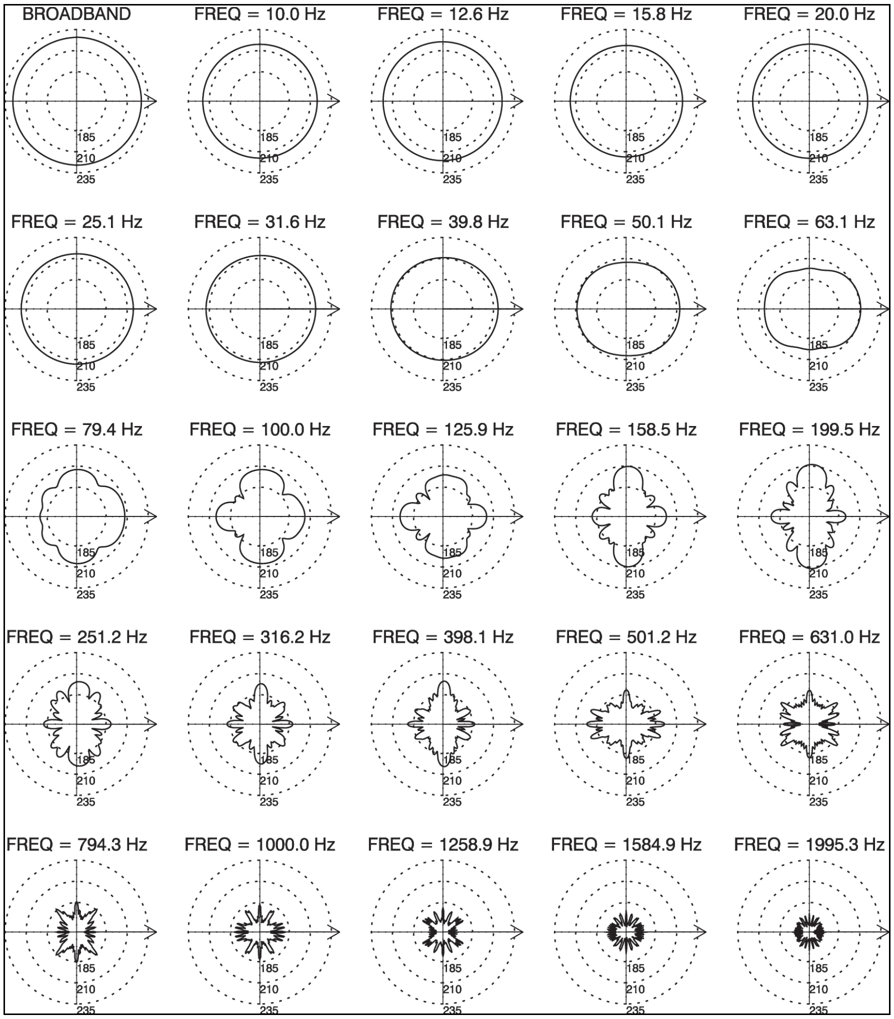

Figure D-8. Azimuthal Directivity Pattern of SLs for the 5,400-in^3 Array at 6.5-m Depth, Shown in Third-Octave Bands by Center Frequency (arrows indicate the front of the array and the solid black curves indicate the source levels in dB re 1 μPa^2 s as a function of angle in the horizontal plane, referenced to a fixed radial dB level scale [dashed circles]).

Table D-4

5,400-in^3 Airgun Array Pressure Characteristics from the AASM Model at 6.5-m Depth (surface ghost effects are excluded)

Metric	Forward Endfire	Broadside
Zero-Peak Pressure (dB re 1 μPa at 1 m)	247.7	246.7
90% rms level (dB re 1 μPa at 1 m)	233.3	232.5
90% rms duration (ms)	500	513
SEL 10–2,000 Hz (dB re 1 μPa^2 at 1 m)	224.7	224.7
SEL 0–1,000 Hz (dB re 1 μPa^2 at 1 m)	230.7	230.0
SEL 1,000–2,000 Hz (dB re 1 μPa^2 at 1 m)	181.7	181.8

The directivity of the airgun arrays source is markedly dependent on the array configuration. The maximum pressure levels in each frequency band (over all directions), on the other hand, are less strongly dependent on the configurations, and can be considered as a function of the total volume of the array. In view of the generalized nature of this study, it was decided to remove the directivity from the source modeling by calculating the maximum level over all azimuths in each third-octave band and using those band levels for all directions. The resulting SLs for the 5,400 in^3 airgun are shown in **Figure D-9**.

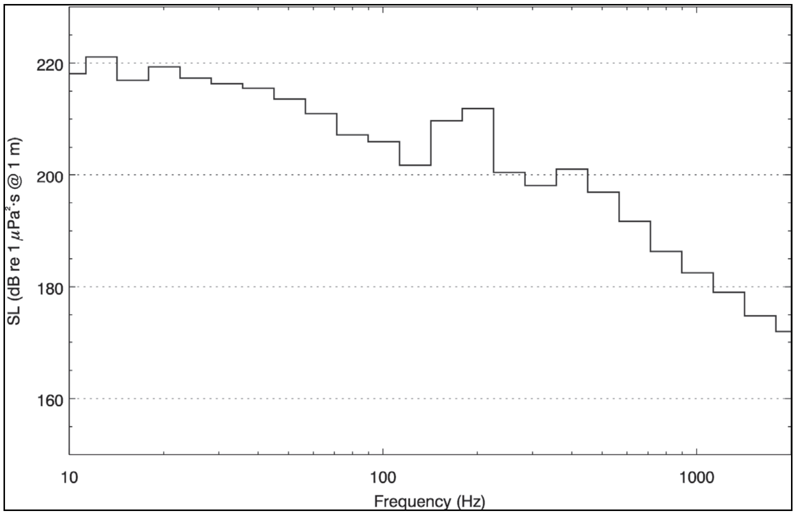

Figure D-9. Maximum Directional SLs in Each Third-Octave Band for the 5,400-in^3 Airgun Array.

3.1.6. Small Airgun Array

A 90 in^3, two airgun array was taken as representative configuration for the purpose of modeling a small seismic source typically used for high-resolution geophysical (HRG) surveys of oil and gas exploration and development sites. The two guns were assumed to be 45 in^3 each, spaced 1 m from each other and deployed at a depth of 6.5 m. The source modeling considerations for the 90 in^3 airgun array were similar to the ones for the large airgun array (see **Section 3.1.5**), including the removal of the directivity from the source function by assuming that the maximum directional acoustic level in each third-octave band is emitted in all directions.

Specific characteristics of the 90 in^3 airgun array pressure signature are provided in **Table D-5**. The observed maximum levels in third-octave bands for the 90 in^3 airgun array are shown in **Figure D-10**.

Table D-5

90-in^3 Airgun Array Pressure Characteristics from the AASM Model at 6.5 m Depth (surface ghost effects are excluded)

Metric	Forward Endfire	Broadside
Zero-peak Pressure (dB re 1 μPa at 1 m)	232.0	231.2
90% rms level (dB re 1 μPa at 1 m)	215.9	215.8
90% rms duration (ms)	247	248
SEL 10–2,000 Hz (dB re 1 μPa^2 at 1 m)	210.2	210.1
SEL 0–1,000 Hz (dB re 1 μPa^2 at 1 m)	210.3	210.2
SEL 1,000–2,000 Hz (dB re 1 μPa^2 at 1 m)	172.6	170.1

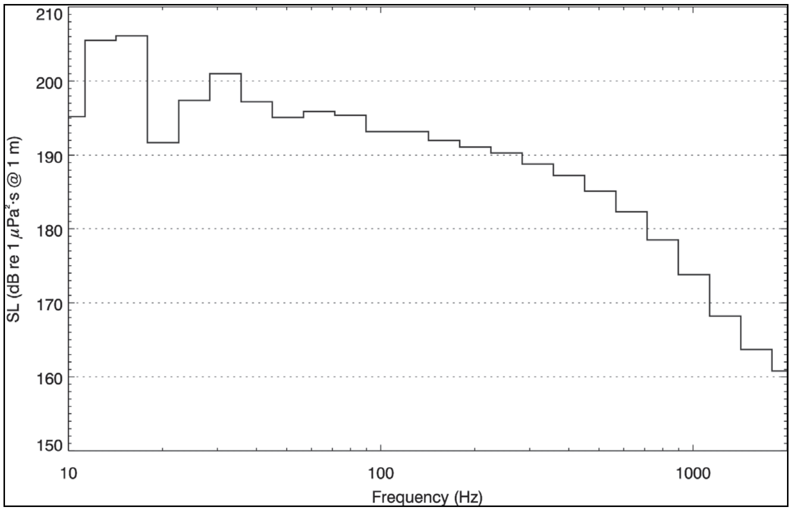

Figure D-10. Maximum Directional SLs in Each Third-Octave Band for the 90-in^3 Airgun Array.

3.2. ELECTROMECHANICAL SOURCES

Mid- and high-frequency underwater acoustic sources for geophysical measurements create an oscillatory overpressure through rapid vibration of a surface, using either electromagnetic forces or the piezoelectric effect of some materials. A vibratory source based on the piezoelectric effect is commonly referred to as a transducer, and may be capable of receiving as well as emitting functionality.

The transducers are usually designed to excite an acoustic wave of a specific frequency, often in a highly directive beam. The directional capability increases with increasing operating frequency. The main parameter characterizing the directivity is the beam width, defined as the angle subtended by diametrically opposite "half power" (-3 dB) points of the main lobe. For different transducers the beam width can vary from 180° (almost omnidirectional) to only a few degrees.

Transducers are usually produced with either circular or rectangular active surfaces. For circular transducers the beam width in the horizontal plane (assuming a downward pointing main beam) is equal in all directions. Rectangular transducers produce more complex beam patterns with variable beam width in the horizontal plane; two beam width values are usually specified for orthogonal axes.

3.2.1. Beam Pattern Calculation

The acoustic radiation pattern, or beam pattern, of a transducer is the relative measure of acoustic transmitting or receiving power as a function of spatial angle. Directionality is generally measured in decibels relative to the maximum radiation level along the central axis perpendicular to the transducer surface. The pattern is defined largely by the operating frequency of the device and the size and shape of the transducer.

Beam patterns generally consist of a main lobe extending along the central axis of the transducer, and multiple secondary lobes separated by nulls. The width of the main lobe depends on the size of the active surface relative to the sound wavelength in the medium, with larger transducers producing narrower beams. **Figure D-11** presents a 3D visualization of a typical beam pattern for a circular transducer.

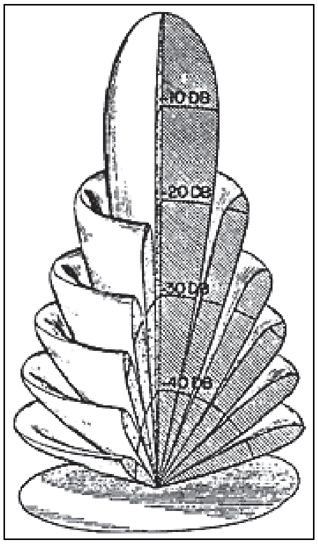

Figure D-11. Typical 3D Beam Pattern for a Circular Transducer (Massa, 1999).

The beam width is a key characteristic of transducers. It is generally defined as the total angular range where the sound pressure level of the main beam is within 3 dB of the on-axis peak power (Massa, 1999). The true beam pattern of a transducer can only be obtained by *in situ* measurement of the emitted energy around the device, as shown in the example of **Figure D-12**. Such data, however, are not always readily available, and for modeling purposes it is often sufficient to estimate the beam pattern based on transducer theory.

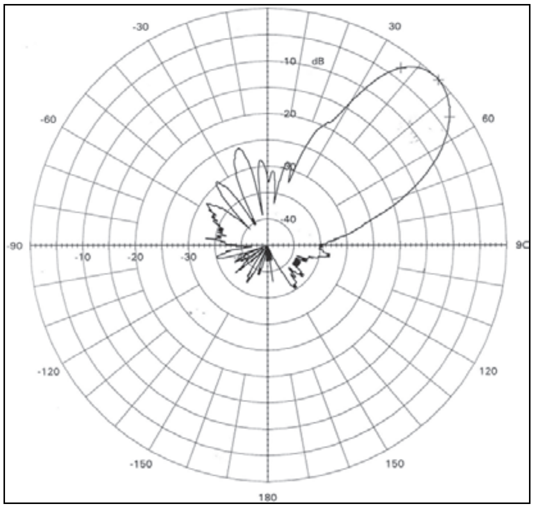

Figure D-12. 2D Polar Representation of a Beam Pattern Obtained by *In Situ* Measurement (vertical slice) of a Transducer Used by Kongsberg (these sample measurements were obtained through personal communications with the manufacturer).

3.2.2. Beam Pattern of a Circular Transducer

The beam of an ideal circular transducer is symmetric about the main axis; the radiated level depends only on the depression angle. In this study, beam directivities were calculated from the standard formula for the beam pattern of a circular transducer (Kinsler et al., 1950; ITC, 1993). The directivity function of a conical beam, relative to the on-axis pressure amplitude, is given by:

$$R(\phi) = \frac{2 \cdot J_1(\pi D_\lambda \sin(\phi))}{\pi D_\lambda \sin(\phi)} \quad \text{and} \quad D_\lambda = \frac{60}{\theta_{bw}}, \tag{9}$$

where J_1 is the Bessel function of the first order, D_λ is the transducer dimension in wavelengths of sound in the water, θ_{bw} is the beam width in degrees, and ϕ is the beam angle from the transducer axis. The beam pattern of a circular transducer can be calculated from the transducer's specified beam width or from the diameter of the active surface and the operating frequency. The calculated beam pattern for a circular transducer with a beam width of 20° is shown in **Figure D-13**. The gray scale represents the SL (in dB re 1 µPa at 1 m) and the declination angle is relative to a central vector (0°, 0°) pointing directly downward at the seafloor.

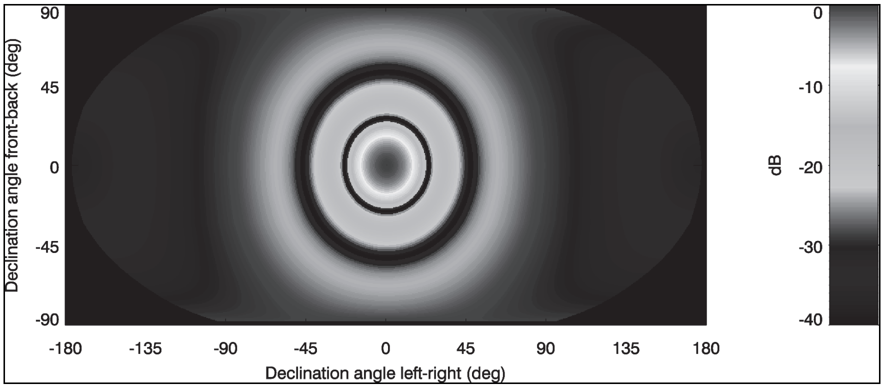

Figure D-13. Calculated Beam Pattern for a Circular Transducer with a Beam Width of 20° (beam power function shown relative to the on-axis level, using the Robinson projection).

Although some acoustic energy is emitted at the back of the transducer, the theory only accounts for the beam power in the front half space (ϕ <90°) and assumes no energy directed into the back half space. The relative power at these rearward angles is significantly lower, generally by more than 30 dB, and consequently the emission in the back half space can be estimated by applying a simple decay rate, in dB per angular degree, which reduces the beam power at ϕ = 90° to a value 30 dB lower than at ϕ = 0°. This simple estimate of the beam power in the back half space allows a conservative estimate of the total beam power.

3.2.3. Beam Pattern of a Rectangular Transducer

Rectangular transducer beam directivities were calculated from the standard formula for the beam pattern of a rectangular acoustic array (Kinsler et al., 1950; International Transducer Corporation, 1993). This expression is the product of the toroidal beam patterns of two line arrays, where the directional characteristics in the along- and across-track directions are computed from the respective beam widths. The directivity function of a toroidal beam, relative to the on-axis pressure amplitude, is given by:

$$R(\phi) = \frac{\sin(\pi L_\lambda \sin(\phi))}{\pi L_\lambda \sin(\phi)} \quad \text{and} \quad L_\lambda = \frac{50}{\theta_{bw}}, \tag{10}$$

where L_λ is the transducer dimension in wavelengths, θ_{bw} is the beam width in degrees, and ϕ is the angle from the transducer axis. The beam pattern of a transducer can be calculated using either the specified beam width in each plane or the dimensions of the active surface and the operating frequency of the transducer. The calculated beam pattern for a rectangular transducer with along- and across-track beam widths of 4° and 10°, respectively, is shown in **Figure D-14**.

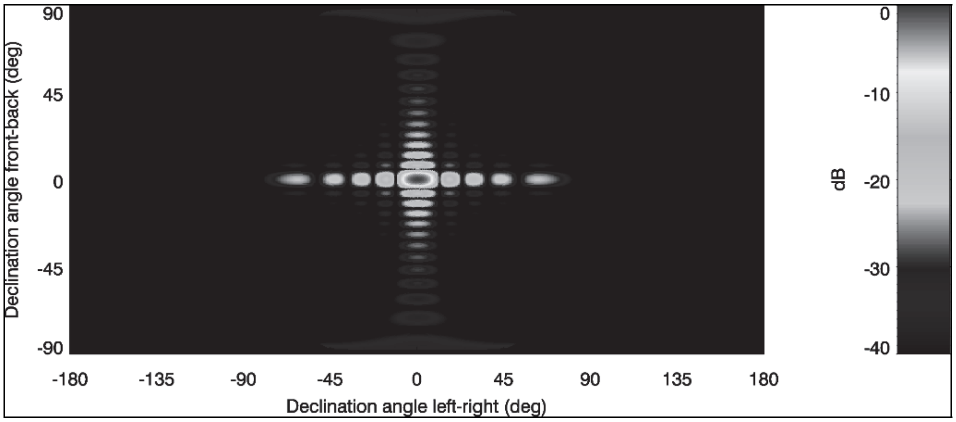

Figure D-14. Calculated Beam Pattern for a Rectangular Transducer with a 4°×10° Beam Width (beam power function shown relative to the on-axis level, using the Robinson projection).

3.2.4. Beam Pattern of a Multibeam System

High-frequency systems often have two or more transducers, as is the case for side-scan sonars and swath bathymetry sonars. Typical side-scan sonar uses two transducers, with the central axes directed perpendicular to the track of the ship and at some depression angle to the horizontal plane. By contrast, multibeam bathymetry survey systems can have upwards of 100 transducers. Such systems generally utilize rectangular transducers and have a narrow beam width in the horizontal plane (0.2°–3°) and a wider beam width in the vertical plane.

For multibeam systems, the beam patterns of individual transducers are calculated separately then combined into the overall pattern of the system based on the engagement type of the beams, which can be simultaneous or successive. If the beams are engaged successively, the SL of the system along a specific direction is assumed to be equal to the maximum SL realized from each of the individual transducers, whereas if the beams are engaged simultaneously, the beam pattern of the system is simply the sum of all beam patterns. **Figure D-15** presents the predicted beam pattern for two rectangular transducers engaged simultaneously. In this example, the individual transducers have along- and across-track beam widths of 1.5° and 50°, respectively.

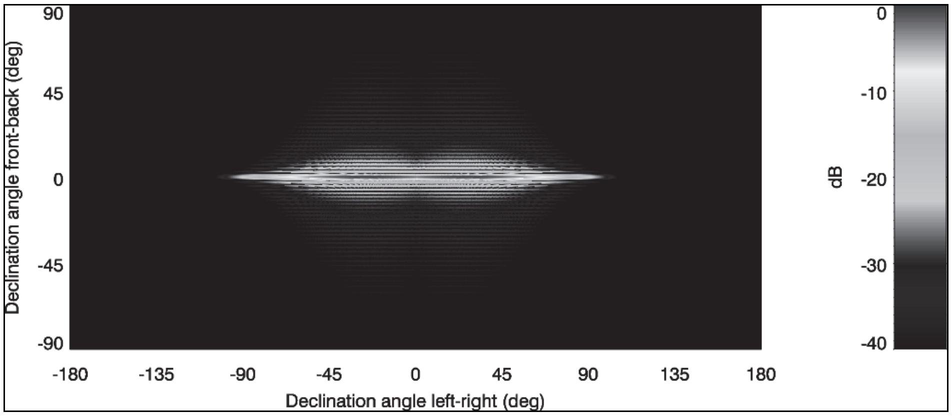

Figure D-15. Calculated Beam Pattern for Two Rectangular Transducers Engaged Simultaneously, with Individual Beam Widths of 1.5°×50°, and a Declination Angle of 25° (beam power function shown relative to the on-axis level, using the Robinson projection).

3.2.5. Boomer

3.2.5.1. Boomer Source Description

Boomers consist of a circular piston moved by electromagnetic force; the emitter plate of a surface towed boomer system is shown in **Figure D-16**. The high voltage energy that excites the boomer plate is stored in a capacitor bank; operating voltages range from 1 to 6 kilovolts (kV), and the energy discharged for a single shot can vary from 50 joules (J) to 1,000 kilojoules (kJ). The typical pulse width is in order of tenths of a millisecond (**Figure D-17**). The narrow pulse allows the boomer to achieve high rms SPL (210–220 dB re 1 μPa at 1 m) with relatively low total energy input. The peak pressure level for a boomer with the input energy less than 400 J do not exceed 220 dB re 1 μPa at 1 m (Simpkin, 2005).

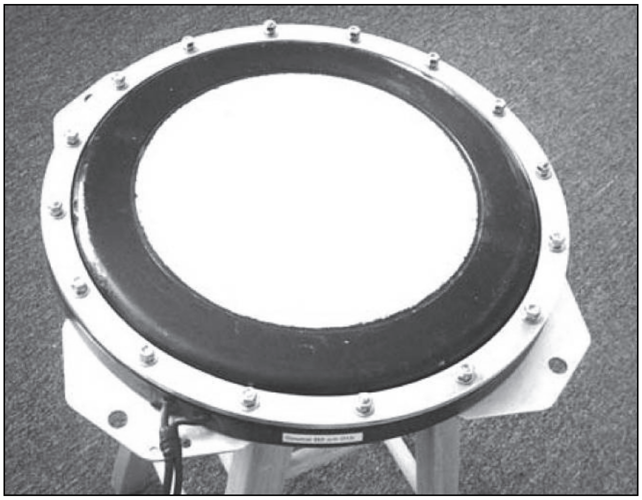

Figure D-16. Surface Towed Boomer Source (Simpkin, 2005).

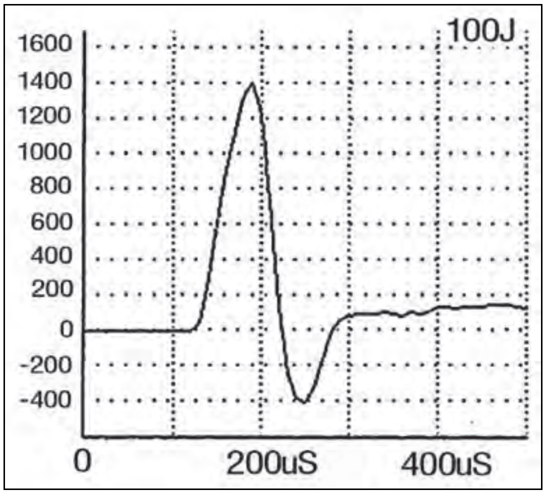

Figure D-17. Source Pulse of the AA201 Boomer at 100 J Energy Output (Applied Acoustic Engineering Ltd., 2011).

The amount of energy discharged is controlled by increasing either the voltage or the size of the capacitor. Increasing the voltage, for a given capacitance, shortens the pulse duration and thus shifts the spectral band of generated acoustic energy toward higher frequencies. Increasing the capacitance for a given voltage increases the pulse length and thus generates lower frequencies. In both cases the peak amplitude and broadband SL increase. By controlling the parameters of the applied electrical impulse, frequencies as high as 20 kHz can be generated. The power spectrum of the acoustic wave generated by a boomer source peaks at 1.5–5 kHz (Simpkin, 2005). Boomer systems can penetrate as deep as 200 m in soft sediments, with a resolution as small as 75 centimeters (cm) (Simpkin, 2005). Boomer sources show some directionality, which increases with the acoustic frequency; at frequencies below 1 kHz they can usually be considered omnidirectional.

3.2.5.2. Acoustic Characteristics

The emitting element of the boomer source is a boomer plate with the diameter of about 30–40 cm mounted on a catamaran-like sled as shown in **Figure D-18** (Applied Acoustic Engineering Ltd., 2011). Because the boomer source is a circular piston surrounded by a rigid baffle, it cannot be considered a point-like source (Verbeek and McGee, 1995). The boomer is a strongly directive source for frequencies at which the boomer dimension is not small compared to the wavelength; by this criterion the boomer becomes directional at frequencies above 1 kHz. In order to produce estimates of the sound field for a generic boomer source, the specifications of the Applied Acoustics AA201 boomer were taken to represent a standard system.

Figure D-18. Example of a Representative Boomer Plate System (Applied Acoustic Engineering Ltd., 2011).

The manufacturer’s product fact-sheet specifies an rms SPL of 212 dB re 1 µPa at 1 m at 200 J (maximum input energy) with a pulse duration less than 0.18 ms and a typical ping rate of 2–3 Hz (**Table D-6**). The peak source level was estimated based on the rms SPL source level using the relation between the peak and rms levels for a sine wave. The source level expressed in SEL units (dB re 1 $\mu Pa^2 \cdot s$) was estimated based on the rms SPL and the pulse length using Equation (4).

Table D-6

Representative Boomer Specifications
(source levels are provided for 200 J power input)

Operational Frequency Range	Broad Band: 200 Hz – 16 kHz
Beam Widths (degrees)	omnidirectional – 8°
Maximum Energy Input (per shot)	300 J
Maximum Power Input	600 W
Pulse Length (at 200 J)	180 µs
rms SPL (dB re 1 µPa at 1 m)	212
Peak Level (dB re 1 µPa at 1 m)	215
SEL (dB re 1 µPa^2·s at 1 m)	174.6

The power spectrum of the boomer signal and the beam width at different frequencies was estimated based on Simpkin's (2005) study of the Huntec '70 Deep Tow Boomer, a typical boomer plate of comparable dimensions. The estimated values are presented in **Table D-7**.

Table D-7

Estimated Source Levels (rms SPL) and Beam Width from the Representative Boomer
Distributed into Twenty 1/3-Octave Bands
(broad band source level is 212 dB 1 µPa at 1 m)

Third-Octave Band Center Frequency (Hz)	rms SPL (dB re 1 µPa at 1 m)	SEL (dB re 1 µPa^2·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°

The beam pattern calculations were then based on the standard formula for the beam pattern of a circular array (Equation [2]), with a decay rate in the back half space of 0.30 dB per degree from the horizontal plane, in order to reduce the back SL to -30 dB or less. **Figures 19** and **20** show the flat image and vertical slice for the calculated beam pattern at (a) 1.25 and (b) 16.0 kHz.

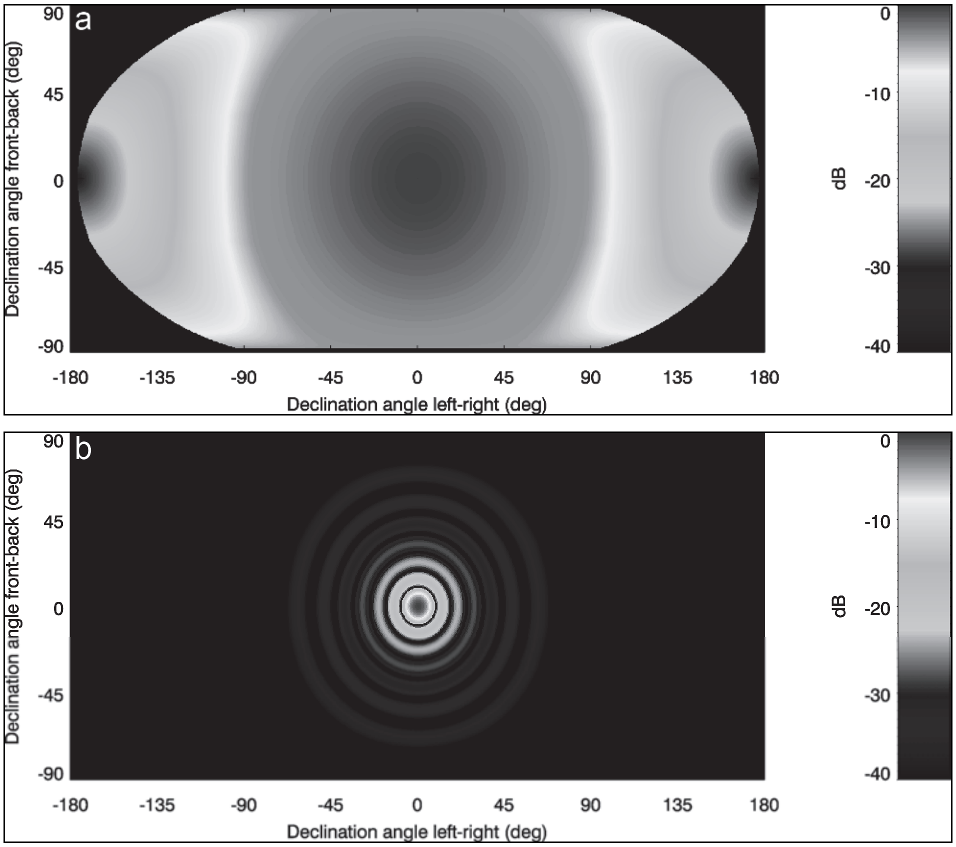

Figure D-19. Calculated Beam Pattern for the Representative Boomer at (a) 1.25 and (b) 16.0 kHz (beam power function shown relative to the on-axis level, using the Robinson projection).

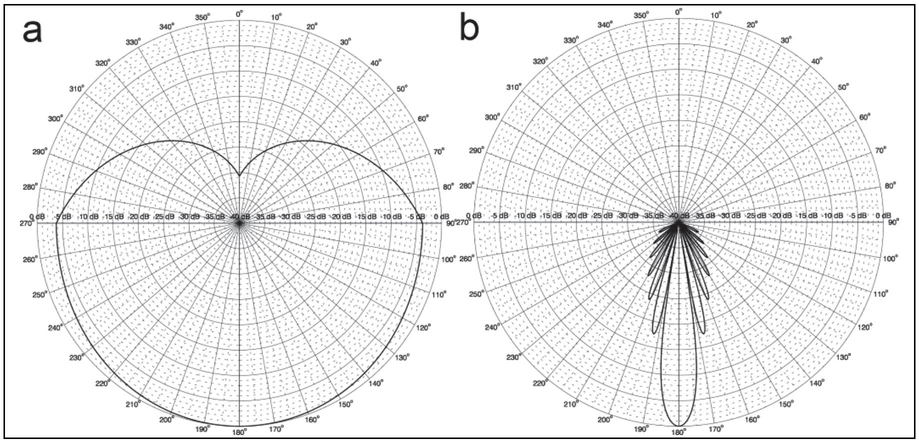

Figure D-20. Calculated Beam Pattern Vertical Slice for the Representative Boomer at (a) 1.25 and (b) 16.0 kHz; Across-Track Direction.

The boomer source can be treated as an omnidirectional source for the frequencies of 1,000 Hz and lower. For frequencies higher than 1,000 Hz the directionality of the boomer was taken into account. The acoustic field projected by the boomer source was modeled using two propagation models: for frequencies of 1,000 Hz and below were modeled using MONM-RAM, while frequencies above 1,000 Hz were modeled using MONM-BELLHOP.

3.2.6. Side-Scan Sonar

The representative side-scan sonar is assumed to be a dual-frequency, side-scan sonar with two simultaneously-engaged transducers, each producing a full spectrum chirp signal (**Figure D-21**). The sonar can be operated in dual-frequency bands with central frequencies of 100/400 kHz. In order to produce estimates of the sound field for a generic side-scan sonar source, the specifications of the EdgeTech 4200-MP side-scan sonar were taken to represent a standard system (EdgeTech, 2011).

Figure D-21. Example of a Representative Side-Scan Sonar System (EdgeTech, 2011).

The sonar is installed inside a streamlined towfish that can be towed behind a vessel at different depths. The central axes of the two transducers are oriented perpendicular to the towing line in the horizontal plane, i.e., at 90° and 270° relative to the ship's course. In the vertical plane, the central axes are tilted downward at 20° to the horizontal plane. The vertical beam width (across-track) is 50° for both frequencies. The horizontal beam width (along-track) varies between 0.4° and 1.26°, depending on the frequency and the operating mode. The relevant modeling parameters for the representative side-scan sonar system are presented in **Table D-8**.

Table D-8

Representative Side-Scan Sonar Parameters for the High-Speed and High-Definition Operating Modes

	100 kHz		400 kHz	
	High-Speed	High-Definition	High-Speed	High-Definition
Output pulse energy (J)	4		2	
Pulse duration (ms)	≤20		≤10	
rms SPL (dB re 1 µPa at1 m)	212	217	215	218
Transducers	2			
Transducer along-track beam width	1.26°	0.64°	0.40°	0.30°
Transducer across-track beam width	50°			
Transducer declination	20°			
Transducer azimuth	90°, 270°			

Each transducer's beam directivity was calculated based on the standard formula for the beam pattern of a rectangular transducer. These 3D beam patterns were then summed to produce the final sonar beam pattern. **Figure D-22** presents the calculated beam power function for the representative side-scan sonar system at 100 kHz, operating in (a) high-speed mode and (b) high-definition mode. **Figure D-23** shows vertical slices of the beam pattern at 100 kHz in the along- and across-track directions, for the sonar operating in high-speed mode.

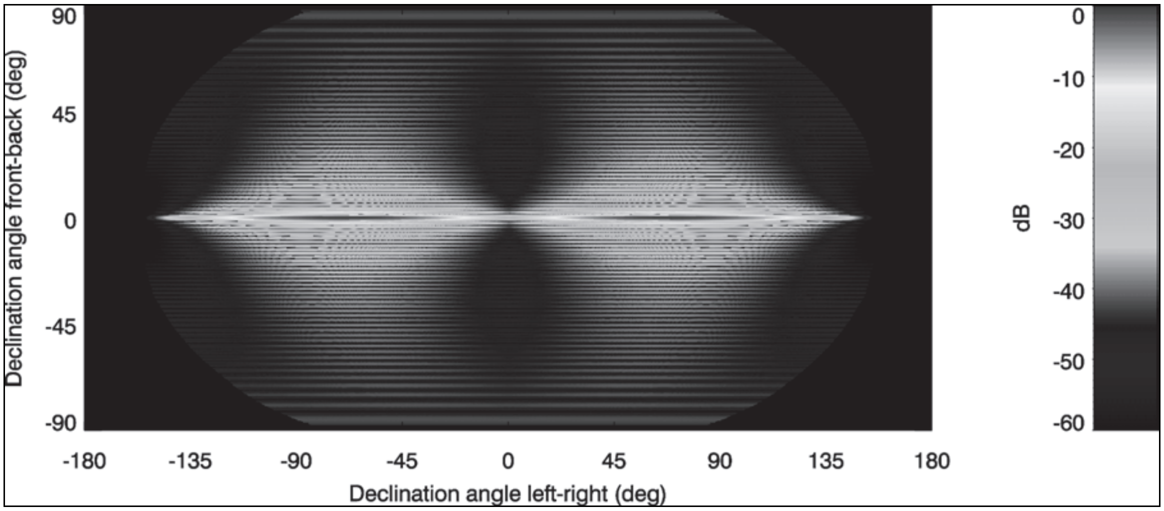

Figure D-22. Calculated Beam Pattern for the Representative Side-Scan Sonar at 100 kHz, Operating in High-Speed Mode (beam power function shown relative to the on-axis level, using the Robinson projection).

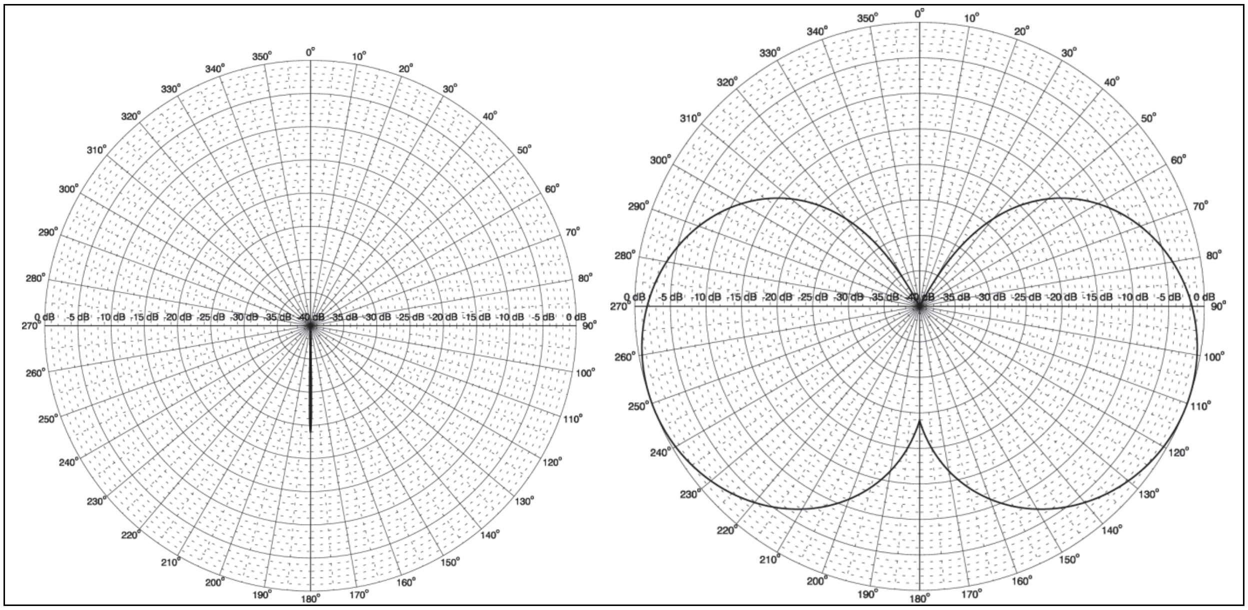

Figure D-23. Calculated Beam Pattern Vertical Slice for the Representative Side-Scan Sonar at 100 kHz Operating in High-Speed Mode; (left) Along- and (right) Across-Track Directions.

Modeling Approach

The side-scan sonar was modeled in the high-speed operation mode with 100/400 kHz frequencies. The SL for the purpose of modeling was chosen to be 223 dB re 1 μPa at 1 m in each of the two frequency bands, for a total broadband rms SPL of 226 dB re 1 μPa at 1 m. The tow depth of the source was chosen to be 5 m for modeling purposes. For the chosen rms SPL source level, the source levels in terms of the peak pressure level was calculated to be 229 dB re 1 μPa at 1 m. The SEL in each of the two bands was estimated at 206 dB re 1 $\mu Pa^2 \cdot s$ at 1 m considering the pulse length of 20 ms.

With a very narrow beam width, the variability of the emitted energy in different directions in the horizontal plane is very high. A circular fan of modeling radials with variable angular step (see **Table D-9**) was created to a maximum range of 1.5 km from the source. The density of the radials was greater in proximity of the broadside, where beam variability is maximum, and lesser toward the endfire. The total number of rays modeled was 660.

Table D-9

Variable Angular Steps of the Modeling Radials in Different Sectors

(only the steps for the first quadrant (0°-90°) are shown; those for the other quadrants were symmetrical)

Sector	Angular Step
0° – 45°	1°
45° – 80°	0.5°
80° – 90°	0.2°

The towing direction for each modeling site was selected individually based on the bathymetry, making the assumption that survey lines would run along the isobaths. The sound field was modeled using the MONM-BELLHOP acoustic propagation code. Since the SL was provided in rms SPL units, the output from the modeling was directly in terms of the rms SPL metric.

3.2.7. Chirp Subbottom Profiler

For the purpose of modeling a generic subbottom profiler source, the Knudsen Chirp 3260 model was chosen as representative example. This device is capable of working in three frequency bands simultaneously, providing subbottom images with acoustic signals at 3.5 kHz, 12 kHz, and 200 kHz. It uses two transducers, one operating at 3.5 kHz and the other at dual frequencies of 12 kHz and 200 kHz. The sonar head is mounted at the bottom of the ship's hull, with the central axes of both transducers oriented directly downward.

The SL of the 3.5 kHz transducer is 222 dB re 1 μPa at 1 m at 3 kilowatt (kW) output power level (LGL, 2010). The maximum output power levels for the 12 kHz and 200 kHz bands are 3 kW and 0.5 kW respectively. As no direct information about SLs was available for the 12 kHz and 200 kHz bands, these were estimated based on the output power levels for these bands relative to the output power level and corresponding SL for the 3.5 kHz band. The specifications of the subbottom profiler used for the modeling are presented in **Table D-10**.

The beam patterns were estimated using a mathematical model based on beam forming theory. Since the transducers are hull mounted, it was assumed that the most of the acoustic energy is emitted in the downward half-space and that the upward component is negligible.

Table D-10

Representative Chirp Subbottom Profiler Specifications

	3.5 kHz	12 kHz	200 kHz
Beam	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

Figures D-24 through **D-26** present the calculated beam power function for the representative chirp subbottom profiler at 3.5, 12, and 200 kHz, respectively. Vertical slices of the beam patterns for the same three frequencies are shown in **Figures D-27** through **D-29**.

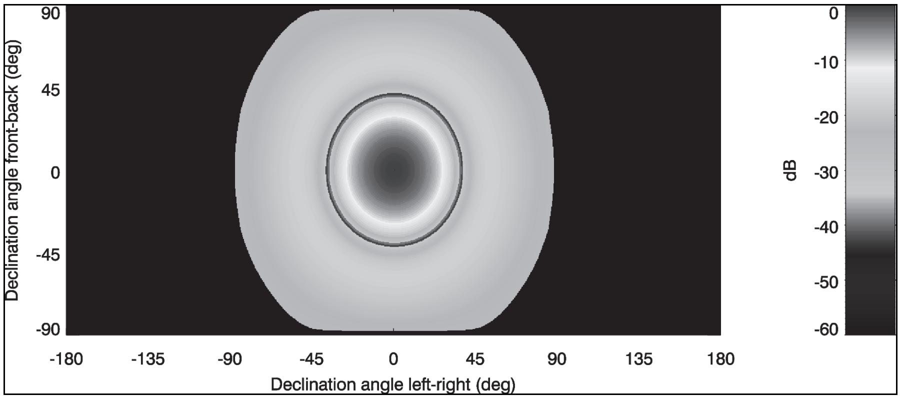

Figure D-24. Calculated Beam Pattern for a Representative Chirp Subbottom Profiler at 3.5 kHz (beam power function shown relative to the on-axis level, using the Robinson projection).

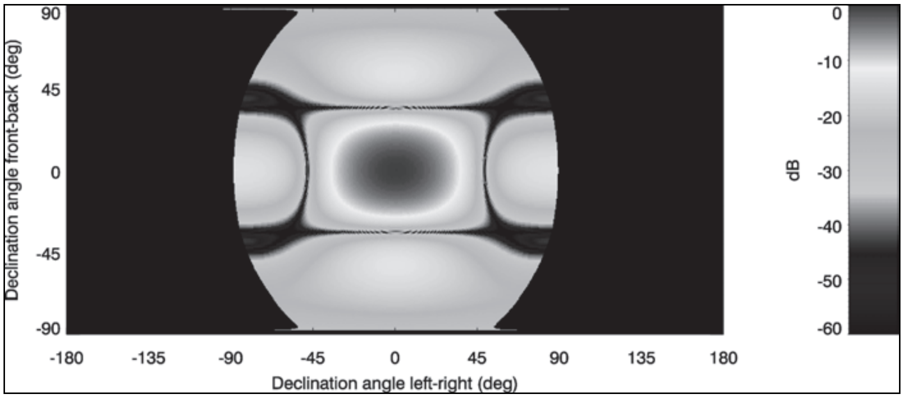

Figure D-25. Calculated Beam Pattern for a Representative Chirp Subbottom Profiler at 12 kHz (beam power function shown relative to the on-axis level, using the Robinson projection).

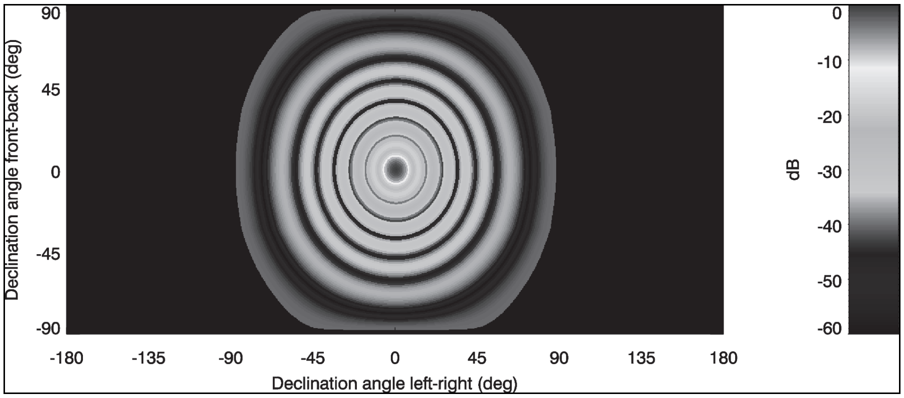

Figure D-26. Calculated Beam Pattern for a Representative Chirp Subbottom Profiler at 200 kHz (beam power function shown relative to the on-axis level, using the Robinson projection).

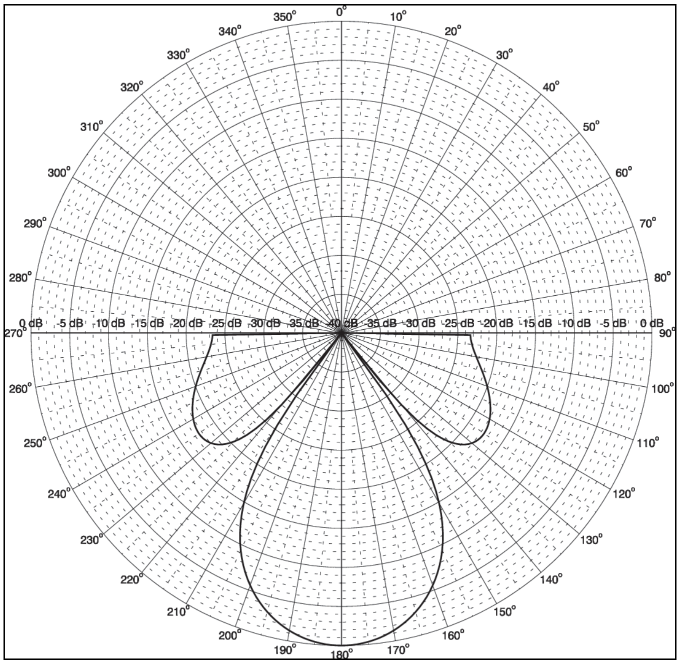

Figure D-27. Calculated Beam Pattern Vertical Slice for a Representative Chirp Subbottom Profiler Operating at 3.5 kHz.

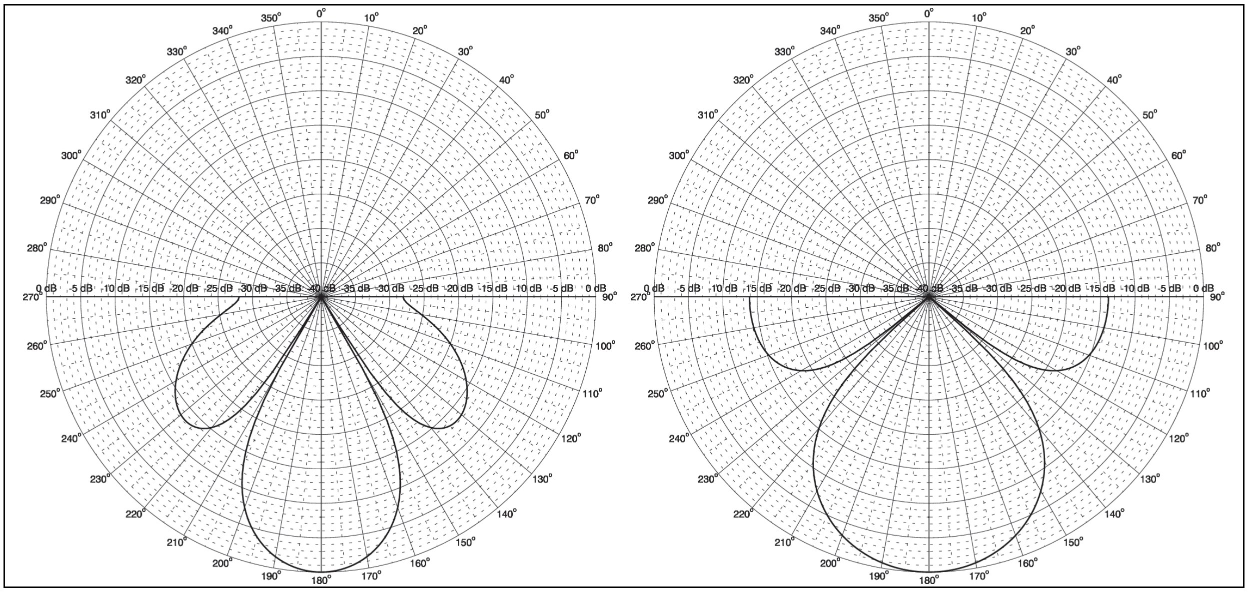

Figure D-28. Calculated Beam Pattern Vertical Slice for a Representative Chirp Subbottom Profiler Operating at 12 kHz (left); Along- and (right) Across-Track Directions.

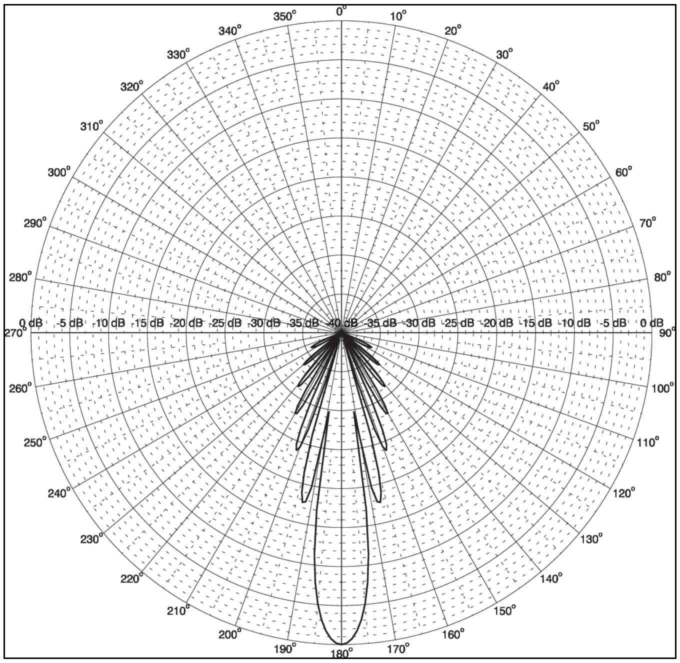

Figure D-29. Calculated Beam Pattern Vertical Slice for a Representative Chirp Subbottom Profiler Operating at 200 kHz.

Modeling Approach

The chirp subbottom profiler was modeled operating at all three frequencies simultaneously. The depth of the source was chosen to be 5 m. A total of 72 radial profiles with equal angular steps of 5° and extending to a maximum range of 20 km from the source were modeled using the MONM-BELLHOP acoustic propagation model. The same assumption about source heading was made for the side-scan sonar. The SLs were provided in rms SPL units; hence the output from the modeling was directly in terms of the rms SPL metric.

3.2.8. Multibeam Depth Sounder

For the purpose of modeling a representative multibeam depth sounder, the RESON SeaBat 7101 model was selected as an example. This depth sounder uses the main working frequency of 240 kHz (RESON, 2009). The system utilizes a single beam transducer and multibeam receiver. The transducer head is mounted at the bottom of the ship's hull. The projector beam width is 1.5° in the along-track direction and 170° in the across-track direction. The specifications of the depth sounder used for the modeling are presented in **Table D-11**.

Table D-11

Representative Multibeam Depth Sounder Specifications

Main Operational Frequency	240 kHz
Beam width along-track	1.5°
Beam width across-track	170°
rms SPL (dB re 1 μPa at 1 m)	210
Peak level (dB re 1 μPa at 1 m)	213
Pulse length	21–225 μs
SEL (dB re 1 $\mu Pa^2 \cdot s$ at 1 m) at 225 μs pulse length	173.5

The beam patterns were again estimated using a mathematical model based on beam forming theory. Since the transducers are hull mounted, it was assumed that most of the acoustic energy is emitted in the downward half-space and that the upward component is negligible.

Figure D-30 presents the calculated beam power function for the representative multibeam depth sounder at 240 kHz. Vertical slices of the beam pattern in along- and across-track directions are shown in **Figure D-31**.

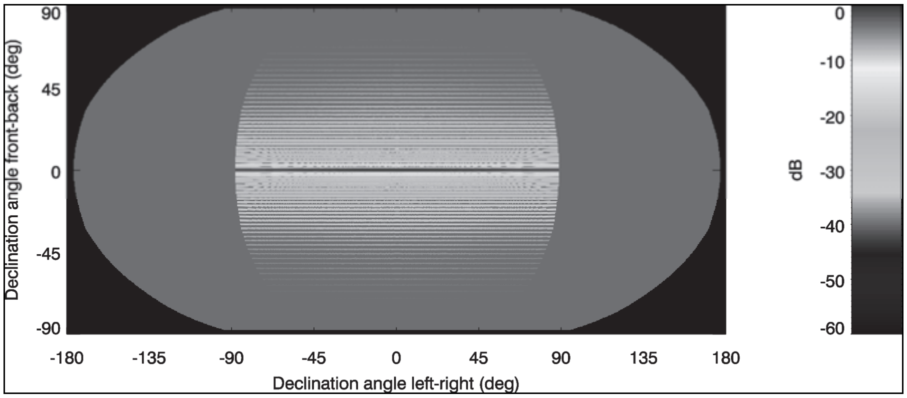

Figure D-30. Calculated Beam Pattern for the Representative Multibeam Depth Sounder at 240 kHz (beam power function shown relative to the on-axis level, using the Robinson projection).

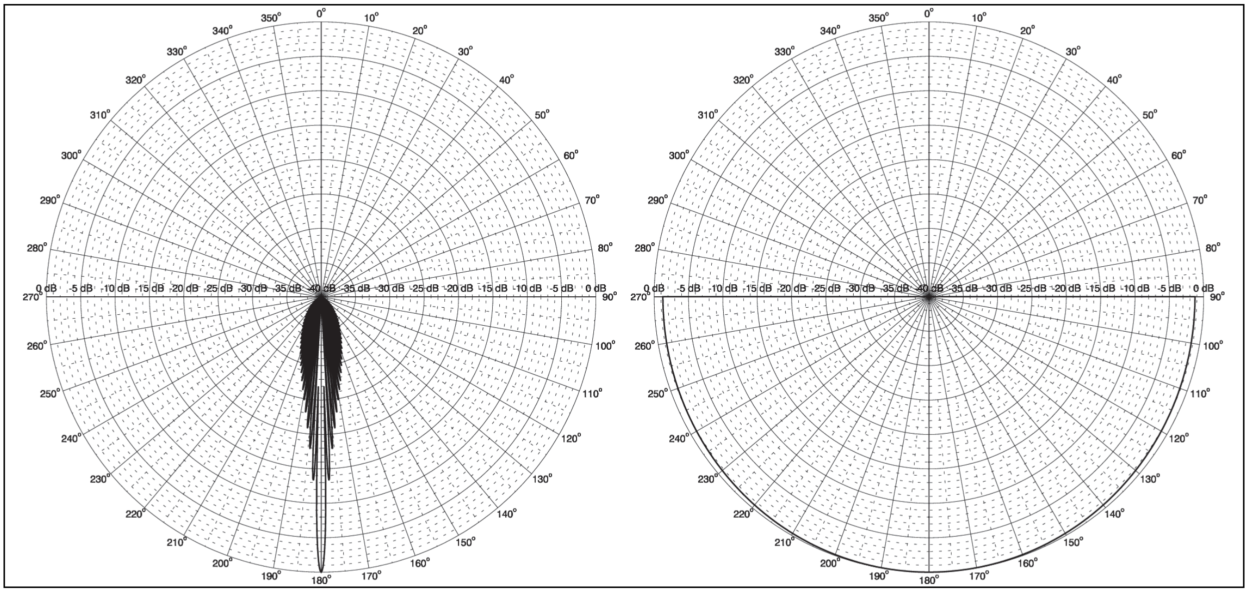

Figure D-31. Calculated Beam Pattern Vertical Slice for the Representative Multibeam Depth Sounder at 240 kHz; (left) Along- and (right) Across-Track Directions.

Modeling Approach

The multibeam depth sounder was modeled at the single frequency of 240 kHz. The depth of the source was chosen to be 5 m. With a very narrow beam width, the variability of the emitted energy in different horizontal directions is very high. A circular fan of modeling radials with variable angular step (**Table D-12**) was created to a maximum range of 20 km from the source. The density of the radials was greater in proximity of the broadside, where beam variability is maximum, and lesser toward the endfire. The total number of rays modeled was 660. The source heading was again chosen for each modeling site considering the bathymetry at that location, with the assumption that the survey lines would run along the isobaths. The SL was provided in rms SPL units, hence the output from the modeling was directly in terms of the rms SPL metric. The depth sounder was modeled only at the sites designated for renewable energy development (water depth ~100 m). The source level for the sonar was chosen to be 210 dB re 1 μPa.

Table D-12

Variable Angular Steps of the Modeling Radials in Different Sectors

(only the steps for the first quadrant (0°-90°) are shown; those for the other quadrants were symmetrical)

Sector	Angular Step
0° – 45°	1°
45° – 80°	0.5°
80° – 90°	0.2°

4. MODELING METHODOLOGY

Distinct modeling approaches were used for the low-frequency sources (airgun arrays) and mid- and high-frequency sources (electromechanical sources).

The modeling of the underwater acoustic field resulting from the operation of a seismic array in a particular area involved the use of two complementary software codes. The AASM, described in **Section 3.1.4**, was used to predict the directional SL of a seismic airgun array. The MONM, an acoustic propagation model, was then used to estimate the acoustic field at any range from the source. Sound propagation modeling uses acoustic parameters appropriate for the specific geographic region of interest, including the water column sound speed profile, the bathymetry, and the bottom geoacoustic properties, to produce site-specific estimates of the radiated noise field as a function of range and depth. MONM-RAM, described in **Section 4.1.1**, was used to predict the directional TL footprint from various source locations corresponding to trial sites for experimental measurements. The RL at any 3D location away from the source is calculated by combining the SL and TL, both of which are direction dependent, using the fundamental relation $RL = SL - TL$. Acoustic TL and RL are a function of depth, range, bearing, and environmental properties of the propagation medium.

The RLs estimated by MONM, like the SLs from which they are computed, are expressed in terms of the so SEL metric over the duration of a single source pulse. Sound exposure level is expressed in units of dB re 1 $\mu Pa^2 \cdot s$. For the purposes of this study, the SEL results were converted to the rms SPL metric using a range dependent conversion coefficient (see **Section 4.1.3**).

To model the sound field from the electromechanical sources a mathematical model (see **Sections 2.2.1–3.24**) was used to estimate the source beam pattern taking into account source specification data. The MONM-BELLHOP propagation code was then used to estimate the acoustic field around the source. Source beam pattern data as well as bathymetry, sediment geoacoustic properties, and water sound velocity profile information were provided as inputs for the propagation code.

Once the unweighted acoustic fields were calculated, the M-weighting filters were applied to the fields to yield M-weighted acoustic fields. The application of the M-weighting filters was performed as outlined in **Section 2.3.1** using Equation (6).

4.1. SOUND PROPAGATION MODEL: MONM

JASCO's MONM was used for the sound field modeling of all the sources in this study, using two variants of the computational engine for handling different frequency ranges. The MONM computes acoustic fields in 3D by modeling TL along evenly spaced 2D radial traverses covering a 360° swath from the source, an approach commonly referred to as N×2D. The model fully accounts for depth and/or range dependence of several environmental parameters including bathymetry and sound speed profiles in the water column and the subbottom. The acoustic environment is sampled at a fixed range step along radial traverses. The acoustic propagation code estimates sound pressure levels at various horizontal distances from the source as well as at different depths. Depending on the input source sound level metric provided, MONM can compute received sound fields in SEL or rms SPL metrics.

4.1.1. Low-Frequency – MONM-RAM

For the acoustic sources in the low-frequency band (below 2 kHz) the MONM-RAM variant of the computational code was used. In this study the sources that operate in the low-frequency bands are the airgun array sources and the boomer. For the former, the directional SLs computed with AASM were input to MONM-RAM to determine the predicted RLs.

The MONM-RAM treats sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation. The PE code used by MONM-RAM is based on a version of the Naval Research Laboratory's RAM, which has been modified to account for an elastic seabed. The PE method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al., 1996). The MONM-RAM also accounts for the additional reflection loss at the seabed that is due to partial conversion of incident compressional waves to shear waves at the seabed and subbottom interfaces. It includes wave attenuations in all layers.

The MONM-RAM treats frequency dependence by computing acoustic TL at the center frequencies of third-octave bands, between 10 Hz and 2 kHz in this study. Third-octave band RLs are computed by subtracting band TL values from the corresponding directional SLs. Broadband RLs are then computed by summing the received band levels. The MONM sound level predictions have been validated against experimental data in a formal study (Hannay and Racca, 2005) and in several instances where operational field measurements were obtained that allowed direct comparison to model estimates.

4.1.2. Mid- and High-Frequency – MONM-BELLHOP

For the acoustic sources in the mid- and high-frequency band (above 2 kHz), the MONM-BELLHOP variant of the computational code was used. In this study the sources that operate in the mid- and high-frequency bands are the boomer, side-scan sonar, chirp subbottom profiler, and multibeam depth sounder.

The MONM-BELLHOP models sound propagation in range-varying acoustic environments using the BELLHOP acoustic ray trace model (Porter and Liu, 1994), which is based on the Gaussian beam tracing technique. In addition to other types of attenuation, MONM-BELLHOP accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water (Fisher and Simmons, 1977). This type of attenuation is significant for frequencies higher than 5 kHz and cannot be neglected without noticeable effect on the modeling results at longer distances from the source.

The geoacoustic layering model for the MONM-BELLHOP propagation code consists of only one interface, namely the sea bottom. This is an acceptable limitation because the influence of the subbottom layers on the propagation of acoustic waves with frequencies above 2 kHz is negligible.

The acoustic model takes into account the variability of the sound levels emitted in different directions from the source, referred to as source directivity. Source directivity is specified to the model as a function of both azimuthal and depression angle where azimuth is the horizontal direction relative to north and depression is the vertical angle relative to the horizontal plane.

4.1.3. Estimating 90 Percent RMS SPL from SEL for Airgun Array Sources

Existing U.S. safety radius regulations for impulsive sound sources are based on the rms SPL metric. An objective definition of pulse duration is needed when measuring the rms level for a pulse. Following suggestions by Malme et al. (1986), Greene (1997), and McCauley et al. (1998), pulse duration is conventionally taken to be the interval during which 90 percent of the pulse energy is received. Although the 90 percent rms SPL can be easily measured *in situ*, this metric is difficult to model in general because the adaptive integration period, implicit in the definition of the 90 percent rms level, is highly sensitive to the specific multipath arrival pattern from an acoustic source and can vary abruptly with distance from the source or with depth of the receiver. To accurately predict the 90 percent rms level, it is necessary to model full-waveform acoustic propagation, which in highly range dependent environments is computationally overwhelming for long range, large water depth (more than 1,000 m), and multiple profile models.

Accurate estimates of airgun array safety ranges must take into account the acoustic energy that is returned to the water column by bottom and surface reflections. This is especially important in the case of shallow water conditions, which are found at many sites in the current study. If multipath reflections were taken into account, the resultant temporal spreading of the received seismic pulse would change the received pulse duration, rms estimates, and safety radii. The MONM algorithm does not attempt to predict the rms pressure directly; rather it models the propagation of acoustic energy in third-octave bands in a realistic, range-dependent acoustic environment. When these third-octave band levels are summed, the result is a broadband SEL, equivalent to the sound pressure level that would occur if the energy for a single airgun array pulse were spread evenly over a nominal time window of 1 s.

From these predicted SEL values, the approximate rms equivalents can be obtained taking into account the interrelationships of SEL, rms SPL, and pulse duration as known from theory and from field studies where these parameters have all been measured for the same received airgun pulses. The rms SPL based on the 90 percent energy pulse duration is related to SEL via a simple function that depends only on the rms integration period T:

$$\mathrm{SPL}_{\mathrm{RMS90}} = \mathrm{SEL} - 10\log(T) - 0.458 \tag{11}$$

Here, the last term accounts for the fact that only 90 percent of the acoustic pulse energy is delivered over the standard integration period. In the absence of *in situ* measurements, the integration period is difficult to predict with any reasonable degree of accuracy.

Two approaches can be used in this case. The first is to use a heuristic value of T, based on field measurements in similar environments, to estimate an rms SPL level from the modeled SEL. Safety radii estimated in this way are approximate since the true time spreading of the pulse has not actually been modeled. In various studies where the $\mathrm{SPL}_{\mathrm{RMS\ 90}}$, SEL, and duration have been determined for individual airgun pulses, the average offset between SPL and SEL has been found to be 5–15 dB, with considerable variation dependent on water depth and geo-acoustic environment (Greene, 1997; McCauley et al., 2000; Blackwell et al., 2007; MacGillivray et al., 2007). On average, the measured SPL–SEL offsets tend to be larger at close distances, where the pulse duration is short (<<1 s), and to diminish at longer distances, where pulse duration tends to increase because of propagation effects.

An alternative approach is to use a full-waveform acoustic propagation model to generate range-dependent estimates of SPL and SEL for a small set of representative transects, and then apply the SPL-SEL offsets obtained in this manner to the full MONM results. This approach combines the accurate pulse length information available from the full-waveform model with the greater computational efficiency of the MONM algorithm. For the conversion of the acoustic field in SEL metrics to rms SPL metrics, appropriate SPL–SEL range dependent functions are selected from the set of available representative transects on the basis of similarity of water depth and bottom type.

For this study, a combination of the two approaches was chosen. The results of the full waveform estimation were combined with the data obtained during field measurements of similar sources in similar environments (e.g., Austin et al., 2003; Funk et al., 2008). Full-waveform results were derived for idealized flat bottom models with water depths of 40, 150, and 1,000 m. The bottom type was sand for the 40 and 150 m models and clay for the 1,000 m model. The estimated range dependent SPL–SEL offset functions used in this study are shown in **Figure D-32**.

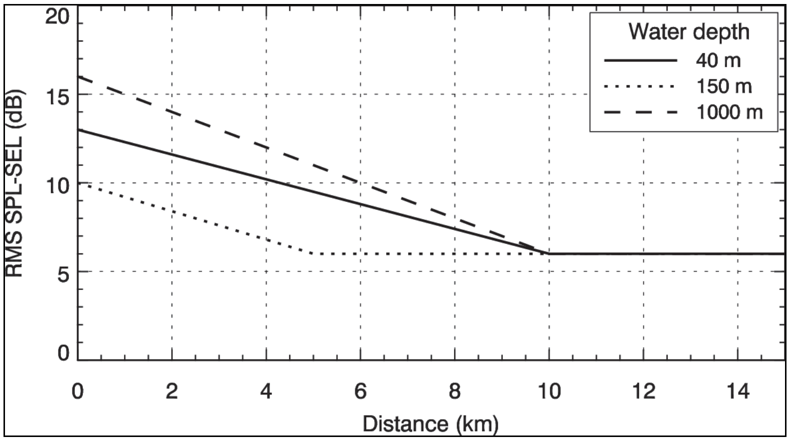

Figure D-32. SPL–SEL Conversion Functions for Different Water Depths.

In applying the above conversions to the model results in this study, the sites with water depths from 30 to 60 m were assigned the SPL–SEL function for 40 m depth, the sites with water depth from 61 to 300 m the function for 150 m, and the sites deeper than 300 m the function for 1,000 m water depth.

4.2. MODELING PROCEDURE

4.2.1. Area of Interest and Proposed Activities

The AOI includes U.S. Atlantic waters from the mouth of Delaware Bay to just south of Cape Canaveral, Florida, and from the shoreline (excluding estuaries) to 648 km (350 nmi) from shore (**Figure D-33**). The total area of the AOI is 854,779 km^2 (330,032 mi^2). The water depths inside the AOI vary from a few meters to more than 5,000 m, covering various types of oceanic bottom: continental shelf, continental slope and rise, and abyssal plain.

Three major program areas of G&G activities are included in this study:

- oil and gas exploration;
- renewable energy development; and
- marine minerals.

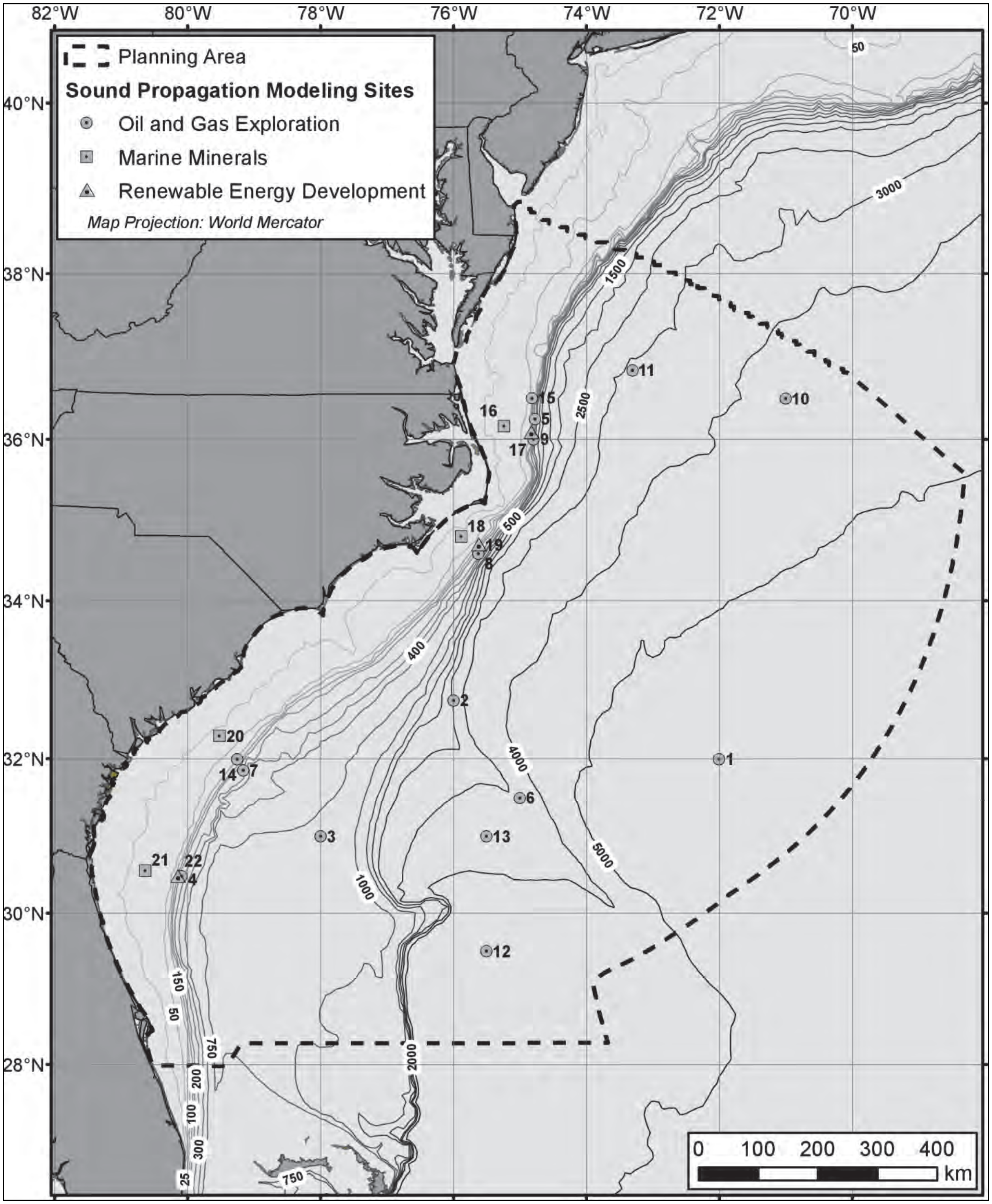

Figure D-33. Area of Interest with the Locations of the Modeling Sites.

Different activities would be performed in specific water depths. The types of acoustic sources are also defined by the type of planned activity (**Table D-13**).

Table D-13

List of Proposed G&G Activities and Sources

Activity Type	Acoustic Source	Representative Modeling	
		Water Depth (m)	Acoustic Source
Oil and Gas Exploration and Development (50–6,000 m)			
2D seismic survey	Airgun array 3,000–9,000 in^3	50 – 6,000	Large airgun array 5,400 in^3
3D seismic survey	Dual airgun array 3,000–9,000 in^3	50 – 6,000	Large airgun array 5,400 in^3
Vertical seismic profiling	Airgun array 1,000–6,000 in^3	50 – 6,000	Large airgun array 5,400 in^3
High-resolution geophysical survey	Single gun or airgun array 45–200 in^3	50 – 6,000	Small airgun array 90 in^3
Renewable Energy (0–100 m)			
Bathymetry data collection	Multibeam depth sounder	100	Multibeam depth sounder
Bottom obstruction detection	Side-scan sonar	100	Side-scan sonar
Shallow sediment mapping (0–100 mbsf)	Shallow penetration subbottom profiler	100	Chirper
Medium depth sediment mapping (0–200 mbsf)	Medium penetration subbottom profiler	100	Boomer
Marine Minerals (0–50 m)			
Bathymetry data collection	Multibeam depth sounder	30	Multibeam depth sounder
Bottom obstruction detection	Side-scan sonar	30	Side-scan sonar
Shallow sediment mapping (0–100 mbsf)	Shallow penetration subbottom profiler	30	Chirper
Medium depth sediment mapping (0–200 mbsf)	Medium penetration subbottom profiler	30	Boomer

Abbreviations: mbsf = meters below seafloor.

Oil and gas explorations surveys could occur at water depths ranging from 50 m to more than 4,000 m, covering all three bottom types – shelf, slope, and abyssal plain. The acoustic sources that would be utilized for these surveys include seismic airgun arrays of different types. The volume of air gun arrays may vary from less than 100 in^3 (high-resolution, geohazard seismic surveys) to more than 5,000 in^3 (2D and 3D seismic surveys).

Renewable energy development and marine mineral surveys would be limited to shallow waters with maximum water depth of about 100 m. The acoustic sources involved would include mid- to high-frequency electromechanical sources (boomers, chirp subbottom profilers, side-scan sonars, multibeam depth sounders, etc.).

The information about the selected modeling sites is provided in **Table D-14**, and the map with the locations of these sites is shown in **Figure D-33**.

Table D-14

Modeling Site Information

Site Number	Geographic Coordinates		UTM Coordinates			Bottom Type	Water Depth at the Source (m)	Towing Azimuth
	North	West	Northing	Easting	Zone			
1	32.00	-72.00	3544000	783000	18	Clay	5,390	N/A
2	32.75	-76.00	3624000	406000	18	Clay	2,560	N/A
3	31.00	-78.00	3433000	214000	18	Sand	880	N/A
4	30.48	-80.09	3373000	588000	17	Sand	249	N/A
5	36.25	-74.77	4012000	520000	18	Sand	288	N/A
6	31.50	-75.00	3485000	500000	18	Clay	3,200	N/A
7	31.85	-79.16	3526000	674000	17	Sand	251	N/A
8	34.59	-75.63	3828000	443000	18	Sand	249	N/A
9	36.00	-74.79	3984000	519000	18	Sand	275	N/A
10	36.50	-71.00	4041000	321000	19	Clay	4,300	N/A
11	36.84	-73.31	4079000	651000	18	Clay	3,010	N/A
12	29.50	-75.50	3263000	452000	18	Clay	4,890	N/A
13	31.00	-75.50	3430000	452000	18	Clay	3,580	N/A
14	32.00	-79.25	3542000	665000	17	Sand	100	N/A
15	36.51	-74.82	4040000	516000	18	Sand	51	N/A
16	36.16	-75.24	4001808	478773	18	Sand	30	N/A
17	36.09	-74.84	3993702	514548	18	Sand	100	10°
18	34.80	-75.89	3851633	418959	18	Sand	30	40°
19	34.70	-75.63	3840310	442218	18	Sand	100	40°
20	32.30	-79.52	3574265	639795	17	Sand	30	35°
21	30.55	-80.64	3380052	534518	17	Sand	30	20°
22	30.49	-80.16	3372884	580545	17	Sand	100	20°

N/A = not applicable. Towing azimuth not needed for calculations because the seafloor is flat.

4.2.2. Model Profiles

Both acoustic propagation models, MONM-RAM and MONM-BELLHOP, compute acoustic fields along one 2D radial traverse at a time. One can obtain a 3D distribution of the acoustic field around a source by combining a set of radial traverses covering a 360° swath from the source. The angular step between the radials can be either constant or variable, depending on the type of source and its horizontal directivity function. This approach commonly is referred to as N×2D.

Assuming that the bottom geoacoustic properties and the water column are uniform in all directions from a given modeling site, the parameters that change from profile to profile are the bathymetry and the SL for a directional source. For an omnidirectional source, the only parameter that would change between profiles is the bathymetry.

For the purpose of this study, an adaptive approach was taken for defining the distribution of modeling profiles. For the boomer and airgun array sources, the profiles were evenly spaced around the source; the number of profiles, however, depended on the water depth observed inside the modeling area, varied from 120 (3° step) to 24 (15° step). Also for the very deep sites (water depth more than 3,000 m), only one profile was modeled and then cloned 24 times along the fan of radials. This approach was considered readily justifiable since the bathymetry, which is the only parameter that would change from profile to profile, is virtually flat at deep sites and at such depths has very little influence on the sound propagation. The angular step and the total number of profiles modeled at different sites for the boomer and airgun arrays sources are provided in **Table D-15**.

Table D-15

Modeling Profile Information for Airgun Array Sources at Different Sites

Site Number	Water Depth at the Source (m)	Number of Profiles	Angular Step	Maximum Receiver Depth (m)
1	5,390	1	–	2,000
2	2,560	24	15°	2,000
3	880	120	3°	1,000
4	249	120	3°	500
5	288	72	5°	2,000
6	3,200	1	–	2,000
7	251	120	3°	600
8	249	72	5°	2,000
9	275	72	5°	2,000
10	4,300	1	–	2,000
11	3,010	1	–	2,000
12	4,890	1	–	2,000
13	3,580	1	–	2,000
14	100	120	3°	650
15	51	72	5°	2,000
16	30	72	5°	40
17	100	72	5°	200
18	30	72	5°	50
19	100	72	5°	1,000
20	30	72	5°	50
21	30	72	5°	40
22	100	72	5°	500

The angular step size for the high-frequency sources was chosen based on the minimum beam width and the directivity pattern. The minimum angular step size was chosen to be no more than half the size of the beam width. The modeling profiles information for the engineering source, except the boomer is provided in **Table D-16**. The same profile pattern was used for all sites where these sources were modeled, namely locations 16-22. The water depth at the source and the maximum receiver depth are the same as shown in **Table D-15**.

Table D-16

Modeling Profile Information for Electromechanical Sources Except the Boomer

Source	Smallest Beam Width	Number of Profiles	Angular Step Size
Side-scan sonar	0.4°	660	Variable: 0.2°–1°
Chirp subbottom profiler	8°	72	Constant: 5°
Multibeam depth sounder	1°	309	Variable: 0.5°–2°

4.2.3. Model Receiver Depths

Model receiver depths are the depths below the water surface at which virtual receivers are placed in the acoustic propagation model and the TL is sampled. From the chosen source positions, the model can generate a grid of predicted acoustic levels over any desired area, as well as at any depth in the water column. The virtual receivers can, in principle, be placed at a vertical step size as fine as the acoustic field modeling grid, which varies from 2 m for low frequencies to 6 cm for high frequencies. Such a fine grid of receivers, however, would be very inefficient and provide too large a quantity of data. The depth spacing between the receiver planes was therefore chosen on the basis of the vertical variability of the acoustic field, which in turn depends on the variability of the sound speed profile – higher at the top of the water column, lower at greater depths. The maximum depth for the virtual receivers (2,000 m) was chosen based on the normal dive depth limits for the marine mammals in the AOI.

The set of virtual receivers depths for the sites designated for oil and gas exploration (water depth from 50 to 5,390 m) was as follows: 2, 5, 10, 15, 20, 25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1,000, 1,100, 1,200, 1,400, 1,600, 1,800, and 2,000 m.

For the sites where electromechanical sources were modeled (water depths at the source 30 and 100 m) several depths were added at the top of the water column. The set of virtual receiver depths for the sites designated for marine minerals and renewable energy development (sites 16–22) was as follows: 2, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 35, 40, 45, 50, 75, 100, 150, 200, 250, 300, 350, 400, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, and 1,000 m.

4.2.4. Model Radial Step Size

The quality of the modeling results is highly dependent on the radial step size, as with too large a step the modeling approximation can become unstable and produce inaccurate results. For the purpose of this study, the radial modeling step size was set at a very finely resolved 5 m. Further reduction of the step size provides virtually no quality benefit for the results while increasing the computational requirements. Before transferring the modeled acoustic field data for use with the Acoustic Integration Model (AIM) individual-based exposure model, however, the radial results were downsampled with a variable step size in order to increase the efficiency of the data processing. The set of distances from the source in meters at which the received acoustic field was reported for use in AIM was generated according to the following equation:

$$r = i^2, \qquad \text{where } i=1,2,3,\ldots,141 \tag{12}$$

4.3. BATHYMETRY AND ACOUSTIC PARAMETERS

4.3.1. Bathymetry

The bathymetry data for this project was provided by CSA International, Inc. The bathymetry grid spans from 28° N to 40° N and from 66.5° W to 82.5° W, fully covering the AOI. The resolution of the grid is about 1.5 arc seconds or approximately 50 m.

For the purpose of modeling, smaller portions of the large grid were extracted for each modeling site. The overall bathymetry information was considered from the start in choosing the locations for the modeling sites, both in terms of selecting locations with desired water depths and of avoiding areas with highly site-specific bathymetry features such as localized sea bottom rises or depressions.

4.3.2. Geoacoustic Properties

In view of the generalized nature of this study, a more generic approach to the definition of geoacoustic properties was exercised than would normally be used for site specific modeling. The AOI spans numerous geological provinces with highly variable stratification profiles. It would not have been opportune to consider site specific geoacoustic profiles, since the acoustic modeling results thus obtained would introduce excessive bias when used as estimation for other locations. Generic geoacoustic profiles were created instead, which only take into account the type of sediment found at the sea bottom with the appropriate porosity value and typical porosity trend with depth below the seafloor (which is sediment type specific). Any layered model of the sediment column was avoided, i.e. there were no interfaces in the geoacoustic profiles at which a rapid change of properties is observed because of sediment type transition. Instead, only a gradual change of properties with depth was introduced.

The acoustic properties of sediment layers that are required by MONM are density (ρ), compressional speed (V_p), compressional attenuation coefficient in decibels per wavelength (α_p), shear wave speed (V_s), and shear wave attenuation coefficient (α_s), also in decibels per wavelength. These geoacoustic parameters were estimated using a sediment grain-shearing model (Buckingham, 2005), which computes the acoustic properties of the sediments from porosity and grain-size measurements. The input parameters required by the geoacoustic model were the bottom type (grain size) and sediment porosity, inferred from the geological description of the modeling region.

Numerous surficial sediment-type data exist for the Atlantic region off-shore U.S. coast, for example the U.S. Geological Survey (USGS) Continental Margin Program (Hathaway, 1977) and the National Geophysical Data Center (NGDC) Seafloor Sediment Descriptions (Bershad and Weiss, 1975). Poppe et al. (1989) provided a map of distribution of the surficial sediments for the region. According to the map, the surficial sediments over 85 percent of the area of interest are represented either by sand or clay. The remaining 15 percent of the area is characterized by transitional sediment types.

The distribution of the specific type of sediment is primarily determined by the bathymetry. Sediments that can be described as sand are found at water depths from 0 to 1,000 m. In deeper environment, the prevailing sediment type is clay, which is found at water depths 900 m and greater.

Clay

The geoacoustic profile for clay sediments was constructed based on the data obtained by the Ocean Drilling Program (ODP) at site 905, leg 150 (Shipboard Scientific Party, 1994). The well was located at a water depth of 2,700 m. The reported porosity for the surficial sediments was 60 percent and did not change with depth, maintaining the same value of 60 percent down to 600 m below the seafloor. The geoacoustic model for clay sediments is presented in **Table D-17**.

Table D-17

Geoacoustic Model for the Clay Sediments

Depth (m)	ρ (g/cm^3)	V_p (m/s)	α_p (dB/λ)	V_s (m/s)	α_s (dB/λ)
0–10	1.70	1,563–1,613	0.19–0.40	61	0.01
10–50	1.70	1,613–1,683	0.40–0.67		
50–150	1.70	1,683–1,763	0.67–0.93		
150–300	1.70	1,763–1,833	0.93–1.14		
300–600	1.70	1,833–1,925	1.14–1.37		
>600	1.70	1,925	1.37		

Sand

The geoacoustic profile for sand sediments was constructed based on the data obtained by the ODP at site 1071, leg 174 (Shipboard Scientific Party, 1998). The well was located at a water depth of 100 m. The reported porosity for the surficial sediments was 50 percent and decreased gradually decreasing with depth below the seafloor; at 150 m below the seafloor the porosity reached 40 percent and did not change for greater depths. The geoacoustic model for sand sediments is presented in **Table D-18**.

Table D-18

Geoacoustic Model for the Sand Sediments

Depth (m)	ρ (g/cm^3)	V_p (m/s)	α_p (dB/λ)	V_s (m/s)	α_s (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–,2276	1.45–1.79		
150–300	2.04	2,276–2,482	1.79–2.08		
300–600	2.04	2,482	2.08		

4.3.3. Sound Speed Profiles

The vertical sound speed profiles used in this modeling study were provided by Marine Acoustics, Inc. (MAI). The selected profiles were to reflect the variation of the sea water properties at different locations throughout the AOI as well as seasonal variation at the same location. They represent various types of sound propagation through the water layer such as ducted propagation, presence of convergence zone, and bottom bounce propagation.

As indicated by MAI, the data for the computation of the sound velocity in the water column were mined from the U.S. Naval Oceanographic Office's Generalized Digital Environmental Model (GDEM) database (Teague et al., 1990). The GDEM database provides average monthly profiles of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25-degree resolution. Profiles in GDEM are provided at 78 fixed-depth points up to a maximum depth of 6,800 m. The profiles in GDEM are based on historical observations of global temperature and salinity from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS). The GDEM provides historical average profiles that extend to the maximum depth in a given 15-arc-minute square. The parameters for the sound speed profiles used in this study are shown in **Table D-19**. The sound speed profiles for the winter, spring, summer, and fall seasons are shown in **Figures D-34** through **D-37**, respectively.

Table D-19

List of Sound Speed Profiles Used in This Study

Profile Number	Season	Propagation Characteristic	Representative Location
1	Winter	Convergence zone (deep water) Bottom bounce (mid-range water depth)	32°45'N 72°00'W
2	Winter	Shallow water	30°30'N 74°45'W
3	Winter	Shallow water	36°15'N 80°15'W
4	Spring	Convergence zone (deep water) Bottom bounce (mid-range water depth)	31°30'N 75°00'W
5	Spring	Bottom bounce (shallow water)	32°00'N 79°15'W
6	Spring	Moderately ducted (shallow water)	35°00'N 76°15'W
7	Summer	Convergence zone (deep water) Bottom bounce (mid-range water depth)	31°30'N 75°00'W
8	Summer	Shallow water	36°00'N 74°45'W
9	Fall	Convergence zone (deep water)	36°30'N 71°30'W
10	Fall	Convergence zone (deep water) Bottom bounce (mid-range water depth)	31°00'N 78°00'W
11	Fall	Shallow water	32°00'N 79°15'W
12	Fall	Shallow water	36°30'N 74°45'W

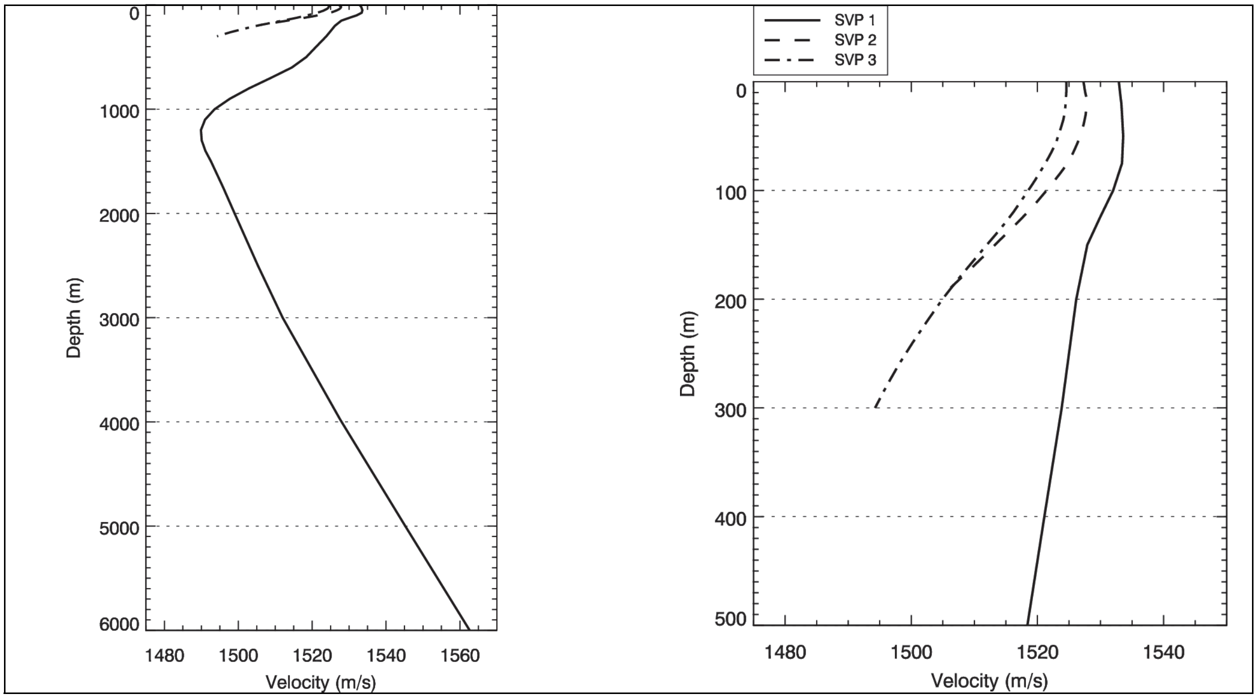

Figure D-34. Sound Velocity Profiles for Winter Season Used in This Modeling Study: Fully Extended to the Maximum Depth (left) and Zoomed-in Upper Portion (right).

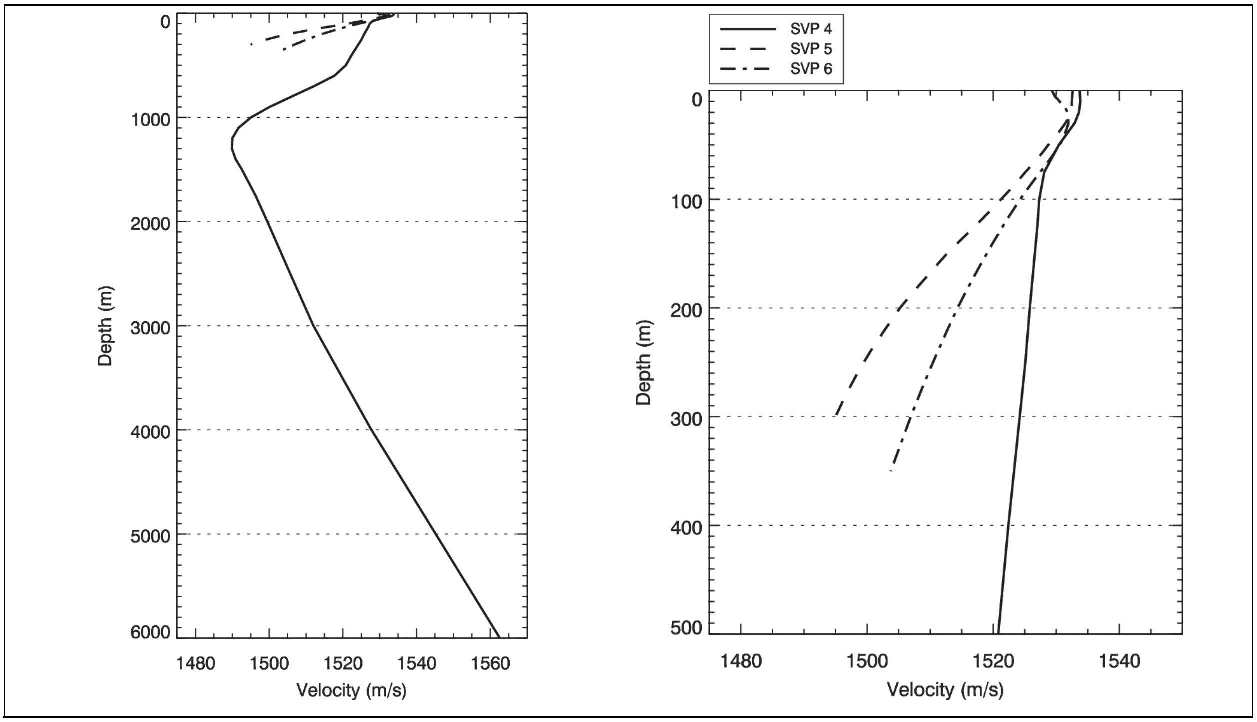

Figure D-35. Sound Velocity Profiles for Spring Season Used in This Modeling Study: Fully Extended to the Maximum Depth (left) and Zoomed-in Upper Portion (right).

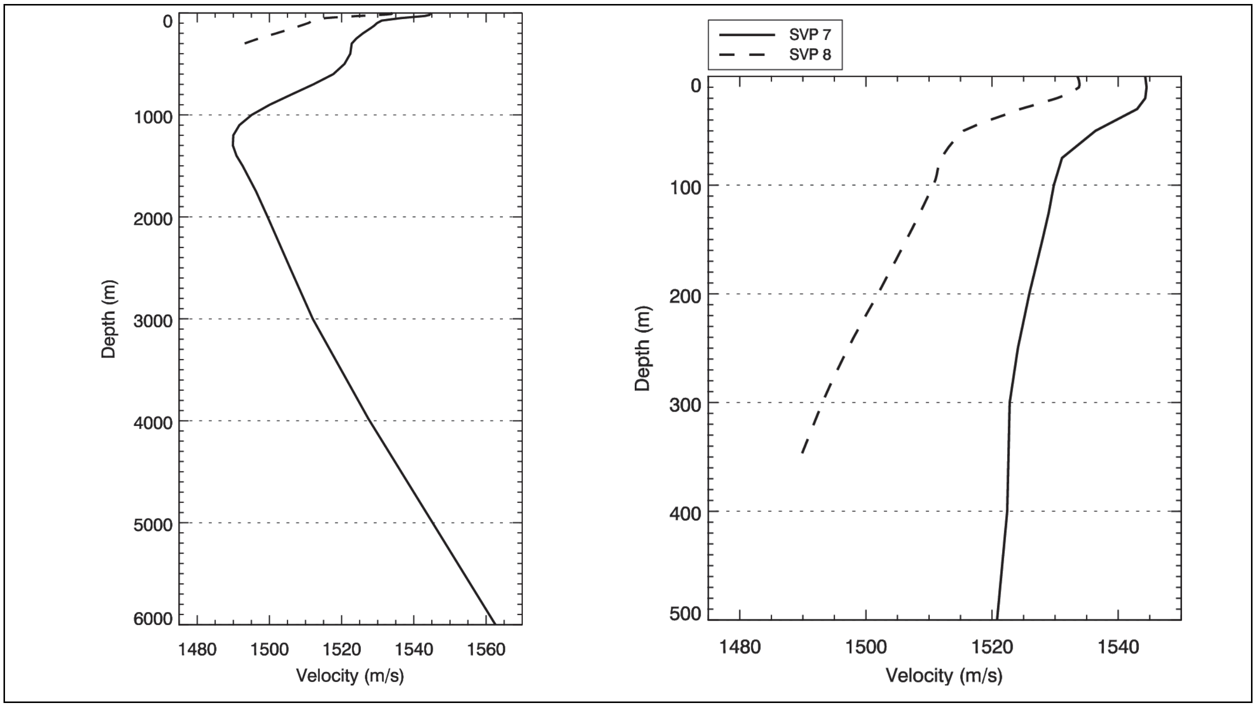

Figure D-36. Sound Velocity Profiles for Summer Seasons Used in This Modeling Study: Fully Extended to the Maximum Depth (left) and Zoomed-in Upper Portion (right).

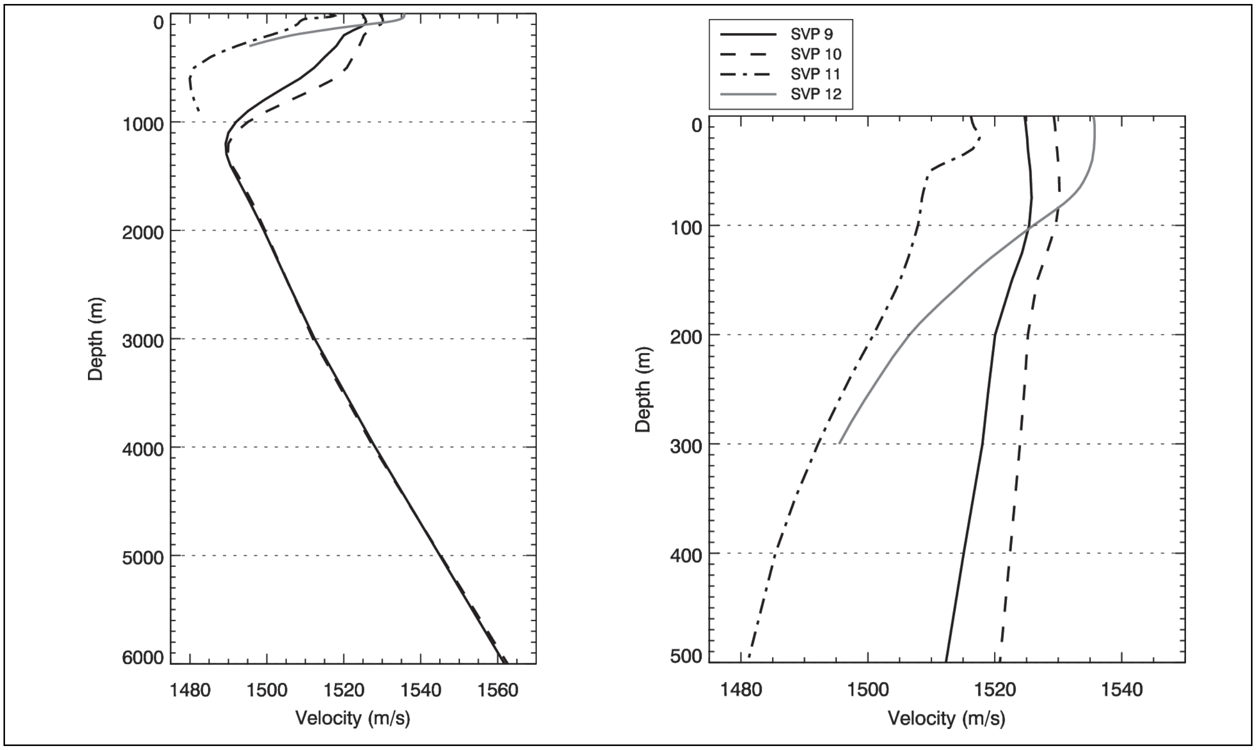

Figure D-37. Sound Velocity Profiles for Fall Season Used in This Modeling Study: Fully Extended to the Maximum Depth (left) and Zoomed-in Upper Portion (right).

4.4. MODELING SCENARIOS

A total of 22 modeling sites was identified in various parts of the AOI (**Table D-14** and **Figure D-33**). For each site, modeling was done using 1-4 different sound velocity profiles (**Table D-19** and **Figures D-34** through **D-37**), for a total of 35 modeling scenarios. The geoacoustic model also varied from site to site. Scenarios from 1 to 21 were designated for modeling oil and gas exploration activities using airgun array sources. Scenarios 22-35 were modeled for marine minerals and renewable energy development using the boomer, side-scan sonar, chirp subbottom profiler, and multibeam depth sounder.

The complete list of scenarios modeled in this study together with indication of the sources that were modeled for each scenario is provided in **Table D-20**. There were a total of 105 combinations of scenarios and sources. For each combination, an acoustic field was modeled and threshold distances to the specified rms SPL value were calculated. Each acoustic field was also downsampled as previously described and provided as an input for exposure modeling with the AIM software.

4.5. CLASSIFICATION OF ACOUSTIC ENVIRONMENTS

Each acoustic modeling scenario is characterized by a unique combination of parameters. The main variables in the environment configuration are the bathymetry and the sound velocity profile in the water column. The geoacoustic properties of the sea bottom are directly correlated with the water depth of the modeling site. The major factor that affects sound propagation in different areas throughout the AOI is the water depth. Four regions can be classified based on the bathymetry:

- shallow continental shelf (<60 m);
- continental shelf (60–150 m);
- continental slope (150–1,000 m); and
- deep ocean (>1,000 m).

Each region exhibits a specific acoustic propagation regime, which will be discussed in following sections and exemplified graphically using frequency versus distance plots. These are useful tools for analysis of the acoustic propagation environment, as they help to understand how the physical conditions, mostly water depth, affect propagation of the acoustic waves at different frequencies.

4.5.1. Shallow Continental Shelf

Shallow continental shelf is defined as the areas with depth less than 60 m. Modeling sites that fall into this region are 15, 16, 18, 20, and 21. The bottom type for this area is sand and the bottom sloping is minimal, usually less than 0.1°. Inside each modeling area (20 km radius) the variability in depth is less than 5 m; such a small variation in bathymetry has virtually no effect on the sound propagation in different directions from the source except for some local features of the sea bottom.

An example of frequency versus distance plot for Scenario 22 (Site 16) is provided in **Figure D-38**. The shallow environment does not favor the propagation of low frequencies as the mode propagation condition cannot be established for the acoustic waves at these frequencies. The TL for frequencies lower than 20 Hz is significantly greater than for higher frequencies. Acoustic waves with frequencies between 20 and 80 Hz also experience higher attenuation due to shallow environment.

The vertical sound speed profile in the water column has very little influence on the propagation of the sound in shallow waters, as the variation in sound velocity is not significant in the top 30 m of the profile. The geometric spreading of the acoustic wave energy transitions from spherical-spreading into a cylindrical-spreading regime very close to the source. A highly reflective bottom interface ensures that most of the acoustic energy is returned into the water column after interaction with the seafloor, and bottom reflections contribute significantly to the total acoustic field.

Table D-20

List of Modeling Scenarios

Scenario Number	Site Number	Water Depth (m)	Season	Sound Profile	Bottom Type	Modeled Sources			
						5,400 in^3 Airgun Array	90 in^3 Airgun Array	Boomer, SSS, SBP	MBE
1	1	5,390	Winter	SVP 01	Clay	X	X		
2	2	2,560	Winter	SVP 01	Clay	X	X		
3	3	880	Winter	SVP 01	Sand	X	X		
4	4	249	Winter	SVP 02	Sand	X	X		
5	5	288	Winter	SVP 03	Sand	X	X		
6	1	5,390	Spring	SVP 04	Clay	X	X		
7	6	3,200	Spring	SVP 04	Clay	X	X		
8	3	8,80	Spring	SVP 04	Sand	X	X		
9	7	251	Spring	SVP 05	Sand	X	X		
10	8	249	Spring	SVP 06	Sand	X	X		
11	1	5,390	Summer	SVP 07	Clay	X	X		
12	6	3,200	Summer	SVP 07	Clay	X	X		
13	3	880	Summer	SVP 07	Sand	X	X		
14	9	275	Summer	SVP 08	Sand	X	X		
15	10	4,300	Fall	SVP 09	Clay	X	X		
16	11	3,010	Fall	SVP 09	Clay	X	X		
17	12	4,890	Fall	SVP 10	Clay	X	X		
18	13	3,580	Fall	SVP 10	Clay	X	X		
19	3	880	Fall	SVP 10	Sand	X	X		
20	14	100	Fall	SVP 11	Sand	X	X		
21	15	51	Fall	SVP 12	Sand	X	X		
22	16	30	Spring	SVP 03	Sand			X	
23	17	100	Spring	SVP 03	Sand			X	X
24	16	30	Summer	SVP 08	Sand			X	
25	17	100	Summer	SVP 08	Sand			X	X
26	16	30	Fall	SVP 12	Sand			X	
27	17	100	Fall	SVP 12	Sand			X	X
28	18	30	Spring	SVP 06	Sand			X	
29	19	100	Spring	SVP 06	Sand			X	X
30	20	30	Spring	SVP 05	Sand			X	
31	14	100	Spring	SVP 05	Sand			X	X
32	20	30	Fall	SVP 11	Sand			X	
33	14	100	Fall	SVP 11	Sand			X	X
34	21	30	Winter	SVP 02	Sand			X	
35	22	100	Winter	SVP 02	Sand			X	X

Abbreviations: MBE = multibeam depth sounder; SBE = chirp subbottom profiler; SSS = side-scan sonar.

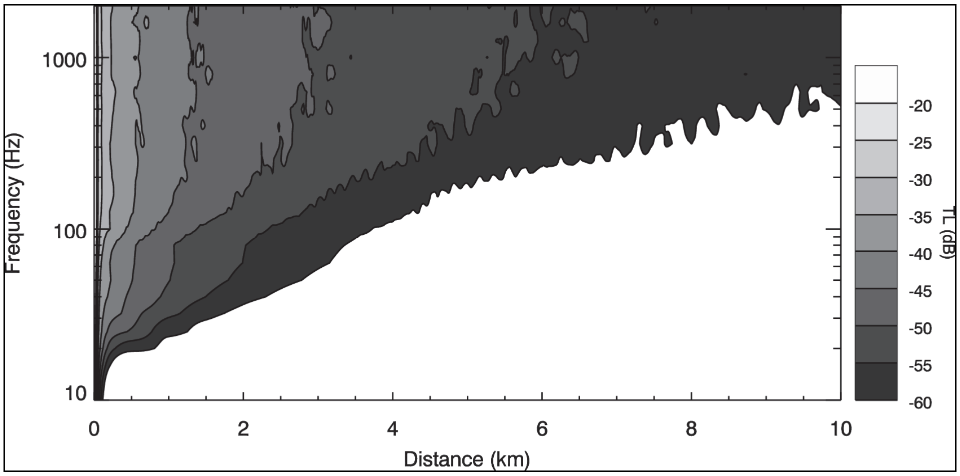

Figure D-38. Frequency Versus Distance Plot Based on Modeled Data for Scenario 22 (SVP 03) (water depth at the source is 30 m).

4.5.2. Continental Shelf

For the purpose of this work, continental shelf is defined as the areas with water depth less than 150 m with the exclusion of areas defined as shallow continental shelf in **Section 4.5.1**. Modeling site numbers that fall into this region are 14, 17, 19, and 22. The bottom type for this area is sand and the bottom sloping is more pronounced than in the shallow continental area, with a slope varying from 0.5° to 1° and a bathymetry condition that can be no longer be considered flat. With a water depth at the source of 100 m, the depth inside the modeling area (20 km radius) can vary from 40 m to as deep as 1,500 m.

An example of frequency versus distance plot for Scenario 23 (Site 17) is provided in **Figure D-39**. With greater water depth than in the shallow continental shelf environment, all modeled frequencies can effectively propagate through the water layer waveguide; very low frequencies (10–15 Hz), however, still experience elevated TL compared with the higher frequencies.

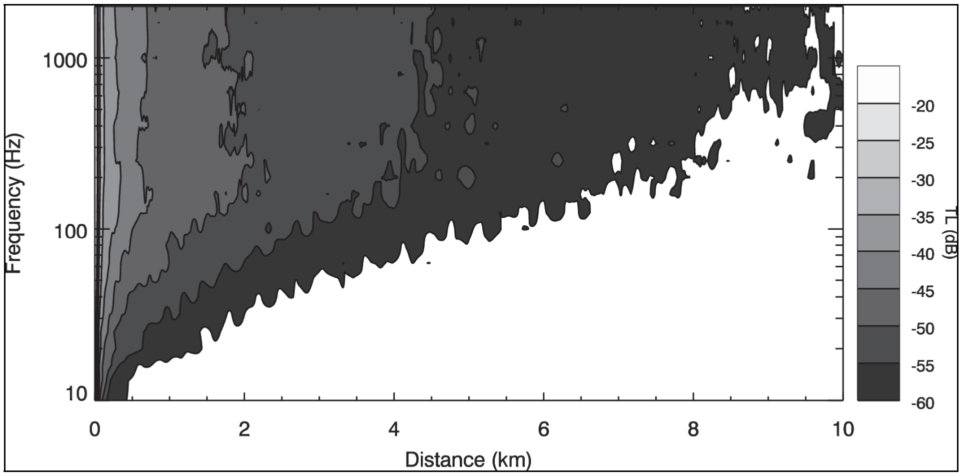

Figure D-39. Frequency Versus Distance Plot Based on Modeled Data for Scenario 23 (SVP 03) (water depth at the source is 100 m).

The vertical sound speed profile in the water column influences the propagation of the sound in the area. Most of the sound speed profiles used in the modeling scenarios feature negative velocity gradient at a depth of 30 m below the sea surface. Negative velocity gradient refracts the acoustic wave downwards and directs it into the seafloor, increasing the effect of bottom loss. The TL for high frequencies (100–2,000 Hz) is greater compared to the shallow continental shelf regions.

The geometric spreading of the acoustic wave energy still transitions into cylindrical spreading regime very close to the source. A highly reflective bottom interface ensures that most of the acoustic energy is returned into the water column after interaction with the seafloor, and bottom reflections contribute significantly to the total acoustic field.

4.5.3. Continental Slope

For the purpose of this work, continental slope is defined as the areas with water depth between 150 and 1,000 m. Modeling site numbers that fall into this category are 3, 4, 5, 7, 8, and 9. The bottom type for this area is sand and the bottom inclination is significant, reaching values as high as 13°. With a water depth at the source between 250 and 900 m, the depth inside the modeling area (20 km radius) can vary from 40 m to as deep as 2,500 m.

Two examples of frequency versus distance plot for Scenario 14 (Site 9) and for Scenario 3 (Site 3) are provided in **Figures D-40** and **D-41**, respectively. With greater water depth than in continental shelf environment, all modeled frequencies can effectively propagate through the water layer waveguide. Low frequencies (10–100 Hz), however, can still experience elevated TL for a shallow location of the source.

The sound speed profile in the water column influences the propagation of the sound in the area. Most of the sound speed profiles used in the modeling scenarios feature negative velocity gradient from 30 m to about 1,200 m below the sea surface. Negative velocity gradient refracts the acoustic wave downward and directs it into the seafloor, increasing the effect of the bottom loss. The TL for high frequencies (100–2,000 Hz) is greater compared to the shallow continental shelf regions.

The geometric spreading of the acoustic wave energy transitions into a cylindrical-spreading regime at about 250 m or farther from the source. A highly reflective bottom interface ensures that most of the acoustic energy is returned into the water column after interaction with the seafloor, and bottom reflections contribute significantly to the total acoustic field near the source; their contribution, however, diminishes for greater water depths at the source.

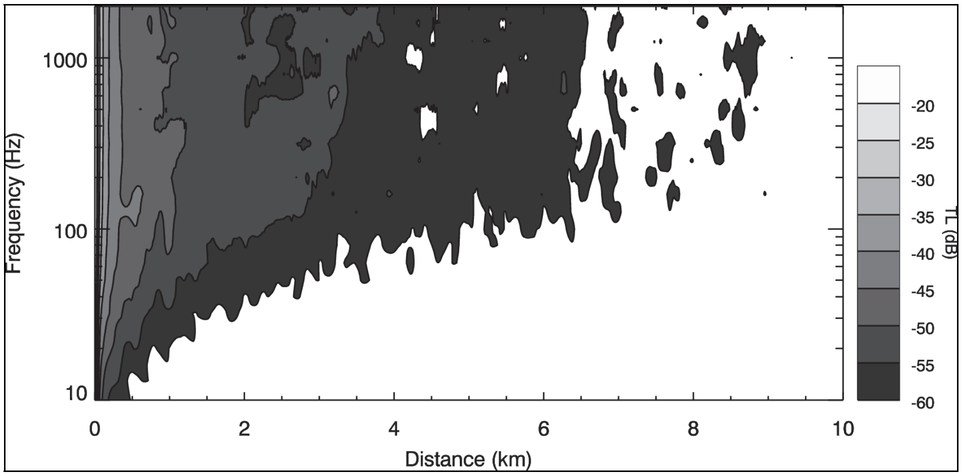

Figure D-40. Frequency Versus Distance Plot Based on Modeled Data for Scenario 14 (SVP 08) (water depth at the source is 250 m).

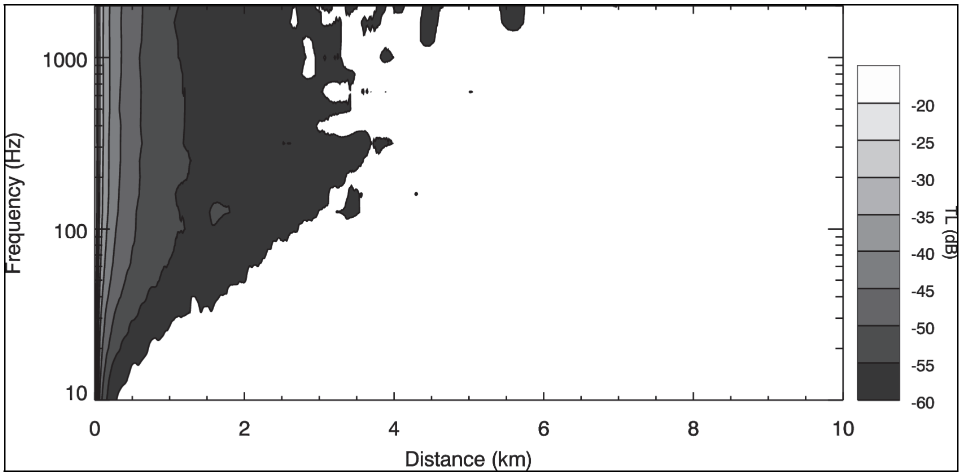

Figure D-41. Frequency Versus Distance Plot Based on Modeled Data for Scenario 3 (SVP 01) (water depth at the source is 880 m).

4.5.4. Deep Ocean

For the purpose of this work, deep ocean is defined as the areas with water depth greater than 1,000 m. Modeling site numbers that fall into this category are 1, 2, 6, and 10–13. The bottom type for this area is clay; bottom sloping can be significant near the continental slope regions and almost absent at depths greater than 2,000 m. The relative variation of the water depth inside a modeling area (radius 20 km) is small.

An example of frequency versus distance plot for Scenario 1 (Site 1) is provided in **Figure D-42**. With larger water depths, all modeled frequencies can effectively propagate through the water layer waveguide. However, low frequencies (10–100 Hz) can still experience elevated TL for a shallow location of the source.

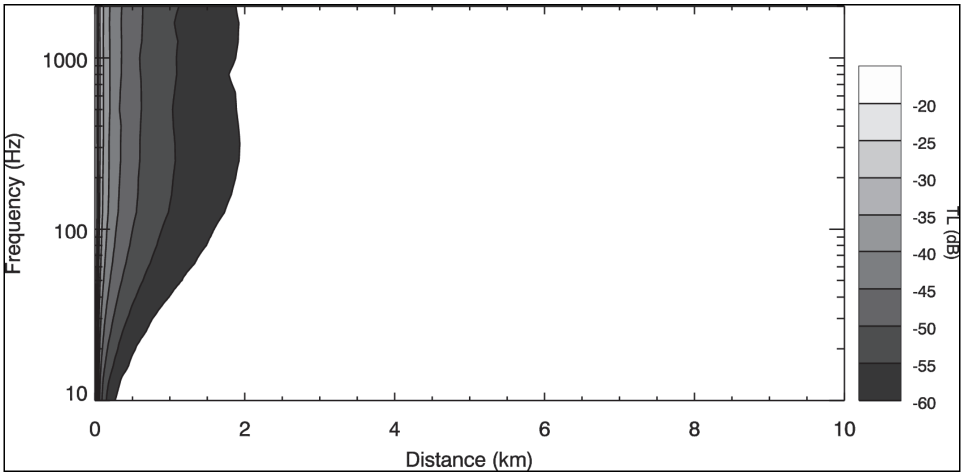

Figure D-42. Frequency Versus Distance Plot Based on Modeled Data for Scenario 1 (SVP 01) (water depth at the source is 5,390 m).

The vertical sound speed profile in the water column has significant effect on the propagation of the sound in the area. All sound speed profiles used in the modeling scenarios feature a deep sound channel at about 1,200–1,300 m below the surface. Positive velocity gradient refracts the acoustic wave upwards and directs it away from the bottom, decreasing the effect of the bottom loss. Also, shadow zones can be established in the water volume because of refraction. At the sites with water depths greater than 4,000 m a ray convergence effect can be observed; such a phenomenon can, over small volumes, lower the TL to as little as 60 dB at distances of 130 km.

Spherical spreading of the acoustic wave energy can persists as far as 5,000 m from the emitter (a range equal to the water depth at the source). Since the reflection coefficient of the clay bottom is low, most of the waterborne acoustic energy reaching the sediment layer experiences substantial loss. There is no significant contribution from bottom reflections to the total acoustic field near the source because of the large difference in travel distance between the direct and reflected wave.

5. MODEL RESULTS

The sound propagation code was run in the full N×2D scheme as described in **Section 4.1.1** for each of the 35 model scenarios and corresponding acoustic sources for a total of 105 combinations of sources and scenarios. The model estimates of received SEL for the airgun array sources were converted to rms SPL as outlined in **Section 4.1.3**.

To produce single maps of received sound level distribution and to calculate threshold distances to specified levels, the maximum level over all modeled receiver depths was calculated at each horizontal point of the modeling regions. The radial grid of modeled profiles was then resampled to produce a regular Cartesian grid with a cell size of 5 m. All contours and threshold ranges were calculated from these flat Cartesian projections of the estimated acoustic fields. The sound level maps, grouped by scenarios, are provided in **Attachment A**, **Figures Attachment A-1** through **A-35**.

For each sound level threshold, two different statistical estimates of the safety radii are provided in the tables in **Attachment B**: the maximum range and the 95 percent range. Given a regularly gridded spatial distribution of modeled RLs, the 95 percent range is defined as the radius of a circle that encompasses 95 percent of the grid points whose value is equal to or greater than the threshold value. This definition is meaningful in terms of potential impact to an animal because, regardless of the geometrical shape of the noise footprint for a given threshold level, it always provides a range beyond which no more than 5 percent of a uniformly distributed population would be exposed to sound at or above that level. The maximum range, which is simply the distance to the farthest occurrence of the threshold level, is the more conservative but may misrepresent the effective exposure zone. Indeed, there are cases where the volume ensonified to a specific level may not be continuous and small pockets of higher RLs may be found far outside the main ensonified volume (for example, because of convergence). If only the maximum range is presented, a false impression of the extent of the acoustic field can be given.

Tables D-21 and **D-22** summarize the results of the acoustic modeling in terms of threshold radii to the 160 dB and 180 dB rms SPL for the airgun arrays and electromechanical sources respectively. The complete sets of predicted threshold radii for each source to levels from 210 dB down to 150 dB rms SPL in 10 dB steps are presented in **Attachment B**, **Table Attachment B-1** through **Table Attachment B-6**.

From the tabulated results, it can be seen that the largest threshold radii for the airgun array sources are typically associated with sites in intermediate water depths (250 and 900 m); this is especially applicable to the 160 dB level. As noted above, low frequencies propagate relatively poorly in shallow water (i.e., water depths on the same order as or less than the wavelength). At intermediate water depths, this stripping of low-frequency sound no longer occurs, and longer-range propagation can be enhanced by the channeling of sound caused by reflection from the surface and seafloor (depending on the nature of the sound speed profile and sediment type).

The modeling results for the radii for the specific threshold levels presented in **Table D-22** do not account for the difference between the length of the pulse emitted by the acoustic instrument and the minimum integration time of the mammalian hearing apparatus. Instead, a receiver with unlimited minimum integration time was considered in the calculations. The calculation of rms SPL depends on the integration time (see Equation [1]). The application of the appropriate minimum integration time assumed for the marine mammals can significantly decrease the received rms SPL levels and, consequently, the threshold radii. The adjustment of the received rms SPL for the different integration time can be calculated with Equation [7]. **Table D-23** provides the adjustment values for the representative electromechanical sources with their respective pulse durations and the assumed minimum integration time of 100 ms.

Table D-21

Summary of the Predicted Threshold Radii (in meters) for the 180 and 160 dB SPL (rms) for Airgun Array Sources

Source	Airgun Array 5,400 in^3				Airgun Array 90 in^3			
dB SPL	180		160		180		160	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
1	835	810	5,379	4,969	148	144	1,295	1,256
2	876	827	5,720	5,184	148	143	1,363	1,291
3	1,557	1,093	9,329	8,104	148	145	2,210	2,038
4	822	748	12,737	8,725	76	75	1,452	1,342
5	816	742	13,337	8,896	76	74	1,568	1,286
6	837	811	5,379	4,989	148	144	1,295	1,256
7	855	829	5,322	5,026	146	142	1,322	1,281
8	1,556	1,091	9,654	8,056	148	145	2,212	2,039
9	801	737	11,056	8,593	76	74	1,464	1,331
10	799	752	11,695	8,615	76	75	1,512	1,108
11	837	811	5,379	4,973	146	143	1,295	1,255
12	853	827	5,320	5,013	146	141	1,321	1,280
13	1,552	1,082	9,316	8,095	147	143	2,211	2,036
14	880	761	15,305	9,122	76	74	1,371	1,100
15	841	816	5,490	5,121	146	143	1,315	1,258
16	871	846	5,360	5,098	149	145	1,325	1,285
17	838	812	5,184	4,959	149	145	1,294	1,255
18	845	819	5,450	5,069	148	145	1,329	1,289
19	1,559	1,094	9,304	8,083	149	145	2,212	2,040
20	1,134	992	12,022	8,531	90	86	2,051	1,681
21	2,109	1,677	11,380	8,384	186	177	3,056	2,493

Table D-22

Summary of the Predicted Threshold Radii (in meters) for 180 and 160 dB SPL (rms) for Electromechanical Sources

Source:	Boomer				Side-Scan Sonar				Chirp Subbottom Profiler				Multibeam Depth Sounder			
dB SPL	180		160		180		160		180		160		180		160	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
22	43	43	1,737	1,490	192	180	604	534	32	28	808	682	--	--	--	--
23	39	38	1,060	818	128	116	512	440	38	35	380	303	27	25	147	142
24	43	42	1,956	1,444	186	176	602	532	32	28	874	772	--	--	--	--
25	38	36	1,566	1,342	138	116	532	455	37	35	376	317	27	25	147	142
26	43	41	1,712	1,428	190	176	600	530	32	28	764	664	--	--	--	--
27	40	40	1,054	807	128	116	500	438	37	35	359	297	27	25	147	142
28	41	40	1,860	1,468	177	156	655	528	33	29	971	876	--	--	--	--
29	39	38	1,129	799	133	125	650	499	42	37	854	677	27	25	156	149
30	43	41	1,730	1,435	171	154	576	510	33	29	831	644	--	--	--	--
31	40	39	1,155	840	129	115	537	462	42	39	557	313	27	25	147	140
32	45	43	2,138	1,552	178	156	600	539	33	29	962	811	--	--	--	--
33	39	38	1,655	898	132	119	567	492	42	39	684	363	27	25	147	140
34	43	43	1,844	1,467	175	159	592	526	32	29	724	634	--	--	--	--
35	40	38	1,035	669	134	121	538	458	42	38	401	300	27	25	149	144

Table D-23

Adjustment of the 180-dB and 160-dB Threshold Radii Based on the Difference between the Pulse Length of the Electromechanical Sources and the Minimum Integration Time of the Mammalian Hearing Apparatus (100 ms)

Source	Pulse Length	Adjustment Value (dB)	Adjusted Radius (m)		Operating Frequency within Cetacean Hearing Range?
			180 dB (Rmax)	160 dB (Rmax)	
Boomer	180 µs	-27.3	<5	16	Yes (0.2-16 kHz)
Side-scan sonar	20 ms	-7.0	65-96	337-450	Yes (100 kHz) No (400 kHz)
Chirp subbottom profiler	64 ms	-1.9	26-35	240-689	Yes (3.5 kHz, 12 kHz) No (200 kHz)
Multibeam depth sounder	225 µs	-26.5	<5	12	No (240 kHz)

Adjustment for the minimum integration time is only applicable to the electromechanical sources for which pulse length is shorter than the specific minimum integration time. The modeling results for the airgun array sources are not subject to adjustment as the length of the acoustic pulse from such sources is usually greater than 100 ms, i.e., longer than the minimum integration time of the mammalian hearing apparatus.

The relatively small effect range for multibeam depth sounders is consistent with a recent analysis by Lurton and DeRuiter (2011) taking into account both the short pulse duration and high directivity of the source.

Operating frequency is another consideration in defining an appropriate safety zone. While airguns and boomers produce sounds within the hearing range of cetaceans, the operating frequency of the representative multibeam system (240 kHz) is above the hearing range of all cetaceans. For side-scan sonar, the 100 kHz operating frequency is within the cetacean hearing range but the 400 kHz frequency is not. For the chirp subbottom profiler, the 3.5 and 12 kHz frequencies are within the cetacean hearing range but the 200 kHz is not. Also, based on sea turtle hearing as reviewed in **Appendix I**, only airguns and boomers are likely to be within their hearing range.

The safety zone radii based on Southall et al. (2007) criteria were also estimated. The safety radii for all sources based on the peak pressure criteria are presented in **Table D-24**. The safety radii based on the sound exposure level criteria are presented in **Table D-25** for the airgun array sources and in **Table D-26** for the electromechanical sources. Only the cetaceans group was considered, as the abundance of pinnipeds inside the AOI is virtually nil.

The peak pressure decrease with distance was assessed based on the spherical spreading loss (**Section 2.2.1**). The furthest calculated range for injury using the Southall criterion was just 7.7 m from the loudest source (airgun array 5,400 in^3). This range is much less than the shallowest water depth out of all scenarios. This fact implies that the approach with spherical spreading loss application to be valid. Also it indicates that the safety range calculation does not depend on the water depth and the same value is good for all scenarios.

The safety zone radii regarding sound exposure levels were calculated using the transmission loss modeling results and corresponding source level for each modeled source expressed in SEL units. Prior to the calculation of the safety zone radii, appropriate M-weighting filter was applied to the sound field to reflect different audiograms of different marine mammals groups.

The effect of M-weighting filters application is different for different sources as their frequency spectrum varies. The airgun array sources would see virtually no change in the safety zone radii for the low-frequency M-weighting filter application, as their dominant frequencies are at the lower end of the spectrum. Application of mid- and high-frequency M-weighting filters would reduce the effective source level of the airgun array sources, as the filter suppresses the low frequency content of the spectrum; hence, the reduction of the safety zone radii. The reverse situation is observed for electromechanical sources, whose spectrum is dominated by higher frequencies. The largest reduction in the effective source levels and safety zone radii would be achieved by application of the low-frequency M-weighting filter, and the mid- and high-frequency M-weighting filter would have smaller effect.

Table D-24

Safety Zone Radii (in Meters) Based on Southall et al. (2007) Injury Criterion for the Maximum Peak Pressure

(Values are applicable to all scenarios.)

Source	Peak Level of Source (dB re 1 μPa at 1 m)	Safety Zone Radii (m)
		230 dB re 1 μPa (peak)
Airgun array 5,400 in^3	247.7	7.7
Airgun array 90 in^3	232.0	1.3
Boomer	215.0	0[1]
Side-scan sonar	229.0	0[1]
Subbottom profiler	228.2	0[1]
Multibeam depth sounder	213.0	0[1]

[1] Source level is less than the criterion.

Table D-25

Safety Zone Radii (in Meters) for the Airgun Array Sources Based on Southall et al. (2007) Injury Criterion for the Sound Exposure Level (198 dB re 1 μPa^2 s)

(Calculations were performed on the modeled sound field after application of the relevant M-weighting filter.)

Source	Airgun Array 5,400 in^3			Airgun Array 90 in^3		
Frequency	Low	Med	High	Low	Med	High
Scenario	198 dB	198 dB	198 dB	198 dB	198 dB	198 dB
1	18	<5	<5	<5	—	—
2	18	<5	<5	<5	—	—
3	18	<5	<5	<5	—	—
4	18	<5	<5	<5	—	—
5	18	<5	<5	<5	—	—
6	18	<5	<5	<5	—	—
7	18	<5	<5	<5	—	—
8	18	<5	<5	<5	—	—
9	18	<5	<5	<5	—	—
10	18	<5	<5	<5	—	—
11	18	<5	<5	<5	—	—
12	18	<5	<5	<5	—	—
13	18	<5	<5	<5	—	—
14	18	<5	<5	<5	—	—
15	18	<5	<5	<5	—	—
16	18	<5	<5	<5	—	—
17	18	<5	<5	<5	—	—
18	18	<5	<5	<5	—	—
19	18	<5	<5	<5	—	—
20	18	<5	<5	<5	—	—
21	18	<5	<5	<5	—	—

Table D-26

Safety Zone Radii (in meters) Based on Southall et al. (2007) Injury Criterion Based on the Sound Exposure Level (198 dB re 1 µPa^2·s)

(Values are applicable to all scenarios. The effective source level (SL_{eff}) was calculated based on the nominal source level and relevant M-reighting filter.)

Cetaceans:	Low-Frequency		Mid-Frequency		High-Frequency	
Source	SL_{eff} (dB re 1 µPa^2·s)	198 dB Radius (m)	SL_{eff} (dB re 1 µPa^2·s)	198 dB Radius (m)	SL_{eff} (dB re 1 µPa^2·s)	198 dB Radius (m)
Boomer	174.4	0[1]	174.2	0[1]	174.1	0[1]
Side-scan sonar	179.3	0[1]	203.3	2	203.9	2
Subbottom profiler	212.0	5	213.1	6	213.1	6
Multibeam depth sounder	131.9	0[1]	163.3	0[1]	164.6	0[1]

[1] Effective source level is less than the criterion.

6. REFERENCES CITED

Applied Acoustic Engineering Ltd. 2011. AA201 and AA301 seismic sound source, boomer plates. Technical specifications. 2 pp. Available at: http://appliedacoustics.com/pdf/BoomerPlates.pdf. Accessed September 29, 2011.

Au, W.L. and M.C. Hastings. 2008. Hearing in marine animals. In: Principles of marine bioacoustics. New York: Springer-Verlag. Pp. 337-400.

Austin, M.E., A.O. MacGillivray, D.E. Hannay, and S.A. Carr. 2003. Acoustic monitoring of Marathon Canada Petroleum ULC 2003 Courland/Empire seismic program. Report prepared by JASCO Research Ltd. for Marathon Canada Petroleum ULC.

Bershad, S. and M. Weiss, eds. 1975. NOAA National Geophysical Data Center, Deck 41 surficial sediment database. Available at: http://www.ngdc.noaa.gov/mgg/geology/deck41.html. Accessed September 29, 2011.

Blackwell, S.B., R.G. Norman, C.R. Greene Jr., and W.J. Richardson. 2007. Acoustic measurements. In: Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–September 2006: 90-day report. LGL Rep. P891-1. Report from LGL Alaska Research Associates Inc., Anchorage, AK, and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Offshore Inc., Houston, TX, National Marine Fisheries Service, Silver Spring, MD, and U.S. Fish & Wildlife Service, Anchorage, AK. Pp. 4-1 to 4-52.

Brekhovskikh, L.M. and Y.P. Lysanov. 2003. Fundamentals of ocean acoustics. New York: Springer-Verlag.

Buckingham, M.J. 2005. Compressional and shear wave properties of marine sediments: Comparison between theory and data. J. Acoust. Soc. Am. 117:137–152.

Clay, C.S. and H. Medwin. 1977. Acoustical oceanography: Principles and applications. New York: John Wiley & Sons, Inc.

Collins, M.D., R.J. Cederberg, D.B. King, and S.A. Chin-Bing. 1996. Comparison of algorithms for solving parabolic wave equations. J. Acoust. Soc. Am. 100(1):178-182.

Dragoset, W.H. 1984. A comprehensive method for evaluating the design of airguns and airgun arrays. 16th Ann. Proc. Offshore Tech. Conf. 3:75-84.

EdgeTech. 2011. 4200 Series side-scan sonar system. Product brochure. Available at: http://www.edgetech.com/docs/4200_series_brochure_052511.pdf. Accessed October 25, 2011.

Federal Register. 2005. Endangered fish and wildlife; Notice of Intent to prepare an Environmental Impact Statement. National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, Department of Commerce January 11, 2005. 70 FR 7, pp. 1871-1875. Available at: http://www.gpo.gov/fdsys/pkg/FR-2005-01-11/pdf/05-525.pdf. Accessed September 29, 2011.

Fisher, F.H. and V.P. Simmons. 1977. Absorption of sound in sea water. J. Acoust. Soc. Am. 62:558-564.

Francois, R.E. and G.R. Garrison. 1982a. Sound absorption based on ocean measurements. Part I: Pure water and magnesium sulfate contributions. J. Acoust. Soc. Am. 72(3):896–907.

Francois, R.E. and G.R. Garrison. 1982b. Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption. Journal of the Acoustical Society of America 72:1879-1890.

Funk, D.W., D. Hannay, D.S. Ireland, R. Rodrigues, and W.R. Koski, eds. 2008. Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–November 2007: 90-day report. LGL Rep. P969-1. Report from LGL Alaska Research Associates Inc., Anchorage, AK, LGL Ltd., and JASCO Research Ltd. for Shell Offshore Inc., Houston, TX, and National Marine Fisheries Service, Silver Spring, MD. 218 pp. + apps.

Gentry, R., A. Bowles, W. Ellison, J. Finneran, C. Greene, D. Kastak, D. Ketten, J. Miller, P. Nachtigall, W.J. Richardson, B. Southall, J. Thomas, and P. Tyack. 2004. Noise Exposure Criteria Group, Advisory Committee on Acoustic Impacts on Marine Mammals, Plenary Meeting Two, Arlington VA, 28-30 April 2004, presentation. Available at: http://www.mmc.gov/sound/plenary2/pdf/gentryetal.pdf. Accessed October 25, 2011.

Greene, C.R., Jr. 1997. Physical acoustics measurements. In*:* Richardson, W.J., ed., Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Report from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and National Marine Fisheries Service. Anchorage, AK, and Silver Spring, MD. Pp. 3-1 to 3-63.

Hannay, D.E. and R.G. Racca. 2005. Acoustic model validation*.* Technical Report prepared by JASCO Research Ltd. for Sakhalin Energy Investment Company. 35 pp. Available at: http://www.sakhalinenergy.com/en/documents/doc_33_jasco.pdf. Accessed September 28, 2011.

Hathaway, J.C. 1977. Continental margin program, Atlantic coast of the United States. NGDC Data Set G00253. Available at: http://www.ngdc.noaa.gov/mgg/geology/conmar.html. Accessed September 28, 2011.

International Transducer Corporation. 1993. Application equations for underwater sound transducers. Pamphlet. International Transducer Corporation, Santa Barbara, CA.

Ireland, D., D. Hannay, R. Rodrigues, H. Patterson, B. Haley, and A. Hunter. 2007. Marine mammal monitoring and mitigation during open water seismic exploration by GX Technology in the Chukchi Sea, October—November 2006: 90-day report. LGL Draft Rep. P891-1. Rep. Silver Spring, MD: LGL Alaska Research Associates Inc., Anchorage, AK, LGL Ltd., King City, Ont., and JASCO Research, Ltd., Victoria, B.C., Canada, for GX Technology, Houston, TX, and National Marine Fisheries Service.

Johnson, C.S. 1968. Relation between absolute threshold and duration-of-tone pulses in the bottlenosed porpoise. J. Acoust. Soc. Am. 43(4):757-763.

Kinsler, L.E., A.R. Frey, A.B. Coppens, and J.V. Sanders. 1950. Fundamentals of acoustics. NY: Wiley.

Landro, M. 1992. Modeling of GI gun signatures. Geophys. Prospect. 40(7):721-747.

Laughton, M.A. and D.F. Warne. 2003. Electrical engineer's reference book. Oxford, UK: Newnes.

Laws, M., L. Hatton, and M. Haartsen. 1990. Computer modeling of clustered airguns. First Break 8(9):331–338.

LGL. 2010. Environmental assessment of a marine geophysical survey by the R/V *Marcus G. Langseth* in the Pacific Ocean off Costa Rica, April–May 2011. Prepared for Lamont-Doherty Earth Observatory and National Science Foundation Division of Ocean Sciences by LGL Ltd., Environmental Research Associates.

Lurton, X. 2002. An introduction to underwater acoustics: Principles and applications. Chichester, U.K.: Springer. 347 pp.

Lurton, X. and S. DeRuiter. 2011. Sound radiation of seafloor-mapping echosounders in the water column, in relation to the risks posed to marine mammals. In: The International Hydrographic Review No. 6, November 2011. Pp. 1-17. Available at: http://www.iho.int/mtg_docs/IHReview/2011/IHR_Nov032011.pdf. Accessed January 4, 2012.

MacGillivray, A.O. 2006. An acoustic modeling study of seismic airgun noise in Queen Charlotte basin. MSc thesis, University of Victoria, BC, Canada.

MacGillivray, A.O., M.M. Zykov, and D.E. Hannay. 2007. Summary of noise assessment. In*:* Marine mammal monitoring and mitigation during open water seismic exploration by ConocoPhillips Alaska, Inc. in the Chukchi Sea, July–October 2006. LGL Rep. P903-2. Report from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for ConocoPhillips Alaska Inc., Anchorage, AK, and National Marine Fisheries Service, Silver Spring, MD. Pp. 3-1 to 3-21.

Malme, C.I., P.W. Smith, and P.R. Miles. 1986. Characterization of geophysical acoustic survey sounds. Prepared by BBN Laboratories Inc., Cambridge, for Battelle Memorial Institute to the Minerals Management Service, Pacific Outer Continental Shelf Region, Los Angeles, CA.

Massa, D.P. 1999. Choosing and ultrasonic sensor for proximity or distance measurement; Part 2: Optimizing sensor selection. Sensors, March 1, 1999. Available at: http://www.sensorsmag.com/sensors/acoustic-ultrasound/choosing-ultrasonic-sensor-proximity-or-distance-measurement-838. Accessed September 28, 2011.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. APPEA J. 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000. Marine seismic surveys–a study of environmental implications. APPEA J. 40:692-708.

Medwin, H. 2005. Sounds in the sea. Cambridge, UK: Cambridge University Press.

Nedwell, J.R. and A.W.H. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. Proceedings of Workshop on Seismics and Marine Mammals. June 1998, London, UK.

Poppe, L.J., J.S. Schlee, B. Butman, and C.M. Lane. 1989. Map showing distribution of surficial sediment, Gulf of Maine and Georges Bank. U.S. Department of the Interior, U.S. Geological Survey Miscellaneous Invest. Ser., Map I-1986-A; scale 1:1,000,000.

Porter, M. and Y.C. Liu. 1994. Finite-element ray tracing. In: Lee, D. and M.H. Schultz, Theoretical and Computational Acoustics, Volume II. Pp. 947-956.

Racca, R.G. and J.A. Scrimger. 1986. Underwater acoustic source characteristics of air and water guns. Contractor report by JASCO Res. Ltd., Victoria, B.C, for DREP, Esquimalt, B.C. Contract No. 06SB 97708-5-7055.

RESON. 2009. SeaBat 7101 operator's manual. Document No. OM11674-1F (preliminary). 141 pp.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. San Diego: Academic Press. 576 pp.

Shipboard Scientific Party. 1994. Site 905. In: Mountain, G.S., K.G. Miller, P. Blum, P.-G. Aim, M.-P. Aubry, L.H. Burckle, B.A. Christensen, J. Compton, J.E. Damuth, J.-F. Deconinck, L. de Verteuil, C.S. Fulthorpe, S. Gartner, G. Guèrin, S.P. Hesselbo, B. Hoppie, M.E. Katz, N. Kotake, J.M. Lorenzo, S. McCracken, C.M. McHugh, W.C. Quayle, Y. Saito, S.W. Snyder, W.G. ten Kate, M. Urbat, M.C. Van Fossen, and A. Vecsei. Proceedings of the Ocean Drilling Program, Initials Reports 150:255–308. College Station, TX (Ocean Drilling Program). Available at: doi:10.2973/odp.proc.ir.150.109.1994. Accessed September 28, 2011.

Shipboard Scientific Party. 1998. Site 1071. In: Austin, J.A., Jr., N. Christie-Blick, M.J. Malone, S. Berné, M.K. Borre, G. Claypool, J. Damuth, H. Delius, G. Dickens, P. Flemings, C. Fulthorpe, S. Hesselbo, K. Hoyanagi, M. Katz, H. Krawinkel, C. Major, F. McCarthy, C. McHugh, G. Mountain, H. Oda, H. Olson, C. Pirmez, C. Savrda, C. Smart, L. Sohl, P. Vanderaveroet, W. Wei, and B. Whiting , Proceedings of the Ocean Drilling Program, Initials Reports 174A: 37–97. College Station, TX (Ocean Drilling Program). Available at: doi:10.2973/odp.proc.ir.174a.103.1998. Accessed September 28, 2011.

Simpkin, P.G. 2005. The boomer sound source as a tool for shallow water geophysical exploration. Marine Geophys. Res. 26:171-181.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4):411-521. Available at: http://www.sea-inc.net/resources/mmnoise_aquaticmammals.pdf. Accessed September 6, 2011.

Teague, W.J., M.J. Carron, and P.J. Hogan. 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. J. Geophys. Res. 95(C5):7167–7183.

Thorp, W.H. 1965. Deep-ocean sound attenuation in the sub- and low-kilocycle-per-second region. J. Acoust. Soc. Am. 38:648–654.

Verbeek, N.H. and T.M. McGee. 1995. Characteristics of high-resolution marine reflection profiling sources. J. Appl. Geophys. 33:251-269.

Ziolkowski, A. 1970. A method for calculating the output pressure waveform from an air gun. Geophys. J. R. Astr. Soc. 21:137–161.

ATTACHMENT A: Sound Maps

Predicted sound field maps are shown below for each of the planned model sites. Locations of the sites are shown in **Figure D-33** of **Section 4.2.1**. The maps are grouped by scenario (see **Table D-19**), i.e. various sources at the same geographic location (site), bottom type, and same sound velocity profile. Approximate SPL (rms), in dB re 1 µPa, is shown in all cases. The modeling results do not account for the specific properties of the mammalian hearing such as hearing integration time. Actual acoustic pulse duration was used to estimate the presented sound fields.

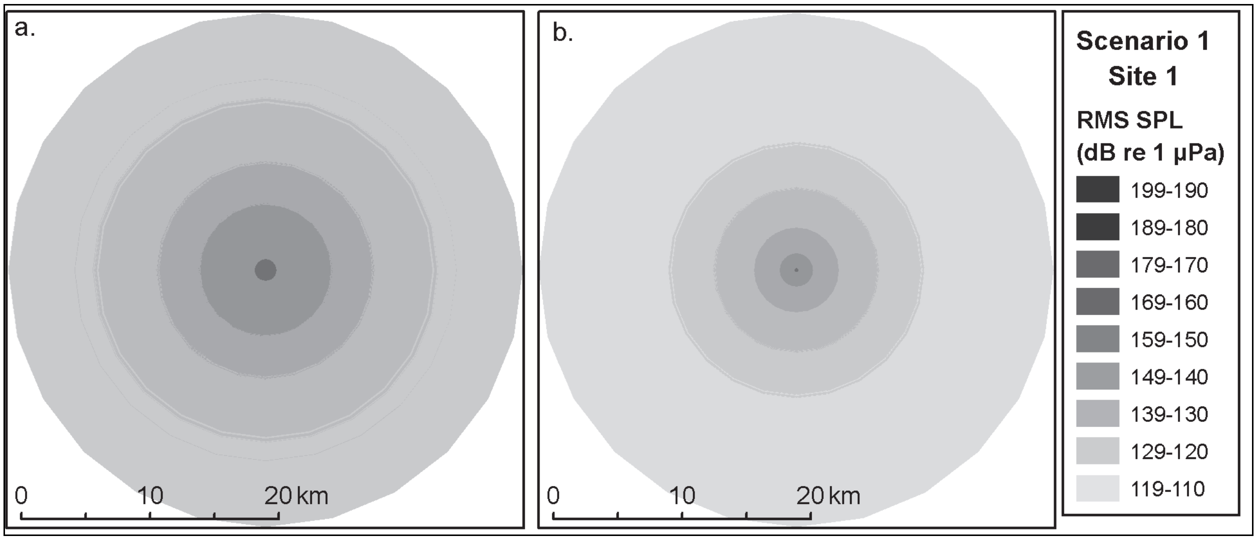

Figure Attachment A-1. Predicted SPL (rms) for Modeling Scenario 1 (Water Depth Is 5,390 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

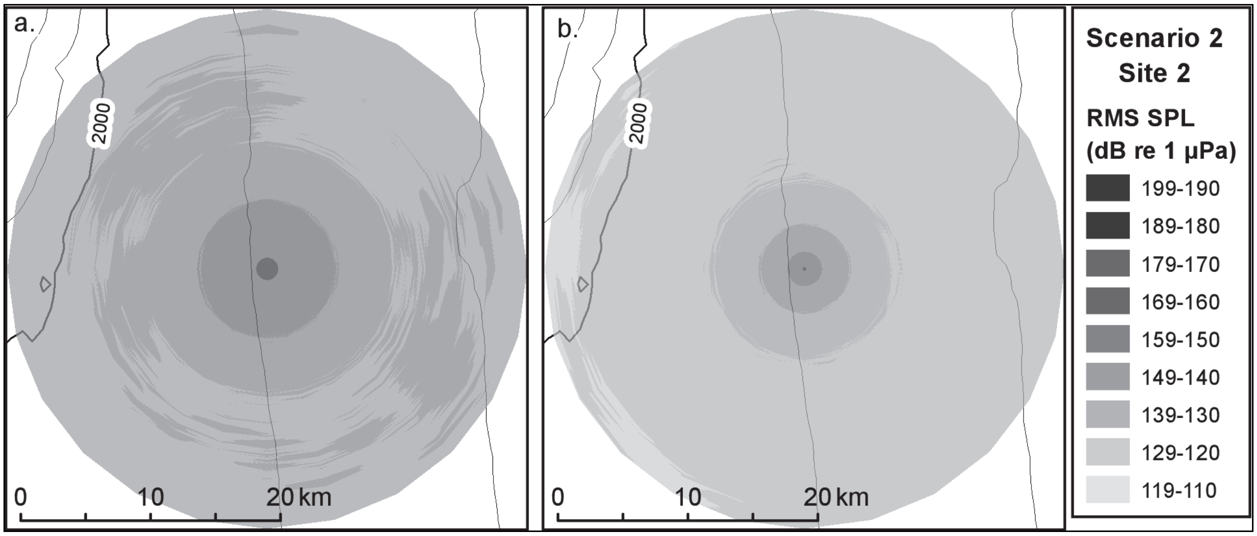

Figure Attachment A-2. Predicted SPL (rms) for Modeling Scenario 2 (Water Depth Is 2,560 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

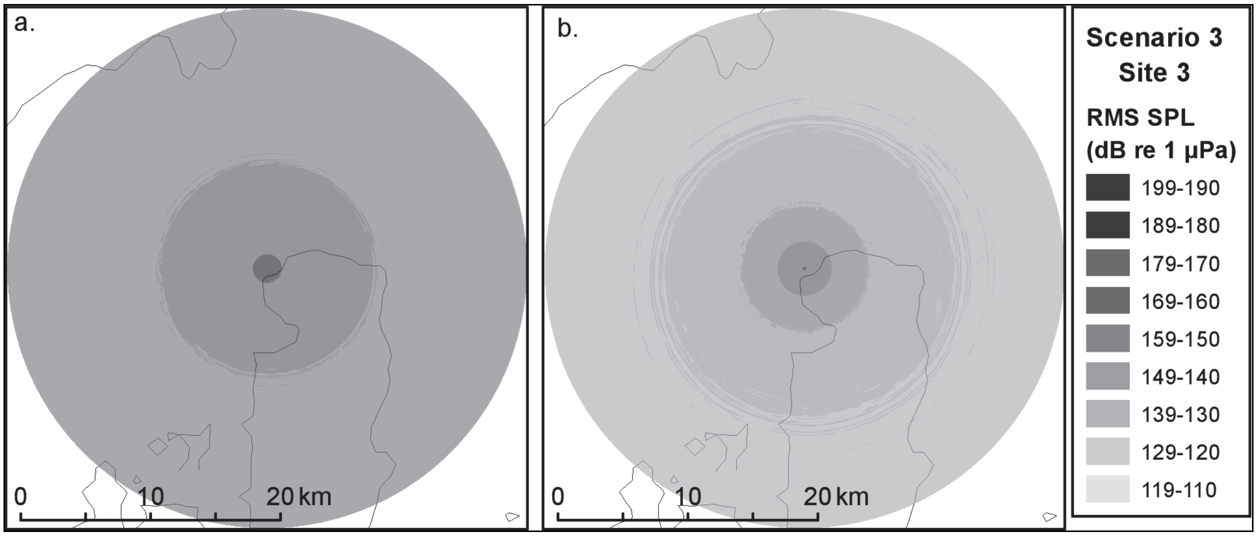

Figure Attachment A-3. Predicted SPL (rms) for Modeling Scenario 3 (Water Depth Is 880 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

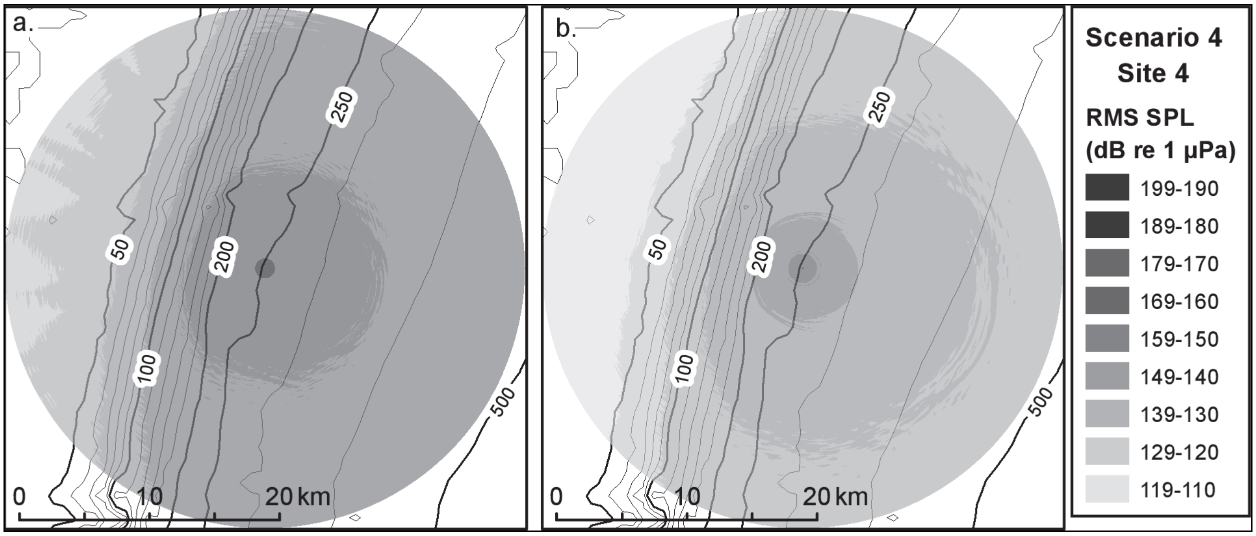

Figure Attachment A-4. Predicted SPL (rms) for Modeling Scenario 4 (Water Depth Is 249 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

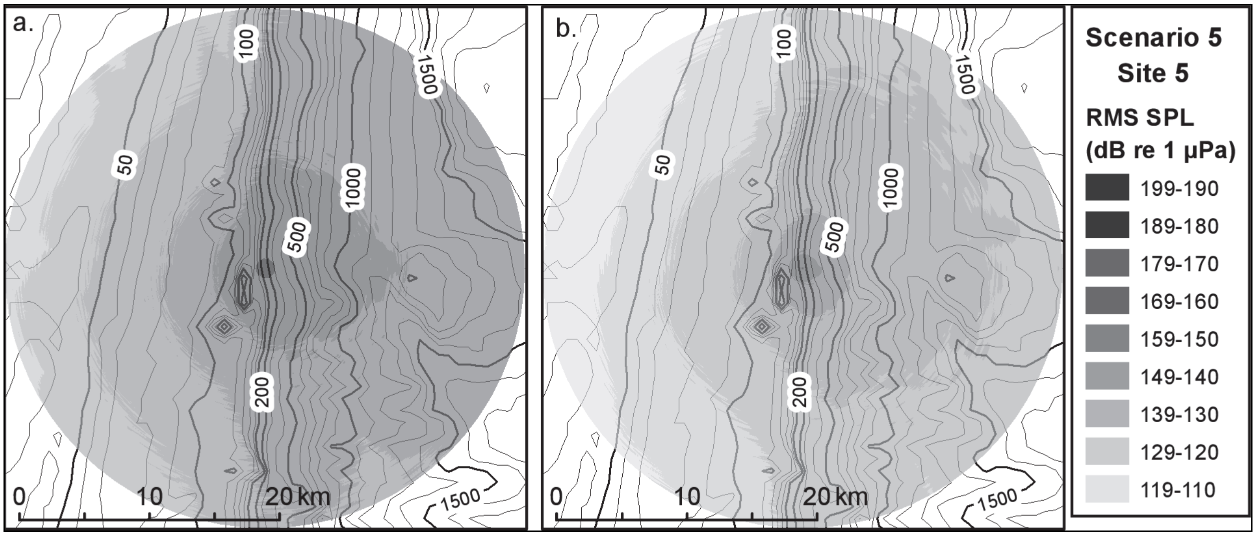

Figure Attachment A-5. Predicted SPL (rms) for Modeling Scenario 5 (Water Depth Is 288 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

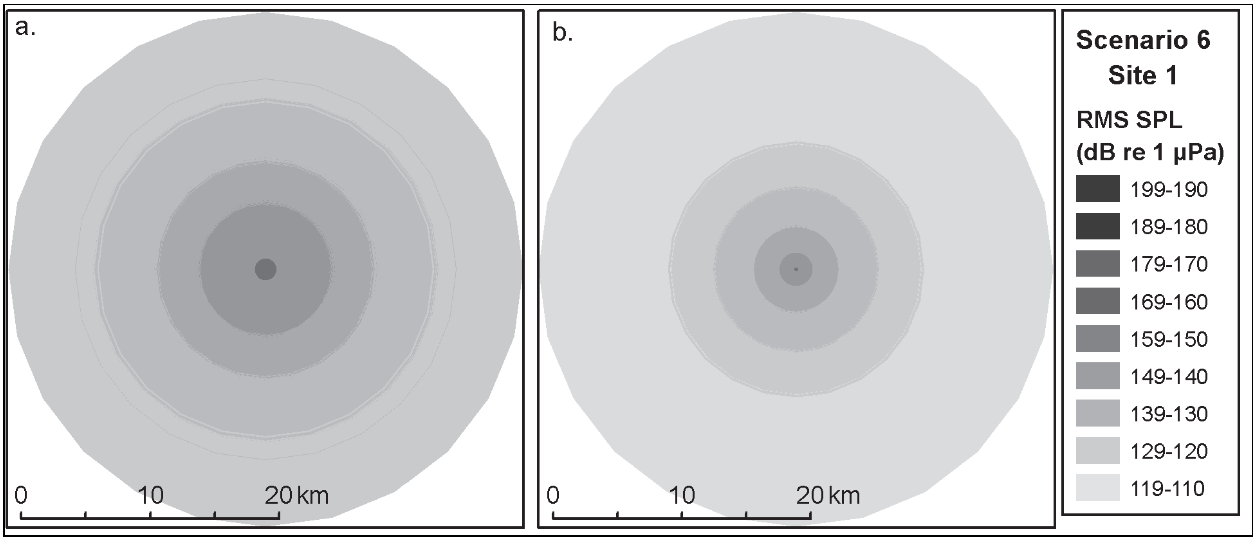

Figure Attachment A-6. Predicted SPL (rms) for Modeling Scenario 6 (Water Depth Is 5,390 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

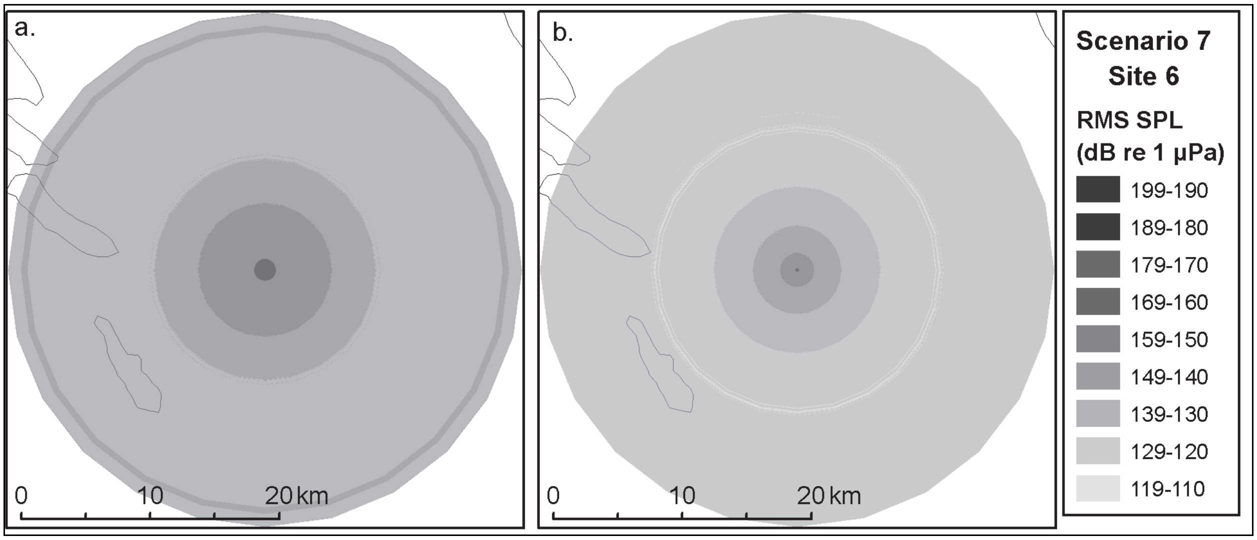

Figure Attachment A-7. Predicted SPL (rms) for Modeling Scenario 7 (Water Depth Is 3,200 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

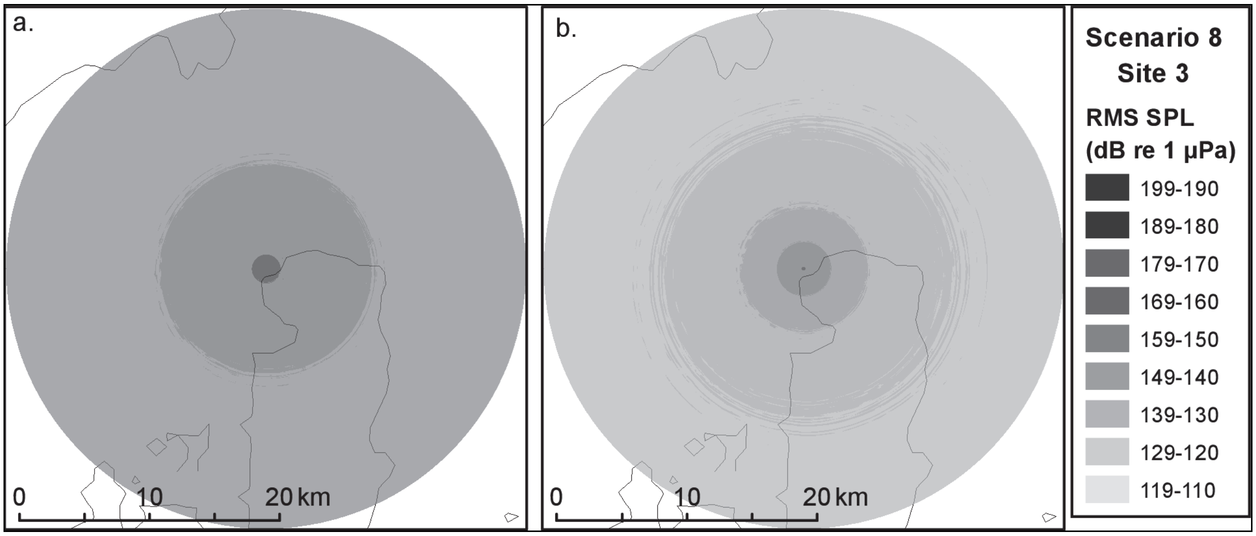

Figure Attachment A-8. Predicted SPL (rms) for Modeling Scenario 8 (Water Depth Is 880 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

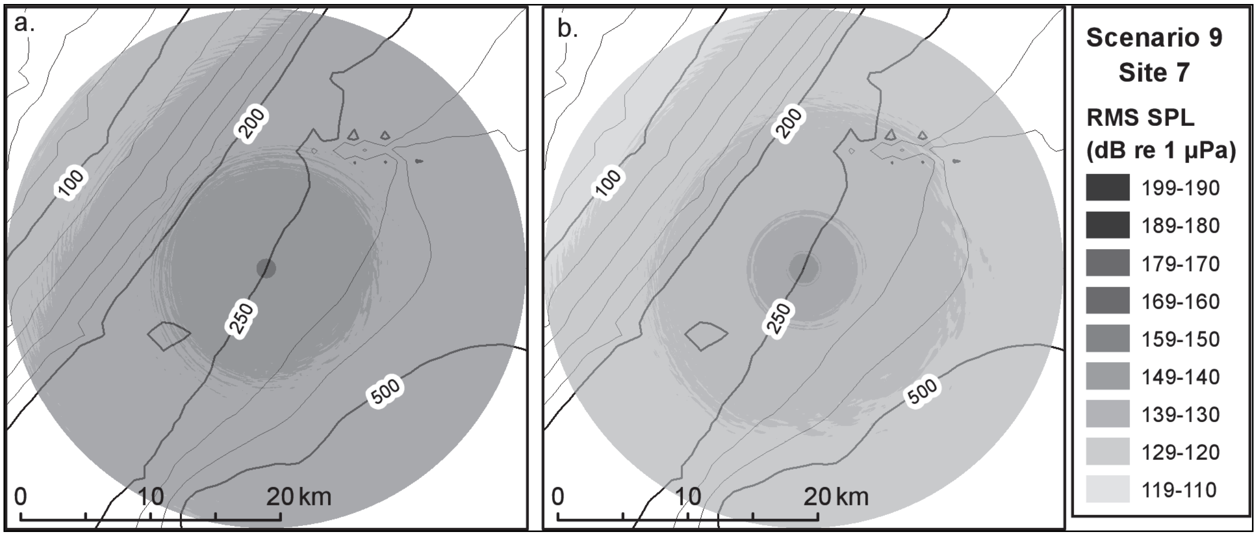

Figure Attachment A-9. Predicted SPL (rms) for Modeling Scenario 9 (Water Depth Is 251 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

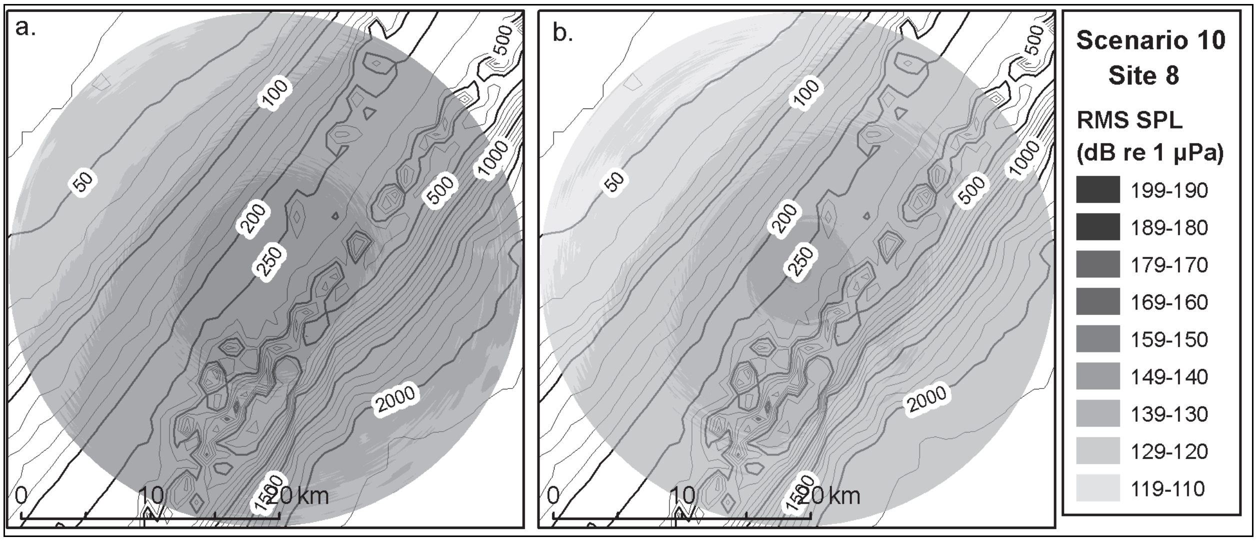

Figure Attachment A-10. Predicted SPL (rms) for Modeling Scenario 10 (Water Depth Is 249 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

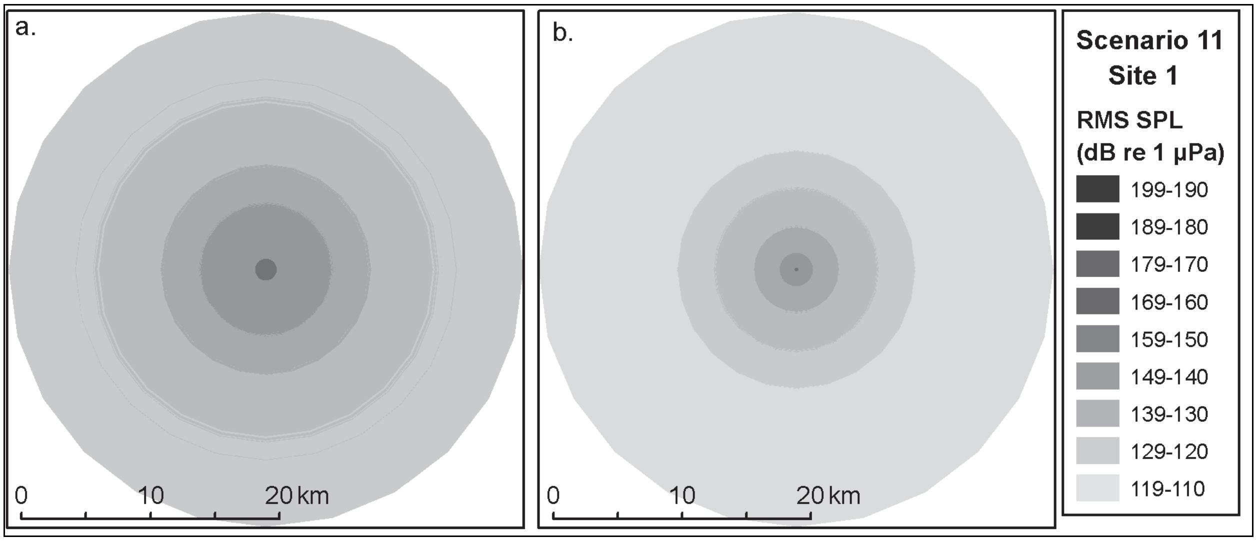

Figure Attachment A-11. Predicted SPL (rms) for Modeling Scenario 11 (Water Depth Is 5,390 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

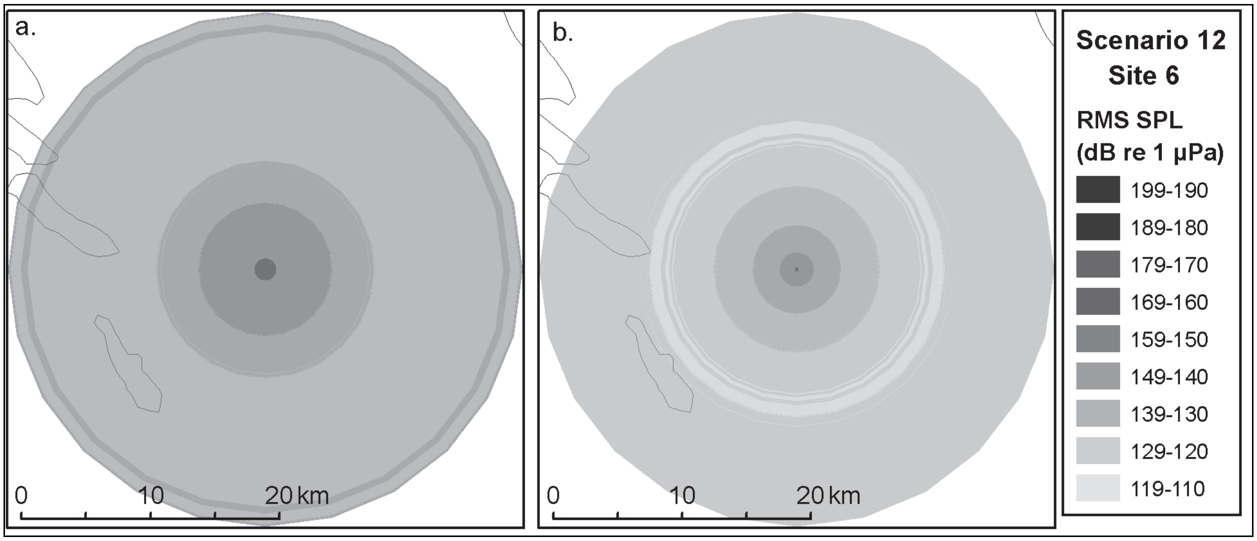

Figure Attachment A-12. Predicted SPL (rms) for Modeling Scenario 12 (Water Depth Is 3,200 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

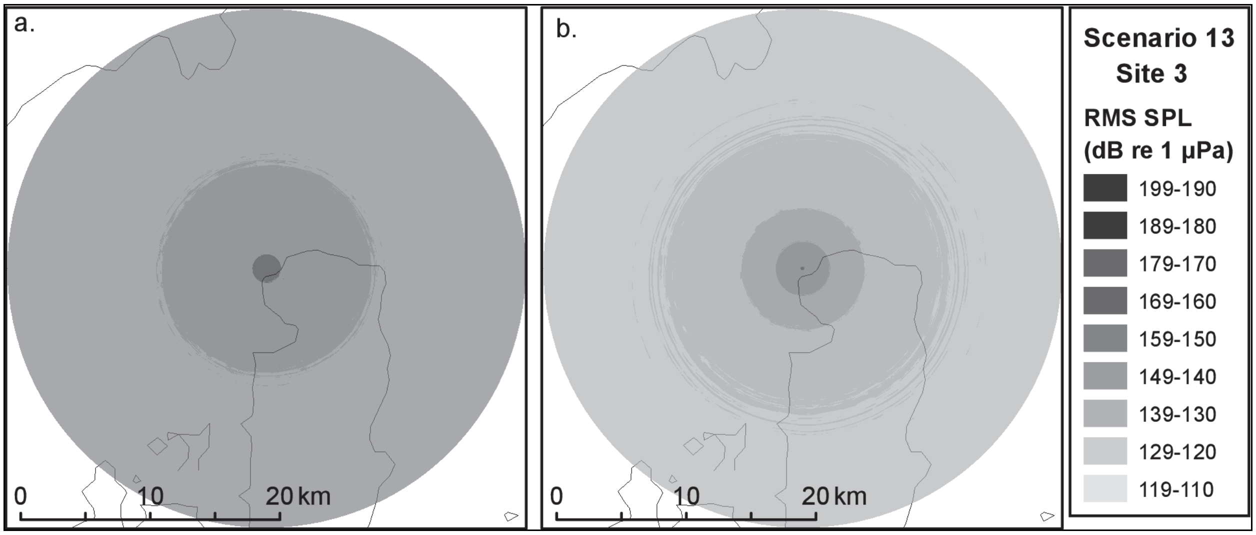

Figure Attachment A-13. Predicted SPL (rms) for Modeling Scenario 13 (Water Depth Is 880 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

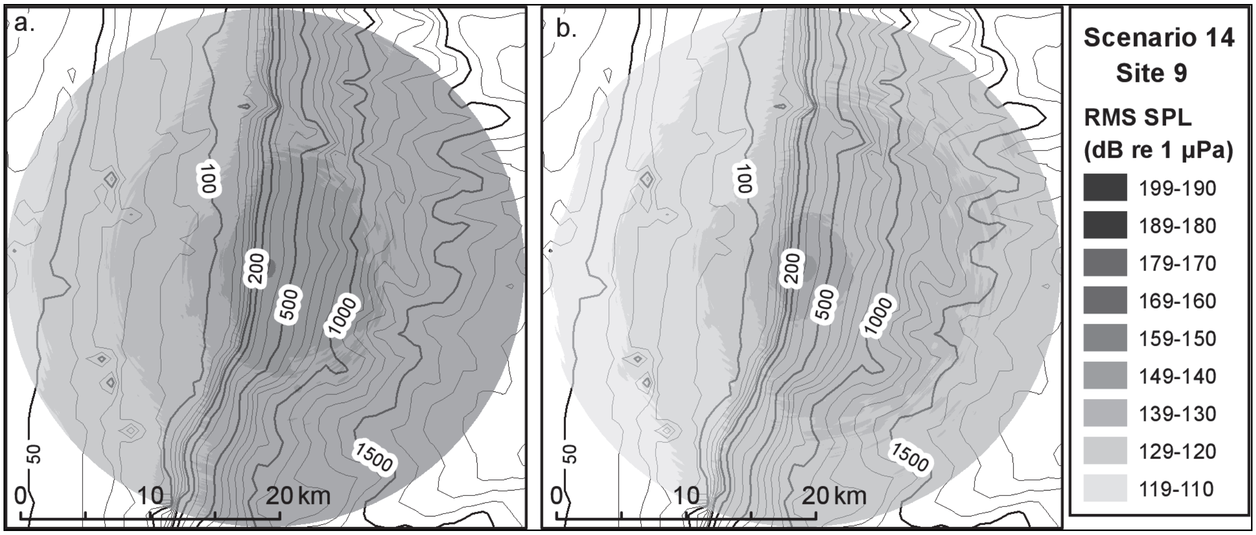

Figure Attachment A-14. Predicted SPL (rms) for Modeling Scenario 14 (Water Depth Is 275 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

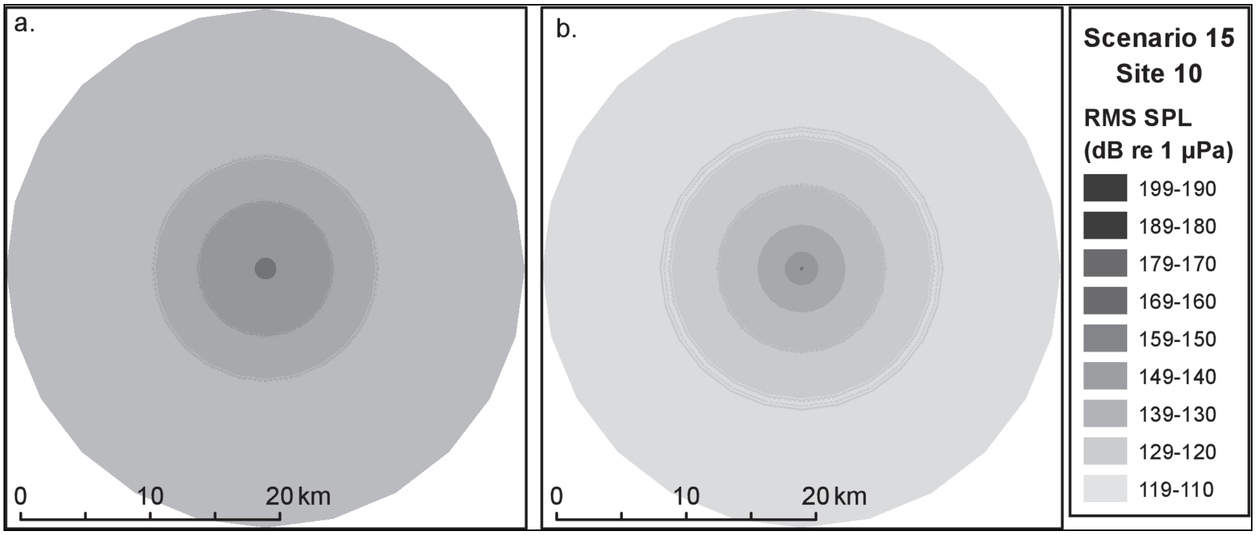

Figure Attachment A-15. Predicted SPL (rms) for Modeling Scenario 15 (Water Depth Is 4,300 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

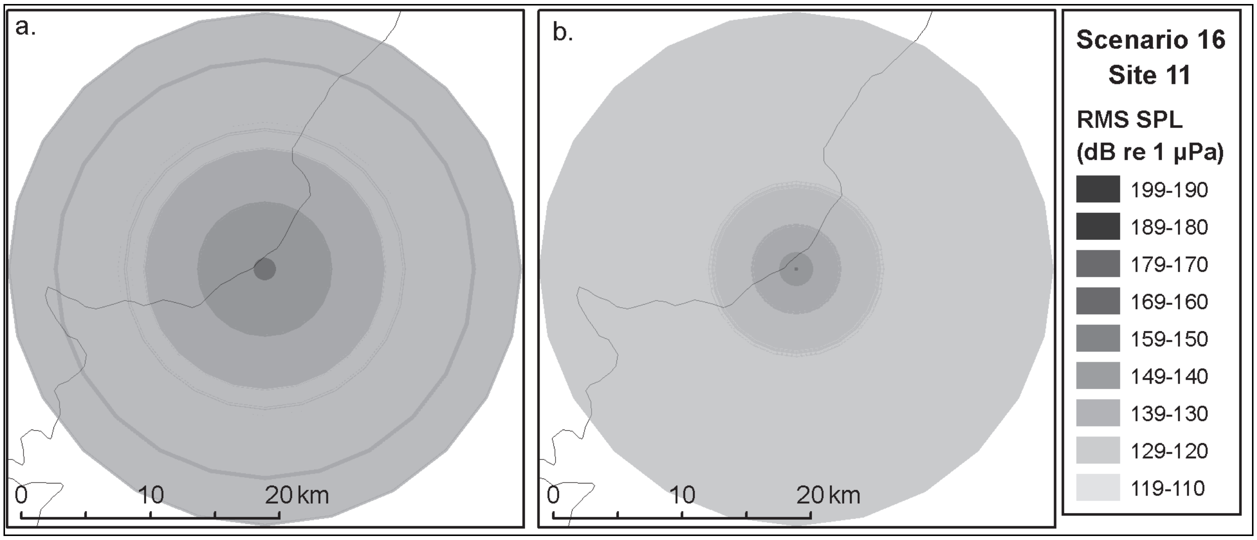

Figure Attachment A-16. Predicted SPL (rms) for Modeling Scenario 16 (Water Depth Is 3,010 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

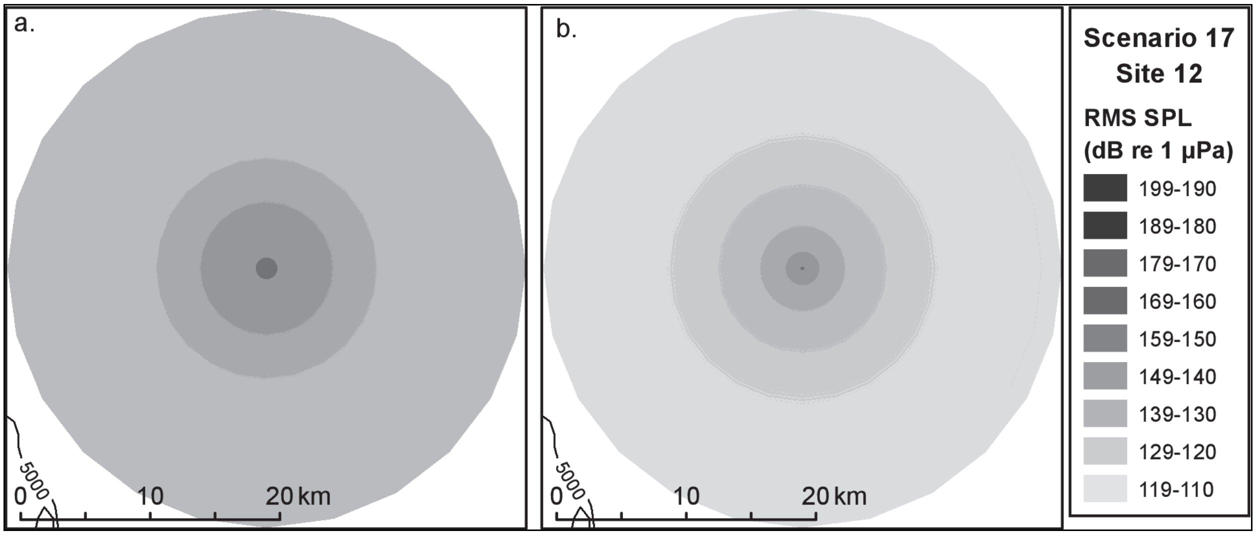

Figure Attachment A-17. Predicted SPL (rms) for Modeling Scenario 17 (Water Depth Is 4,890 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

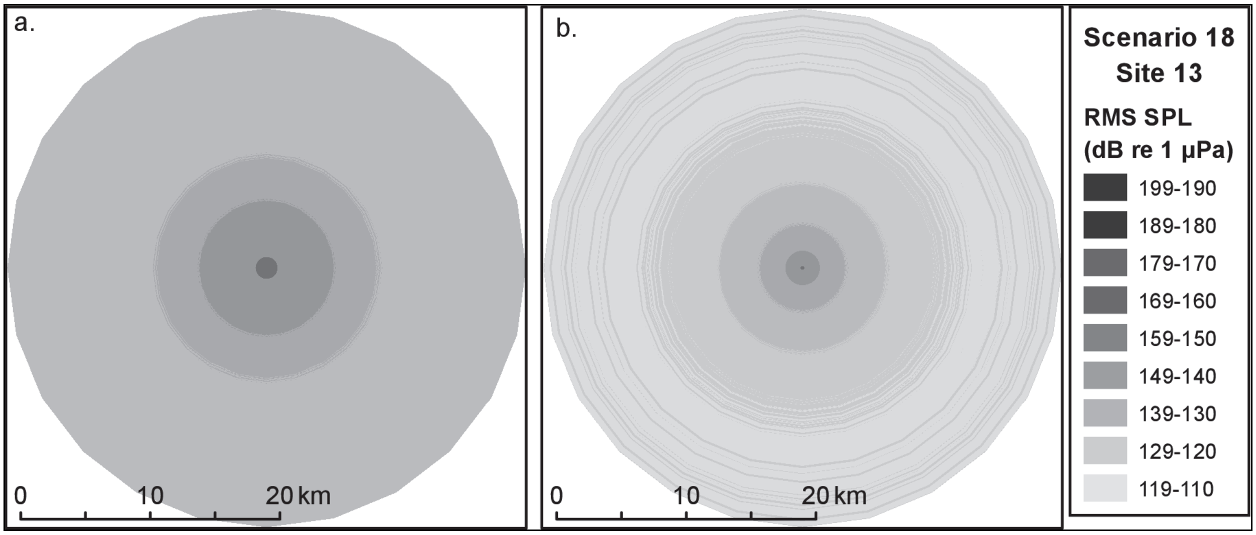

Figure Attachment A-18. Predicted SPL (rms) for Modeling Scenario 18 (Water Depth Is 3,580 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

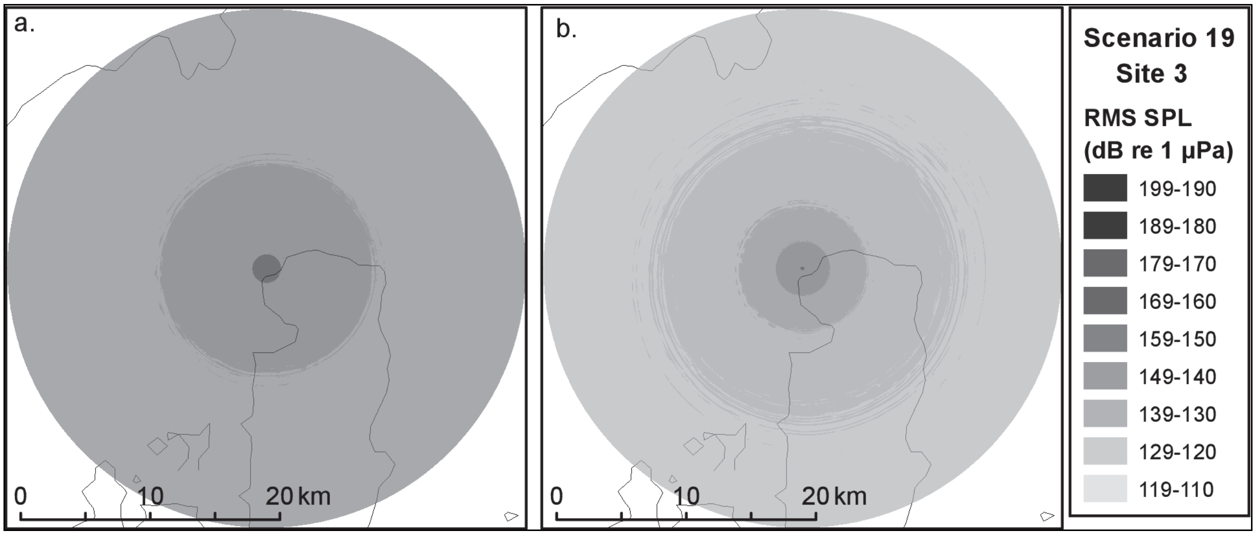

Figure Attachment A-19. Predicted SPL (rms) for Modeling Scenario 19 (Water Depth Is 880 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

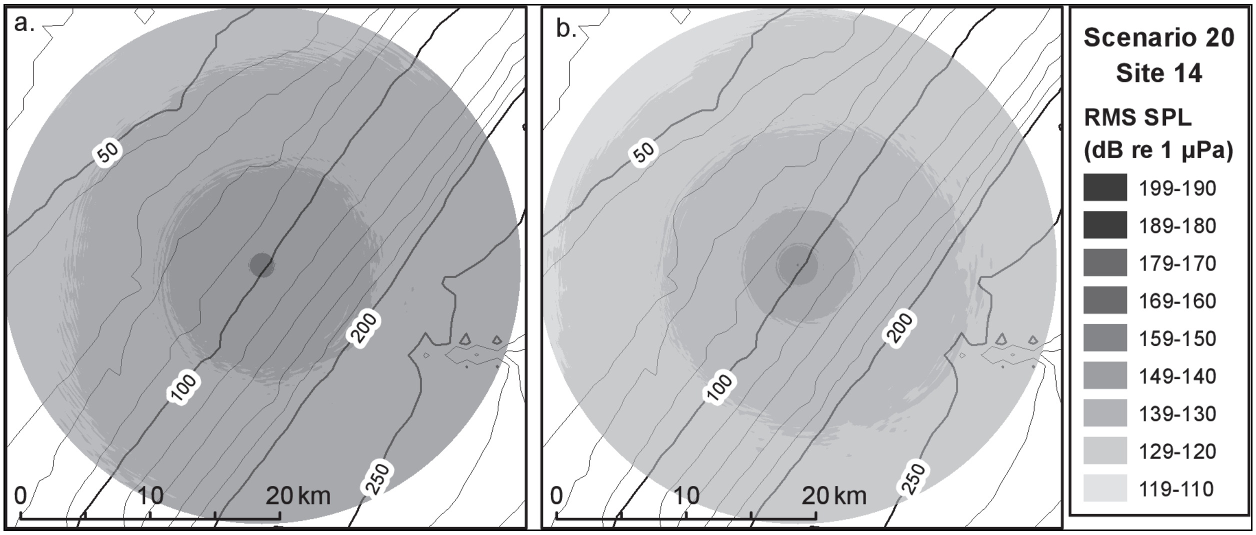

Figure Attachment A-20. Predicted SPL (rms) for Modeling Scenario 20 (Water Depth Is 100 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

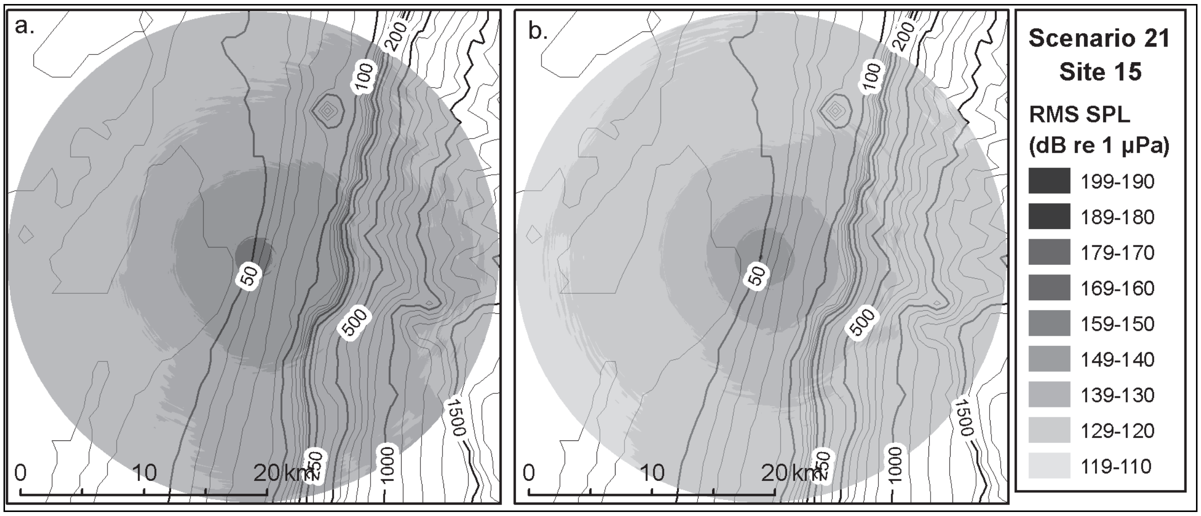

Figure Attachment A-21. Predicted SPL (rms) for Modeling Scenario 21 (Water Depth Is 51 m at the Source). The Sources Are (a) 5,400 in^3 and (b) 90 in^3 Airgun Arrays.

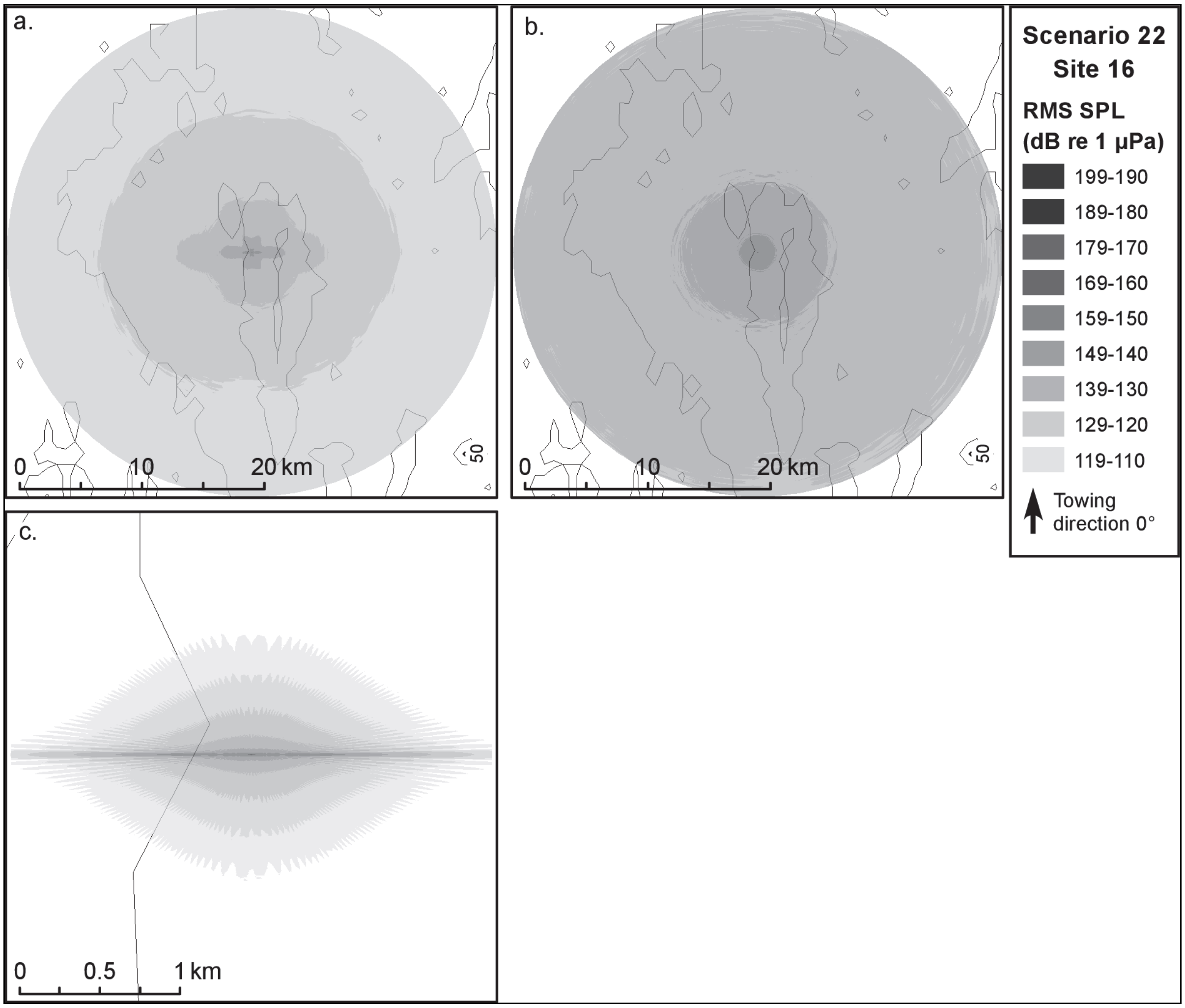

Figure Attachment A-22. Predicted SPL (rms) for Modeling Scenario 22 (Water Depth Is 30 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, and (c) Side-Scan Sonar.

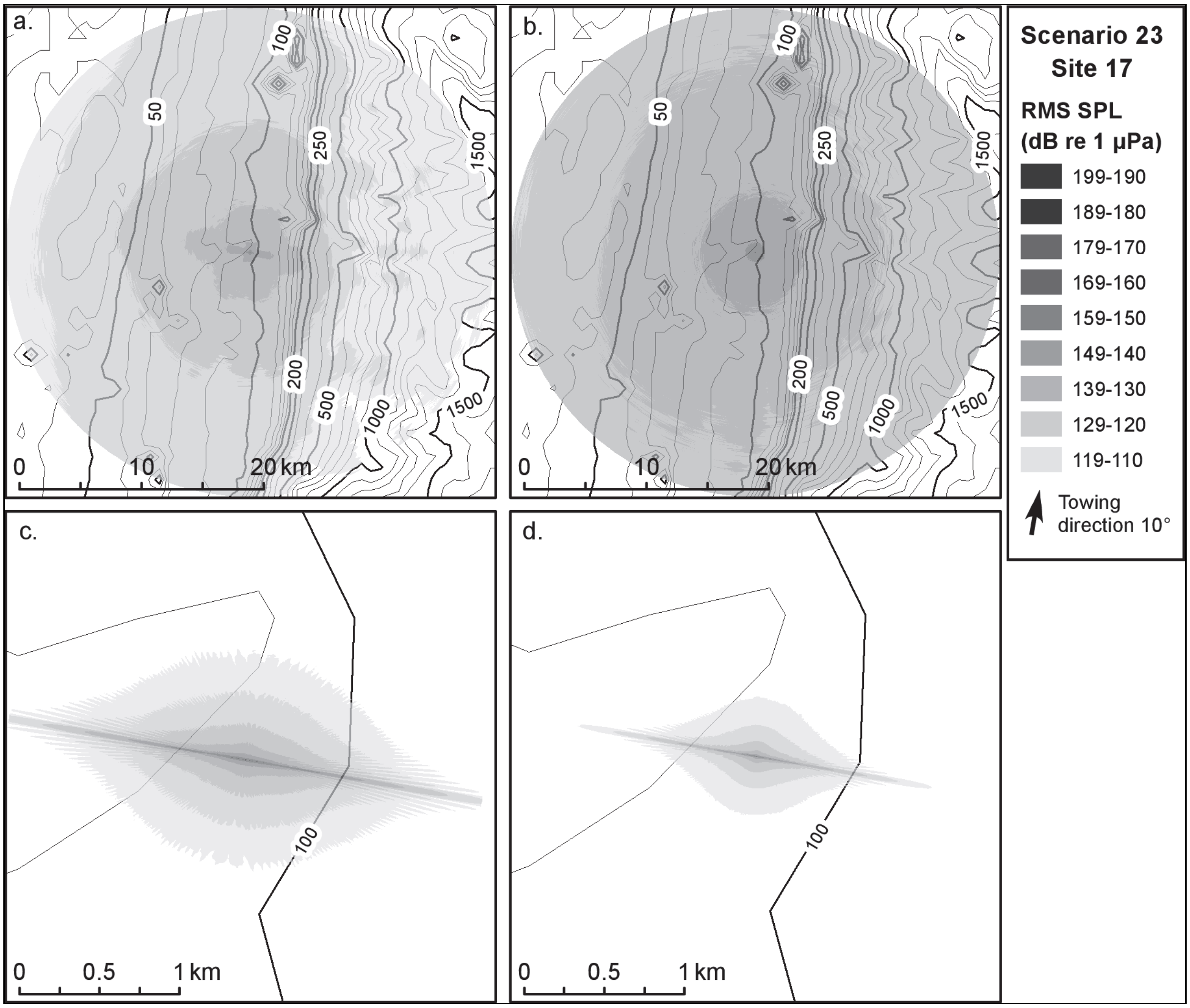

Figure Attachment A-23. Predicted SPL (rms) for Modeling Scenario 23 (Water Depth Is 100 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, (c) Side-Scan Sonar, and (d) Multibeam Depth Sounder.

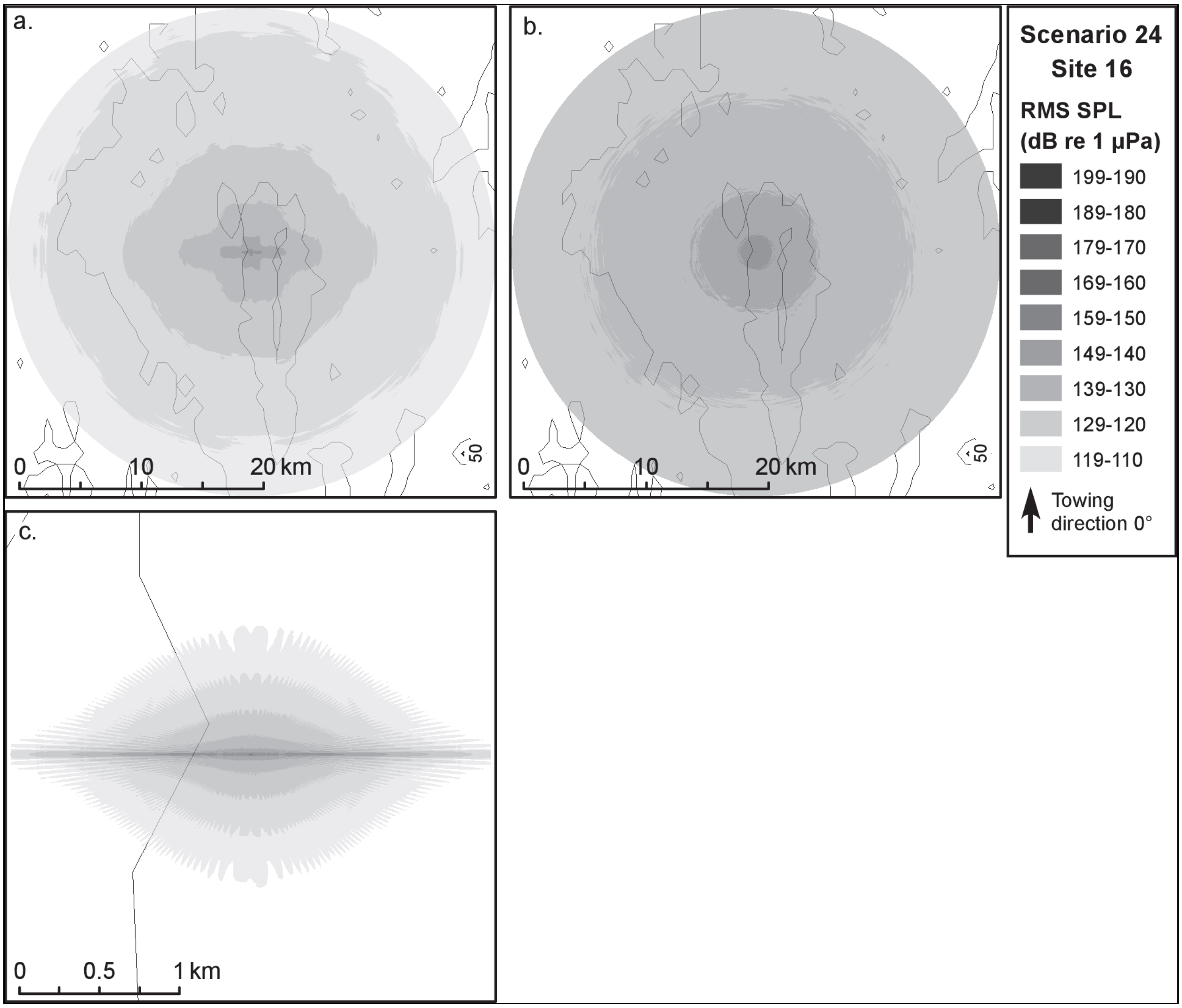

Figure Attachment A-24. Predicted SPL (rms) for Modeling Scenario 24 (Water Depth Is 30 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, and (c) Side-Scan Sonar.

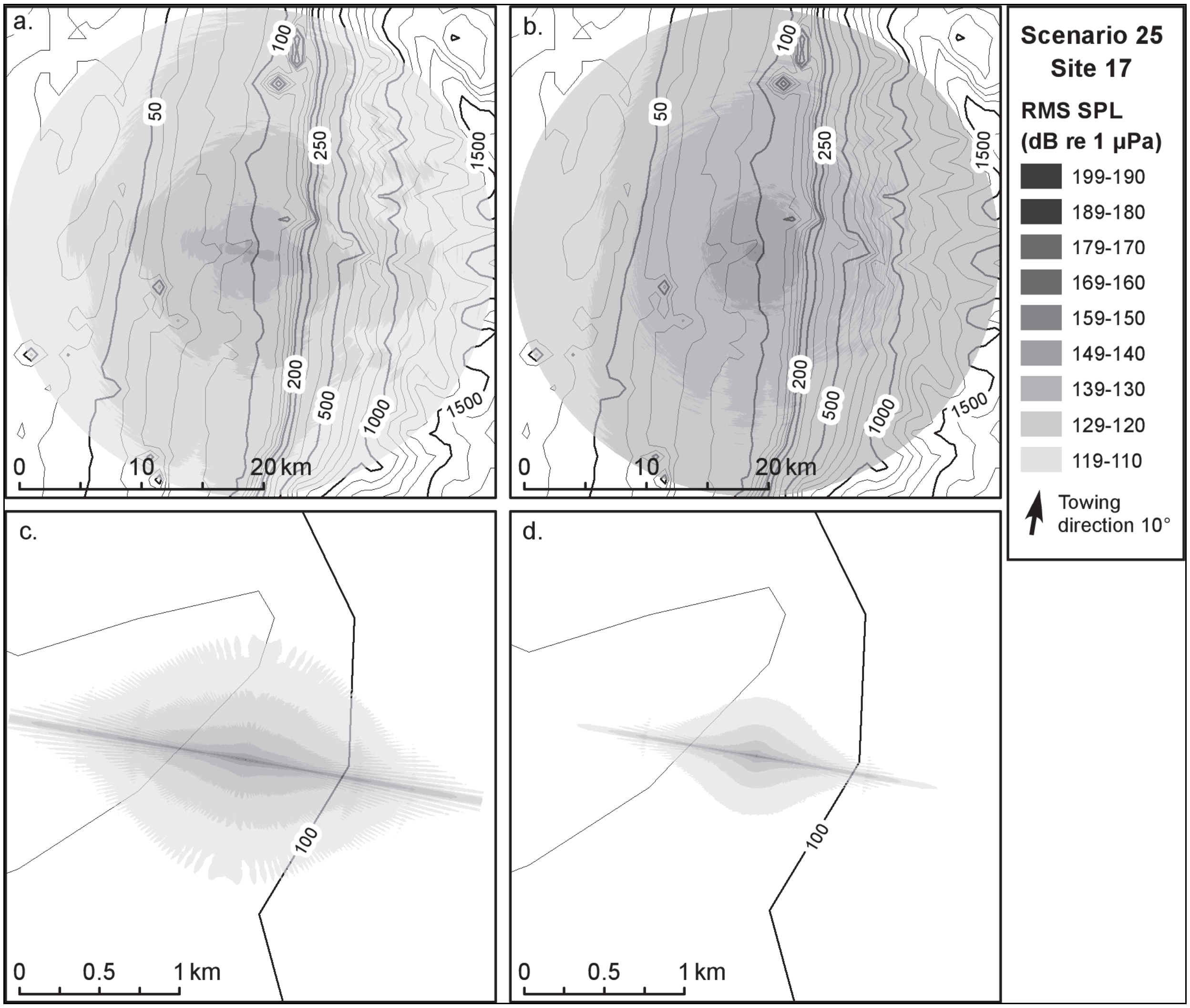

Figure Attachment A-25. Predicted SPL (rms) for Modeling Scenario 25 (Water Depth Is 100 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, (c) Side-Scan Sonar, and (d) Multibeam Depth Sounder.

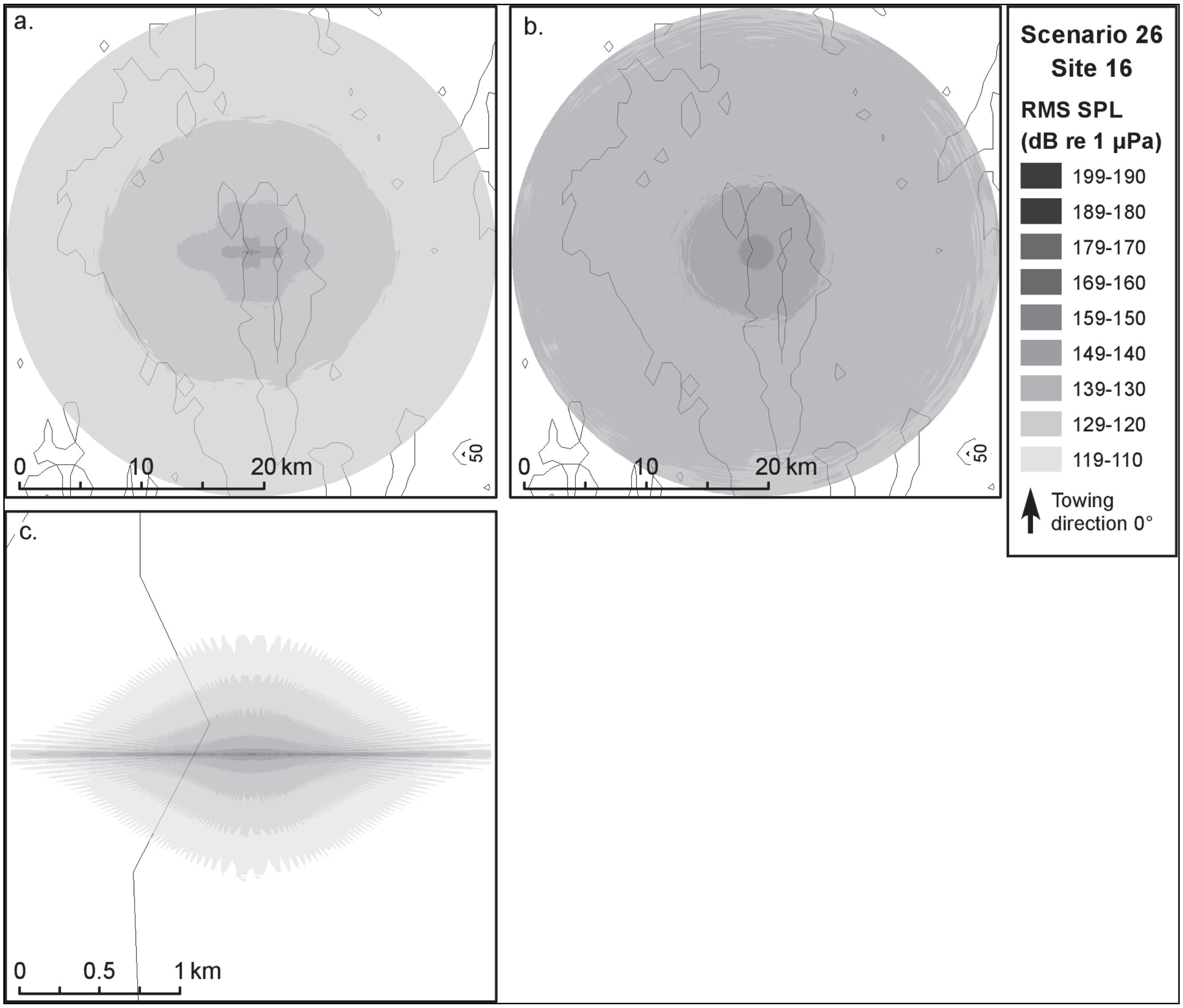

Figure Attachment A-26. Predicted SPL (rms) for Modeling Scenario 26 (Water Depth Is 30 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, and (c) Side-Scan Sonar.

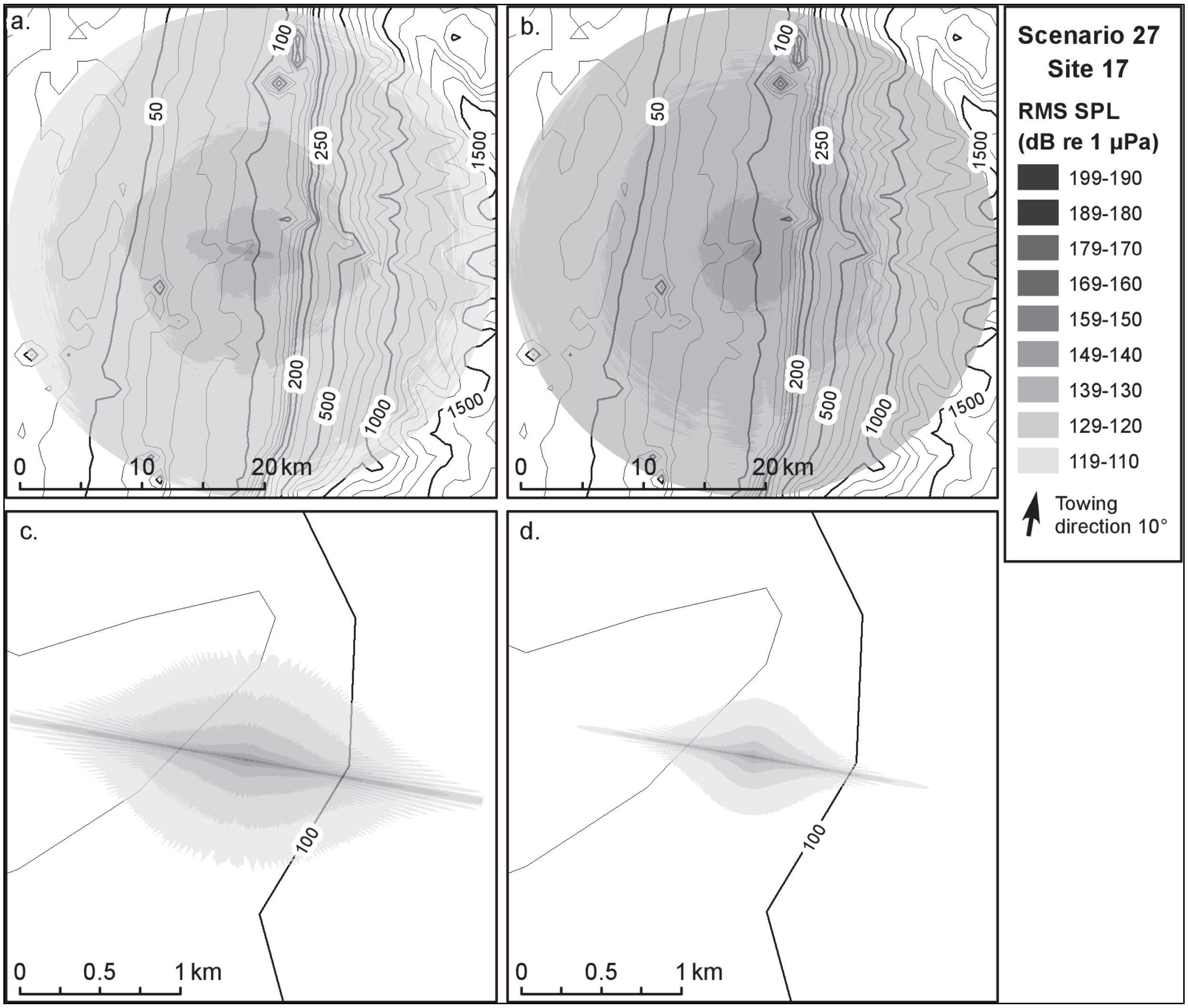

Figure Attachment A-27. Predicted SPL (rms) for Modeling Scenario 27 (Water Depth Is 100 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, (c) Side-Scan Sonar, and (d) Multibeam Depth Sounder.

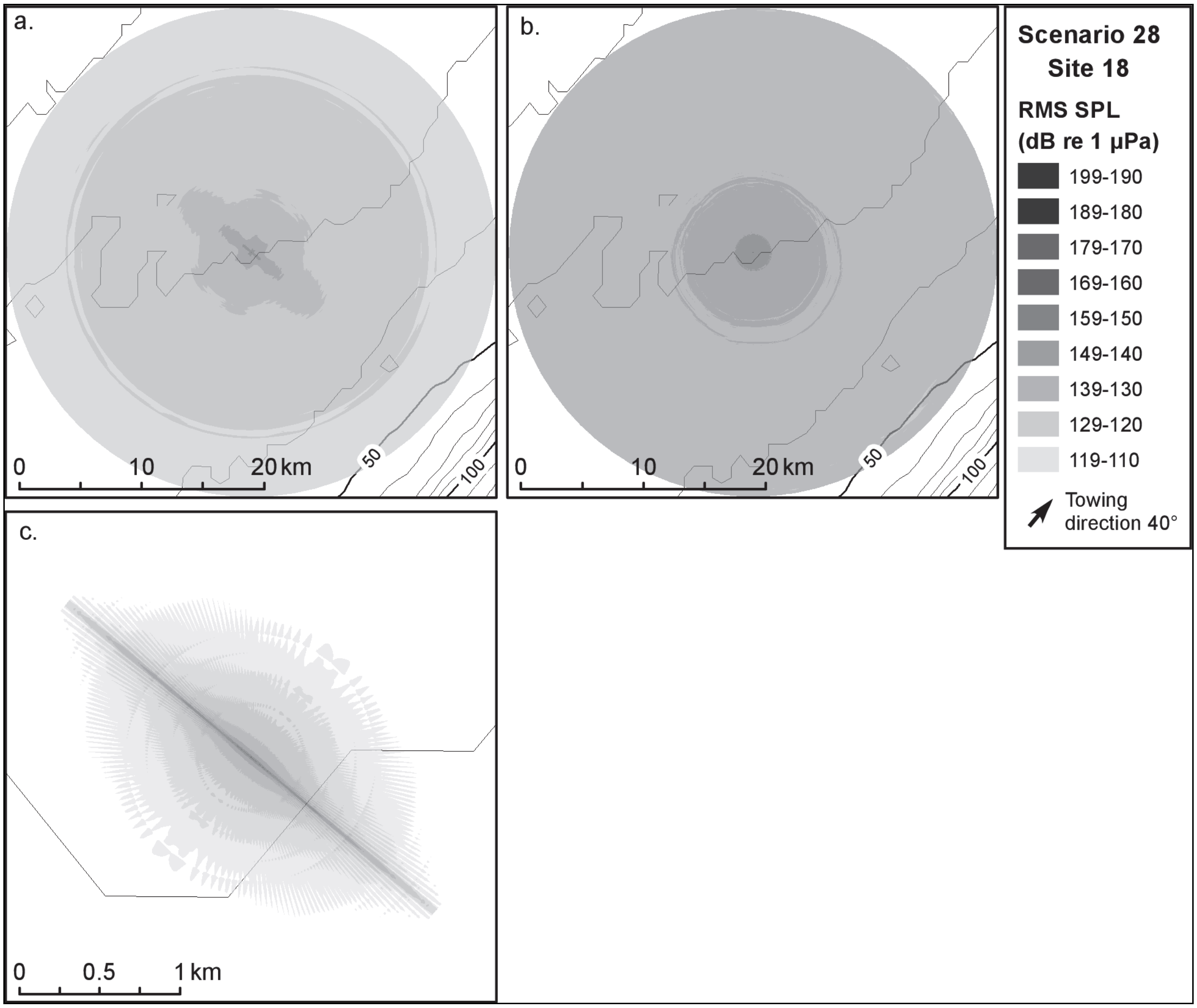

Figure Attachment A-28. Predicted SPL (rms) for Modeling Scenario 28 (Water Depth Is 30 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, and (c) Side-Scan Sonar.

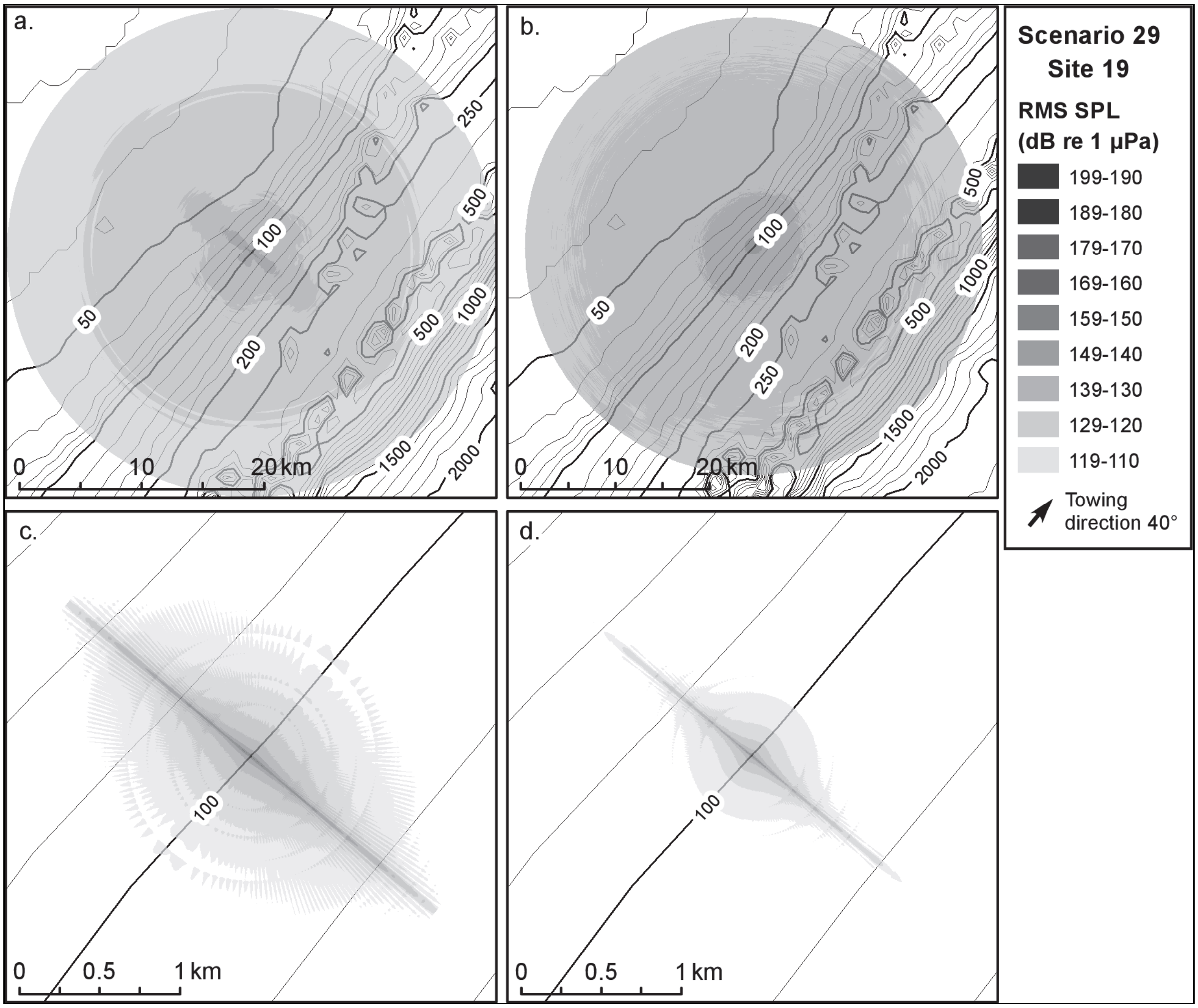

Figure Attachment A-29. Predicted SPL (rms) for Modeling Scenario 29 (Water Depth Is 100 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, (c) Side-Scan Sonar, and (d) Multibeam Depth Sounder.

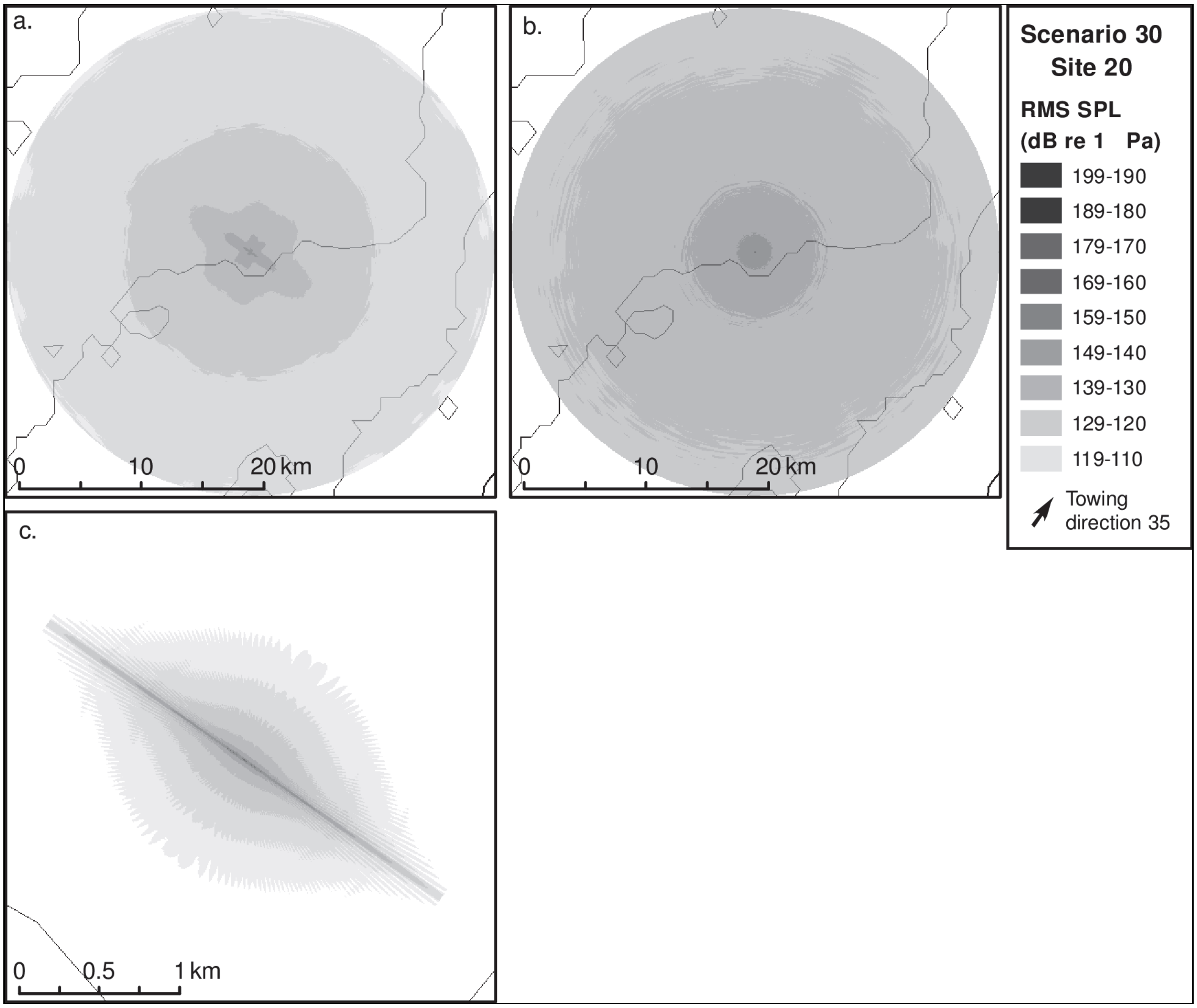

Figure Attachment A-30. Predicted SPL (rms) for Modeling Scenario 30 (Water Depth Is 30 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, and (c) Side-Scan Sonar.

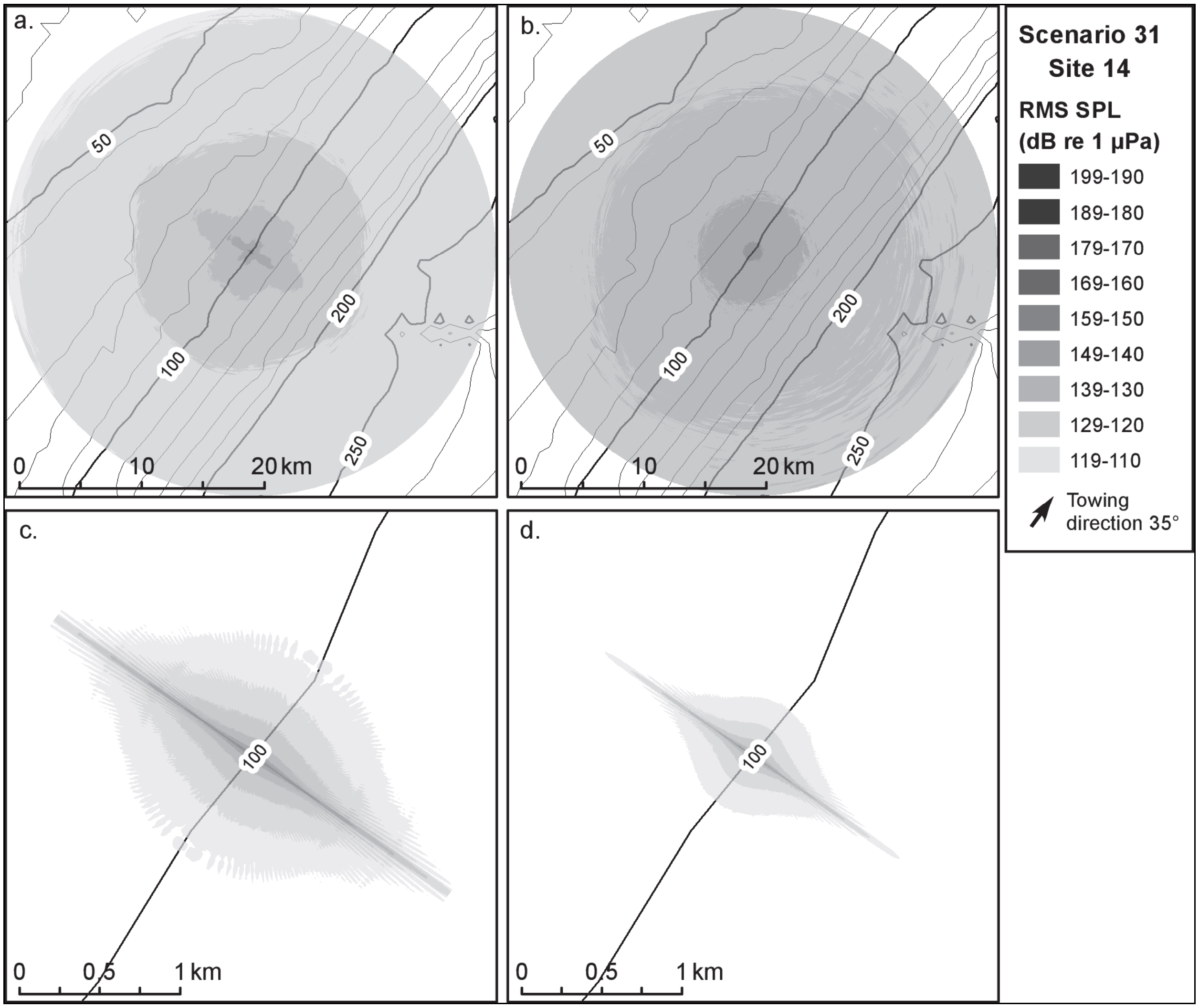

Figure Attachment A-31. Predicted SPL (rms) for Modeling Scenario 31 (Water Depth Is 100 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, (c) Side-Scan Sonar, and (d) Multibeam Depth Sounder.

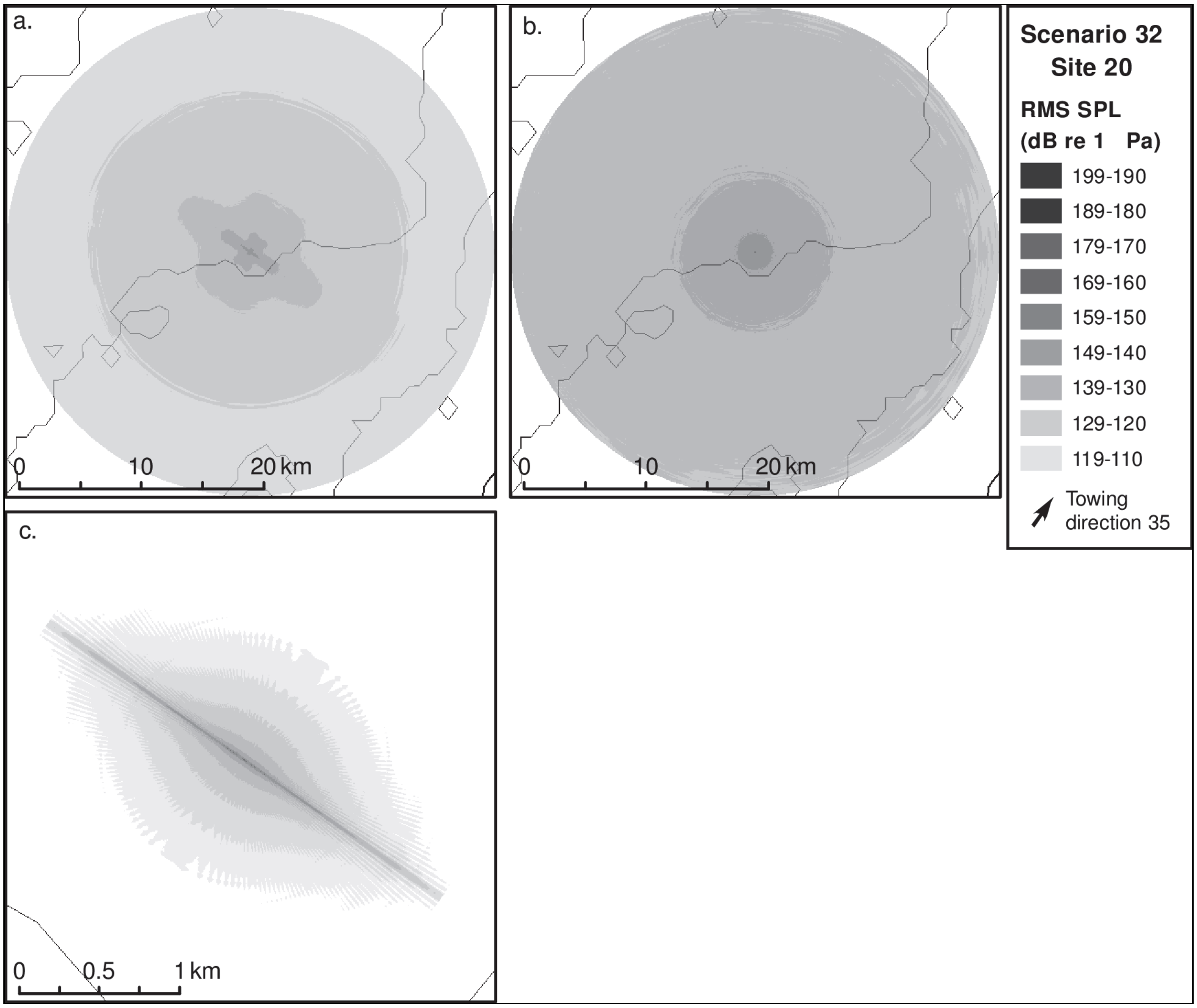

Figure Attachment A-32. Predicted SPL (rms) for Modeling Scenario 32 (Water Depth Is 30 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, and (c) Side-Scan Sonar.

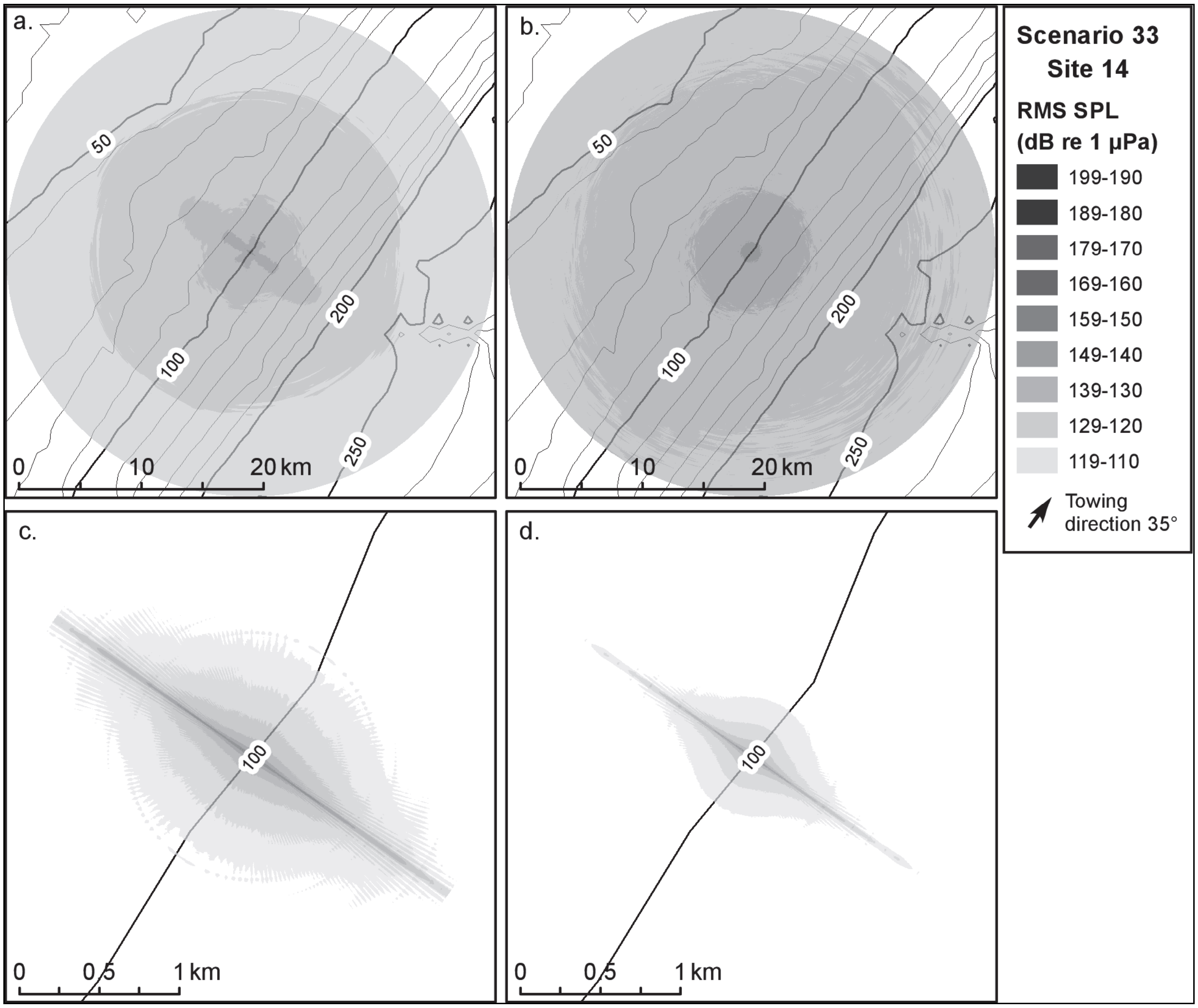

Figure Attachment A-33. Predicted SPL (rms) for Modeling Scenario 33 (Water Depth Is 100 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, (c) Side-Scan Sonar, and (d) Multibeam Depth Sounder.

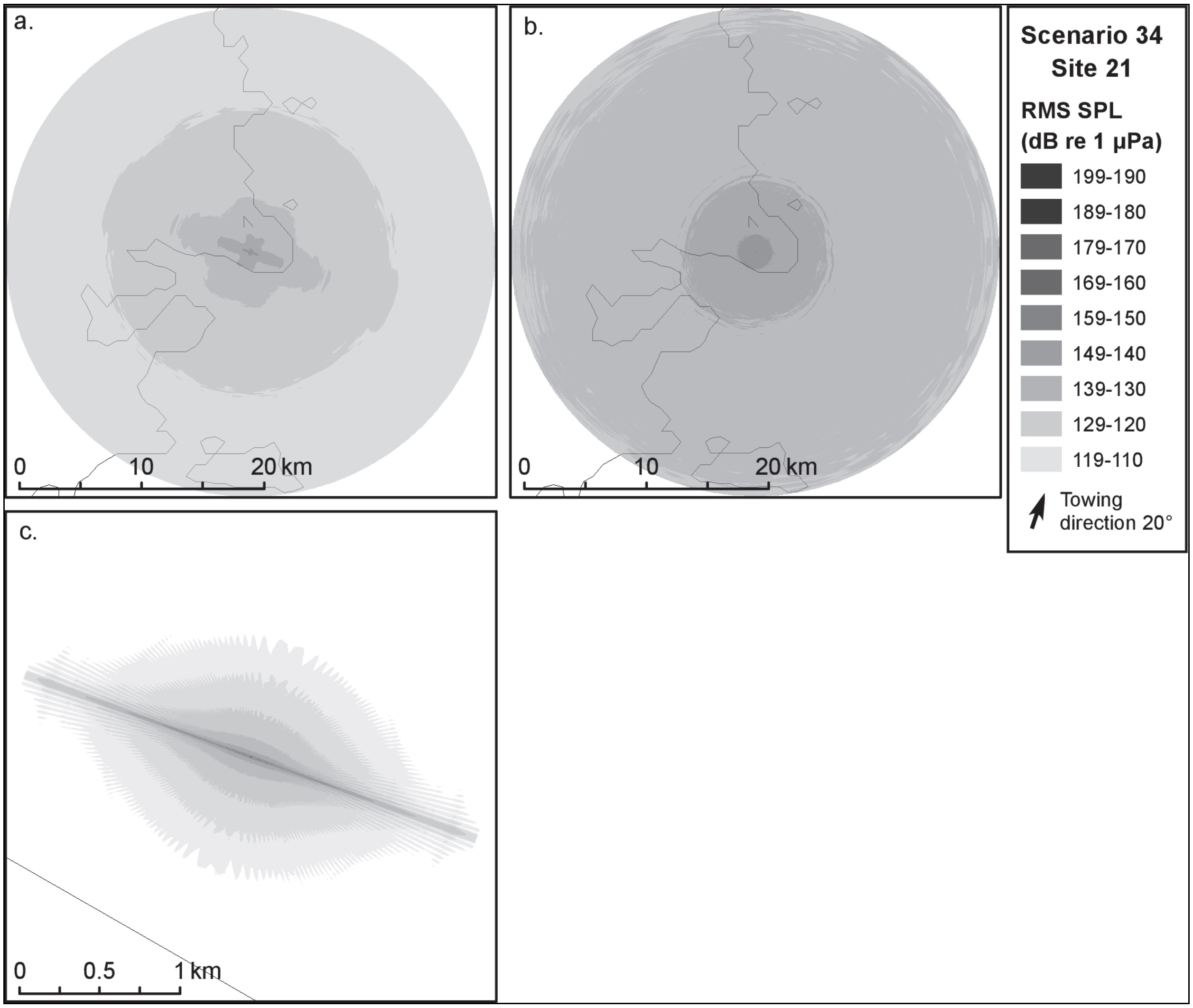

Figure Attachment A-34. Predicted SPL (rms) for Modeling Scenario 34 (Water Depth Is 30 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, and (c) Side-Scan Sonar.

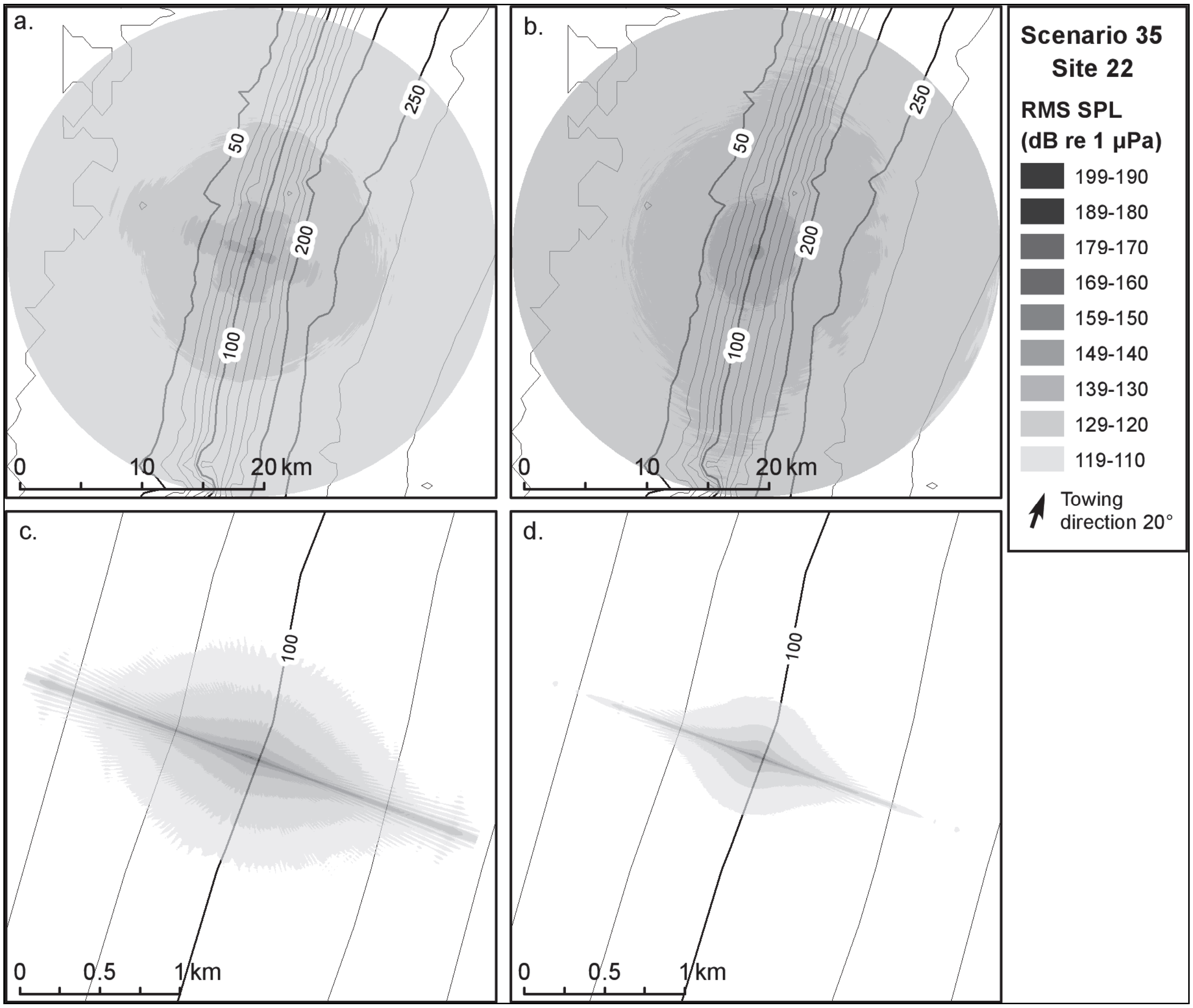

Figure Attachment A-35. Predicted SPL (rms) for Modeling Scenario 35 (Water Depth Is 100 m at the Source). The Sources Are (a) Subbottom Profiler, (b) Boomer, (c) Side-Scan Sonar, and (d) Multibeam Depth Sounder.

ATTACHMENT B: Predicted Ranges to Specified Threshold Levels

Table Attachment B-1

Predicted Ranges (in Meters) to Specified Threshold Levels for 5,400 in^3 Airgun Array Source

rms dB	210		200		190		180		170		160		150	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
1	29	29	90	87	278	270	835	810	2,297	2,213	5,379	4,969	8,730	8,107
2	29	29	92	89	284	273	876	827	2,557	2,358	5,720	5,184	19,735	16,479
3	30	30	91	89	292	280	1,557	1,093	3,753	3,445	9,329	8,104	>20,000	19,489
4	16	16	46	46	151	145	822	748	3,406	2,793	12,737	8,725	>20,000	19,338
5	16	16	47	45	166	153	816	742	3,635	2,709	13,337	8,896	>20,000	19,265
6	29	29	90	87	278	270	837	811	2,298	2,215	5,379	4,989	8,740	8,146
7	29	29	90	87	285	276	855	829	2,422	2,300	5,322	5,026	19,950	18,775
8	30	30	91	89	292	280	1,556	1,091	3,748	3,452	9,654	8,056	>20,000	19,489
9	16	16	46	46	154	148	801	737	3,305	2,787	11,056	8,593	>20,000	19,327
10	16	16	45	43	152	146	799	752	3,361	2,704	11,695	8,615	>20,000	18,989
11	29	29	89	86	277	269	837	811	2,296	2,212	5,379	4,973	8,320	7,883
12	29	29	89	87	283	275	853	827	2,420	2,291	5,320	5,013	>20,000	19,758
13	30	29	90	88	292	280	1,552	1,082	3,737	3,151	9,316	8,095	>20,000	19,489
14	16	16	45	43	157	150	880	761	3,253	2,648	15,305	9,122	>20,000	19,387
15	30	29	91	89	280	273	841	816	2,365	2,262	5,490	5,121	8,846	8,394
16	30	29	90	87	285	277	871	846	2,456	2,339	5,360	5,098	19,852	16,233
17	29	29	90	88	279	271	838	812	2,281	2,212	5,184	4,959	8,590	8,235
18	30	29	90	87	278	270	845	819	2,362	2,267	5,450	5,069	8,912	8,384
19	30	30	91	89	292	280	1,559	1,094	3,754	3,497	9,304	8,083	>20,000	19,489
20	16	16	49	47	292	275	1,134	992	4,127	3,282	12,022	8,531	>20,000	19,151
21	21	21	92	87	460	434	2,109	1,677	5,257	4,441	11,380	8,384	>20,000	18,421

Table Attachment B-2

Predicted Ranges (in Meters) to Specified Threshold Levels for 90 in^3 Airgun Array Source

rms dB	200		190		180		170		160		150	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
1	16	16	46	46	148	144	450	437	1,295	1,256	3,412	3,205
2	16	16	46	46	148	143	458	441	1,363	1,291	3,719	3,355
3	16	16	47	47	148	145	486	460	2,210	2,038	5,537	4,786
4	7	7	22	22	76	75	325	293	1,452	1,342	4,990	4,154
5	7	7	22	22	76	74	395	328	1,568	1,286	5,324	3,927
6	16	16	46	46	148	144	450	437	1,295	1,256	3,412	3,202
7	16	16	46	46	146	142	453	439	1,322	1,281	3,565	3,302
8	16	16	47	47	148	145	483	459	2,212	2,039	5,516	4,810
9	7	7	22	22	76	74	332	306	1,464	1,331	4,910	4,374
10	7	7	25	25	76	75	310	291	1,512	1,108	5,189	4,126
11	16	16	46	46	146	143	448	435	1,295	1,255	3,412	3,203
12	16	16	46	46	146	141	450	437	1,321	1,280	3,425	3,307
13	16	16	47	46	147	143	482	458	2,211	2,036	5,197	4,623
14	7	7	25	25	76	74	336	308	1,371	1,100	5,456	3,947
15	16	16	47	46	146	143	450	436	1,315	1,258	3,403	3,284
16	16	16	46	46	149	145	455	442	1,325	1,285	3,529	3,404
17	16	16	46	46	149	145	455	442	1,294	1,255	3,351	3,194
18	16	16	46	46	148	145	456	443	1,329	1,289	3,510	3,294
19	16	16	47	47	149	145	483	459	2,212	2,040	5,518	4,859
20	7	7	25	25	90	86	371	341	2,051	1,681	5,181	4,356
21	11	11	35	35	186	177	852	755	3,056	2,493	6,464	5,888

Table Attachment B-3

Predicted Ranges (in Meters) to Specified Threshold Levels for Boomer Source.
No Adjustment for Pulse Duration Has Been Applied

rms dB	200		190		180		170		160		150	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
22	<5	<5	7	7	43	43	386	336	1,737	1,490	8,243	6,088
23	<5	<5	7	7	39	38	140	135	1,060	818	6,655	4,757
24	<5	<5	7	7	43	42	364	299	1,956	1,444	6,280	5,056
25	<5	<5	7	7	38	36	142	132	1,566	1,342	7,820	4,792
26	<5	<5	7	7	43	41	386	317	1,712	1,428	7,293	5,752
27	<5	<5	7	7	40	40	141	135	1,054	807	6,003	4,519
28	<5	<5	7	7	41	40	259	252	1,860	1,468	8,202	6,252
29	<5	<5	7	7	39	38	144	137	1,129	799	6,484	4,805
30	<5	<5	7	7	43	41	315	310	1,730	1,435	6,776	5,563
31	<5	<5	10	10	40	39	146	137	1,155	840	6,480	4,550
32	<5	<5	7	7	45	43	377	318	2,138	1,552	7,802	6,287
33	<5	<5	7	7	39	38	148	142	1,655	898	7,089	5,046
34	<5	<5	7	7	43	43	376	313	1,844	1,467	7,755	6,011
35	<5	<5	7	7	40	38	143	137	1,035	669	6,085	4,339

Table Attachment B-4

Predicted Ranges (in Meters) to Specified Threshold Levels for Side-Scan Sonar Source.
No Adjustment for Pulse Duration Has Been Applied

rms dB	210		200		190		180		170		160		150	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
22	<5	<5	18	16	70	66	192	180	376	334	604	534	856	732
23	<5	<5	12	8	47	36	128	116	280	250	512	440	760	650
24	<5	<5	18	16	70	66	186	176	376	336	602	532	864	752
25	<5	<5	12	8	47	36	138	116	290	256	532	455	812	715
26	<5	<5	18	16	70	66	190	176	374	330	600	530	852	728
27	<5	<5	12	8	47	36	128	116	280	246	500	438	770	651
28	<5	<5	14	12	50	47	177	156	379	345	655	528	919	791
29	<5	<5	14	12	50	47	133	125	348	330	650	499	867	774
30	<5	<5	13	9	49	42	171	154	356	319	576	510	850	737
31	<5	<5	13	9	49	39	129	115	286	247	537	462	816	702
32	<5	<5	13	9	49	42	178	156	366	323	600	539	903	745
33	<5	<5	13	9	49	39	132	119	293	256	567	492	806	697
34	<5	<5	13	9	53	40	175	159	362	324	592	526	836	719
35	<5	<5	13	9	47	30	134	121	281	249	538	458	768	655

Table Attachment B-5

Predicted Ranges (in Meters) to Specified Threshold Levels for Chirp Subbottom Profiler.
No Adjustment for Pulse Duration Has Been Applied

rms dB	200		190		180		170		160		150	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
22	<5	<5	12	12	32	28	136	110	808	682	2,863	2,325
23	<5	<5	13	13	38	35	106	90	380	303	2,456	1,781
24	<5	<5	12	12	32	28	138	112	874	772	2,908	2,379
25	<5	<5	13	13	37	35	108	90	376	317	2,855	2,357
26	<5	<5	12	12	32	28	128	107	764	664	2,839	2,275
27	<5	<5	13	13	37	35	106	90	359	297	2,480	1,741
28	<5	<5	13	12	33	29	122	102	971	876	3,222	2,857
29	<5	<5	13	13	42	37	110	91	854	677	3,189	2,704
30	<5	<5	13	12	33	29	122	103	831	644	2,680	2,199
31	<5	<5	13	13	42	39	112	91	557	313	2,324	1,969
32	<5	<5	13	12	33	29	125	104	962	811	3,494	2,519
33	<5	<5	13	13	42	39	112	92	684	363	2,889	2,446
34	<5	<5	13	12	32	29	123	104	724	634	2,869	2,590
35	<5	<5	13	13	42	38	108	90	401	300	2,766	2,086

Table Attachment B-6

Predicted Ranges (in Meters) to Specified Threshold Levels for Multibeam Depth Sounder.
No Adjustment for Pulse Duration Has Been Applied

rms, dB	210		200		190		180		170		160		150	
Scenario	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
23	0	0	<5	<5	10	10	27	25	61	57	147	142	320	275
25	0	0	<5	<5	10	10	27	25	61	57	147	142	320	275
27	0	0	<5	<5	10	10	27	25	61	57	147	142	315	269
29	0	0	<5	<5	10	10	27	25	55	51	156	149	359	337
31	0	0	<5	<5	10	10	27	25	61	57	147	140	294	262
33	0	0	<5	<5	10	10	27	25	61	57	147	140	305	273
35	0	0	<5	<5	10	10	27	25	59	55	149	144	293	266

APPENDIX E

ACOUSTIC MODELING AND MARINE MAMMAL INCIDENTAL TAKE METHODOLOGY, ANALYSIS, AND RESULTS

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LIST OF ACRONYMS AND ABBREVIATIONS

µPa	micropascals
2D	two-dimensional
3D	three-dimensional
4D	four-dimensional
AIM	Acoustic Integration Model©
ANSI	American National Standards Institute
AOI	Area of Interest
BOEM	Bureau of Ocean Energy Management
CIE	Center for Independent Experts
CZ	convergence zone
dB	decibel
DTAG	digital acoustic recording tag
EIS	environmental impact statement
FEIS	Final Environmental Impact Statement
FSEIS	Final Supplemental Environmental Impact Statement
ft	feet
G&G	geological and geophysical
GIS	geographic information system
GDEM	Generalized Digital Environmental Model
GDEM_V	Generalized Digital Environmental Model Variable Resolution
hr	hour
HRG	high-resolution geophysical
Hz	hertz
ITA	incidental take authorization
JASCO	JASCO Applied Sciences
kHz	kilohertz
km	kilometer
LFA	low-frequency active
LOE	level of effort
m	meter
MMPA	Marine Mammal Protection Act
MONM	Marine Operations Noise Model
NGDC	National Geophysical Data Center
NMFS	National Marine Fisheries Service
nmi	nautical mile
NODE	Navy Operating Area Density Estimates
NRC	National Research Council
OCS	Outer Continental Shelf
OPAREA	operating area
Pa	pascal
PTS	permanent threshold shift
RMS	root-mean-square
s	second
SAG	surface active group
SD	standard deviation
SE	standard error
SEFSC	Southeast Fisheries Science Center
SEL	sound exposure level
SL	source level
SPL	sound pressure level
SURTASS	Surveillance Towed Array Sensor System
SVP	sound velocity profile
TDR	time-depth recorder
TL	transmission loss
TTS	temporary threshold shift
VSP	vertical seismic profile
WAZ	wide azimuth

1. INTRODUCTION AND OVERVIEW

The Bureau of Ocean Energy Management (BOEM) has prepared this Programmatic Environmental Impact Statement (EIS) to evaluate the potential environmental effects of geological and geophysical (G&G) activities on the Mid- and South Atlantic Outer Continental Shelf (OCS) and adjacent state waters. The purpose of this appendix is to explain the methodology that was used to calculate incidental takes of marine mammals for the Programmatic EIS. This appendix documents the overall approach and identifies the specific models, acoustic sources, and modeling techniques that were used, as well as the operational, environmental, and biological data that were needed to support the modeling. Some of the details of this analysis are specific to the work performed by JASCO as part of their acoustic source and acoustic propagation loss modeling; in those instances, this appendix refers to **Appendix D**, which covers those details.

The term "incidental take" derives from Section 101(a)(5) (A-D) of the Marine Mammal Protection Act of 1972 (MMPA), as amended (16 U.S.C. 1371(a)(5)), which provides a mechanism for allowing, upon request, the incidental, but not intentional, taking of small numbers of marine mammals by U.S. citizens who engage in a specified activity (other than commercial fishing) within a specified geographic region. Under the 1994 amendments to the MMPA, harassment is statutorily defined as, "any act of pursuit, torment, or annoyance that has the potential to injure a marine mammal or marine mammal stock in the wild" (Level A harassment); "or has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild" (Level B harassment).

Accurate predictive modeling of potential acoustic impacts requires knowledge of (1) the specific source(s) that would be used at each site of survey operations; (2) the exact environmental acoustic conditions present at each site; (3) the timing and type of each survey; and (4) the marine animals present at each site. Because these facts could not be known ahead of time (without extensive surveys immediately prior to or during the survey) and particularly not for the period of this document (i.e., through the year 2020), the following analytical estimation is necessary. The reasonable approach described in this report, in general, examines the potential range of each variable and identifies typical values expected to be used during the proposed action.

There are many instances where the numerous permutations needed to capture the effects of the range of values for a variable may be able to be reduced because of minimal effects on the results, or because the low occurrence of some of the values in the range allows an obvious selection for modeling. For example, nearly all of the deepwater sites have very fine silts, clayey silt, and clay as the predominant bottom types, and the use of clay characteristics in the acoustic propagation modeling for all of these deep sites is adequate, because the bottom properties of the other sediments would be similar. Similarly, in the case of the airgun source used for modeling, there are numerous possible source arrays that could be used based on the company performing the survey, the location, the ships available, etc. In this case, a nominal source identified by the BOEM as a typical source for these surveys was used in the modeling. Although it is not necessarily the strongest source identified, it better represents a typical source array and its potential impacts. It is estimated that the percentage of time that strong and weak sources are used over the duration of the proposed action would only slightly change the overall estimated impacts and, over time, tend to average out to an impact similar to that predicted for the modeled array. As can be seen in **Appendix D**, the 5,400 cubic inch airgun is conservatively used for all survey types (e.g., a two-dimensional [2D] survey might be expected to typically use a smaller and less powerful source), with the source level only being corrected for the water depth and M-weighting.

The basic acoustic terminology used in this report is presented in numerous published sources (e.g., American National Standards Institute [ANSI], 1984, 1986, 2004; Richardson et al., 1995; National Research Council [NRC], 2003; Southall et al., 2007). The main definitions used in this assessment are provided below, from Southall et al. (2007):

- *Pulses*: Pulses are brief, broadband, atonal, transient sounds; e.g., explosions, gun shots, airgun pulses, and pile driving strikes. Pulses are characterized by a rapid rise from ambient pressure to maximal pressure, and (at least near the source) by short duration.

- *Nonpulse (intermittent or continuous) Sounds*: Nonpulse sounds can be tonal, broadband, or both. Nonpulse sounds can be of short duration but they lack the rapid rise times of true pulses. Nonpulse sounds include those from shipping, aircraft, drilling, and active sonar systems. Due to certain propagation effects, it is possible that a sound that is pulsed near the source may be perceived by a distant receiver as a nonpulse sound.
- *Peak Sound Pressure*: This is the maximum instantaneous sound pressure measurable in the water at a specified distance from the source airgun. The units of pressure are typically bars (English) or, in metric units, either Pascals (Pa) or microPascals (µPa). The metric values are commonly expressed in logarithmic form as decibels relative to 1 µPa (dB re 1 µPa).
- *Peak-to-Peak Sound Pressure*: This is the algebraic difference between the peak positive and peak negative sound pressures. Units are the same as for peak pressure. When expressed in dB, peak-to-peak pressure is typically ~6 dB higher than peak pressure.
- *Root-Mean-Square (RMS) Sound Pressure*: In simple terms, this is an average sound pressure over some specified time interval. For airgun pulses, the averaging time is commonly taken to be the approximate duration of one pulse, which in turn is commonly assumed to be the time interval within which 90 percent of the pulse energy arrives. The RMS sound pressure level (in dB) is typically ~10 dB less than the peak level, and ~16 dB less than the peak-to-peak level.
- *Sound Pressure Levels (SPLs)*: The SPLs are given as the dB measures of the pressure metrics defined above. The RMS SPL is given as dB re: 1 µPa for underwater sound and dB re: 20 µPa for aerial sound.
- *Source Level (SL)*: The SL is the received level measured or estimated at a nominal distance of 1 meter (m) from the source. It is often expressed as dB re: 1 µPa at 1 m or in bar-m. For a distributed source, such as an array of airguns, the nominal overall SL, as used in predicting received levels at long distances, exceeds the level measurable at any one point in the water near the sources.
- *Sound Exposure Level (SEL or energy flux density)*: This measure represents the total energy contained within a pulse, and is in the units dB re 1 µPa2-s. For a single airgun pulse, the numerical value of the SEL measurement, in these units, is usually 5–15 dB lower than the RMS sound pressure in dB re 1 µPa, with the "RMS – SEL" difference often tending to decrease with increasing range (Greene, 1997; McCauley et al., 1998).
- *Duration*: Duration is the length of the sound, usually measured in seconds. For an impulsive sound such as an airgun pulse, the duration may be calculated in a number of different ways. Greene (1997) described duration of an airgun pulse as the interval over which 90 percent of the sound energy arrives at the receiver.

Over the past decade, the National Marine Fisheries Service (NMFS) guidelines regarding levels of impulsive sound that might cause injury or behavioral disturbance have been based on the "RMS sound pressure" metric. However, the RMS value depends on the extent to which the sound pulse has been "stretched" in duration during propagation, which varies with environmental conditions, so the RMS measure is often criticized (e.g., Madsen, 2005). There is now reason to believe that auditory effects (especially physiological effects like permanent threshold shift [PTS] and temporary threshold shift [TTS]) of transient sounds on marine mammals are better correlated with the amount of received energy than with the level of the strongest pulse and therefore SEL is increasingly the unit of choice in evaluations (Southall et al., 2007).

2. ACOUSTIC MODELING APPROACH

There are two steps to the modeling effort: (1) the determination of the three-dimensional (3D) acoustic field emanating from the sound sources and how it propagates through the water; and (2) the determination of the net exposure of marine animals that reside in the exposed volume.

Historically, the geophysical community and NMFS have used a simplified approach (referred to here as the "transect methodology") to estimate the potential impacts to marine mammals for airgun sources. Essentially, this methodology consisted of: (1) determination of the estimated threshold isopleth range from the source for harassment under the MMPA for the airgun sources. Nominally these thresholds were the 160 dB received level for Level B harassment of any marine mammal and the 180 and 190 dB received levels for Level A harassment of cetaceans and pinnipeds, respectively; (2) assumption that a cylinder whose radius matched the range to these isopleths and encompassed the entire water column was ensonified to that threshold; (3) calculating the surface area ensonified by this water column as the source moved along its track; and (4) multiplying that resultant ensonified surface area by the density of each marine mammal species present to estimate that species' numbers of MMPA Level A and B potential harassment takes. This methodology was not used in the Programmatic EIS.

For the Programmatic EIS a more sophisticated approach was used. This approach used a more detailed modeling of the source and its properties, the acoustic propagation field in 3D, and 3D animal placement and movement to better calculate the potential impacts to marine mammals. For this methodology, the first step is largely controlled by properties of the source, such as its movement in time and space, and the sound field it generates at any point in time. This is a function of the geometric organization (array configuration) of its sound generators, and the spatial, spectral, and temporal properties of the sound field that they produce. Propagation modeling further analyzes the effects of the physical properties of the ocean, the bottom and the surface, on the sound field as it propagates out from the source.

The second step requires knowledge of the diving and movement characteristics of the animals residing in the exposed region. Time-based integration models, such as the Acoustic Integration Model© (AIM)[1], as used in this modeling effort, are necessary to fully evaluate the exposure. The advantage of these tools is that they not only provide a more accurate and detailed model of the exposures of a population of marine animals in 3D and time, but they also provide: (1) statistical data on each individually modeled animal and the population as a whole; (2) rate of exposure (sounds per unit of time) over the duration of a survey; and (3) the data necessary to determine effects based on more sophisticated thresholds, such as SEL.

2.1. PROPAGATION MODELING

2.1.1. Overall Modeling Assumptions

For the more complex modeling effort in this appendix, the following general assumptions were made:

- the far-field broadband signal from the typical airgun array nominally includes significant components up to 2,000 hertz (Hz), with the peak amplitude in the far-field near-horizontal spectrum typically occurring between 50 and 100 Hz;
- the modeling needs to address all of the seismic airgun survey types identified in the scope of work for this effort – i.e., 2D and 3D surveys, wide azimuth (WAZ) surveys, vertical seismic profiles (VSP), and high-resolution geophysical (HRG) surveys;
- the modeling also needs to address HRG surveys for renewable energy and marine minerals sites, which use non-airgun active acoustic sources including side-scan sonars, boomers, chirp subbottom profilers, and single or multibeam depth sounders;
- there would also be non-acoustic surveys (i.e., controlled source electromagnetic surveys, magnetotelluric surveys, gravity and gradiometry surveys, magnetic surveys, deep stratigraphic and shallow test drilling, bottom sampling, and several remote sensing methods), but they are not addressed by this acoustic modeling effort;

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[1] MAI's Acoustic Integration Model©, or AIM, is a software package developed to predict the acoustic exposure of marine animals from an underwater sound source. The unique and principal component of AIM is a 3D movement engine, which programs the geographic and vertical movements of sound sources and simulated marine animals. In 2006, the Center for Independent Experts (CIE) conducted a review and assessment of AIM. The CIE panel concluded that AIM is a credible tool for developing application models (Independent System for Peer Review, 2006).

- nominal or representative sources, as identified by the BOEM, were used for source modeling and source specification identification;
- conditions to be modeled include all potential survey areas in the Area of Interest (AOI) for the Programmatic EIS, including all water depths from the coastline (outside of estuaries) to 350 nautical miles (nmi) (648 kilometers [km]) from shore and including all four seasons;
- animal density estimates would use the best available data, specified by location and season for the modeling effort; and
- animal movement modeling would use the best available input data.

2.1.2. Acoustic Propagation Model Selection

The details of the acoustic propagation modeling are provided in **Appendix D** and will not be repeated here.

2.2. OVERALL MODELING APPROACH

The following step-wise modeling approach is included to illustrate the overall approach to predict the acoustic impacts of G&G activities in the Mid- and South Atlantic for the proposed action:

- The Generalized Digital Environmental Model (GDEM) database was used to extract sound velocity profiles (SVPs) for the Mid- and South Atlantic Planning Areas to characterize the entire water body into a discreet number of specific SVP regions, or propagation regions;
- The SVPs for winter, spring, summer, and fall were then examined for the entire area covered by this Programmatic EIS. After examination of the SVPs, it was determined each season had unique characteristics which prevented any combination of seasons with similar propagation characteristics. Additionally, the SVPs for each season were group into about 17 areas or regions with similar propagation characteristics and representative SVPs for each region were selected. Finally, the bottom characteristics for each of these 17 regions were examined to determine if any region needed to be divided to accommodate the influence of the various bottom types on that regions propagation. The result was 21 separate modeling regions that taken in total captured the propagation for the entire area covered by this Programmatic EIS for all four seasons;
- Additionally, the seasonal distribution of marine mammals was examined using the best available databases to see if there was any additional correlation with bathymetry and SVP regions. Using this database, the seasonal distribution for each species was examined by overlaying the charts of the 21 acoustic modeling regions; the average density of each species was then numerically determined for each region.
- One final acoustic characterization was then conducted in order to allow the correct acoustic modeling for the shallowest water activities. Of the 21 modeling regions, 7 regions covered the area of the continental shelf, but these areas included water depths of up to approximately 200 m (656 feet [ft]). Since all of the marine mineral and renewable energy HRG surveys would be conducted in water less than 100 m (328 ft) deep, a refined propagation analysis using 50 and 100 m (164 and 328 ft) deep sites were identified for each of these 7 shallow water regions. The acoustics modeling would use these 14 additional sites to properly capture the acoustic propagation for these two categories of non-airgun HRG surveys;
- JASCO Applied Sciences (JASCO) provided the acoustic propagation modeling and results for all sources and the regions that they would potentially operate in as described in **Appendix D**;
- The AIM was used to estimate the impacts per survey block for each species, based on the typical planned geometry for each type of survey in each modeled area where the surveys would be conducted, using the appropriate thresholds for that species.

3. ACOUSTIC THRESHOLDS

3.1. HISTORICAL AND PROPOSED CURRENT CRITERIA

Since the mid-1990s, the NMFS has specified that marine mammals exposed to pulsed sounds with received levels exceeding 180 or 190 dB re 1 µPa (RMS) for cetaceans and pinnipeds, respectively, were considered to exceed Level A (Injury) levels. Similarly, NMFS specifies that cetaceans and pinnipeds exposed to levels exceeding 160 dB re 1 µPa (RMS) were considered to exceed Level B (Behavioral Harassment) criteria (**Table E-1**). For all of these criteria, the exposure level was the maximum acoustic RMS pressure level received by an animal.

Table E-1

Historical Injury and Behavioral Disturbance Criteria for Cetaceans and Pinnipeds for Airgun Signals, as Recognized and Used by the National Marine Fisheries Service

Group	Level A (Injury) Pressure (dB re 1 µPa RMS)	Level B (Behavioral Disturbance) Pressure (dB re 1 µPa RMS)
Cetaceans	180	160
Pinnipeds	190	160

3.1.1. Injury Criteria

The 180- and 190-dB re 1 µPa (RMS) criteria were determined before there was specific information about the received levels of underwater sound that would cause temporary or permanent hearing damage in marine mammals. Subsequently, data on received levels that cause the onset of TTS have been obtained for certain toothed whales and pinnipeds (Kastak et al., 1999, 2005; Finneran et al., 2002, 2005). A group of specialists in marine mammal acoustics, the "noise criteria group," has recommended new criteria, based on current scientific knowledge, to replace the somewhat arbitrary 180 and 190 dB (RMS) criteria (Southall et al., 2007).

Recently acquired data indicate that TTS-onset in marine mammals is more closely correlated with the received energy levels than with RMS levels. In odontocetes and the more sensitive pinnipeds exposed to nonpulse sound, TTS onset occurs near 195 and 183 dB re 1 μPa^2 -s, respectively (Southall et al., 2007). In odontocetes exposed to impulse sounds, the TTS threshold can be as low as approximately 186 dB re 1 μPa^2-s. The corresponding value for pinnipeds is less well defined. There are published data on levels of nonpulse sound (Kastak et al., 1999, 2005) but not of impulse sound eliciting TTS in pinnipeds. Based on the results for nonpulse sound, plus the known tendency in other mammals for lower TTS thresholds with impulse than with nonpulse sound, the TTS thresholds for pinnipeds exposed to impulse sound may be as low as 171 dB re 1 μPa^2-s in the more sensitive species, such as the harbor seal.

There are no specific data concerning the levels of underwater sound necessary to cause PTS in any species of marine mammal. However, data from terrestrial mammals provide a basis for estimating the difference between the (unmeasured) PTS thresholds and the measured TTS thresholds. A conservative (precautionary) estimate of this offset between TTS and PTS thresholds, when sound exposure is measured on a SEL basis (received energy levels), is to add 15 dB to the TTS value for impulsive sounds and 20 dB for nonpulse sounds (Southall et al., 2007). Thus, now-available data indicate that the lowest received levels of impulsive sounds (e.g., airgun pulses) that might elicit slight auditory injury (i.e., PTS) are 198 dB re 1 μPa^2-s in cetaceans (i.e., 183 + 15 dB), and 186 dB re 1 μPa^2-s in the more sensitive pinnipeds (i.e., 171 + 15 dB). Corresponding values for nonpulse sounds (e.g., boomers, side-scan sonars, chirp subbottom profilers, and single beam or multibeam depth sounders) are 215 re 1 μPa^2-s in cetaceans (i.e., 195 + 20 dB) and 203 dB re 1 μPa^2-s in the more sensitive pinnipeds (e.g., 183 + 20 dB) (Southall et al., 2007). These SEL measures are all assumed to be taken using M-weighting; i.e., somewhat down-weighting the energy for frequencies near and especially beyond the lower and upper frequency limits of hearing in the relevant marine mammal group (Southall et al., 2007).

The noise criteria group also concluded that receipt of an instantaneous flat-weighted peak pressure exceeding 230 dB re 1 µPa (peak) for cetaceans or 218 dB re 1 µPa (peak) for pinnipeds might also lead to auditory injury even if the aforementioned cumulative energy-based criterion was not exceeded (**Table E-2**).

The primary measure of sound used in the proposed new criteria is the received sound energy, not just in the single strongest pulse, but accumulated over time. The most appropriate interval over which the received airgun signal should be accumulated is not well defined. However, pending the availability of additional relevant information, the noise criteria group has suggested considering noise exposure over 24-hour (hr) periods.

Included in Southall et al. (2007) is a discussion and proposed application of M-weighting, which would be used to adjust a species' threshold slightly in order to account for its relative sensitivity to signals at various frequencies. M-weighting was used as described in **Appendix D**.

Table E-2

Injury and Behavioral Disturbance Exposure Criteria for Cetaceans and Pinnipeds, as proposed by Southall et al. (2007)

Group	Level A (Injury)		Level B (Behavioral Disturbance)
	Pressure (dB re 1 µPa RMS) (peak) (flat)	Energy (dB re 1 µPa2-s)	Pressure (dB re 1 µPa RMS)
Multiple Pulsed Signals/Systems			
Low-frequency Cetaceans	230	198	*
Mid-frequency Cetaceans	230	198	*
High-frequency Cetaceans	230	198	*
Pinnipeds (in water)	218	186	*
Nonpulsed Signals/Systems			
Low-frequency Cetaceans	230	215	*
Mid-frequency Cetaceans	230	215	*
High-frequency Cetaceans	230	215	*
Pinnipeds (in water)	218	203	*

* = not specified in Southall et al., 2007.

3.1.2. Behavioral Disturbance Criteria

As noted above, the existing NMFS criterion for potential behavioral disturbance to marine mammals from airgun-based seismic surveys is 160 dB re 1 µPa (RMS). The noise criteria group concluded that available data are insufficient as a basis for recommending any specific alternative behavioral disturbance criteria applicable to multiple-pulse sounds like airgun array sounds (Southall et al., 2007). Behavioral reactions to acoustic exposure are generally more variable, context-dependent, and less predictable than effects of noise exposure on hearing or physiology (Southall et al., 2007). There is no consensus on the appropriate noise exposure metric for assessing behavioral reactions, and it is recognized that many variables other than exposure level affect the nature and extent of responses to a particular stimulus (Southall et al., 2007). Finally, it is often difficult to differentiate brief, minor, biologically unimportant reactions from profound, sustained, and/or biologically meaningful responses related to growth, survival, and reproduction (NRC, 2005; Southall et al., 2007; Ellison et al., 2011). Therefore, in the Programmatic EIS, only the 160 dB criterion was used for the calculation of Level B incidental takes. This criteria applies to both multiple pulse signals/systems including: (1) the large (5,400 cubic inch) seismic airgun array and (2) the small (90 cubic inch) airgun array; as well as the nonpulsed electromechanical sources/systems including (1) boomers, (2) multibeam depth sounders, (3) side-scan sonars, and (4) chirp subbottom profilers. The justification for the use of this criterion for the seismic airgun sources is that it has historic precedent. For the nonpulse systems, this threshold has also been historically used for nonpulsed systems and even extended to continuous nonpulsed systems. Even though these systems are not technically "continuously" transmitting, they can transmit very short signals (i.e., signals that are tens of thousandths to tenths of a second long) every second but in different beams or frequencies. Additionally, it should be pointed out that many of the transmission frequencies of these nonpulsed systems are greater than 200 kilohertz (kHz), and therefore are above the hearing spectrum of nearly all of the marine species, with the exception of the harbour porpoise. Thus, the use of the 160 dB SPL criterion for the Level B threshold for both the multiple pulsed and nonpulsed systems is a reasonable combination of the historic values used and best current science and precedents available. Other methodologies, including the possible use of a risk continuum function as was used in the Surveillance Towed Array Sensor System (SURTASS) Low-Frequency Active (LFA) Sonar Final Environmental Impact Statement (FEIS) and Final Supplemental Environmental Impact Statement (FSEIS) (U.S. Dept. of the Navy, 2001, 2007a) are being examined for Level B impact assessment for various sources at this time, but none has been applied to the impact analysis for this Programmatic EIS.

Acoustic impact criteria applicable to other types of biota are less well-developed than the criteria for cetaceans and pinnipeds. There is an ongoing effort to develop science-based criteria for fish and sea turtles.

4. ACOUSTIC SOURCE MODELING

A detailed discussion of acoustic sources, including both airguns and electromechanical sources, as well as how they were modeled acoustically, can be found in **Appendix D**. Sources modeled in **Appendix D** include a large (5,400 cubic inch) airgun array, small (90 cubic inch) airgun array, boomer, side-scan sonar, chirp subbottom profiler, and multibeam depth sounder.

5. AREA ACOUSTIC PROPAGATION CHARACTERIZATION

5.1. GENERAL CHARACTERIZATION OF ALL OPERATIONAL AREAS

This section discusses the methodology used to characterize the underwater acoustic propagation environment of the Area of Interest (AOI) (**Figure E-1**) for propagation modeling to be used for impact analysis of underwater acoustic source transmissions. This characterization attempts to eliminate the need to account for existing environmental features that do not impact the final analysis while maintaining an adequate representation of the environment of the AOI that impacts the analysis. The characterization was conducted in two parts. First, the sound speed environment was sorted into areas of like propagation for each of the four seasons. Second, bottom sediments were examined and classified as two sub-areas to account for the different acoustic bottom loss areas expected in the study. The two parts were then combined to yield defined subareas of unique propagation modes and bottom loss.

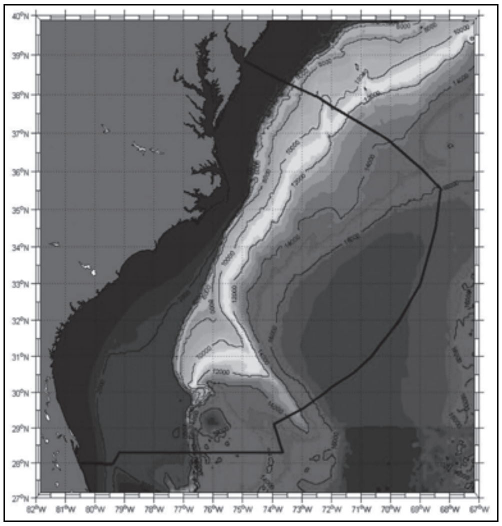


Figure E-1. Area of Interest (black line) Plotted over Bathymetry from the Digital Bathymetric Data Base Variable Resolution Database (depth in feet).

5.1.1. Propagation

Available sound speed profile databases were evaluated to find an appropriate database to use that contained data for the AOI throughout the year. The Provinced (GDEM) monthly sound speed database was selected to characterize the sound speed environment of the deep water modeling regions (water depths greater than 1,000 ft). The Provinced GDEM database represents the AOI using 13 sound speed areas or provinces and groups like-sound speed profiles in provinces for each month of the year (**Figure E-2**). This database does not have a shallow water component. The GDEM Variable Resolution (GDEM_V) database was selected to characterize the sound speed environment of the shallow water regions (water depths less than 305 m [1,000 ft]). The GDEM_V database was interrogated at a 15-minute spacing to yield sound speed profiles in the shallow water portion of the AOI for water depth from 9 to 305 m (30 to 1,000 ft).

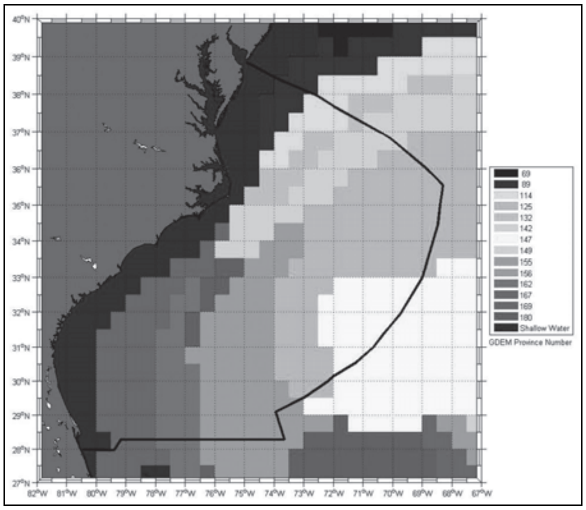


Figure E-2. Provinced Generalized Digital Environmental Model (GDEM) Areas within the Area of Interest (black line).

Profiles were examined from each database using the months presented in **Table E-3** to represent each season. To eliminate the redundant effort needed to conduct impact analysis on each sound speed profile extracted for the AOI, each profile was examined and grouped into areas of similar acoustic propagation and therefore similar acoustic impact. The acoustic propagation was modeled for each profile, for each season, using a standard raytrace model. An acoustic raytrace will show the propagation path for acoustic energy as it travels from a source and through the water. The representative sound source used for this raytrace modeling was omni-directional at a depth of 6 m (20 ft). The propagation paths were modeled by computing all ray paths (±90°) of the acoustic energy along an environmentally range-independent radial (one sound speed profile and a flat bottom) for each profile and each season.

Table E-3

Month Used to Represent Each Season in Sound Speed Database Extraction

Season	Representative Month
Winter	February
Spring	May
Summer	August
Fall	November

The raytraces for each season were examined and grouped into like propagation areas which yielded areas with similar acoustic propagation for both shallow and deep water areas. The distinguishing characteristics of acoustic propagation paths in the AOI can be grouped into the following:

1. *Presence of a Surface Duct*

The presence or absence of a surface layer that trapped some energy from a shallow source depth is the first discriminator of propagation characteristics. A surface layer that traps acoustic energy is also called a surface duct. A surface duct occurs when the sound speed increases with depth from the surface to a depth below the source depth. Generally this occurs in colder seasons where colder air temperature and higher winds cool and mix waters in the surface layer. Surface ducts can also occur when water masses of different densities mix, such as north-flowing Gulf Stream water mixing with south-flowing North Atlantic waters. The acoustic ray paths trapped in the surface duct do not hit the bottom, but are either turned upward to reflect off the surface over-and-over (**Figure E-3**) or turned downward to be trapped again. Not all transmitted acoustic energy is trapped in a surface duct. In fact, most transmitted energy from shallow source in a surface duct is reflected off the bottom. But surface layer trapped energy propagations with less loss than bottom bounce paths, therefore increasing the potential range of impact of the transmitted acoustic energy from the source.

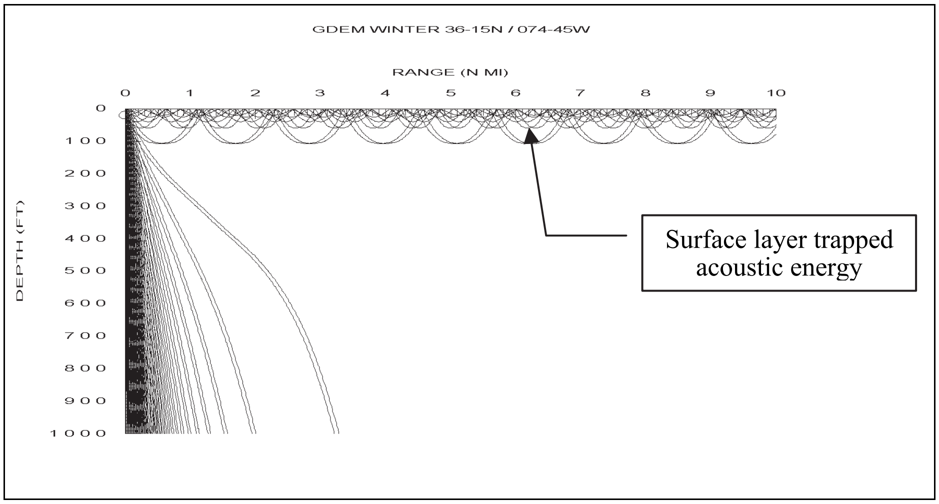


Figure E-3. Example of Surface Layer Trapped Acoustic Energy.

2. *Strength of the Surface Duct*

If a surface layer is present, the relative amount of acoustic angles that are trapped in the surface duct is the next discriminator of propagation characteristics. Generally, the deeper the surface layer, the more acoustic angles are trapped in the layer; additional angles can be trapped if the gradient of sound speed is greater, but this is not seen in the AOI. The more acoustic source angles trapped in the surface duct, the more energy is transmitted from the source to the surrounding environment without attenuation from bottom reflection and therefore have more potential to effect the environment.

3. *Presence of a Convergence Zone*

The third discriminator of propagation characteristics is the presence of a Convergence Zone (CZ). The CZ propagation only occurs in very deep water where the sound speed eventually increases with great depth (due to pressure) and the deep-going acoustic propagation rays are bent back toward the surface (**Figure E-4**). These deep-going rays will travel back to the source depth (usually at a range of 30-40 nmi from the source) and turn toward the deep again or be reflected off the surface and travel deep again. The deeper the water depth, more rays will travel in the CZ. These deep-going rays travel a relatively great distance without reflection off the bottom and without the corresponding reflection loss. The water depth needed for a CZ to occur varies with the season and the depth of the source. If the source depth is constant, the water depth needed increases with warmer seasons. The presence of a CZ will support propagation of acoustic energy to relatively long distances without attention of bottom reflection and could increase the potential to effect the environment at a relatively long range. The presence or absents of surface ducts is independent of CZ propagation.

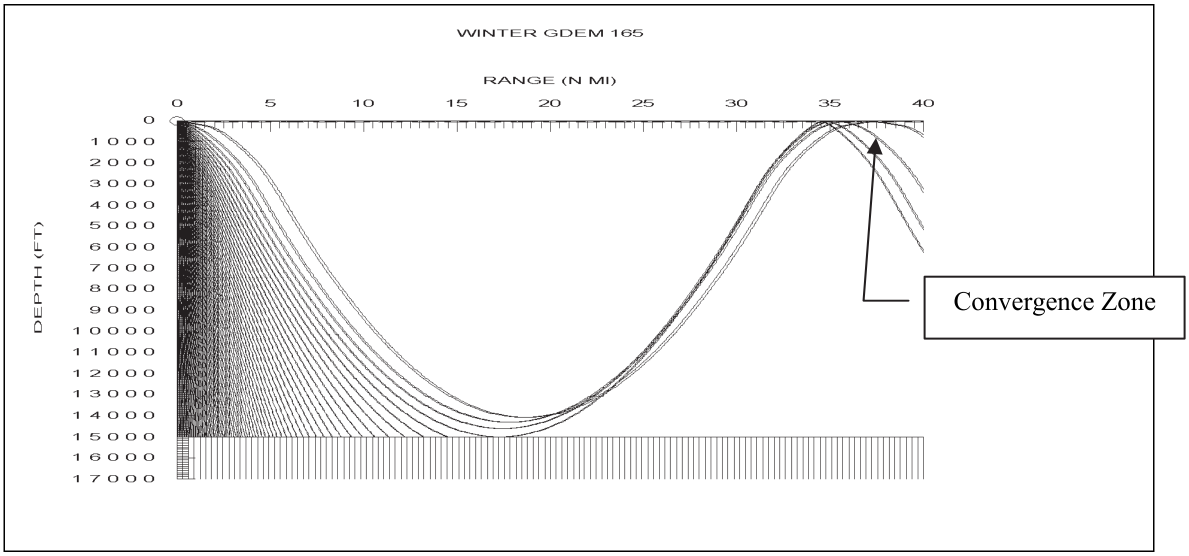


Figure E-4. Example of the Convergence Zone Propagation.

4. *Bottom Bounce Paths*

The last acoustic propagation discriminator, and the most dominate in the AOI, is total bottom bounce propagation. Total bottom bounce propagation is not trapped in a surface layer nor CZ propagated, but travels downward from the source to reflect off the bottom. The amount of acoustic energy reflected off the bottom back into the water is dependent on the composition of the bottom. A rocky bottom reflects more energy back into the water than a muddy bottom. Therefore, the bottom composition must be considered when estimating the environmental impact of bottom bounce acoustic energy that is of sufficient strength to contribute to the environmental impact.

5.1.1.1. Winter

The acoustic propagation environment of the AOI in winter can be characterized with a single profile for deep water areas and two unique sound speed profiles for shallow water areas. The winter profile from GDEM Province 180 is selected to represent all deep water areas (>305 m [1,000 ft]) of the AOI. This profile supports only shallow angles in ducted propagation, but does support CZ propagation in water depths greater than 4,267 m (14,000 ft). Therefore, there are four unique types used to characterize winter propagation in the AOI (**Figure E-5**):

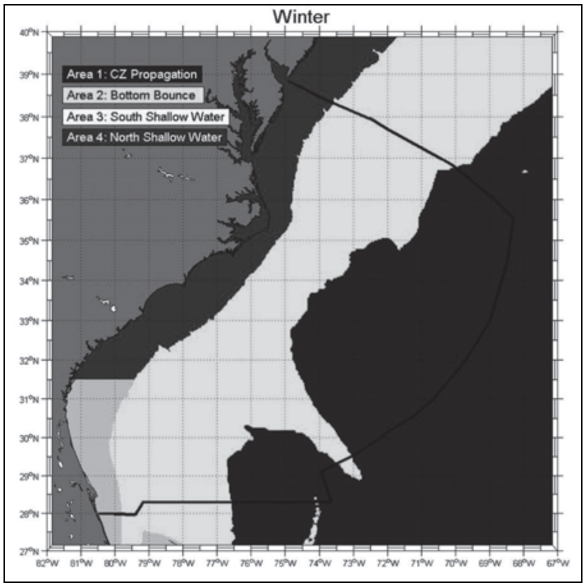


Figure E-5. Winter Propagation Characteristics of the Area of Interest (black line).

1. *Deep Water CZ propagation*, represented by GDEM Province 180/February, for water depths greater than 4,267 m (14,000 ft) in the AOI. The representative location for this propagation type is 32-00° N/72-00° W. Only acoustic energy transmitted at shallow angles (0° to ±1°) from the source is trapped in the surface duct, if any. Steep source angles are transmitted into the bottom. Source angles between ±1° and ±6° (or more depending on water depth) are converted to CZ propagation.
2. *Deep Water Bottom Bounce propagation*, represented by GDEM Province 180/February, for water depths greater than 305 m (1,000 ft), but less than 4,267 m (14,000 ft), in the AOI. The representative location for this propagation type is 32-45°N/76-00°W. Only acoustic energy transmitted at shallow angles (0° to ±1°) from the source is propagated in the surface duct, if any. All other source angles are transmitted into the bottom.
3. *Southern Shallow Waters*, represented by the GDEM February profile at 30-30° N/80-15° W, for water depths less than 1,000 ft (305 m) and south of 31-30° N. Only acoustic energy transmitted at shallow angles (0° to ±1°) from the source is propagated in the surface duct, if any. All other source angle paths are transmitted into the bottom.
4. *Northern Shallow Waters*, represented by the GDEM February profile at 36-15° N/74-45° W, for water depths less than 305 m (1,000 ft) and north of 31-30°N. This profile traps a moderate amount of acoustic energy in the surface duct. At least ±2° of source energy paths are trapped in the surface layer, but generally ±4° are trapped. All other source angle paths are transmitted into the bottom.

5.1.1.2. Spring

The acoustic propagation environment of the AOI in spring can be characterized with a single profile for deep water areas and two unique sound speed profiles for shallow water areas. The spring profile from GDEM Province 156 is selected to represent all deep water areas of the AOI. This profile supports only shallow angles in ducted propagation, but does support CZ propagation in water depths greater than

4,267 m (14,000 ft). Therefore there are four unique types used to characterize spring propagation in the AOI (**Figure E-6**):

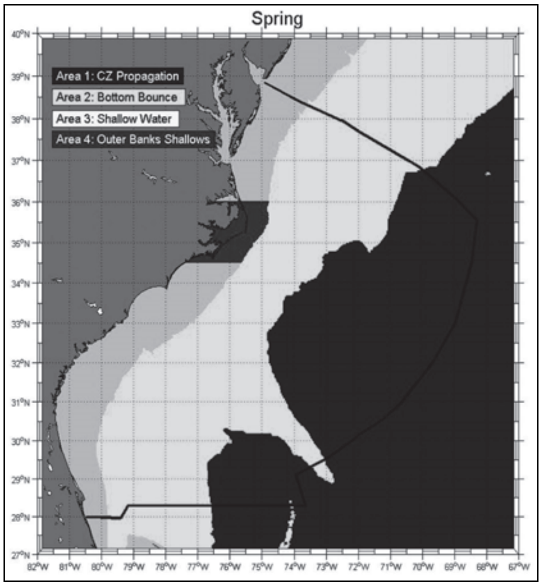


Figure E-6. Spring Propagation Characteristics of the Area of Interest (black line).

1. *Deep Water CZ propagation*, represented by GDEM Province 156/May, for water depths greater than 4,267 m (14,000 ft) in the AOI. The representative location for this propagation type is 32-00° N/72-00° W. Only acoustic energy transmitted at the shallowest angles from the source is propagated in the surface duct, if any. Steep source angles are transmitted into the bottom. Source angles between ±1° and ±4° (or more, depending on water depth) are converted to CZ propagation.
2. *Deep Water Bottom Bounce propagation*, represented by GDEM Province 156/May, for water depths greater than 305 m (1,000 ft), but less than 4,267 m (14,000 ft), in the AOI. The representative location for this propagation type is 31-30° N/75-00° W. Only acoustic energy transmitted at the shallowest angles from the source is trapped in the surface duct, if any. All other source angles are transmitted into the bottom.
3. *Bottom Bounce Shallow Waters*, represented by the GDEM May profile at 32-00° N/79-15° W, for water depths less than 305 m (1,000 ft, south of 34-30° N or north of 36-00° N. Only acoustic energy transmitted at shallow angles (0° to ±1°) from the source is trapped in the surface duct, if any. All other source angles paths are transmitted into the bottom.
4. *Moderately-ducted (Outer Banks) Shallow Waters*, represented by the GDEM May profile at 35-00° N/76-15° W, for water depths less than 305 m (1,000 ft), between 36-00° N and 34-30° N. This area is roughly the Outer Banks area of North Carolina. This profile traps a moderate amount of acoustic energy in the surface duct. At least ±2° of source energy paths are trapped in the surface duct, but generally ±4° are trapped. All other source angle paths are transmitted into the bottom.

5.1.1.3. Summer

The acoustic propagation environment of the AOI in summer can be characterized with a single profile for deep water areas and one sound speed profile for shallow water areas. The summer profile from GDEM Province 156 is selected to represent all deep water areas of the AOI. This profile supports only the shallowest angle in ducted propagation, but does support CZ propagation in water depths greater than 4,877 m (16,000 ft). The depth of CZ propagation has increased from spring because of surface warming of waters in the AOI. There are three unique types used to characterize summer propagation in the AOI (**Figure E-7**):

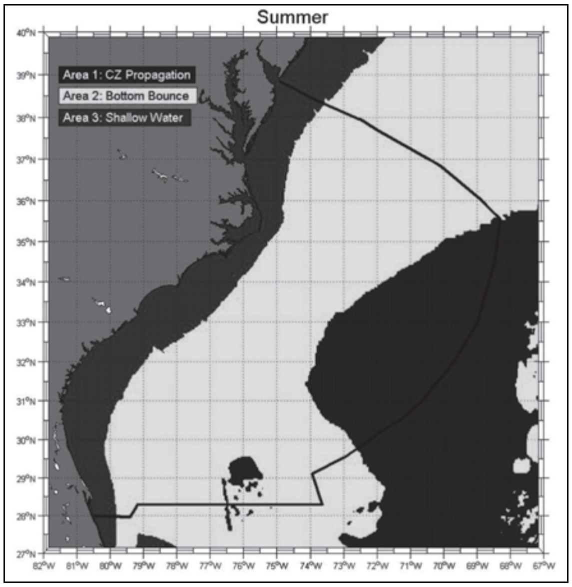


Figure E-7. Winter Propagation Characteristics of the Area of Interest (black line).

1. *Deep Water CZ propagation*, represented by GDEM Province 156/August, for water depths greater than 4,877 m (16,000 ft) in the AOI. The representative location for this propagation type is 32-00° N/72-00° W. Only acoustic energy transmitted at the shallowest angles from the source is propagated in the surface duct, if any. Steep source angles are transmitted into the bottom. Source angles between ±1° and ±4° (or more depending on water depth) are converted to CZ propagation.
2. *Deep Water Bottom Bounce propagation*, represented by GDEM Province 156/August, for water depths greater than 305 m (1,000 ft), but less than 4,877 m (16,000 ft), in the AOI. The representative location for this propagation type is 31-30° N/75-00° W. Only acoustic energy transmitted at the shallowest angles from the source is propagated in the surface duct, if any. All other source angles are transmitted into the bottom.
3. *Shallow Waters*, represented by the GDEM August profile at 36-00° N/74-45° W, for water depths in water depths less than 305 m (1,000 ft). Only acoustic energy transmitted at the shallowest angle from the source is propagated in the surface duct, if any. All other source angle paths are transmitted into the bottom.

5.1.1.4. Fall

Fall is the most complex season for underwater sound propagation characterization within the AOI. The southern portion of the AOI still exhibits summer-like propagation while the northern portion has transitioned toward winter-like propagation. The acoustic propagation environment of the AOI in fall is characterized by two deep water areas and two shallow water areas. Each of the deep water areas support either bottom bounce or CZ propagation. There are six unique propagation types used to characterize fall propagation in the AOI (**Figure E-8**):

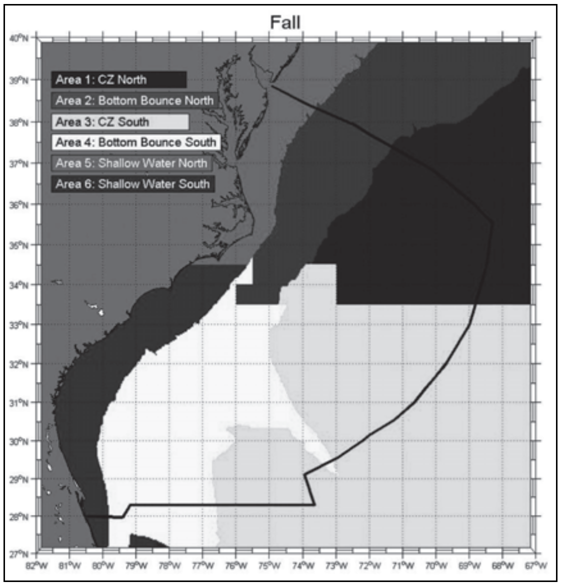


Figure E-8. Fall Propagation Characteristics of the Area of Interest (black line).

1. *Northern Deep Water CZ propagation*, represented by GDEM Province 142/November, for water depths greater than 3,810 m (12,500 ft) in the AOI. The representative location for this propagation type is 36-30° N/71-30° W. Only acoustic energy transmitted at shallow angles (0°-±2°) from the source is propagated in the surface duct. Steep source angles are transmitted into the bottom. The narrow range of source angles between ±2° and ±4° (or more depending on water depth) are converted to CZ propagation.
2. *Northern Deep Water Bottom Bounce propagation*, represented by GDEM Province 142/November, for water depths greater than 305 m (1,000 ft), but less than 3,810 m (12,500 ft), in the AOI. The representative location for this propagation type is 36-30° N/72-30° W. Only acoustic energy transmitted at shallow angles (0°- ±2°) from the source is propagated in the surface duct. All other source angles are transmitted into the bottom.
3. *Southern Deep Water CZ propagation*, represented by GDEM Province 156/November, for water depths greater than 4,115 m (13,500 ft) in the AOI. The representative location for this propagation type is 29-30° N/75-30° W. Only acoustic energy transmitted at the shallowest angles from the source is propagated in the surface duct, if any. Steep source angles are transmitted into the bottom. The narrow range of source angles between ±2° and ±4° (or more depending on water depth) are converted to CZ propagation.
4. *Southern Deep Water Bottom Bounce propagation*, represented by GDEM Province 156/November, for water depths greater than 305 m (1,000 ft), but less than 4,115 m (13,500 ft), in the AOI. The representative location for this propagation type is 31-00° N/75-30° W. Only acoustic energy transmitted at the shallowest angles from the source is propagated in the surface duct, if any. All other source angles are transmitted into the bottom.
5. *Southern Shallow Waters*, represented by the GDEM November profile at 32-00° N/79-15° W, for water depths in water depths less than 305 m (1,000 ft) and areas south of 34-30° N. Only acoustic energy transmitted at the shallowest angle from the source is propagated in the surface duct, if any. All other source angle paths are transmitted into the bottom.

6. *Northern Shallow Waters*, represented by the GDEM November profile at 36-30° N/74-45° W, for water depths in water depths less than 305 m (1,000 ft) and areas northern of 34-30° N. A moderate amount of acoustic energy is trapped in the surface duct for source angle transmitted up to ±5°. All other source angle paths are transmitted into the bottom.

5.1.2. Bottom Loss

The above work shows that a great deal of acoustic energy transmitted in the AOI will reflect off the bottom. In addition, the nature of the intended acoustic work will "aim" the transmitted energy toward the bottom. Therefore, acoustic bottom loss should be considered to evaluate the impact of transmitted acoustic energy in the AOI.

Bottom loss is dependent on the type of sediment that reflects the acoustic energy, along with the frequency of the sound reflecting off the bottom and the angle that the sound reflects off the bottom. This study assumes that frequency and angle do not change with location and examines changes in sediment type over location to understand the bottom loss in the AOI. More than 10,000 observations from the National Geophysical Data Center (NGDC) Surficial Sea Floor Sediment database were used to characterize sediments in the study. Bottom sediment grain size index was assigned to each observation (**Table E-4**) according to the University of Washington Applied Physics Laboratory Technical Report 9407 on bottom loss modeling (University of Washington Applied Physics Laboratory, 1994).

The results of the above processing yielded an irregularly spaced dataset of observation location and grain size throughout the AOI. This dataset was used to create a 1 nmi spacing grid to represent the geographic distribution of grain size for the AOI by using the closest measured data for each grid point (**Figure E-9**).

Fine grain sediment, such as clays (with high grain size index) can be seen to dominate the areas of water depth greater than 1,219 m (4,000 ft). Coarser sediments, such as sand and gravel (lower grain size index) can be seen to dominate areas of water depth less than 1,219 m (4,000 ft). Bottom loss curves were computed with the Rayleigh Bottom Loss Model using the dominate grain size indexes seen in the AOI (**Figure E-10**).

A mix of gravels and sands dominate the sediment types in water depths less than 1,219 m (4,000 ft). These corresponding grain size indexes (-1 and 1) result in very similar bottom loss curves (**Figure E-10**). The difference seen is insignificant when considering impact analysis. A grain size index of -1 is selected to represent the sediment for areas of water depth less than 1,219 m (4,000 ft). The bottom loss for a -1 grain size index is less, resulting in more energy reflected back into the water column, and therefore is the worst case for impact analysis.

Bottom loss in deep water areas has little effect on impact analysis because results are driven by the direct path propagation from the source directly to the animal. Propagation losses of the sound traveling to the bottom and back are very high compared to direct path losses. In water depths greater than 1,219 m (4,000 ft), spherical spreading loss of acoustic energy traveling from a near-surface source to the bottom and back to the near surface is at least 67 dB. Therefore efforts to model the details of different bottom loss regions in deep water would have no consequence in impact analysis. A sediment grain size index of 7 is therefore used characterized areas of water depth greater than 1,219 m (4,000 ft).

Table E-4

Grain Size Index for Sediment Type

Sediment Type	Bottom Sediment Grain Size Index
Rough Rock	-9.0
Rock	-7.0
Cobble	-3.0
Gravel	-3.0
Pebble	-3.0
Sandy Gravel	-1.0
Very Coarse Sand	-0.5
Muddy Sandy Gravel	0.0
Coarse Sand	0.5
Gravelly Sand	0.5
Gravelly Muddy Sand	1.0
Sand	1.5
Medium Sand	1.5
Muddy Gravel	2.0
Fine Sand	2.5
Silty Sand	2.5
Muddy Sand	3.0
Very Fine Sand	3.5
Clayey Sand	4.0
Coarse Silt	4.5
Sandy Silt	5.0
Medium Silt	5.5
Sand-Silt-Clay	5.5
Silt	6.0
Sandy Mud	6.0
Fine Silt	6.5
Clayey Silt	6.5
Sandy Clay	7.0
Very Fine Silt	7.5
Silty Clay	8.0
Clay	9.0

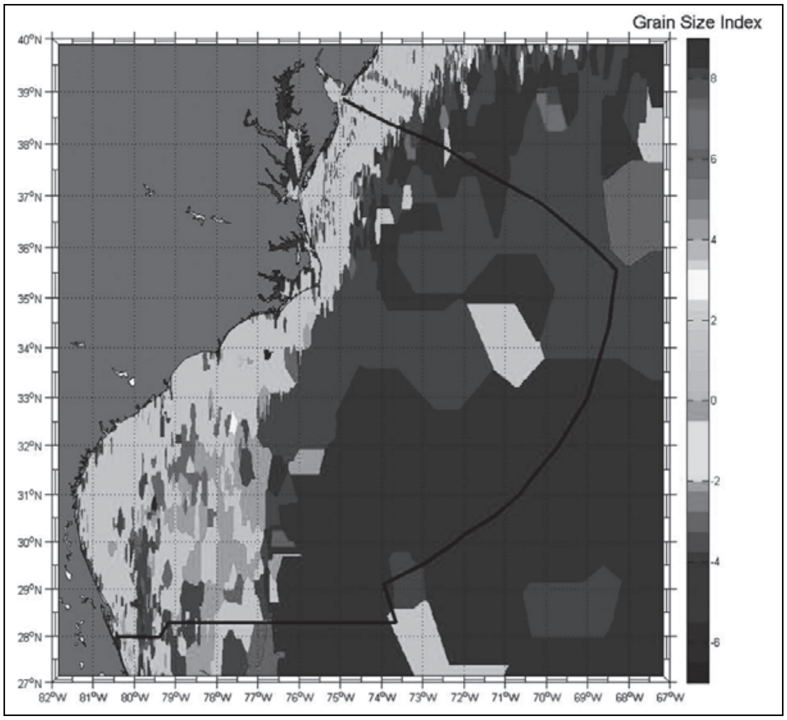


Figure E-9. Grain Size Index for the Area of Interest.

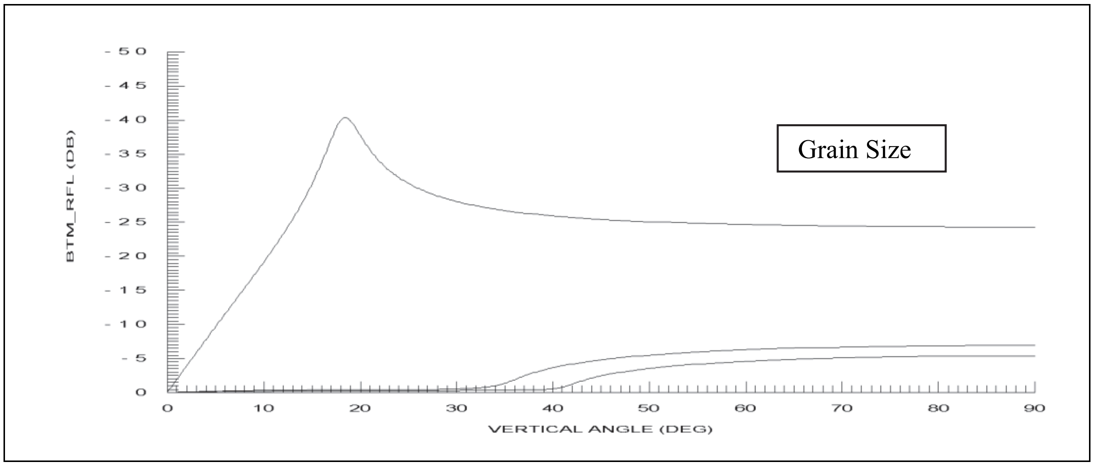


Figure E-10. Rayleigh Bottom Loss Estimates for Grain Size Index 7, 1, and -1.

5.1.3. General Characterization Summary

Combining the defined area of sound speed profiles and bottom sediments presented above results in a definition of 21 unique propagation modes and bottom loss regions in the AOI. These 21 modeling regions are defined in **Table E-5** and cover all four seasons. Each region is intended to define one sound speed profile and grain size index to be used for each transmission loss (TL) model run to be used for impact analysis. The SVPs used for this characterization are specified in **Table E-6**. The resulting seasonal plots show these 21 modeling regions (**Figures E-11** through **E-14**).

This study defines the change between shallow and deep sound speed environments at 305 m (1,000 ft) water depth. This is because the deep water database of sound speed does not extend into water depths less than 305 m (1,000 ft). This study also defined a change in the sediment type at 1,219 m

(4,000 ft) water depth. This change is defined from direct observation of the sediment grain size data. Where appropriate, a unique propagation/sediment region has been assigned to this area between 305-1,219 m (1,000-4,000 ft) of water depth. This is especially true for the Blake Plateau areas of the southern portion of the AOI, south of 33-30° N (**Figure E-1**). However, north of 33-30° N, the distance between the 305 m and 1,219 m (1,000 ft and 4,000 ft) isobaths is a relatively small area; no distinction has been drawn between areas defined by the these isobaths north of 33-30° N. This can be seen in the water depth definition of the Fall Northern Deep Bottom Bounce area.

Table E-5

Summary of Propagation and Bottom Loss Characterization in the Area of Interest

Modeling Region	Season	Propagation Characterization	Water Depth (kft)	GDEM Profile	Representative Location	Sediment	Grain Size Index
1	Winter	Convergence Zone	>14	Province 180/February	32-00N 72-00W	Clay	7
2	Winter	Bottom Bounce (Clay)	4-14	Province 180/February	32-45N 76-00W	Clay	7
3	Winter	Bottom Bounce (Sand)	1-4	Province 180/February	31-00N 78-00W	Sand	-1
4	Winter	Southern Shallow Water	<1	February @ representative location	30-30N 80-15W	Sand	-1
5	Winter	Northern Shallow Water	<1	February @ representative location	36-15N 74-45W	Sand	-1
6	Spring	Convergence Zone	>14	Province 156/May	32-00N 72-00W	Clay	7
7	Spring	Bottom Bounce (Clay)	4-14	Province 156/May	31-30N 75-00W	Clay	7
8	Spring	Bottom Bounce (Sand)	1-4	Province 156/May	31-00N 78-00W	Sand	-1
9	Spring	Bottom Bounce Shallow Water	<1	May @ representative location	32-00N 79-15W	Sand	-1
10	Spring	Moderately-ducted (Outer Banks) shallow water	<1	May @ representative location	35-00N 76-15W	Sand	-1
11	Summer	Convergence Zone	>16	Province 156/August	32-00N 72-00W	Clay	7
12	Summer	Bottom Bounce (Clay)	4-16	Province 156/August	31-30N 75-00W	Clay	7
13	Summer	Bottom Bounce (Sand)	1-4	Province 156/August	31-00N 78-00W	Sand	-1
14	Summer	Shallow Water	<1	August @ representative location	36-00N 74-45W	Sand	-1
15	Fall	Northern Convergence Zone	>12.5	Province 142/November	36-30N 71-00W	Clay	7
16	Fall	Northern Deep Bottom Bounce	1-12.5[a]	Province 142/November	36-30N 72-00W	Clay	7
17	Fall	Southern Convergence Zone	>13.5	Province 156/November	29-30N 75-30W	Clay	7
18	Fall	Southern Deep Bottom Bounce (Clay)	4-13.5	Province 156/November	31-00N 75-30W	Clay	7
19	Fall	Southern Deep Bottom Bounce (Sand)	1-4	Province 156/November	31-00N 78-00W	Sand	-1
20	Fall	Southern Shallow Water	<1	November @ representative location	32-00N 79-15W	Sand	-1
21	Fall	Northern Shallow Water	<1	November @ representative location	36-30N 74-45W	Sand	-1

[a] Note: In the Fall Northern Deep Bottom Bounce sub-area, the area defined by the 305 m and 1,219 m (1,000 ft and 4,000 ft) isobaths, occurs on the shelf break and occupies a relatively small area, therefore this sub-area is re-defined as starting at 305 m (1,000 ft) water depth.

Table E-6

Summary Table of the Sound Velocity Profiles Used in the Characterization of the Area

	Sound Velocities (m/s)											
	Modeling Regions											
Depth (m)	1,2,3	4	5	6,7,8	9	10	11,12,13	14	15,16	17,18, 19	20	21
0	1532.9	1527.3	1524.6	1533.7	1532.6	1529.3	1544.3	1533.6	1524.7	1529.3	1516.2	1535.5
2		1527.4	1524.6		1532.6	1529.5		1533.7			1516.3	1535.6
4		1527.4	1524.6		1532.5	1529.7		1533.8			1516.4	1535.7
6		1527.5	1524.6		1532.5	1529.9		1533.8			1516.5	1535.7
8		1527.5	1524.6		1532.5	1530.2		1533.9			1516.6	1535.7
10	1533.1	1527.6	1524.6	1533.8	1532.5	1530.5	1544.5	1533.8	1524.9	1529.5	1516.7	1535.7
15		1527.8	1524.5		1532.4	1531.3		1532.5			1517.4	1535.7
20	1533.3	1527.8	1524.5	1533.6	1532.3	1531.8	1544.3	1530.3	1525.1	1529.6	1517.6	1535.7
25		1527.7	1524.4		1531.9	1531.9		1527.5			1517.2	1535.7
30	1533.4	1527.7	1524.3	1532.9	1531.4	1531.9	1543.0	1524.5	1525.2	1529.8	1516.5	1535.6
35		1527.5	1524.1		1530.8	1531.7		1522.2			1515.1	1535.5
40		1527.3	1523.8		1530.2	1531.3		1519.7			1513.3	1535.4
45		1527.0	1523.6		1529.4	1531.0		1517.4			1511.4	1535.1
50	1533.6	1526.8	1523.3	1530.4	1528.7	1530.5	1536.4	1515.5	1525.6	1530.1	1509.8	1534.8
55		1526.4	1523.0		1528.1	1530.0		1514.5			1509.4	1534.4
60		1526.1	1522.6		1527.4	1529.4		1513.8			1509.2	1534.0
65		1525.7	1522.2		1526.7	1528.8		1513.1			1508.9	1533.4
70		1525.2	1521.7		1525.9	1528.1		1512.5			1508.7	1532.7
75	1533.4	1524.7	1521.2	1528.1	1525.1	1527.4	1531.1	1512.0	1525.8	1530.2	1508.5	1531.9
80		1524.1	1520.7		1524.4	1526.8		1511.6			1508.4	1530.9
85		1523.5	1520.2		1523.6	1526.1		1511.4			1508.3	1529.8
90		1522.8	1519.7		1522.9	1525.5		1511.3			1508.2	1528.5
95		1522.2	1519.1		1522.1	1524.9		1511.0			1508.0	1527.3
100	1532.0	1521.4	1518.5	1527.3	1521.2	1524.3	1529.8	1510.7	1525.4	1529.6	1507.9	1526.1
110		1520.0	1517.4		1519.6	1523.2		1509.9			1507.4	1523.8
120		1518.4	1516.2		1517.9	1522.0		1509.0			1506.9	1521.6
125	1529.9			1527.0			1529.0		1524.3	1528.2		
130		1516.8	1514.9		1516.2	1521.0		1508.2			1506.3	1519.3
140		1515.0	1513.5		1514.4	1520.0		1507.3			1505.7	1517.3
150	1527.9	1513.3	1512.0	1526.6	1512.7	1519.0	1528.0	1506.4	1522.7	1526.7	1505.1	1515.3
160		1511.6	1510.5		1511.1	1518.0		1505.6			1504.3	1513.5
170		1509.8	1509.1		1509.6	1517.1		1504.7			1503.5	1511.6
180		1508.0	1507.7		1508.1	1516.1		1503.7			1502.6	1509.8
190		1506.1	1506.3		1506.6	1515.2		1502.8			1501.7	1508.1
200	1526.2		1504.9	1525.8	1505.2	1514.4	1525.9	1501.9	1520.1	1525.2	1500.9	1506.6
220			1502.5		1502.8	1512.8		1500.0			1499.0	1504.0
240			1500.2		1500.5	1511.2		1498.1			1497.2	1501.7
250	1525.0			1525.1			1524.1		1519.0	1524.7		
260			1498.0		1498.5	1509.7		1496.3			1495.4	1499.5
280			1496.1		1496.6	1508.3		1494.6			1493.8	1497.4
300	1523.9		1494.3	1524.2	1495.0	1506.9	1522.8	1493.1	1518.1	1524.0	1492.2	1495.5
350						1503.8		1489.7			1488.5	
400	1521.1			1522.4			1522.4		1515.1	1522.4	1485.4	
500	1518.4			1520.8			1520.8		1512.3	1520.8	1481.1	
600	1514.5			1517.7			1517.7		1508.6	1517.7	1480.0	
700	1508.8			1512.2			1512.2		1503.8	1512.2	1480.3	
800	1502.9			1506.1			1506.1		1499.2	1506.1	1481.1	
900	1497.7			1500.1			1500.1		1495.1	1500.1	1482.3	
1000	1493.6			1495.1			1495.1		1492.0	1495.1		
1100	1491.0			1491.7			1491.7		1490.0	1491.7		
1200	1489.9			1490.0			1490.0		1489.3	1490.0		
1300	1490.1			1489.9			1489.9		1489.5	1489.9		
1400	1491.1			1490.9			1490.9		1490.5	1490.9		
1500	1492.6			1492.6			1492.6		1492.0	1492.6		
1750	1495.9			1496.3			1496.3		1495.7	1496.3		
2000	1499.0			1499.5			1499.5		1499.2	1499.5		
2500	1505.3			1505.7			1505.7		1505.7	1505.7		
3000	1512.0			1512.0			1512.0		1512.4	1512.0		
4000	1527.6			1527.4			1527.4		1527.8	1527.4		
5000	1545.2			1545.2			1545.2		1545.0	1545.2		
6000	1562.6			1562.6			1562.6		1561.8	1562.6		

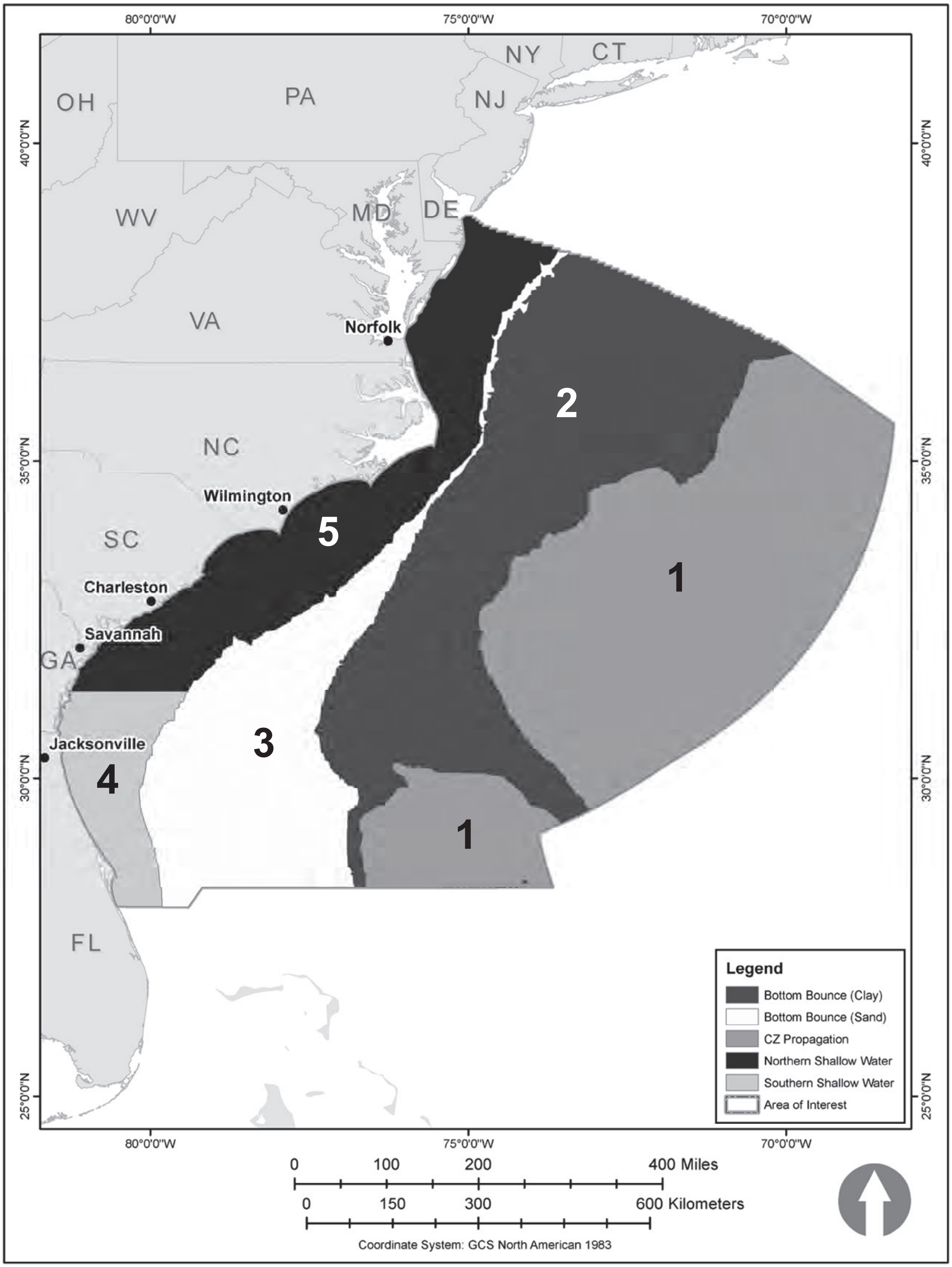


Figure E-11. Final Modeling Regions for the Winter.

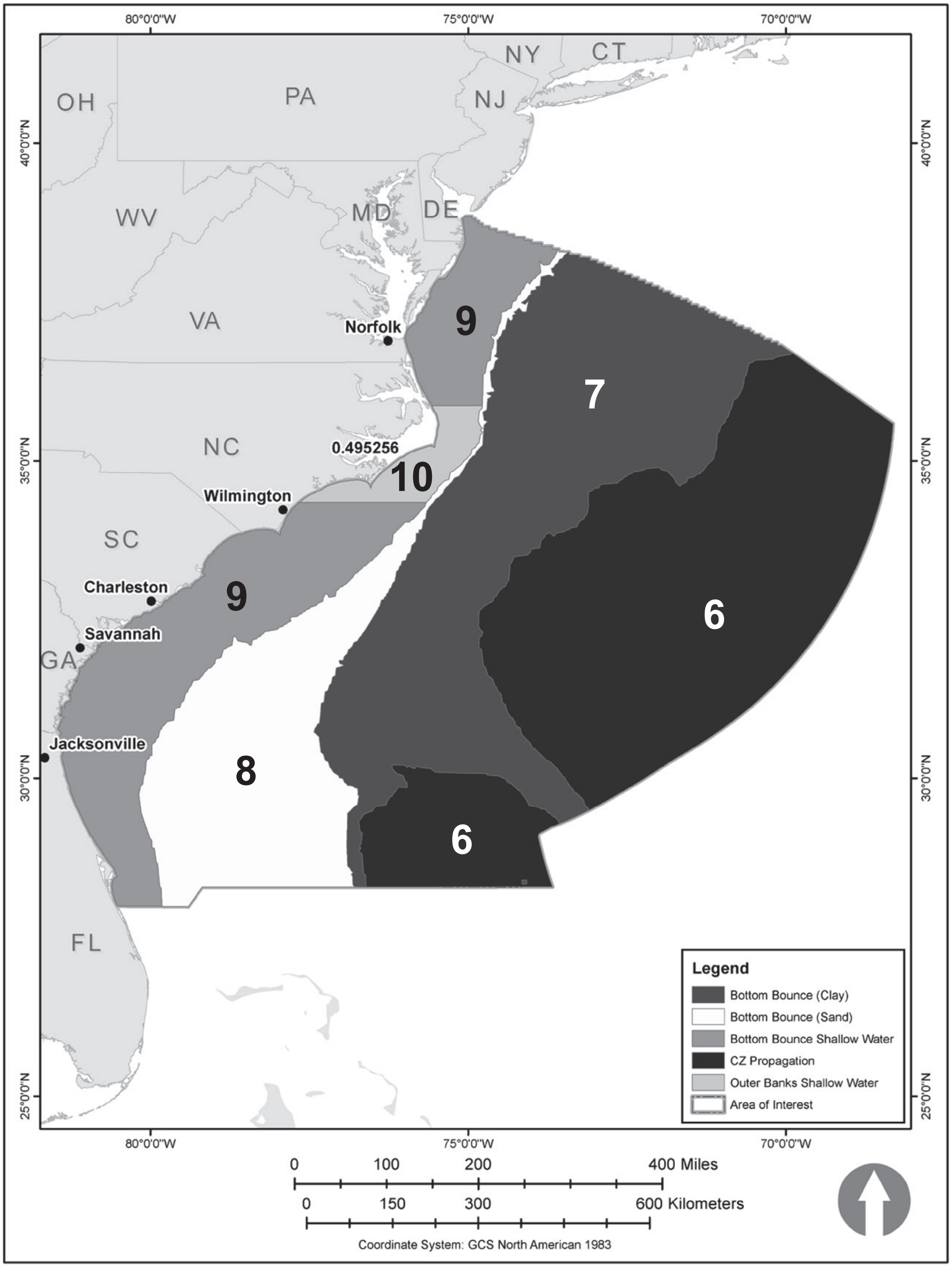


Figure E-12. Final Modeling Regions for the Spring.

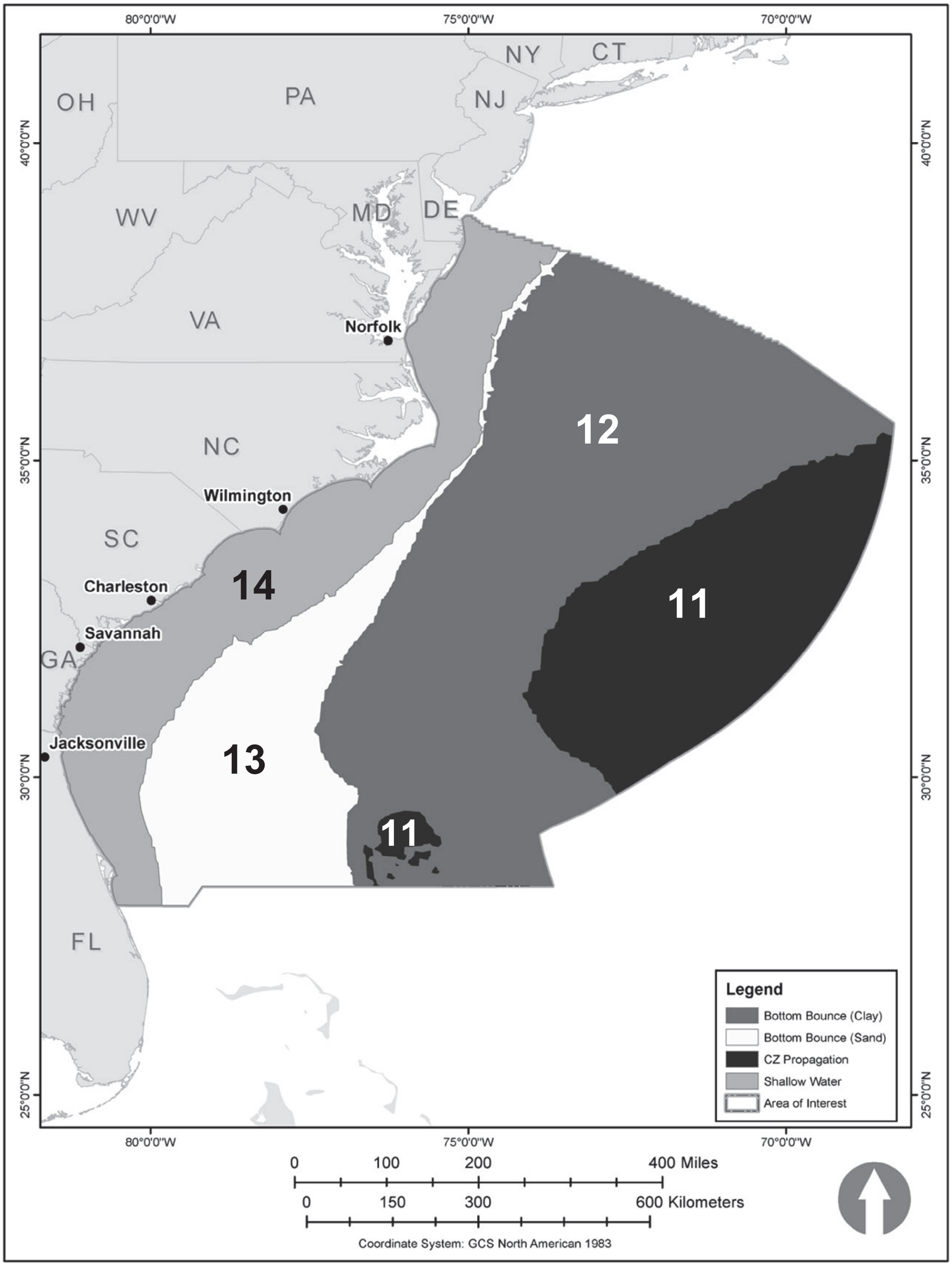


Figure E-13. Final Modeling Regions for the Summer.

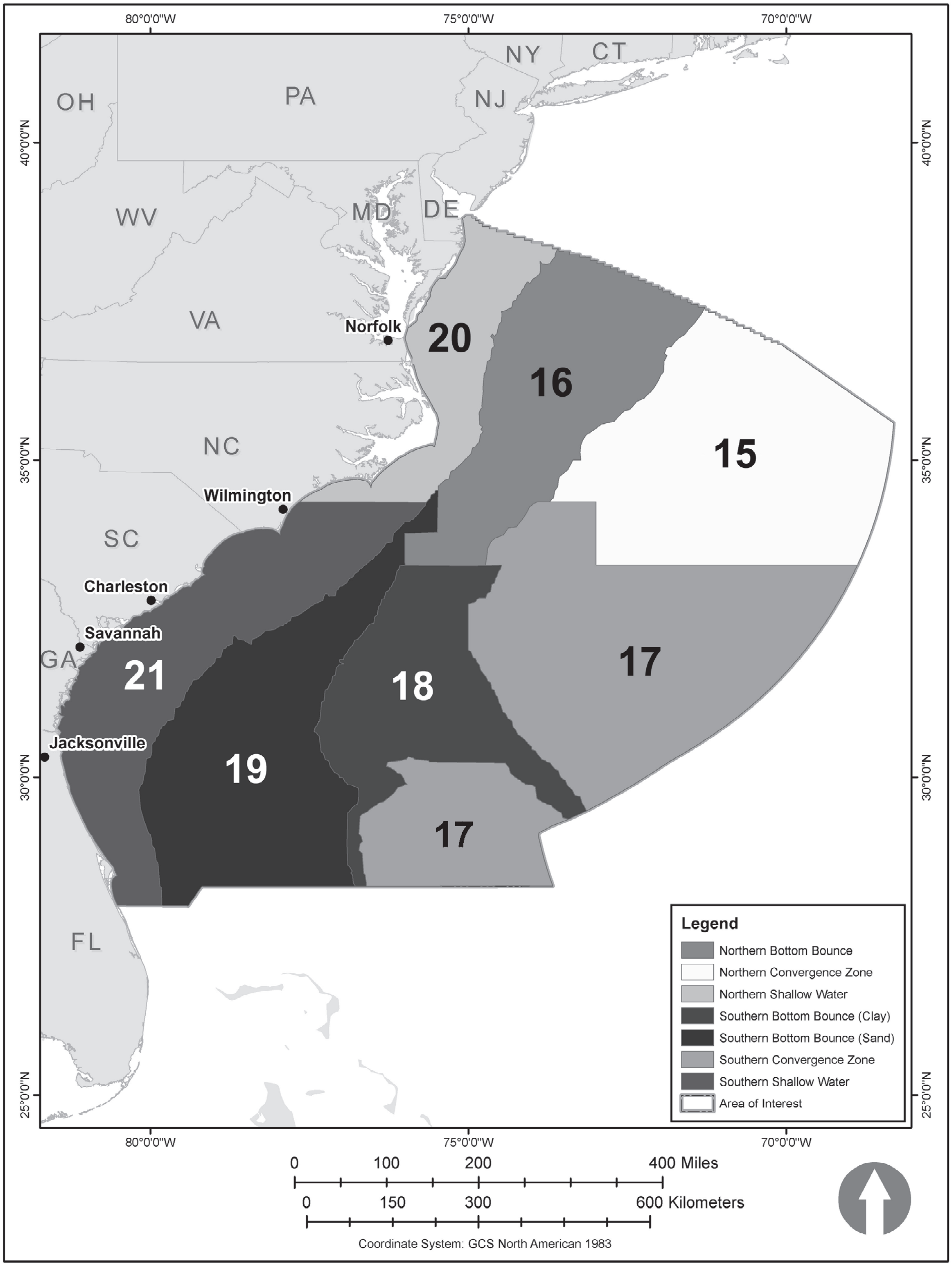


Figure E-14. Final Modeling Regions for the Fall.

5.2. SHALLOW WATER MODELING FOR MARINE MINERALS AND RENEWABLE ENERGY

The characterization of the acoustic propagation conducted in the previous section was designed to capture the variability and the general sound field structure produced by large and small airgun arrays used in support of oil and gas exploration and development throughout the proposed areas covered by this Programmatic EIS. However, acoustic modeling was also conducted to address the potential impacts for the active acoustic sound sources (e.g., side-scan sonars, boomers, chirp subbottom profilers, and single or multibeam depth sounders) used in conjunction with the other two programs covered by this Programmatic EIS, marine minerals and renewable energy. Not only do these programs use different acoustic systems than those typically used in oil and gas seismic surveys (i.e., airguns are not expected to be used), but these programs are only conducted in water nominally 100 m (328 ft) deep or less. This, therefore, limits their activities to the shallowest regions of the continental shelf, which are nominally within about 30 nmi (56 km) from the coast.

The location and depth of water used for these programs effectively constitutes a change in several of the basic assumptions made for the general characterization of the area including: (1) a significant change in the range of water depth covered; (2) a very large reduction in the area covered; (3) a concentration of the sources in waters that only allow strong and repeated interactions of the acoustic sound field with the ocean surface and bottom; (4) a change in signal type from multiple pulsed to nonpulse; (5) a significant change in the typical frequencies used by the systems; and (6) the utilization of systems using higher frequencies which allows finer acoustic beam patterns (and in general better special resolution of the areas being examined). The result of these differences was that an additional set of acoustic sites were added to the original 21 from the general characterization in order to examine and ensure that the propagation modeling in the shallow water for these two programs was adequate.

This subsequent shallow water characterization built on the existing work by using the seven shallow water sites (i.e., sites # 4, 5, 9, 10, 14, 20, and 21 as shown in **Table E-6**), and selecting two additional sites near the original "representative" location for that area. These new sites would therefore have the same SVP and propagation characteristics, but the additional stipulation was that these sites be located in 30 and 100 m (98 and 328 ft) water depths. By examining the propagation in these two water depths for each source used, the analysts would ensure that a conservative estimation of the sound propagation field (i.e., the larger impacts) was used in the impact analysis and that the potential for local variability in the bathymetry would not cause an underestimation of the potential impacts. Subsequent analysis has shown that variability of the impacts for all of the sources examined in this Programmatic EIS only varied a few percentage points (i.e., <5 percent) for the two water depths examined. Therefore, the use of the larger impact values were conservative, but not excessively so.

Table E-7 provides the details of the 14 additional shallow water sites used for this characterization.

Table E-7

Summary of Details of the Sites Identified in the Shallow Water Characterization

Modeling Region	Season	Propagation Characterization	Water Depth (m)	Original Region	Representative Location	Sediment	Grain Size Index
22	Winter	Southern Shallow Water	30	4	30-33N 80-38W	Sand	-1
23	Winter	Northern Shallow Water	30	5	36-10N 75-15W	Sand	-1
24	Spring	Bottom Bounce Shallow Water	30	9	32-18N 79-31W	Sand	-1
25	Spring	Moderately-ducted (Outer Banks) Shallow Water	30	10	34-48N 75-53W	Sand	-1
26	Summer	Shallow Water	30	14	36-10N 75-14W	Sand	-1
27	Fall	Southern Shallow Water	30	20	32-18N 79-31W	Sand	-1
28	Fall	Northern Shallow Water	30	21	36-10N 75-14W	Sand	-1
29	Winter	Southern Shallow Water	100	4	30-29N 80-10W	Sand	-1
30	Winter	Northern Shallow Water	100	5	36-06N 74-50W	Sand	-1
31	Spring	Bottom Bounce Shallow Water	100	9	32-00N 79-15W	Sand	-1
32	Spring	Moderately-ducted (Outer Banks) Shallow Water	100	10	34-42N 75-37W	Sand	-1
33	Summer	Shallow Water	100	14	36-06N 74-50W	Sand	-1
34	Fall	Southern Shallow Water	100	20	32-00N 79-15W	Sand	-1
35	Fall	Northern Shallow Water	100	21	36-06N 74-50W	Sand	-1

Note: These shallow water modeling regions were re-ordered after the completion of the JASCO propagation modeling and may be in a different order than reported by JASCO in **Appendix D**. This was done to: (1) mirror the order of the general regions these sites refine; and (2) to group the model results by depth. All subsequent impact analyses and reported take numbers use this re-ordered numbering assignment.

6. MARINE MAMMAL ABUNDANCES AND DENSITIES

At the time of this analysis, the best available marine mammal density estimates for the Western Atlantic Ocean, and specifically for the BOEM Mid- and South Atlantic Planning Areas were the U.S. Navy's Navy Operating Area (OPAREA) Density Estimates (NODE) database (U.S. Dept. of the Navy, 2007b). These density estimates were based on the NMFS-Southeast Fisheries Science Center (SEFSC) shipboard surveys conducted between 1994 and 2006, and were derived using a model-based approach and statistical analysis of the existing survey data using the model DISTANCE (Buckland et al., 2001). The outputs from the NODE database are four seasonal surface density plots of the Western Atlantic Ocean for each of the marine mammal species occurring there. **Figure E-15** is an example of the fall surface density plots for the Atlantic spotted dolphins. The resolution or grid size in these plots is dependent on the amount of data available for each species. For a fairly common species, like the Atlantic spotted dolphin, the grid has a fairly high-resolution (i.e., each displayed grid box is approximately 10 nmi^2). Additionally, the actual density values for this species range from 0.0 (very light shading) to 3.6 animals per square nmi (darkest shading). The density gradations are specific to each plot, but the higher value for each gradation is used in the subsequent analysis. This figure has been overlaid with the boundaries of the seven fall acoustic model regions used in this analysis. For each of these seven regions, the average density was computed. The resulting densities are presented in **Table E-8**, for each species and all 21 modeling regions.

An examination of **Figure E-15** shows that the existing NODE database does not provide data for the entire region of this Programmatic EIS; specifically, the most seaward areas of Regions 15, 17, and 18 show as white (i.e., no data was available). In instances like this, the general known densities were extrapolated outward to cover data-less areas. In this instance, the occurrence of this species appears to have a strong dependency on the location of the Gulf Stream, even when it moves offshore north of Cape Hatteras. Therefore, the extrapolation of the near-zero densities at the eastern edge of the known data appears reasonable. For more pelagic species, it is also reasonable to extend their relatively higher offshore densities into these areas without data.

It should be noted that while the U.S. Navy was creating the NODE database, the NMFS was routinely consulted on the process, provided much of the data on which the analysis is based, and reviewed the resulting database. Additionally, the Atlantic data was used in the FEIS for Atlantic Fleet Active Sonar Training (U.S. Dept. of the Navy, 2008).

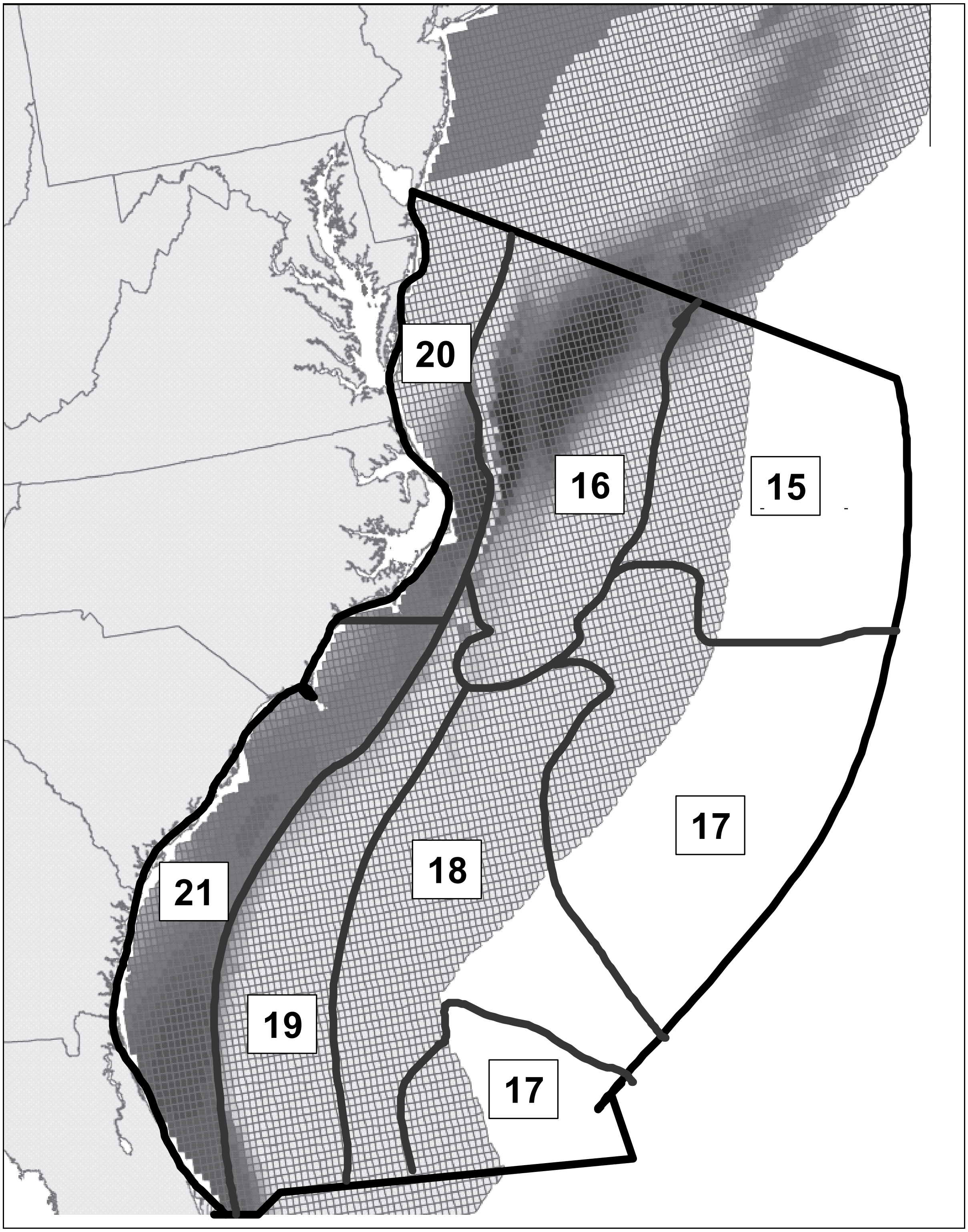


Figure E-15. Density Plot for Atlantic Spotted Dolphin for Fall based on the Navy Operating Area Density Estimate Database (U.S. Dept. of the Navy, 2007b).

Table E-8

Marine Mammal Densities for the 21 Modeling Regions (U.S. Dept. of the Navy, 2007b)

	Modeling Regions																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Mysticetes																					
Minke whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sei whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Bryde’s whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Blue whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Fin whale	0.0001	0.0001	0.0005	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0001	0.0001	0.0001	0.0005	0.0001	0.0001	0.0005	0.0001	0.0001	0.0001	0.0002	0.0001
North Atlantic right whale	0.0000	0.0000	0.0000	0.0038	0.0021	0.0000	0.0000	0.0000	0.0005	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0001
Humpback whale	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Odontocetes																					
Common dolphin	0.0547	0.0653	0.1808	0.0547	0.1808	0.0547	0.0653	0.1808	0.1808	0.0547	0.0547	0.0547	0.1808	0.1808	0.0547	0.1914	0.0547	0.0547	0.0547	0.1808	0.0547
Pygmy killer whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Short-finned pilot whale	0.0084	0.0826	0.1505	0.0018	0.0021	0.0025	0.0527	0.1490	0.0878	0.0019	0.0012	0.0527	0.0914	0.0296	0.0527	0.0100	0.0024	0.0839	0.0982	0.0014	0.0017
Long-finned pilot whale	0.0028	0.0207	0.0191	0.0000	0.0005	0.0008	0.0164	0.0213	0.0125	0.0006	0.0004	0.0164	0.0131	0.0052	0.0176	0.0033	0.0008	0.0194	0.0094	0.0005	0.0001
Risso's dolphin	0.0226	0.0451	0.0897	0.0239	0.0664	0.0014	0.0460	0.1104	0.0455	0.0005	0.0006	0.0880	0.1110	0.0447	0.0012	0.0882	0.0009	0.0230	0.0902	0.0236	0.0447
Northern bottlenose whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Pygmy sperm whale	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Dwarf sperm whale	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
Atlantic white-sided dolphin	0.0017	0.0014	0.0008	0.0000	0.0013	0.0005	0.0005	0.0003	0.0003	0.0005	0.0005	0.0005	0.0003	0.0003	0.0005	0.0005	0.0005	0.0004	0.0002	0.0005	0.0001
Fraser’s dolphin	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Sowerby's beaked whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Blainville's beaked whale	0.0000	0.0032	0.0032	0.0000	0.0000	0.0000	0.0025	0.0028	0.0000	0.0000	0.0000	0.0021	0.0014	0.0000	0.0021	0.0028	0.0000	0.0021	0.0028	0.0000	0.0000
Gervais' beaked whale	0.0000	0.0032	0.0032	0.0000	0.0000	0.0000	0.0025	0.0028	0.0000	0.0000	0.0000	0.0021	0.0014	0.0000	0.0021	0.0028	0.0000	0.0021	0.0028	0.0000	0.0000
True's beaked whale	0.0000	0.0032	0.0032	0.0000	0.0000	0.0000	0.0025	0.0028	0.0000	0.0000	0.0000	0.0021	0.0014	0.0000	0.0021	0.0028	0.0000	0.0021	0.0028	0.0000	0.0000
Killer whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Melon-headed whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Harbor porpoise	0.0010	0.0008	0.0005	0.0000	0.0008	0.0005	0.0005	0.0003	0.0003	0.0005	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	0.0005	0.0004	0.0002	0.0005	0.0001
Sperm whale	0.0002	0.0138	0.0182	0.0001	0.0001	0.0002	0.0138	0.0093	0.0001	0.0001	0.0001	0.0183	0.0092	0.0001	0.0092	0.0184	0.0002	0.0002	0.0002	0.0001	0.0001
False killer whale	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Pantropical spotted dolphin	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223	0.0223
Clymene dolphin	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106	0.0106
Striped dolphin	0.0269	0.2312	0.2312	0.0269	0.0332	0.0269	0.2092	0.0269	0.0269	0.0269	0.0269	0.0552	0.2092	0.0332	0.0495	0.2658	0.0269	0.0269	0.0269	0.0269	0.0269
Atlantic spotted dolphin	0.0021	0.2070	0.1870	0.2918	0.3168	0.0021	0.1570	0.0880	0.2019	0.2518	0.0021	0.1870	0.1970	0.3168	0.0221	0.2469	0.0021	0.0021	0.0121	0.2669	0.1918
Spinner dolphin	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Rough-toothed dolphin	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Bottlenose dolphin	0.0179	0.0413	0.2829	0.2829	0.0647	0.0179	0.2595	0.2946	0.0296	0.0296	0.0179	0.2595	0.3764	0.2743	0.0296	0.2946	0.0179	0.2829	0.3414	0.1816	0.2283
Cuvier's beaked whale	0.0001	0.0221	0.0222	0.0001	0.0001	0.0001	0.0173	0.0198	0.0001	0.0001	0.0001	0.0148	0.0100	0.0001	0.0148	0.0197	0.0001	0.0148	0.0197	0.0001	0.0001
Sirenians																					
West Indian manatee	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Pinnipeds																					
Hooded seal	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Harbor seal	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Gray seal	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

7. IMPACT MODELING APPROACHES

7.1. AIM MODELING AND METHODOLOGY

The AIM© is a four-dimensional (4D), individual-based, Monte Carlo-based statistical model designed to predict the exposure of receivers to any stimulus propagating through space and time. The central component of AIM is the animat movement engine, which moves the stimulus source and animal receivers through four dimensions (time and space) according to user inputs. AIM uses external range-dependent stimulus propagation models (e.g., the Marine Operations Noise Model [MONM] model for this modeling effort) and additional propagation models can be integrated to accommodate any class of propagation stimuli, including acoustic or explosive signal.

To estimate how changing the acoustic source characteristics affects the acoustic exposure of animals, the AIM was utilized (Frankel et al., 2002). The AIM is strongly based on two earlier models: a whale movement and tracking model developed for the census of the bowhead whale (Ellison et al., 1987), and an underwater acoustic back-scattering model for a moving sound source in an under-ice Arctic environment (Bishop et al., 1987). Because the exact positions of sound sources and animals (sound receivers for the purpose of this analysis) in any given simulation cannot be known, multiple runs of realistic predictions are used to provide statistical validity. The movement and/or behavioral patterns of sources and receivers can be modeled based on measured field data, and these patterns can be incorporated into the model. Each source and/or receiver is modeled via the "animat" concept, where each has parameters that control its speed and direction in three dimensions. In the case of the source, it is also imbued with the parameters describing its source operation over time (i.e., SL, signal duration, and spectral characteristics). It is also possible to simulate the type of diving pattern that an animal exhibits in the real world. Furthermore, the movement of the animat can be programmed to respond to environmental factors, such as water depth and sound level (this latter feature was not used in this analysis). In this way, species that normally inhabit specific environments can be constrained in the model to stay within that habitat.

Once the behavior of the animats has been programmed, the model is run. The run consists of a user-specified number of steps forward in time. For each time step, each animat is moved according to the rules describing its behavior. For each time step of the model run, the received sound levels at each receiver (i.e., each marine mammal) animat are calculated. For this analysis, AIM returns the movement patterns of the animats, and the received sound levels are calculated separately using the acoustic propagation predictions provided by JASCO (see details in **Appendix D**) for the different source types at different locations.

At the end of each time step, each animat "evaluates" its environment, including its 3D location, the time, and the received sound level (if anthropogenic sound is present). If an environmental variable has exceeded the user-specified boundary value (e.g., water too shallow), then the animat will alter its course to react to the environment. These responses to the environment are entitled "aversions." There are a number of potential aversion variables that can be used to build an animat's behavioral pattern. For this modeling effort they primarily consisted of bathymetric aversions and modeled area boundary aversions.

A separate simulation was created and run for each combination of location, movement pattern, and marine mammal species. Marine mammals were simulated by creating animats that were programmed with behavioral values describing dive depth, surfacing and dive durations, swimming speed, and course change. A minimum and maximum value for each of these parameters was specified. These data were extracted from the behavioral database. These data were used to simulate movements and dive characteristics of individual animats for each species or species group relative to the simulated vessel source tracks at both modeling locations.

After the animats' movement patterns were defined, the animats were randomly distributed over each simulation area. The simulation area was delineated by four boundaries composed of a combination of latitude and longitude lines. These boundaries extend at least one degree of latitude or longitude beyond the extent of the vessel track to ensure an adequate number of animats in all directions, and to ensure that the simulation areas extended beyond the area where substantial behavioral reactions might be anticipated. Each simulation had approximately 4,000 animats representing each species. In most cases, this represents a higher density of animats in the simulation (0.1 animats/km^2) than occurs in the real environment. This "over-population" allowed the calculation of smoother distribution tails and in the final analysis, all results were normalized back to actual predicted population counts by species. During the AIM modeling, animats were programmed to remain within the simulation area boundaries. This behavior was incorporated to prevent the animats from diffusing out of the simulation, the result of which, if allowed, would be a systematic decrease in animat density over time. Thus, the simulations modeled the animals as a closed population with a high residency factor. This approach is clearly conservative in terms of allowing for more prolonged exposures than would be expected from species with a lower residency factor.

The AIM simulations created a realistic animal movement track for each animat and were based on the best available animal behavioral data. It was assumed that, collectively, the ~4,000 animat tracks derived for each simulation (area/species combination) were a reasonable representation of the movements of the animals in the population under consideration. Animat positions along each of these tracks were converted to polar coordinates (range and bearing) from the source to the receivers. These data, along with the depth of the receiver, were used to extract received level estimates from the acoustic propagation modeling results provided by JASCO for each source type. Specific to the modeling effort for this Programmatic EIS, the source levels, and therefore subsequently the received levels, include the embedded corrections for signal pulse length and M-weighting as discussed in **Appendix D**. For each bearing, distance, and depth from the source when it was operating at that site, the received level values were expressed as SPLs with units of dB re 1µ Pa.

Each animat's received levels were converted back to intensity and summed over the duration of the exercise to generate the integrated energy level. These were expressed in terms of dB re 1µPa^2-sec or dB SEL. These exposure metrics were evaluated with the following criteria.

The acoustic threshold criteria, previously discussed in **Section 3.0** of this appendix, were then applied to the results of the AIM modeling, then the number of animats that exceeded each criterion was determined. These values were then scaled by the ratio of model-to-real world densities and corrected for the number of blocks or square kilometers modeled. These scaled values were reported as the predicted impact of each survey type, at each location, for each applicable source.

The output results from AIM provided the number of Level A and Level B harassment takes for each species, by season, modeled region, and survey type that exceed the specific threshold considered. These results will then be corrected to adjust for two parameters in the modeling: (1) the density of animats/animals in the modeled area; and (2) actual number of blocks that would be surveyed in each modeled region. The animal densities used in the AIM modeling are deliberately kept high to ensure that a statistically valid result is obtained. Typically, these "modeled" densities are at least an order of magnitude greater than the actual marine mammal density present in the region. Therefore, the modeling result is corrected or scaled by the ratio of the actual density divided by the modeled density. Similarly, the number of potential impacts is also scaled to derive a "per block survey" level of potential impacts. The predicted potential impacts can then be calculated by multiplying this value by the number of surveys of that type to be performed in that year, and summing the potential impacts to that species from all survey types combined.

7.2. AIM MODELING OF THE SOURCE MOVEMENT

For this assessment, the creation of each modeling simulation began with the creation of a movement pattern for the seismic airgun source vessel representing a different survey type. The seismic airgun survey types modeled included 2D, 3D, WAZ, VSP, and HRG. (Note that these last two surveys use the small array airgun only). The parameters for each survey type are provided in **Table E-9**.

The marine mineral and renewable energy programs also conduct HRG surveys, but these surveys are not expected to use airguns; they would use active acoustic sound sources such as boomer and chirp subbottom profilers, side-scan sonars, and multi-beam depth sounders. The details of how these sources were modeled in AIM are provided in **Table E-10**.

Table E-9

Seismic Airgun Source Vessel Parameters for AIM Simulations

Survey Type	Spacing of Horizontal and Vertical Lines (km)	Gridded?	Comments	Number of Blocks Modeled	Shot Interval (seconds)
2D	2.0 x (NA)	No		5 x 5 = 25	15
3D	1.0 x 1.0	Yes		2 x 2 = 4	15
Wide Azimuth (WAZ)	1.0 x 1.0	Yes	Use multiples of 3D surveys	2 x 2 = 4	15 (per survey)
Vertical Seismic Profile (VSP)	1.0 x 1.0	Yes	Use 3D surveys	1 x 2 = 2	15
High-resolution Geophysical (HRG)	0.08 x NA	No	Uses small airgun	1 x 1 = 1	variable

The marine mineral and renewable energy programs also conduct HRG surveys, but these surveys are not expected to use airguns; they would use active acoustic sound sources such as boomer and chirp subbottom profilers, side-scan sonars, and multi-beam depth sounders. The details of how these sources were modeled in AIM are provided in **Table E-10**.

Table E-10

Marine Mineral and Renewable Resource Source Vessel Parameters for AIM Simulations

Survey Type	Area Modeled (km)	Spacing of Horizontal and Vertical Lines (km)	Gridded?	Comments
Marine Mineral Exploration	1.8 x 1.8	0.03 x (NA)	No	Multiple electromechanical sources (no airguns)
Marine Mineral Exploration	1.8 x 1.8	0.2 x (NA)	No	Multiple electromechanical sources (no airguns)
Renewable Energy Hazard	3.5 x 3.5	0.15 x 0.15	Yes	Multiple electromechanical sources (no airguns)
Renewable Energy Exploration	2.1 x 2.0	0.03 x 0.15	Yes	Multiple electromechanical sources (no airguns)

7.3. AIM MODELING OF THE ANIMAL MOVEMENT

7.3.1. Movement

Animals move through four dimensions: 3D space plus time. Several movement parameters are used in the model to produce a simulated movement pattern that accurately represents real animal movements. A typical dive pattern is shown below in **Figure E-16**. It consists of two phases; the first is a shallow respiratory sequence, which is followed by a deeper, longer dive.

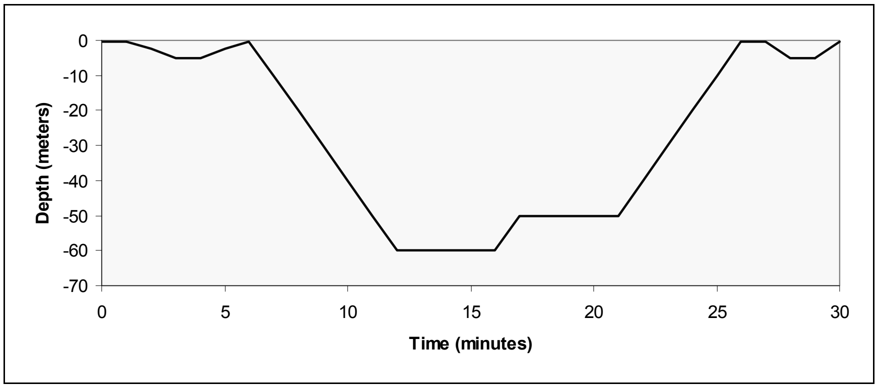
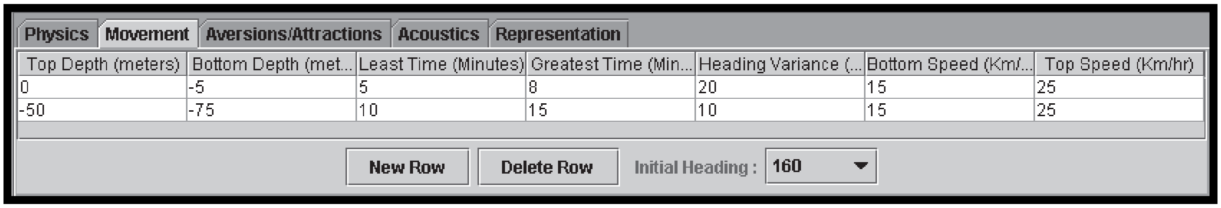


Figure E-16. Typical Dive Pattern.

These two phases are represented in the model with the values as input into the box below in **Figure E-17**.



Top Depth (meters)	Bottom Depth (met...	Least Time (Minutes)	Greatest Time (Min...	Heading Variance (...	Bottom Speed (Km/...	Top Speed (Km/hr)
0	-5	5	8	20	15	25
-50	-75	10	15	10	15	25

Initial Heading : 160

Figure E-17. Parameters Used to Specify the Typical Dive Pattern Shown in Figure E-16.

The top row has the values for the shallow, respiratory dives. In this case, the animal dives from the surface to a maximum depth of 5 m. The second row describes the second phase of the dive. In this phase the animal dives to a depth between 50 and 75 m (164 and 246 ft). In this example, the animal spends time at both 60 and 50 m (197 and 164 ft) before surfacing. The pattern then repeats.

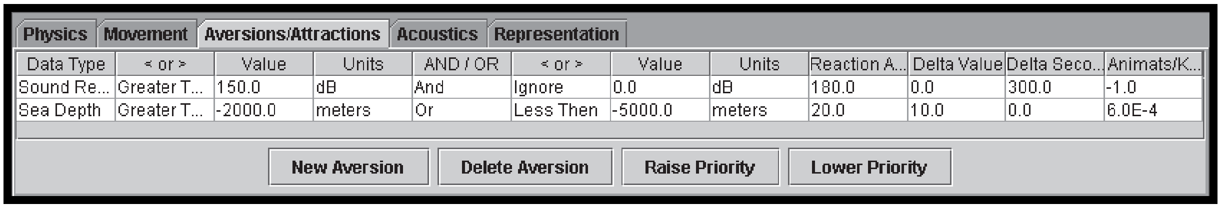
The horizontal component of the course is handled with the "heading variance" term. It allows the animal to turn up to a certain number of degrees at each movement step. In this case, the animal can change course 20 degrees on the surface, but only 10 degrees underwater. This example is for a narrowly constrained set of variables, appropriate for a migratory animal.

7.3.2. Heading Variance

There are few published data that summarize marine mammal movement in terms of heading variance, or the amount of course change per unit time. The default setting allows the course to deviate between 0 and 30 degrees per minute.

7.3.3. Aversions

In addition to movement patterns, the animats can be programmed to avoid certain environmental situations. For example, this option can be used to constrain an animal to a particular depth regime. The following example (**Figure E-18**) constrains the animal to waters between 2,000 and 5,000 m (6,562 and 16,404 ft) deep. One modification was made for these simulations in the animal's habitat. Normally deep-water species were allowed to move into waters as shallow as 100 m (328 ft).



Data Type	< or >	Value	Units	AND / OR	< or >	Value	Units	Reaction A...	Delta Value	Delta Seco...	Animats/K...
Sound Re...	Greater T...	150.0	dB	And	Ignore	0.0	dB	180.0	0.0	300.0	-1.0
Sea Depth	Greater T...	-2000.0	meters	Or	Less Then	-5000.0	meters	20.0	10.0	0.0	6.0E-4

Figure E-18. Example Showing the Aversions to Limit an Animat to Waters between 2,000 and 5,000 m (6,562 and 16,404 ft).

7.3.4. Species Behavior Parameters

The specific animal behavioral parameters that were used in this analysis are provided below. Where the "Surfacing/Dive Angle" column is empty, there were no meaningful data available so, 75º was used as a default value. Under the "Speed Distribution" column, "Normal" indicates that the distribution of speed values between the limits was normally distributed. Under the "Depth Limit/Reaction Angle" column, the first number indicates the minimum depth limit in meters, and "reflect" indicates that if an animat moves to that shallow water limit, it will move away from the shallow water and back into deeper water.

7.3.4.1. Minke Whale

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Minke Whale	1/3	75°	20/100	2/6	Surface 45 Dive 20	1/18	Gamma (3.25,2)	10/reflect

Surface Time

A mean surface time of 1.72 minutes, with a range of 0.63-2.35 minutes was reported by (Stern, 1992).

Dive Depth

Inferred from other species, however reduced in depth, since minkes are likely to be pelagic feeders, feeding on species found near the surface (Olsen and Holst, 2001).

Dive Time

The mean dive time reported by (Stern, 1992) was 4.43 (+/- 2.7) minutes. Dive times measured off Norway range from approximately 1-6 minutes (Joyce et al., 1989). Dive times also show small diel and seasonal variability (Stockin et al., 2001), but the variability is small enough to be considered not significant for AIM modeling. Dive times were non-normal, as indicated by the figure on the right, taken from (Øien et al., 1990).

Speed

The mean speed value for minke whales in Monterey Bay was 4.5 (+/- 3.45) knots (8.3 +/- 6.4 km/hr) (Stern, 1992). Satellite tagging studies have shown movement of up to 79 km/day (49 mi/day) (3.3 km/hr [2.1 mi/hr]). Minke whales being pursued by killer whales were able to swim at 15-30 km/hr (Ford et al., 2005).

A gamma function was fit to the available speed data. The modal speed of this function is 4.5 km/hr (2.8 mi/hr), matching the Stern (1992) data, and has a maximum of 18 km/hr (11 mi/hr), somewhat less than the maximum speed achievable (30 km/hr [19 mi/hr]), observed during predation. “Cruising” minkes have been reported at 3.25 m/s (10.66 ft/s) (Blix and Folkow, 1995).

Habitat

Minke whales in Monterey Bay were reported to be in a median depth of 48.6 m (159.4 ft) (Stern, 1992). They are known to move into very shallow water as well as deep oceanic basins. The 10-m (33-ft) limit and reflection aversion are intended to let minkes roam freely, but to stay off the beach.

Group Size

Mean group size in the Antarctic was 1.6 individuals (Blix and Folkow, 1995).

Residency

Foraging minke whales have been shown to exhibit small scale site fidelity (Morris and Tscherter, 2006). Therefore, foraging minke whales should have their course change parameters set to be variable to allow for small net movements.

7.3.4.2. Sei/Bryde's Whale

There is a paucity of data for these species. Since they are similar in size, data for both species have been pooled to derive parameters for these two species.

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Sei/Bryde's Whale	1/1	90/75°	10/40 (80) 50/267 (20)	2/11	30/300 (50%) 90/300 (50%)	1/20	5/1

Surface Time

No direct data available, fin whale values used.

Dive Depth

A limited number of Bryde's whales have been tagged with time-depth recorders (TDRs) (Alves et al., 2010). Shallow dives, less than 40 m (131 ft) were recorded 85 percent of the time, while deep dives occurred 15 percent of the time. The maximum dive depth reported was 267 m (876 ft).

Two distinct dive types were noted for Bryde's whales. Both performed a long series of shallow dives of less than 40 m (131 ft) until 1.5 hours before sunset. The animals then made the deepest dives. During the night, sequential deep dives took place. Foraging lunges were recorded during about half of these night time dives.

Dive Time

Sei whale dive times ranged between 0.75 and 11 minutes, with a mean duration of 1.5 minutes (Schilling et al., 1992). Most of the dives were short in duration, presumably because they were associated with surface or near-surface foraging. The same paper reported surface times that ranged between 2 s and 15 minutes. The maximum dive time reported for two Bryde's whales was 9.4 minutes (Alves et al., 2010) with mean durations of 4-6 minutes.

Heading Variance

Observations of foraging sei whales found that they had a very high reorientation rate, frequently resulting in minimal net movement (Schilling et al., 1992).

Speed

A tagging study found an overall speed of advance for sei whales was 4.6 km/hr (2.9 mi/hr) (Brown, 1977). The highest speed reported for a Bryde's whale was 20 km/hr (Cummings, 1985). A Bryde's whale being attacked by killer whales traveled ~9 km in 94 minutes, with most of the travel occurring in first 50 minutes, producing an estimated speed of 10.8 km/hr (6.7 mi/hr) (Silber et al., 1990). The maximum speed of sei whales reported from a satellite tracking study was 7.6 m/s (25 ft/s), although the distribution of speeds was highly skewed toward lower values (Olsen et al., 2009). The speed parameters used in AIM are 0-20 km/hr (0-12.4 mi/hr), using a gamma distribution with alpha and beta parameters of 5 and 1. These values produce the following distribution, which covers the reported range of speed (Olsen et al., 2009) and approximated the mean value reported by Brown (1977).

Habitat

Sei whales are known to feed on shallow banks such as Stellwagen Bank (Kenney and Winn, 1986). Therefore, sei and Bryde's whales are allowed to move into shallow water.

Group Size

Sei whales in the Gulf of Maine were seen in groups of 1-6 animals with a mean group size of 1.8 whales (Schilling et al., 1992). Bryde's whales in the Gulf of California were seen in groups of 1-2 animals, with a mean size of 1.2 whales (Silber et al., 1994).

7.3.4.3. Blue Whale

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Blue Whale (non-foraging)	1/2	75°	20/100	2/18	30/300 (50%) 90/300 (50%)	3/14	Norm.	100/reflect
Blue Whale (foraging)	1/2	75°	20/100 (50) 100/300 (50)	2/18 4/18	30/300 90/90	3/14	Norm.	100/reflect

Surface Time

Only one of four satellite tagged blue whales reported surface intervals of 7-90 s with a mean of 48 s. The other three did not report intervals >60 s, indicating that the surface time was short (Lagerquist et al., 2000).

Dive Depth

Croll et al. (2001) reported a mean dive depth of 140 m (459 ft) (+/- 46.01) for non-foraging animals, while foraging whales had a mean dive depth of 67.6 m (221.8 ft) (+/- 51.46). Satellite tagged whales off California had a maximum dive depth of 192 m (630 ft) (Lagerquist et al., 2000). The distribution of dive depths was bimodal, as typified by the plot below (note that this is from one animal). A series of blue whales had crittercam's attached to them off California and Mexico. The maximum dive depth reported was 293 m (961 ft) (Calambokidis et al., 2008). Many of these animals had deep feeding dives, with lunges occurring 200-260 m (656-853 ft). Notably, one animal transitioned from deep feeding dives of decreasing depth as the sun set, transitioning into shallow non-feeding dives. This indicated that there may be a diurnal character to some blue whale behavior.

Separate animats for foraging and non-foraging blue whales were created. Foraging animats will have a 50:50 distribution between deep dives (200-300 m [656-984 ft]) and shallower dives (20-100 m [66-328 ft]).

Dive Time

Mean dive times of 4.3, 7.8, 4.9 5.7, 10, and 7 minutes have been reported for blue whales (Laurie, 1933; Doi, 1974; Lockyer, 1976; Croll et al., 1998; Croll et al., 2001). The best estimate of the maximum dive time is 14.7 minutes (Croll et al., 2001), although a max time of 30 minutes was reported by (Laurie, 1933). The longest dive reported for satellite tagged whales was 18 minutes, although the mean dive times for all whales was 5.8 (+/- 1.5) minutes (Lagerquist et al., 2000).

Speed

Dive descent rates of 1.26 m/s (4.13 ft/s) have been recorded (Williams et al., 2000). A mean surface speed of 1.25 m/s (4.10 ft/s) with a maximum speed of 2.0 m/s (6.6 ft/s) was reported from satellite tags (Mate et al., 1999), although satellite data tend to smooth the track and therefore underestimate speed. A second satellite tag study found straight-line speed (under) estimates from 1.3 to 14.2 km/hr (0.8 to 8.8 mi/hr).

Group Size

Blue whales in the Eastern Tropical Pacific had a modal group size of one, although pods of two were somewhat common (Reilly and Thayer, 1990). The mean group size of blue whales off Australia (*B. m. brevicauda*) was 1.55 (Gill, 2002).

7.3.4.4. Fin Whale

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Fin Whale	1/1	75°	20/250 (90) 250/470 (10)	5/8 1/20	20	1/16	Norm.	30/reflect

Surface Time

Remarkably good data for surface times exist for fin whales. A log survivorship analysis of all inter-blow intervals was used to determine an inflection point of 28 and 31 s between surface and dive activity for feeding and non-feeding animals, respectively (Kopelman and Sadove, 1995). The mean surface duration for fin whales without boats present off Maine was 54.63 s (standard deviation [SD]=59.61) while dive times were 200.84 s (SD=192.91) (Stone et al., 1992).

Dive Depth

Foraging fin whales had mean dive depths of 97.9 +/- 32.59 m, while traveling fin whales had mean dive depths of 59.3 +/- 29.67 m (Croll et al., 2001). Migrating fin whales were determined to have a maximal dive depth of 364 m (1,194 ft), (Charif et al., 2002). Fin whales in the Mediterranean Sea typically dove to ~100 m (~382 ft), occasionally dove to 470 m (1,542 ft) or more (Panigada et al., 1999), however these are unusually deep dives. The animats here model the more typical dive pattern 90 percent of the time. Foraging fin whales off California had a mean maximum dive depth of 248 m (814 ft) (Goldbogen et al., 2006). Based on this study, the most frequent AIM dive depth is extended to 250 m.

Dive Time

Foraging fin whales had mean dive times of 6.3 +/- 1.53 minutes, while traveling fin whales had mean dive times of 4.2 +/- 1.67 minutes (Croll et al., 2001). The maximum dive time observed was 16.9 minutes. Fin whales off the east coast of the U.S. were observed to have mean dive times of 2.9 minutes. Ranges for feeding animals ranged from 29 to 1,001 s, while non-feeding animals had longer dives between 32 and 1,212 s (Kopelman and Sadove, 1995). Panigada et al. (1999) found that shallow (<100 m [<328 ft]) dives had a mean dive time of 7.1 minutes, while deeper dives had dive times of 11.7 and 12.6 minutes. Fin whales foraging on Jeffrey's Ledge in the Gulf of Maine had mean dive times of 5.83-5.89 minutes (Ramirez et al., 2006).

Speed

Watkins (1981) reported a mean speed of 10 km/hr (6 mi/hr) ranging from 1 to 16 km/hr (0.6 to 10 mi/hr) with bursts of 20 km/hr (12 mi/hr) reported. Mean descent speeds of 3.2 m/s (10.5 ft/s) (SD=1.82) and ascent speeds of 2.1 m/s (6.9 ft/s) (SD=0.82) have been reported from fin whales in the Mediterranean (Panigada et al., 1999).

Habitat

Fin whales are found feeding on shallow banks and in bays (Woodley and Gaskin, 1996) as well as in the abyssal plains of the ocean (Watkins, 1981). Fin whales are allowed to move into shallow water in AIM, with a 30-m (98-ft) inshore limit to keep them out of the very shallow waters.

Group Size

Fin whales in the Gulf of Mexico had a mean group size of 5.7 with a range in group sizes from 1 to 50 (Silber et al., 1994). In the Mediterranean Sea the mean group size over a number of years was 1.75 animals (Panigada et al., 2005).

7.3.4.5. North Atlantic Right Whale

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)
Right Whale	4/5	75°	113/130	11/13	30	3/6	Norm.

Surface Time

Mean surface time for right whales was less than 60 s (Winn et al., 1995). Therefore a one minute surface time was used for AIM.

Dive Depth

Right whale feeding dives in the northwest Atlantic were characterized by rapid descent to depths between 80 and 175 m (262 and 574 ft). The median depth was 119 m (390 ft) with a 90 percent confidence interval between 113 and 130 m (371 and 427 ft) (Baumgartner and Mate, 2003). This 90 percent confidence range was used for the dive depth range. In a nearby area, right whales dove to depths between approximately 120 and 180 m (394 and 591 ft) (Nowacek et al., 2004).

Dive Time

The median dive time for foraging right whales was 12.65 minutes, with a 95 percent confidence interval of 11.4-12.9 minutes (Baumgartner and Mate, 2003).

Speed

Descent speed of diving right whales had a 95 percent confidence interval of 1.3-1.5 m/s (4.3-4.5 ft/s) while the ascent speed was 1.4-1.7 m/s (4.6-5.6 ft/s) (Baumgartner and Mate, 2003). Radio tagged whales that remained in the Bay of Fundy had a mean speed of 1.1 km/hr while those that left the bay had a mean speed of 3.5 km/hr (2.2 mi/hr) (Mate et al., 1997). Note that radio tagging tends to underestimate whale speed, since the data greatly smooth the recorded course of the animal.

Habitat

Northern right whales are currently found in the northwest Atlantic Ocean and the North Pacific. In the North Atlantic, they are found offshore eastern Canada and the U.S. northeast coast during the summer foraging season. They migrate along the coast and their breeding area is in the shallow waters offshore of Florida and Georgia. It is believed that a portion of the population migrates to an undiscovered location.

Group Size

The group size of surface active groups (SAGs) in the Bay of Fundy ranged from 2 to 15 animals (Parks and Tyack, 2005).

7.3.4.6. Humpback Whale (Feeding)

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Feeding Humpback Whale	1/2	75°	10/60 (20) 40/100 (75) 100/150 (5)	5/10	90/300 90/90 90/90	1/8	Norm.	(Min = 100)/ reflect

Surface Time

Approximately 65 percent of all surfacing observed in Alaska were 2 minutes in length or less (Dolphin, 1987a). Surface times in Hawaii are similar with the exception of surface active groups (Frankel, pers. obs.).

Dive Depth

Humpback whale dive depths have been measured on the feeding grounds. Seventy-five percent of their dives were to 40 m (131 ft) or less with a maximum depth of 150 m (492 ft) (Dolphin, 1988). Dive depth appears to be determined by prey distribution. Whales in this study were primarily foraging upon euphausiids. There is also a strong correlation of dive depth and dive time and is described by the following equation (Dolphin, 1987a):

Time (s) = 0.52 * depth (m) +3.95, $r^2 = 0.93$

Feeding humpbacks off Kodiak Alaska had a mean maximum depth of 106.2 m (348 ft) with 62 percent of the dives occurring between 92 and 120 m (302 and 394 ft) with a maximum of ~160 m (~348 ft) (Witteveen et al., 2008). The humpbacks appeared to be feeding largely on capelin and pollock.

There are strong differences in the data between these two studies. This difference may reflect the distribution of prey rather than behavioral abilities of the whales.

Dive Time

The maximum of the continuous portion of the distribution of dive times was 15 minutes (Dolphin, 1987a). The distribution was skewed toward shorter dives. Several dive steps can be programmed in AIM to capture this variability.

Heading Variance

Satellite tracking of feeding humpback whales in the Southern Ocean showed very erratic travel, and animals frequently remained in a specific area for up to a week at a time. There were periodic movements between feeding areas (Dalla Rosa et al., 2008). Therefore, the heading variance for feeding humpbacks was set relatively high, for 80 percent of the time. Twenty percent of the time the heading variance was set as low to simulate movement between feeding areas.

Speed

Mean speeds for humpbacks are near 4.5 km/hr (2.8 mi/hr). The measured range is 2-11.4 km/hr (1-7 mi/hr) (excluding stationary pods) (Gabriele et al., 1996). Feeding humpbacks in the Southern Ocean had mean measured speeds between 2.26 and 4.03 km/hr (1.4 and 2.5 mi/hr) (Dalla Rosa et al., 2008). These values were derived from short segments of satellite tracking data; therefore, they are likely underestimates of speed.

Ascent rates during dives range from 1.5 to 2.5 m/s (4.8 to 8.2 ft) while descent rates range between 1.25 and 2 m/s (4.1 and 6.6 ft/s) (Dolphin, 1987b). The mean speed for all pod types in Glacier Bay was 3.31 km/hr (1 mi/hr) (Baker and Herman, 1989).

Habitat

Migrating humpbacks swim both along the coast (California population) as well as through the abyssal plains. Humpbacks swim along coastal regions are known to swim further offshore than gray whales. Therefore, the minimum depth for this species has been set at 100 m (328 ft).

Group Size

Ninety-six percent of 27,252 pods in the Gulf of Maine were composed of 1-3 animals with a modal size of one adult (Clapham, 1993).

7.3.4.7. Humpback Whale (Winter Grounds: Singer)

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Humpback Singer	1/1	75°	10/25	5/25	20	0/1	Norm.	>1,000/reflect

Surface Time

Singers typically surface for <1 minute. Singers in the Caribbean blew between 2 and 8 times per surfacing (Chu, 1988).

Dive Depth

Humpback singers have relatively shallow depths.

Dive Time

Dive times typically range from 10 to 25 minutes. Observations of 20 singers in the Caribbean found dive times between five and 20 minutes in duration (Chu, 1988).

Heading Variance

The heading variance is set very low for singers. While traveling very slow to stationary, they tend to swim along the coast.

Speed

Most singers are stationary although very few move at high speeds.

Habitat

On the wintering grounds most singers are found within the 100 fathom contour, but a few are found in deeper waters.

Group Size

The vast majority of singers are found alone. The largest pod reported containing a singer was four animals (Frankel et al., 1995).

7.3.4.8. Humpback Whale (Migrating)

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Migrating Humpback Whale	1/2	75^o	10/40	5/10	10	2/10	Norm.	(Min =100)/ reflect

Dive Depth

Humpback whale dive depths have been measured on the feeding grounds. Seventy-five percent of their dives were to 40 m (131 ft) or less (Dolphin, 1988). It is likely that migrating animals would also predominantly dive to these shallow depths. Humpbacks foraging off California had a mean maximum dive depth of 156 m (512 ft) (Goldbogen et al., 2008).

Dive Time

Surface times range between 1 and 2 minutes while dive times range between 5 and 10 minutes (Gabriele et al., 1996). Foraging humpbacks off California had mean dive times of 7.8 +/- 2.0 minutes (Goldbogen et al., 2008).

Heading Variance

The heading variance was set very low for migrating animals. Most non-competitive group breeding animals also have linear travel. Migrating humpbacks swam very close to magnetic north from Hawaii with very little deviation (Mate et al., 1998).

Speed

Mean speeds for humpbacks are near 4.5 km/hr (2.8 mi/hr). The measured range is 2-11.4 km/hr (1.2-7.1 mi/hr) (excluding stationary pods) (Gabriele et al., 1996). Satellite tracked migrating humpback whales moved at a minimum of 150 km/day (93 mi/day) (6.25 km/hr [3.9 mi/hr]) for a mother and calf pod, while another two whales moved 110 km/day (68 mi/day) (4.5 km/hr [2.8 mi/hr]). Humpbacks off Australia were estimated to migrate at a mean speed of 8 km/hr (5 mi/hr), with a range between 4.8 and 14.2 km/hr (3 and 9 mi/hr) (Chittleborough, 1953). More recent studies of Australian humpbacks found a mean northern migration speed of 5.47 km/hr (3.4 mi/hr), while the southern migration speed had a mean of 5.02 km/hr (3.12 mi/hr) for non-calf pods, while calf pods had mean speeds of 5.03 and 4.25 km/hr respectively (Chaudry, 2006).

Habitat

Migrating humpbacks swim both along the coast (California population) as well as through the abyssal plains. Humpbacks swim along coastal regions are known to swim further offshore than gray whales. Therefore, the minimum depth for this species has been set at 100 m (328 ft). Non-calf pods migrating off Australian had a mean offshore distance of 3,177 m (10,423 ft) during the northern migration and 2,560 m (8,399 ft) during the southern migration. Calf pods migrated “significantly” closer inshore (Chaudry, 2006).

7.3.4.9. Common Dolphin

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Common Dolphin	1/1	75°	50/200	1/5	30	2/9	Norm.	100-1,000/ reflect

Dive Depth

Dive depths are reported to be between 50 and 200 m (164 and 656 ft) (Evans, 1994).

Dive Time

The maximum dive time reported was five minutes (Heyning and Perrin, 1994).

Speed

The maximum sustainable speed for common dolphins was measured at 2.5 m/s (8.2 ft/s) (9 km/hr [5.6 mi/hr]) (Hui, 1987).

Habitat

Common dolphins off the NE United States were concentrated along the shelf edge between 100 and 200 m (328 and 656 ft) (Selzer and Payne, 1988). In the Mediterranean common dolphins were found in waters between 25 and 1,300 m (82 and 4,265 ft) deep with 95 percent of the animals in water between 247 and 326 m (810 and 1,070 ft) (Cañadas et al., 2002).

Group Size

Common dolphins in the Gulf of California were found in groups of 4-1,100 animals, with a mean size of 254.3 dolphins (Silber et al., 1994). Off the Pacific Coast of Costa Rica, the mean group size was 220.67 (SD=220.6) (May-Collado et al., 2005).

7.3.4.10. Blackfish: False Killer Whale, Pygmy Killer Whale, Melon-headed Whale

Studies describing the movements and diving patterns of these animals are rare and sparse. Therefore, they have been combined into a single “blackfish” category.

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
False/Pygmy killer whales	1/1	75°	5/50 (80) 50/100 (20)	2/12	30	2/22.4	Gamma.	200/reflect

Surface Time

Individual melon-headed whales spend less than one minute on the surface although the group may remain near the surface for long periods of time (Frankel, pers. obs.).

Dive Depth

The maximum dive depth of a single false killer whale off the Madeira Islands was 72 m (236 ft). Most of the time was spent at depths deeper than 20 m (66 ft) and the dives were V-shaped (Alves et al., 2006). Three false killer whales in Hawaii had shallow dives as well with maximum depths of 22, 52, and 53 m (72, 171, and 174 ft) (Ligon and Baird, 2001). It should be noted that these animals were feeding on fish.

Dive Time

No directly measured data were available for "blackfish" whales so data from pilot whales was used for dive time.

Speed

Maximum speed recorded for false killer whales was 28.8 km/hr (17.9 mi/hr) (Rohr et al., 2002), although the typical cruising speed is typically 20-24 percent less than the maximum speed (Fish and Rohr, 1999). This "typical" maximum of 22 km/hr (14 mi/hr) was used as the maximum speed for AIM.

Habitat

False killer whales off the Madeira Islands were found in water depths from 900 to 2,000 m (900 to 6,562 ft) (Alves et al., 2006).

Group Size

False killer whales in the Gulf of Mexico had group sizes between 20 and 35 (mean=27.5, standard error [SE]=7.5, n=2) (Mullin et al., 2004). False killer whales off Costa Rica had a mean group size of 36.16 (+/- 52.38) (May-Collado et al., 2005).

7.3.4.11. Shortfin and Longfin Pilot Whales

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Pilot Whales	1/1	75°	5/100 (80) 10/1,000 (20)	1/10 5/21	30	2/12	Norm.	200/reflect

Surface Time

A rehabilitated long-finned pilot whale in the North Atlantic was equipped with a satellite tag and a TDR. The log survivorship plot of dive time from this animal had an inflection point at about 40 s (Mate et al., 2005). The authors did not feel that this qualified as a breakpoint to separate surface and dive behavior. However, it does suggest that most surface intervals are less than one minute.

Dive Depth

Long-finned pilot whales in the Mediterranean were observed to display considerable diurnal variation in their dive depths. During the day, they never dove to more than 16 m (52 ft). However, at night, they dove to maximum depths of 360 and 648 m (1,181 and 2,126 ft) with mean depth of 308 and 416 m (1,011 and 1,365 ft) (Baird et al., 2002). Rehabilitated long-finned pilot whales dove to 312 m (1,024 ft) on Georges Bank which has a depth of 360 m (1,181 ft), so these values should not be taken as the maximum. The distribution of dive depths was also skewed toward lower values (Nawojchik et al., 2003).

Short-finned pilot whales off the Canary Islands had maximum depth of 1,019 m (3,343 ft) (Aguilar Soto et al., 2008). The majority of these were to depths of less than 100 m (328 ft) while the remainder of depths were approximately evenly distributed between 100 and 1,000 m (328 and 3,281 ft).

Dive Time

Baird et al. (2002) reported on dives of two individual long-finned pilot whales and dive times varied between 2.14 and 12.7 minutes during the night. During the day animals spent all of their time in the top 16 m (52 ft).

A rehabilitated long-finned pilot whale in the North Atlantic had dive times between 1 and 6 minutes (Mate et al., 2005). Other rehabilitated long-finned whales were reported to dive to at least 25 minutes although the distribution is skewed toward shorter dives with most lasting about two minutes (Nawojchik et al., 2003). Long-finned pilot whales off the Faroe Islands never dove longer than 18 minutes (Heide-Jørgensen et al., 2002).

Short-finned pilot whales off the Canary Islands had maximum foraging dive times of 21 minutes (Aguilar Soto et al., 2008). They demonstrated a near-linear relationship between dive depth and dive duration. Therefore shallow dives had times ranging between 1 and 10 minutes, while deep dives were set to have times between 5 and 21 minutes.

Speed

Shane (1995) reported a minimum speed of 2 km/hr (1.24 mi/hr) and a maximum of 12 km/hr (7.5 mi/hr) for pilot whales. During the day in the Mediterranean, animals slowly swam, with mean values for two animals of 2.85 and 3.18 km/hr (1.8 and 2 mi/hr), while at night, they swam faster at 6.83 and 5.48 km/hr (4.24 and 3.4 mi/hr) (Baird et al., 2002). A single satellite tracked long-finned pilot whale had a minimum speed of 1.4 km/hr (0.9 mi/hr) (Mate et al., 2005). The speed of traveling pilot whales (*G. scammoni*) was estimated at 4-5 knots (Norris and Prescott, 1961, cited in Mate et al., 2005). Vertical dive speeds of three TDR tagged long-finned pilot whales ranged from 0.79 to 3.38 m/s (2.6 to 11.1 ft/s) with a mean of 1.99 m/s (6.5 ft/s) (Heide-Jørgensen et al., 2002).

Habitat

The minimum water depth for pilot whales in the Gulf of Mexico was 246 m (807 ft) (Davis et al., 1998), while off of Spain, they preferred water deeper than 600 m (1,969 ft) (Cañadas et al., 2002).

Group Size

Short-finned pilot whales in the Gulf of Mexico ranged in group size between 5 and 50 (mean=20.4, SE=3.6, n=11) (Mullin et al., 2004). Off the Pacific Coast of Costa Rica the mean group size of pilot whales was 14.22 individuals (SD=12.06) (May-Collado et al., 2005).

7.3.4.12. Risso's Dolphin

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Risso's Dolphin	1/3	75^{o}	150/1,000	2/12	30	2/12	Norm.	150/reflect

Dive Depth

Dive depths of 150-1,000 m (492-3,281 ft) were inferred from the Risso's squid-eating habits and from similar species.

Dive Time

No data on dive times could be found. The values for blackfish were used which have a similar ecological niche.

Speed

Risso's dolphins off Santa Catalina Island were reported to have speeds ranging between 2 and 12 km/hr (1.24 and 7.5 mi/hr) (Shane, 1995).

Habitat

Risso's dolphins were seen in water deeper than 150 m (492 ft) in the Gulf of Mexico, most often observed between 300 and 750 m (984 and 2,461 ft) (Davis et al., 1998). Off Chile they were seen in waters deeper than 1,000 m (3,281 ft) (Olavarria et al., 2001) and off Spain, they were found deeper than 600 m (1,969 ft) (Cañadas et al., 2002). In all cases this association seems to be driven by the local oceanographic upwelling conditions that increase primary productivity.

Group Size

In the Pacific group sizes were measured between 1 and 220 animals with a geometric mean of 10.7. An estimated 76.4 percent of the groups contained fewer than 20 animals (Leatherwood et al., 1980). Group sizes in the Gulf of Mexico ranged between 2 and 78 animals with a mean of 12.7 (SE=2.0, n=39) (Mullin et al., 2004). The mean group size off the Pacific Coast of Costa Rica was 11.57 (SD=9.64) (May-Collado et al., 2005).

7.3.4.13. Large Beaked Whales

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Berardius	1/7	75°	800/1,453 (90) 50/200 (10)	48/68 12/70	30/300 (50) 90/300 (50)	3/6	Norm.	253/reflect

Surface Time

Surface times in Arnoux's beaked whales ranged from 1.2 to 6.8 minutes (Hobson and Martin, 1996). Sowerby's beaked whales had surface times of 1-2 minutes during which they would blow 6-8 times (Hooker and Baird, 1999a).

Dive Depth

The minimum and maximum dive depth measured for a beaked whale was 120 and 1,453 m (394 and 4,767 ft) respectively (Hooker and Baird, 1999b). *Ziphius* tagged off the Canary Islands had foraging dives between 824 and 1,267 m (2,703 and 4,157 ft) while Blainsville's beaked whales dove to depths between 655 and 975 m (2,149 and 3,199 ft) (Johnson et al., 2004).

Northern Bottlenose whales performed shallow dives with a range of 41-332 m (135-1,089 ft) (n=33), while deep dives ranged from 493 to 1,453 m (1,617 to 4,767 ft) (n=23). Dive depth and dive duration were strongly correlated (Hooker and Baird, 1999b).

Blainsville's beaked whales in Hawaii performed dives to mid-water depth (100-600 m [328-1,969 ft]) approximately six times more frequently than at night. Dives deeper than 800 m (2,625 ft had no diurnal difference (Baird et al., 2008).

Dive Time

The minimum and maximum dive time measured was 16 and 70.5 minutes, respectively (Hooker and Baird, 1999b). Sowerby's beaked whales had dives between 12 and (at least) 28 minutes in the Gully in Canada (Hooker and Baird, 1999a). Arnoux's beaked whale had modal dive times between 35-65 minutes (mean=46.4 min, SD=13.1), with a maximum dive time of at least 70 minutes (Hobson and Martin, 1996). Tagging results with Cuvier's beaked whale had one animal diving for 50 minutes

(Johnson et al., 2004). *Mesoplodon stejnegeri* were observed to dive for "10-15 minutes" in Alaska (Loughlin, 1982).

Blainsville's beaked whales and Cuvier's beaked whales both regularly dived for 48-68 minutes on deep dives (>800 m [>2,625 ft]).

Heading Variance

Sowerby's beaked whales surfacing in the Gully were reported to have no apparent orientation, and would change orientation up to 180° between surfacing (Hooker and Baird, 1999a).

Speed

Dive rates averaged 1 m/s (3.3 ft/s) or 3.6 km/hr (2.2 mi/hr) (Hooker and Baird, 1999b). A mean surface speed of 5 km/hr (3 mi/hr) was reported by (Kastelein and Gerrits, 1991).

Habitat

The minimum sea depth in which beaked whales were found in the Gulf of Mexico was 253 m (830 ft) (Davis et al., 1998). In the Gully in Canada, Sowerby's beaked whales were found in water ranging from 550 to 1,500 m (1,804 to 4,921 ft) in depth (Hooker and Baird, 1999a). Blainsville's beaked whales (*M. densirostris*) were found in water depths of 136-1,319 m (446-4,327 ft) in the Bahamas, and were found most often in areas with a high bathymetric slope (MacLeod and Zuur, 2005). *Mesoplodons* were found in waters from 700 to >1,800 m (2,297 to >5,906 ft) off Scotland and the Faroe Islands (Weir, 2000) and between 680 and 1,933 m (2,231 and 6,342 ft) in the Gulf of Mexico (Davis et al., 1998).

Baird et al. (2006) reported that Blainsville's beaked whales off Hawaii were found in waters from 633 to 2,050 m (2,077 to 9,726 ft) deep (mean=1,119) while Cuvier's beaked whales were found in waters from 1,381 to 3,655 m (4,531 to 11,992 ft) deep (mean=2,131).

Group Size

Mesoplodon stejnegeri in Alaska had pod sizes between 5 and 15 animals (Loughlin, 1982). Sowerby's beaked whale in the Gully in Canada had group sizes between 3 and 10 (Hooker and Baird, 1999a). Dense-beaked whales off the Canary Islands had group sizes ranging between 2 and 9 with a mean size of 3.44 whales (Ritter and Brederlau, 1999). Sightings of Longman's beaked whale in the western Indian Ocean found group sizes between 1 and 40 with a mean size of 7.2 whales (Anderson et al., 2006).

7.3.4.14. Dwarf and Pygmy Sperm Whales (Kogia spp.)

The data on dwarf and pygmy sperm whales are rare. Data for these two similar species have been combined.

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Kogia spp.	1/2	75°	200/1,000	5/12	30	1/11	Norm.	117/reflect

Surface Time

Observations of *Kogia* off Hawaii found that they remained at the surface for up to a "few" minutes then dove (Baird, 2005).

Dive Depth

Kogia were found in the Gulf of Mexico in waters less than 1,000 m (3,281 ft) along the upper continental slope (Baumgartner et al., 2001). The dive limits of 200-1,000 m (656-3,281 ft) were chosen based on similar species diving deeply to feed and within the physical constraints of the environment. It should be noted that *Kogia* have been seen in waters almost 2,000 m (6,562 ft) deep (Davis et al., 1998) but they may not be diving to the bottom.

Dive Time

Maximum dive time reported for *Kogia* is 12 minutes (Hohn et al., 1995). A rehabilitated pygmy sperm whale made long dives from 2 to 11 minutes in length at night and shorter dives during the day (Scott et al., 2001).

Speed

Tracking of a rehabilitated pygmy sperm whale found that speeds range from 0 to 6 knots (11 km/hr [7 mi/hr]) with a mean value of 3 knots (Scott et al., 2001).

Habitat

Kogia were found in the Gulf of Mexico at a minimum depth of 176 m (577 ft) (Davis et al., 1998). They were found off Hawaii in waters between 450 and 3,200 m (1,476 and 10,499 ft) deep, with a mean of 1,425 m (4,675 ft) (Baird, 2005). *Kogia* in the Philippines were found in waters from 117 to 3,744 m (384 to 12,284 ft) in depth (Dolar and Perrin, 2003).

Group Size

Group sizes off Hawaii ranged between 1 and 6 animals (Baird, 2005) and group sizes in the Gulf of Mexico range between 1 and 3 (Mullin et al., 2004).

7.3.4.15. Lagenorhynchus Species

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)
Lags	1/1	75°	25/125	1/3	30	2/9	Norm.

Surface Time

Surface times for tagged white-sided dolphins were less than one minute (Mate et al., 1994).

Dive Depth

No direct data on dive depth are available for any of the *Lagenorhynchus*. However, in the Atlantic they feed on herring and in the Pacific they feed on squid and mesopelagic fishes. For Atlantic white-sided dolphin a maximum dive depth of 125 m (410 ft) is used since this covers the depth range of herring; it is slightly shallower than the other dolphin species due to the *Lagenorhynchus*' short dive time.

Dive Time

Maximum dive time for a tagged white-sided dolphin was 4 minutes, although the mean time was <1 minute (Mate et al., 1994). Peale's dolphin (*L. australis*) dove from 1 to 130 s (de Haro and Iniguez, 1997).

Speed

The mean minimum speed of 5.7 km/hr (3.5 mi/hr) was estimated by the straight line distance between satellite tag locations, which is almost certainly an underestimate of real-world swimming speeds (Mate et al., 1994). The maximum "minimum speed" was 14.22 km/hr (8.83 mi/hr). A white-sided dolphin in captivity swam between 1.5 and 3.5 m/s (5 and 11.5 ft/s) (5.4 and 12.6 km/hr [3.4 and 7.8 mi/hr) (Curren et al., 1994). Theodolite tracking of dusky dolphins (*L. obscurus*) produced mean speeds between 3.68 and 6.08 km/hr (2.4 and 3.8 mi/hr) with 10th and 90th percentiles of ~2 and ~9 km/hr (~ 1 and ~ 6 mi/hr) (Yin, 1999).

Group Size

The mean size of Atlantic white-sided dolphin groups was 52 (Weinrich et al., 2001). The mean group size of Pacific white-sided dolphins was 30.8 (Barlow, 1995). In Southeast Alaska, the group size was extremely variable, ranging from 1 to 500 animals, with an overall mean of 35.6 animals (Dahlheim and Towell, 1994).

7.3.4.16. Fraser's Dolphin

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Fraser's Dolphin	1/1	75°	10/700	1/6	30	2/9	Norm.	100/reflect

Dive Depth

Fraser's dolphins dive to about 600-700 m (1,969-2,297 ft) to feed which is much deeper than spinner dolphins (Dolar et al., 2003). Numerous records indicated that the primary prey of Fraser's dolphins is found at great depth (Caldwell et al., 1976; Miyazaki and Wada, 1978; Robison and Craddock, 1983), although there has been at least one report of near-surface feeding (Watkins et al., 1994). All other behavioral parameters are taken from *Stenella* species since there are no direct data for Fraser's dolphin. The dive time has been increased to six minutes to account for the deeper dives.

Group Size

A single group of Fraser's dolphins was seen off the Pacific Coast of Costa Rica and had a group size of 158 (May-Collado et al., 2005).

7.3.4.17. Small Beaked Whales (Mesoplodon, Ziphius, Tasmacetus)

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Beaked Whales	1/7	75°	1,000/1,453 (60) 100/800 (40)	48/68 12/30	30/300 (50) 90/300 (50)	3/6	Norm.	253/reflect

Surface Time

Surface times in Arnoux's beaked whales ranged from 1.2 to 6.8 minutes (Hobson and Martin, 1996). Sowerby's beaked whales had surface times of 1-2 minutes, during which they would blow 6-8 times (Hooker and Baird, 1999a).

Dive Depth

The minimum and maximum dive depth measured for a beaked whale was 120 and 1,453 m (394 and 4,767 ft) respectively (Hooker and Baird, 1999b). Cuvier's beaked whales tagged off the Canary Islands had foraging dives between 824 and 1,267 m (2,703 and 4,157 ft) while Blainsville's beaked whales dove to depths between 655 and 975 m (2,149 and 3,199 ft) (Johnson et al., 2004).

Northern Bottlenose whales performed shallow dives with a range of 41-332 m (135-1,089 ft) (n=33), while deep dives ranged from 493 to 1,453 m (1,617 to 4,767 ft) (n=23). Dive depth and dive duration were strongly correlated (Hooker and Baird, 1999b).

Blainsville's beaked whales in Hawaii performed dives to mid-water depth (100-600 m [328-1,969 ft]) approximately six times more frequently than at night. Dives deeper than 800 m (2,625 ft) had no diurnal difference (Baird et al., 2008).

Dive Time

The minimum and maximum dive time measured was 16 and 70.5 minutes respectively (Hooker and Baird, 1999b). Sowerby's beaked whales had dives between 12 and (at least) 28 minutes in the Gully in Canada (Hooker and Baird, 1999a). Arnoux's beaked whale had modal dive times between 35-65 minutes (mean=46.4 min, SD=13.1) with a maximum dive time of at least 70 minutes (Hobson and Martin, 1996). Tagging results with *Ziphius* had one animal diving for 50 minutes (Johnson et al., 2004). *Mesoplodon stejnegeri* were observed to dive for 10-15 minutes in Alaska (Loughlin, 1982).

Blainsville's beaked whales and Cuvier's beaked whales both regularly dove for 48-68 minutes on deep dives (>800 m [>2,625 ft]).

Heading Variance

Sowerby's beaked whales surfacing in the Gully were reported to have no apparent orientation, and would change orientation up to 180° between surfacing (Hooker and Baird, 1999a).

Speed

Dive rates averaged 1 m/s (3.3 ft) or 3.6 km/hr (2.2 mi/hr) (Hooker and Baird, 1999b). A mean surface speed of 5 km/hr (3.1 mi/hr) was reported by Kastelein and Gerrits (1991).

Habitat

The minimum sea depth in which beaked whales were found in the Gulf of Mexico was 253 m (830 ft) (Davis et al., 1998). Sowerby's beaked whales in the Gully in Canada were found in water ranging from 550 to 1,500 m (1,804 to 4,921 ft) in depth (Hooker and Baird, 1999a). Blainsville's beaked whales (*M. densirostris*) were found in water depths of 136-1,319 m (446-4,327 ft) in the Bahamas, and were found most often in areas with a high bathymetric slope (MacLeod and Zuur, 2005). *Mesoplodons* were found in waters from 700 to >1,800 m (2,297 to 5,906 ft) off Scotland and the Faroe Islands (Weir, 2000) and between 680 and 1,933 m (2,231 and 6,342 ft) in the Gulf of Mexico (Davis et al., 1998).

Baird et al. (2006) reported that Blainsville's beaked whales off Hawaii were found in waters from 633 to 2,050 m (2,077 to 6,726 ft) deep (mean=1,119 m [3,671 ft]) while Cuvier's beaked whales were found in waters from 1,381 to 3,655 m (4,531 to 11,992 ft) deep (mean=2,131 m [6,991 ft]).

Group Size

Mesoplodon stejnegeri in Alaska had pod sizes between 5 and 15 animals (Loughlin, 1982). Sowerby's beaked whale in the Gully in Canada had group sizes between 3 and 10 (Hooker and Baird, 1999a). Dense-beaked whales off the Canary Islands had group sizes ranging between 2 and 9 with a mean size of 3.44 whales (Ritter and Brederlau, 1999). Sightings of Longman's beaked whale in the western Indian Ocean found group sizes between 1 and 40, with a mean size of 7.2 whales (Anderson et al., 2006).

7.3.4.18. Killer Whale

There is a remarkable paucity of quantitative data available for killer whales considering their coastal habitat and popular appeal. Nevertheless, most data from "blackfish" were used to model orca with the exception of dive depth. The different feeding ecology of these species makes very deep dives apparently unnecessary. When additional data allow, separate animats need to be developed for "resident" and "transient" killer whales.

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Killer Whale	1/1	75°	10/180	1/10	30	3/12	Norm.	25/reflect

Dive Depth

Killer whales feeding on herring were observed to dive to 180 m (591 ft) (Nøttestad et al., 2002). Killer whales are found in at least two "races", transients and residents. Transients feed primarily on marine mammals whereas residents feed primarily on fish. Residents were reported to dive to the bottom (173 m [568 ft]) (Baird, 1994). Baird (1994) also reported that while residents dive deeper than transients, the transients spent a far greater amount of time in deeper water. Individual resident killer whales in the Pacific northwest had maximum dive depths ranging between 24 and 264 m (79 and 866 ft) with a group mean maximum depth of 140.8 m (462 ft) (SD=61.8, n=34) (Baird et al., 1995). The distribution of dive depths reported by Baird et al. (2005) was strongly skewed toward shallow values.

Dive Time

The daytime dive times for males were 2.79 minutes, significantly longer than the 2.09 minute dive times for females (Baird et al., 2005).

Speed

Uncalibrated swim speed data were presented by Baird et al. (2005). Killer whales chasing minke whales had prolonged speeds of 15-30 km/hr (9-19 mi/hr) (Ford et al., 2005) although these speeds are probably obtained only during predation. A shore-based study of southern resident killer whales in Washington State had a mean speed of 9.5 km/hr (5.9 mi/hr) with a mean range of 4.7-16.1 km/hr (2.9-10 mi/hr) (Kriete, 2002). The mean speed of control animals was approximately 5.3 km/hr (3.3 mi/hr), measured during a study of the response of killer whales to vessels (Williams et al., 2002). A similar study reported a mean speed of 6.64 km/hr (4.13 mi/hr) without vessels and 6.478 km/hr (4.03 mi/hr) in the presence of vessels (Bain et al., 2006). Taken together, these three studies produced a speed range of 3-12 km/hr (1.9-7.5 mi/hr) for use in AIM.

Habitat

Killer whales are known to occur in very shallow water (e.g., rubbing beaches) as well as cross open ocean basins. However, they are usually coastal and most often found in temperate waters.

Killer whales in the Gulf of California were seen in groups of 2-15 whales with a mean of 8.5 and a SD of 9.19 (n=2) (Silber et al., 1994). Off the Pacific Coast of Costa Rica, the mean group size was 3.51 (SD=2.99, n=7) (May-Collado et al., 2005).

7.3.4.19. Harbor Porpoise

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Harbor Porpoise	1/1	17/31	1/10 (35) 10/40 (45) 40/100 (15) 100/230 (5)	1/4	30	2/7	Norm.	100-1,000/ reflect

Surface Time

Mean surface time was reported as 3.9 s (Otani, 2000).

Dive Depth

Maximum observed dive depth for a free-ranging harbor porpoise was 64.7 m (212 ft) (Otani, 2000). However, the same study reported that >90 percent of dives were less than 10 m (33 ft). Another TDR study with seven animals tagged had dive depths that ranged from a mean of 14 +/- 16 m (46 +/- 52 ft) to 41 +/- 32 m (135 +/- 105 ft) while the mean for all animals tagged was 25 +/- 30 m (82 +/- 98 ft) (Westgate et al., 1995). One large female made a very deep dive to 226 m (741 ft) although dives this deep were infrequent.

Dive Time

Maximum observed dive time for a free-ranging harbor porpoise was 193 s (Otani, 2000) although most dives were less than one minute in length. The mean dive duration of seven animals in the Bay of Fundy was 65 +/-33 s (Westgate et al., 1995).

Speed

Mean descent speed was 2.9 km/hr (1.8 mi/hr) with a maximum descent speed of 15.5 km/hr (9.6 mi/hr). Ascent speeds were similar, with a mean of 3.24 km/hr (2 mi/hr) and a maximum of 14.5 km/hr (9 mi/hr) (Otani, 2000). TDR tagged animals moved at least 51 km (32 mi) in a 24 hr period (2.125 km/hr [1.3 mi/hr]) (Westgate et al., 1995). A captive harbor porpoise swam between 3.6-7.2 km/hr (2.2-4.5 mi/hr) (Curren et al., 1994). A speed range of 2-7 km/hr (1.2-4.3 mi/hr) was used in AIM to represent the harbor porpoise speed.

Group Size

The mean group size of harbor porpoise off California was 5.0 individuals (n=31) (Barlow, 1995).

7.3.4.20. Sperm Whale

There are indications of diurnal differences in diving behavior (Aoki et al., 2007). There is also evidence of large-scale variability between environments. Therefore, these parameters should be considered generalized and warrant location specific refinement.

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Sperm Whale	8/11	90/75º	600/1,400 (90) 200/600 (10)	18/65	20	1/10	Norm.	200/reflect
Atlantic Ocean Model Parameters								
Atlantic Sperm Whale	5/9	90/75º	600/1,000	35/65	30/300 (50) 90/300 (50)	1/8	Norm.	200/reflect

Surface Time

Male sperm whales in New Zealand had a mean duration on the surface of 9.1 minutes, with a range of 2-19 minutes (Jaquet et al., 2000). The distribution of surface times was non-normal, with 68 percent of the surface times falling in between 8 and 11 minutes. These values were used for AIM modeling.

Surfacing and Dive Angles

Surfacing angles of 90° and diving angles between 60° and 90° have been reported (Miller et al., 2004).

Dive Depth

The maximum, accurately measured, sperm whale dive depth was 1,330 m (4,364 ft) (Watkins et al., 2002). Foraging dives typically begin at depths of 300 m (984 ft) (Papastavrou et al., 1989). Digital acoustic recording tag (DTAG) data from the Gulf of Mexico show that most foraging dives were between the depths of 400-800 m (1,312-2,625 ft), with occasional dives between 900 and 1,000 m (2,953 and 3,281 ft) (Jochens et al., 2008, Figure 5.2.2).

Sperm whale diving is not uniform. As an example, data from a paper on sperm whale diving reported different dive types (Amano and Yoshioka, 2003). The AIM can now accommodate these different dive types at different frequencies of use.

		Depth		Time	
Type of Dive	N	AIM min	AIM max	AIM min	AIM max
Dives w/ active bottom period	65	606	1082	33.17	41.63
Dives w/o active bottom period	4	417	567	31.29	33.71
V shaped dives	3	213	353	12.77	20.83
Total	72				

Dive depths have also been shown to have diel variation in some areas while others do not show this variation (Aoki et al., 2007). These differences have been attributed to the behavior of the prey species. Tagged whales off California changed their dive patterns in response to changes in the depth of tagged squid (Davis et al., 2007).

Male sperm whales foraging in high latitude waters dove to a maximum depth of 1,860 m (6,102 ft), but the median dive depth was only 175 m (574 ft) (Teloni et al., 2008).

In the Atlantic, maximum dive depths ranged from 639 to 934 m (2,096 to 3,064 ft) (Palka and Johnson, 2007).

Area	Average Duration (min)				
	Foraging Dive			Inter-Dive Interval	Surface Interval
	Total	Descent	Ascent		
North Atlantic	44.6	24.4	20.2	7.1	70.0
Gulf of Mexico	44.7	22.2	22.4	8.2	63.7
Mediterranean	40.3	24.4	19.3	9.7	57.5

Area	Average Depth (m)		
	Maximum Depth of Foraging Dives	Inter-Dive Interval	Surface Interval
North Atlantic	933.9	1.15	5.6
Gulf of Mexico	638.7	0.45	4.6
Mediterranean	797.3	0.34	4.9

Sperm whales showed diel variability off Ogasawara, Japan. Whales dove deeper during the day (mean=853 +/- 130 m [2,799 +/- 427 ft]) than at night (mean=469 +/- 122 m [1,539 +/- 400 ft]) (Aoki et al., 2007). However, off the Kumano Coast, there was not a large difference in depths (561 versus 646 m [1,841 versus 2,119 ft]).

Dive Time

Sperm whale dive times average 44.4 minutes in duration and range from 18.2 to 65.3 minutes (Watkins et al., 2002). In the Gulf of Mexico, the modal dive time is about 55 minutes (Jochens et al., 2008, Figure 4.4.3). Dive times in the Atlantic averaged 40-45 minutes (Palka and Johnson, 2007).

Dive times off Ogasawara, Japan had an average of 40.1 minutes (SD=4.5) during the day and a mean of 32.3 minutes (SD=5.3) at night (Aoki et al., 2007). Off the Kumano Coast of Japan, they had intermediate values of 36.1 minutes (SD=3.7) during the day and 34.1 (SD=7) minutes at night.

Heading Variance

Whales in the Gulf of Mexico tend to follow bathymetric contours (Jochens et al., 2008). Relative angles between direction of movements and direction of contours have been calculated and transformed so that 0 shows alignment with the orientation of the contour, -90 would be moving directly offshore, and +90 would indicate a movement directly inshore (Jochens et al., 2008, Figure 4.4.5).

Speed

Sperm whales are typically slow or motionless on the surface. Mean surface speeds of 1.25 km/hr (0.78 mi/hr) were reported by Jaquet et al. (2000) and 3.42 km/hr (2.13 mi/hr) (Whitehead et al., 1989). Their mean dive rate ranges from 5.22 to 10.08 km/hr (3.24 to 6.26 mi/hr) with a mean of 7.32 km/hr (4.55 mi/hr) (Lockyer, 1997). In Norway, horizontal swimming speeds varied between 0.72 and 9.36 km/hr (0.45 and 5.8 mi/hr) (Wahlberg, 2002). Sperm whales in the Atlantic Ocean swam at speeds between 2.6 and 3.5 km/hr (1.6 and 2.2 mi/hr) (Jaquet and Whitehead, 1999; Watkins et al., 1999). Mean speeds in the Gulf of Mexico were 3.3 km/hr (2.1 mi/hr) (Jochens et al., 2008). Based on these data, a minimum speed of 1 km/hr (0.6 mi/hr) and a maximum speed of 8 km/hr (5 mi/hr) was set for sperm whales specified with a normal distribution so that mean speeds would be about 4 km/hr (2.5 mi/hr).

Off Ogasawara Japan, sperm whales swam faster during the day (mean=2.0 m/s [6.6 ft/s], SD=0.3) than during the night (mean=1.5 m/s [5 ft/s], SD=0.3).

Habitat

Sperm whales are found almost everywhere, but they are usually in water deeper than 480 m (1,575 ft) (Davis et al., 1998). However, there have been sightings of animals in shallow water (40-100 m [131-328 ft]) (Whitehead et al., 1992; Scott and Sadove, 1997). In the Gulf of California there was no relationship between depth or bathymetric slope and abundance and animals were seen in water as shallow as 100 m (328 ft) (Jaquet and Gendron, 2002). Based on these reports, a compromise value of 200 m (656 ft) was used as the shallow water limit for sperm whales.

Group Size

Social, female-centered groups of sperm whales in the Pacific have "typical" group sizes of 25-30 animals, based on the more precise measurements in (Coakes and Whitehead, 2004), although less precise estimates are as high as 53 whales in a group.

7.3.4.21. Stenella: Spinner, Spotted and Striped Dolphins

Most *Stenella* species have strong diurnal variation in their behavior. Separate daytime and nighttime animats was built for this species by programming two dive behaviors. The relative proportion of these dive types can be scaled by the local photoperiod with the AIM weighting parameter.

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Stenella	1/1	75^o	Day: 5/25 (50) Night: 10/400 (10) Night: 10/100 (40)	1/4	30	2/9	Norm.	10/reflect

Dive Depth

Spinner dolphins feed during the night and rest inshore during the daytime. At night they dive to about 400 m (1,312 ft) to feed (Dolar et al., 2003).

Pantropical spotted dolphins off Hawaii also dive deeper at night than during the day. The daytime depth had a mean of 12.8 m (42 ft), with a maximum of 122 m (400 ft), whereas the night-time mean was 57 m (187 ft), with a maximum of 213 m (699 ft) (Baird et al., 2001).

Spinner dolphins off Hawaii typically track and forage upon the mesopelagic boundary layer as it migrates both vertically and horizontally at night. It appears that dolphins have to dive deeply only at the very beginning and end of the migration (Benoit-Bird and Au, 2003) foraging mostly at moderate depths.

Therefore, 10 percent of the dives were set to be deep, 40 percent of the dives were "typical" foraging depths, with a maximum of 150 m (492 ft), and 50 percent of the dives were set to represent the daytime resting behavior ranging between 5 and 25 m (16 and 82 ft).

Dive Time

A single spotted dolphin has dive times ranging between 1 and 204 s (Leatherwood and Ljungblad, 1979). Pantropical spotted dolphins off Hawaii had a mean dive duration of 1.95 minutes (SD=0.92) (Baird et al., 2001). An Atlantic spotted dolphin tagged with a satellite linked TDR had a maximum dive time of 3.5 minutes (Davis et al., 1996). A four minute dive time maximum was used for modeling purposes in AIM.

Speed

The mean speed of striped dolphins in the Mediterranean was estimated at 6.1 knots (11 km/hr [6.8 mi/hr]) and burst to 32 knots were observed (Archer and Perrin, 1999). A maximum speed of 20 km/hr (12 mi/hr) was chosen as a typical (non-burst) maximum speed. A tagged spotted dolphin was tracked at estimated average speeds of 2.3-10.7 knots with bursts exceeding 12 knots (Leatherwood and Ljungblad, 1979). The estimated burst speed of spotted dolphins in the Eastern Tropical Pacific was 21.6 km/hr (13.4 mi/hr) for adults and 10.8 km/hr (6.7 mi/hr) for neonates. The estimated long-term top speed is 9 km/hr (5.6 mi/hr) for adults and 3.6 km/hr (2.2 mi/hr) for neonates (Edwards, 2006). The

Edwards (2006) paper also summarized speed estimates and duration for a number of species. Therefore their estimate of 9 km/hr (5.6 mi/h) was used for long-term movements, as modeled in AIM.

Habitat

In the Gulf of Mexico spinner dolphins were seen in water deeper than 526 m (1,726 ft), striped dolphins were seen in water deeper than 570 m (1,870 ft), and spotted dolphins were seen in water deeper than 102 m (335 ft) (Davis et al., 1998). Spinner dolphins in Hawaii are known to move into shallow bays during the day (Norris and Dohl, 1980).

Group Size

Group size estimates were summarized, and the majority of striped dolphin groups were less than 500 animals. The mean of the smaller groups was 101 animals (Archer and Perrin, 1999). Spotted dolphins off Costa Rica had group sizes between 1 and 50 (mean=10.16, SD=9.61) (May-Collado and Ramirez, 2005).

Summary of Gulf of Mexico Data (Source: Mullin et al., 2004)

Species	Min Group Size	Max Group Size	Mean	SE	N
Pantropical spotted dolphin	5	210	49.0	4.5	47
Atlantic spotted dolphin	5	48	22.4	3.9	12
Striped dolphin	7	150	46.3	16.0	8
Spinner dolphin	48	200	91.3	36.4	4
Clymene dolphin	9	168	59	19.5	7

Clymene dolphins off Costa Rica had a mean group size of 76.1 (SE=11, n=109) (Fertl et al., 2003).

Summary of Pacific Costa Rica Data (May-Collado et al., 2005)

Species	Mean	SD
Pantropical spotted dolphin	29.38	58.28
Striped dolphin	48.9	43.05
Spinner dolphin	100.59	107.7

7.3.4.22. Bottlenose Dolphin

In many environments, there can be coastal and pelagic stocks of bottlenose dolphins. This is certainly the case off the east coast of the U.S., however defining the range of offshore form is difficult (Wells et al., 1999). Regardless of the genetic differences that may exist between these two forms, they frequently occur at different densities and are split into two animat categories.

Model Parameters

	Min/Max Surface Time (min)	Surface/Dive Angle	Dive Depth (m) Min/Max (Percentage)	Min/Max Dive Time (min)	Heading Variance (angle/time)	Min/Max Speed (km/hr)	Speed Distribution (α,β)	Depth Limit/Reaction Angle
Bottlenose (Coastal)	1/1	75°	15/98	1/3	30	2/16	Norm.	10/reflect
Bottlenose (Pelagic)	1/1	75°	6/50 (80) 50/100 (5) 100/250 (5) 250/450 (10)	1/2 2/3 3/4 5/6	30/300 (45) 90/90 (45) 90/90 (10)	2/16	Norm.	101/1,226 reflect

Dive Depth

An early maximum recorded dive depth for wild bottlenose dolphins is 200 m (656 ft) (Kooyman and Andersen, 1969). More recently, offshore bottlenose dolphins were reported to dive to depths greater than 450 m (1,476 ft) (Klatsky et al., 2007).

A satellite tagged dolphin in Tampa Bay, Florida had a maximum dive depth of 98 m (322 ft) (Mate et al., 1995). This value was used as the maximum dive depth for the coastal form of bottlenose.

Dive Time

Measured surface times ranged from 38 s to 1.2 minutes (Lockyer and Morris, 1986, 1987; Mate et al., 1995). Dive depths for a juvenile bottlenose had a mean value of 55.3 s although the distribution was skewed toward shorter dives (Lockyer and Morris, 1987). However, pelagic bottlenose dolphins were observed to dive for periods longer than five minutes (Klatsky et al., 2007).

Speed

Bottlenose dolphins were observed to swim for extended periods at speeds of 4-20 km/hr (2.5-12.4 mi/hr), although they could burst (for about 20 s) at up to 54 km/hr (34 mi/hr) (Lockyer and Morris, 1987). Dolphins in the Sado Estuary, Portugal had a mean speed of 4.3 km/hr (2.7 mi/hr) and maximum speed of 11.2 km/hr (7 mi/hr) (Harzen, 2002). A more recent analysis found that maximum speed of wild dolphins was 20.5 km/hr (12.7 mi/hr), although trained animals could double this speed when preparing to leap (Rohr et al., 2002). Maximum speeds of wild dolphins in France was 4.8 m/s (15.7 ft/s), with an average speed (relative to water) of 7.9 km/hr (4.9 mi/hr) (Ridoux et al., 1997). Bottlenose dolphins off Argentina swam much faster (14 km/hr [9.7 mi/hr]) when in water >10 m (>33 ft) than while in shallow water (5.8 km/hr [3.6 mi/hr]) (Würsig and Würsig, 1979).

Habitat

In the Gulf of Mexico, bottlenose dolphins where observed in water depths between 101 and 1,226 m (331 and 4,022 ft) (Davis et al., 1998). However tagged animals have been observed to swim into water 5,000 m (16,404 ft) deep (Wells et al., 1999).

Group Size

Bottlenose dolphins in the Gulf of California were seen in groups of 1-60 dolphins with a mean group size of 10.1 (Silber et al., 1994). In the Gulf of Mexico they were seen in groups of 1-68 individuals (mean=14.5, SE=1.5, n=83) (Mullin et al., 2004). Off the Pacific Coast of Costa Rica the mean group size was 21.5 (SD=33.73, n=176) (May-Collado et al., 2005).

7.4. ESTIMATIONS OF SOURCE LEVEL OF EFFORT

The final information needed to calculate the overall impact from the proposed action and the alternatives is the number and timing of the various surveys to be performed. The two major components of the estimates of the survey Level of Effort (LOE) are: (1) the annual estimations of the total number of each survey type to be conducted; and (2) the spatial distribution of these surveys in the 35 modeling regions (regions 1-21 for seismic airgun surveys for oil and gas exploration, plus regions 22-35 for renewable energy and marine minerals HRG surveys). A brief discussion of these components follows.

There are several assumptions embedded in the modeling which are necessary because this analysis is being performed far in advance of the actual surveys efforts. These embedded assumptions include:

- the estimation that surveys would have an even temporal distribution throughout the year. This allows all seasons to be examined in the analysis and enables to analysts to observe particularly time periods which could cause higher impacts than others. The reality of Western Atlantic Ocean operations is that winter operations could possibly encounter the worst conditions in general, aside from operations during a hurricane;

- the marine mammal densities are averaged for each area and this value is used in the analysis. This is reasonable because the exact location of each survey is unknown and on average, much or most of these regions would eventually be surveyed;
- nominal values used to describe the survey geometries are subject to change and most likely would be based on previous surveys conducted and their results; and
- nominal source levels and configurations were modeled.

7.4.1. Annual Survey Levels of Effort (LOE)

The BOEM has provided the annual LOE for each of the survey types out to the year 2020. The tables showing these LOE are included in the Programmatic EIS (**Chapter 3**), and a condensed version is presented in **Table E-11**.

Table E-11

Projected Levels of Seismic Airgun Surveys for Oil and Gas Exploration in the Mid- and South Atlantic Planning Areas, 2012-2020

Year	Mid-Atlantic Planning Area					South Atlantic Planning Area				
	2D (km)	3D (blocks)[a]	WAZ (blocks)[b]	HRG (line km)	VSP (line km)	2D (km)	3D (blocks)[a]	WAZ (blocks)[b]	HRG (line km)	VSP (line km)
2012	0	0	0	0	0	0	0	0	0	0
2013	83,400	0	0	0	0	28,450	0	0	0	0
2014	160,950	0	0	0	0	56,900	0	0	0	0
2015	12,875	0	0	0	0	8,050	0	0	0	0
2016	64,375	400	0	0	0	48,300	300	0	0	0
2017	41,800	200	0	0	0	38,624	200	0	3,220	0
2018	16,100	200	100	3,220	0	32,200	200	100	32,200	0
2019	16,100	200	100	16,100	160	8,050	200	200	16,100	320
2020	800	300	200	64,375	320	800	300	200	40,250	480
TOTAL	**396,400**	**1,300**	**400**	**83,695**	**480**	**221,374**	**1,200**	**500**	**91,770**	**800**

Abbreviations: 2D = two-dimensional; 3D = three-dimensional; HRG = high-resolution geophysical; VSP = vertical seismic profile; WAZ = wide azimuth.

[a] 3D surveys include ocean bottom cable and nodal surveys, vertical cable surveys, and 4D (time-lapse) surveys. Typically, one OCS block is 9 mi^2 (23.3 km^2, 2,331 ha or 5,760 ac).

[b] WAZ estimates include coil shooting (exclusive to WesternGeco).

7.4.2. Spatial Distribution of the 2D Survey Effort

The BOEM also provided the nine G&G survey applications from geophysical companies wishing to conduct seismic 2D surveys for oil and gas exploration in the AOI. Included in these applications were the descriptions of the areas to be surveyed and the planned survey geometries.

An analysis using geographic information system (GIS) programming was conducted on these applications and the resulting graphic was a density plot of the entire survey effort for the Mid- and South Atlantic Planning Areas (**Figure E-19**). In the analysis, this plot was handled in a manner similar to that used to determine the average marine mammal densities in each modeled region. Essentially, the number of survey miles for each modeled region was summed and then converted into the number of standard blocks in each region that would be surveyed. The description included in each of the nine applications changed the overall geometry employed to conduct the 2D survey. This necessitated an analysis of the variation in these surveys, and a nominal or average 2D survey for these applications had a linear miles per standard block surveyed conversion of 1.54 nmi per block (2.85 km/block). This average value is less than that typically used in the Gulf of Mexico for 2D surveys (e.g., approximately 6.24 nmi/block), but it conforms to the applications and it was used in all subsequent 2D survey calculations. Similarly, an average 2D HRG survey conversion of 200 nmi/block (370.40 km/block) is used for this analysis. This value is a compromise between the 70 nmi/block value typically used in the Gulf of Mexico and the 360 nmi/block calculated by BOEM from the applications. By using these conversion factors and the

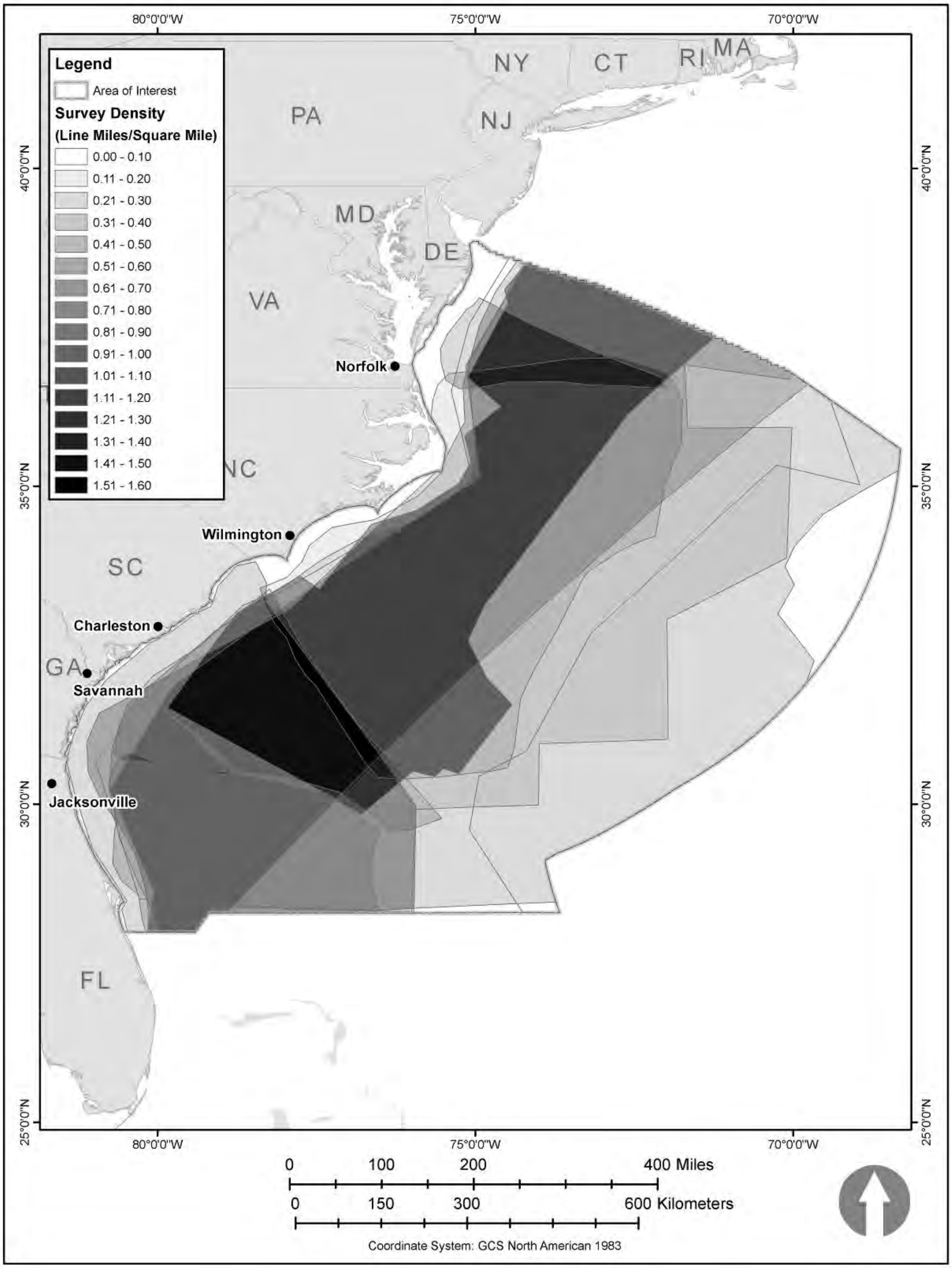


Figure E-19. Level of Effort Density Plot for Future 2D Seismic Airgun Surveys Based on Overlay of Seismic Survey Applications Submitted to BOEM. Areas with darker shading would be expected to have higher levels of survey effort due to overlapping survey areas.

applications, the spatial distribution of the various seismic airgun surveys throughout the 21 modeling regions was estimated. For the non-airgun HRG surveys the conversion factor used was 666.3 nmi per block (1234.0 km/block).

The final adjustment to each regions 2D survey effort was to distribute temporally as per the distribution discussed in **Section 7.4.1**. The result is a distribution of the entire 2D survey effort over the years and modeling regions addressed in this Programmatic EIS.

Finally, the same spatial distribution of the 2D surveys over the 21 modeling regions was also used to distribute the 3D, WAZ, HRG, and VSP surveys, since it follows that the 2D surveys would essentially act as the gateway to the follow-up surveys by showing where they would be most productive.

7.4.3. Temporal Correction to Level of Effort (LOE) Tables to Account for Area Closures

The Proposed Action includes a suite of existing regulations as well as mitigation measures that were developed specifically for this Programmatic EIS (**Chapter 2.1.2**). Specifically, all survey activity which was planned to occur in North Atlantic right whale critical habitat or the Southeast U.S. Seasonal Management Area was assumed to be rescheduled for a period other than the November 1 to April 30 period when those areas are established. In order to incorporate this prohibition into the modeling the following steps were followed:

- all surveys which would have occurred in these closure areas and occur in modeled areas 4 and 5 (winter), 9 and 10 (2 months of spring) and 20 and 21 (the last month of fall) where rescheduled to the open and available time periods at the same sites for periods when the North Atlantic right whales are absent;
- since these closure areas constitute a large portion of some modeling regions (in some cases up to roughly 50 percent), each of the species densities were examined to ensure that the density being used was correct or at least conservative; and
- the LOE for these cancelled surveys was then evenly distributed over the remaining months when these surveys could be performed. This was reflected in the final LOE tables, **Tables E-12** through **E-15** for 2D, 3D, WAZ, and VSP surveys respectively. The LOE tables for HRG surveys of oil and gas sites using the 90 cubic airgun are shown in **Table E-16**. The LOE estimates for non-airgun HRG surveys for marine minerals and renewable energy sites are shown in **Tables E-17** and **E-18**, respectively.

Similarly, the number of potential impacts also is scaled to derive a “per block survey” level of potential impacts. The predicted potential impacts can then be calculated by multiplying this value by the number of surveys of that type to be performed in that year, and summing the potential impacts to that species from all survey types combined.

Table E-12

Adjusted Level of Effort in Blocks for 2D Seismic Airgun Surveys

	Years								
Modeled Area	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	0.0	1795.4	3465.8	278.9	1398.2	911.3	539.1	347.8	17.5
2	0.0	4461.0	8626.8	721.2	3677.6	2452.6	1098.7	883.9	47.5
3	0.0	2398.8	4738.9	571.1	3297.3	2539.6	1929.0	603.5	51.9
4	0.0	166.5	333.0	47.1	282.6	226.0	188.4	47.1	4.7
5	0.0	571.2	1118.8	118.2	656.7	285.9	329.1	131.2	9.8
6	0.0	2233.8	4310.9	344.8	1724.2	1119.6	431.2	431.2	21.4
7	0.0	4110.7	7949.8	665.4	3394.9	2256.6	1018.6	815.1	43.9
8	0.0	1802.5	3569.4	444.7	2590.1	2012.3	1563.5	464.4	41.3
9	0.0	842.1	1665.4	204.0	1182.8	914.9	702.8	214.3	18.7
10	0.0	253.8	489.9	39.2	195.9	127.2	49.0	49.0	2.4
11	0.0	1181.1	2279.3	182.3	011.7	592.0	228.0	228.0	11.3
12	0.0	4826.6	9321.0	756.8	3809.7	2496.9	1017.0	939.9	48.0
13	0.0	2509.1	4947.9	580.9	3330.4	2546.8	1897.5	619.7	52.0
14	0.0	1618.1	3201.2	393.6	2284.7	1769.0	1362.5	412.9	36.2
15	0.0	963.0	1858.5	148.7	743.4	482.7	185.9	185.9	9.2
16	0.0	1294.3	2497.9	199.8	999.1	648.7	249.9	249.9	12.4
17	0.0	1134.8	2191.8	178.6	900.7	591.7	244.2	221.5	11.4
18	0.0	2733.2	5305.3	477.8	2512.1	1742.1	935.6	566.7	34.3
19	0.0	2592.8	5106.4	588.5	3356.9	2553.4	1875.0	632.2	52.0
20	0.0	497.0	974.2	104.3	582.3	432.8	297.3	115.2	8.7
21	0.0	1231.0	2403.6	290.7	1675.0	1287.4	972.5	308.0	26.3

Table E-13

Adjusted Level of Effort in Blocks for 3D Seismic Airgun Surveys

	Years								
Modeled Area	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	0.0	0.0	0.0	0.0	24.8	12.5	12.5	12.5	18.7
2	0.0	0.0	0.0	0.0	65.2	33.9	33.9	33.9	50.8
3	0.0	0.0	0.0	0.0	58.4	37.0	37.0	37.0	55.6
4	0.0	0.0	0.0	0.0	5.0	3.3	3.3	3.3	5.0
5	0.0	0.0	0.0	0.0	11.6	7.0	7.0	7.0	10.5
6	0.0	0.0	0.0	0.0	30.6	15.3	15.3	15.3	22.9
7	0.0	0.0	0.0	0.0	60.2	31.3	31.3	31.3	46.9
8	0.0	0.0	0.0	0.0	45.9	29.4	29.4	29.4	44.1
9	0.0	0.0	0.0	0.0	21.0	13.4	13.4	13.4	20.0
10	0.0	0.0	0.0	0.0	3.5	1.7	1.7	1.7	2.6
11	0.0	0.0	0.0	0.0	16.2	8.1	8.1	8.1	12.1
12	0.0	0.0	0.0	0.0	67.5	34.2	34.2	34.2	51.3
13	0.0	0.0	0.0	0.0	59.0	37.0	37.0	37.0	55.6
14	0.0	0.0	0.0	0.0	40.5	25.8	25.8	25.8	38.8
15	0.0	0.0	0.0	0.0	13.2	6.6	6.6	6.6	9.9
16	0.0	0.0	0.0	0.0	17.7	8.9	8.9	8.9	13.3
17	0.0	0.0	0.0	0.0	16.0	8.1	8.1	8.1	12.2
18	0.0	0.0	0.0	0.0	44.5	24.4	24.4	24.4	36.7
19	0.0	0.0	0.0	0.0	59.5	37.1	37.1	37.1	55.6
20	0.0	0.0	0.0	0.0	10.3	6.2	6.2	6.2	9.3
21	0.0	0.0	0.0	0.0	29.7	18.8	18.8	18.8	28.1

Table E-14

Adjusted Level of Effort in Blocks for WAZ Seismic Airgun Surveys

	Years								
Modeled Area	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	0.0	0.0	0.0	0.0	0.0	0.0	6.2	6.4	12.5
2	0.0	0.0	0.0	0.0	0.0	0.0	16.9	19.5	33.9
3	0.0	0.0	0.0	0.0	0.0	0.0	18.5	34.2	37.0
4	0.0	0.0	0.0	0.0	0.0	0.0	1.7	3.3	3.3
5	0.0	0.0	0.0	0.0	0.0	0.0	3.5	5.8	7.0
6	0.0	0.0	0.0	0.0	0.0	0.0	7.6	7.6	15.3
7	0.0	0.0	0.0	0.0	0.0	0.0	15.6	18.0	31.3
8	0.0	0.0	0.0	0.0	0.0	0.0	14.7	27.7	29.4
9	0.0	0.0	0.0	0.0	0.0	0.0	6.7	12.5	13.4
10	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	1.7
11	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	8.1
12	0.0	0.0	0.0	0.0	0.0	0.0	17.1	18.0	34.2
13	0.0	0.0	0.0	0.0	0.0	0.0	18.5	33.6	37.0
14	0.0	0.0	0.0	0.0	0.0	0.0	12.9	24.1	25.8
15	0.0	0.0	0.0	0.0	0.0	0.0	3.3	3.3	6.6
16	0.0	0.0	0.0	0.0	0.0	0.0	4.4	4.4	8.9
17	0.0	0.0	0.0	0.0	0.0	0.0	4.1	4.3	8.1
18	0.0	0.0	0.0	0.0	0.0	0.0	12.2	16.6	24.4
19	0.0	0.0	0.0	0.0	0.0	0.0	18.5	33.2	37.1
20	0.0	0.0	0.0	0.0	0.0	0.0	3.1	5.3	6.2
21	0.0	0.0	0.0	0.0	0.0	0.0	9.4	17.2	18.8

Table E-15

Adjusted Level of Effort in Blocks for VSP Seismic Airgun Surveys

	Years								
Modeled Area	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.6
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4

Table E-16

Adjusted Level of Effort in Blocks for 90 Cubic Inch Airgun HRG Surveys for Oil and Gas Sites

	Years								
Modeled Area	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.6
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4

Table E-17

Adjusted Level of Effort in Blocks for Non-Airgun HRG Surveys for Marine Minerals Sites

	Years								
Modeled Area	2012	2013	2014	2015	2016	2017	2018	2019	2020
22	0.004	0.004	0.030	0.030	0.030	0.015	0.015	0.015	0.015
23	0.083	0.083	0.355	0.355	0.355	0.243	0.243	0.243	0.243
24	0.087	0.087	0.340	0.340	0.340	0.135	0.135	0.135	0.135
25	0.000	0.000	0.046	0.046	0.046	0.123	0.123	0.123	0.123
26	0.087	0.087	0.386	0.386	0.386	0.258	0.258	0.258	0.258
27	0.083	0.083	0.279	0.279	0.279	0.016	0.016	0.016	0.016
28	0.004	0.004	0.107	0.107	0.107	0.241	0.241	0.241	0.241
29	0.004	0.004	0.030	0.030	0.030	0.015	0.015	0.015	0.015
30	0.083	0.083	0.355	0.355	0.355	0.243	0.243	0.243	0.243
31	0.087	0.087	0.340	0.340	0.340	0.135	0.135	0.135	0.135
32	0.000	0.000	0.046	0.046	0.046	0.123	0.123	0.123	0.123
33	0.087	0.087	0.386	0.386	0.386	0.258	0.258	0.258	0.258
34	0.083	0.083	0.279	0.279	0.279	0.016	0.016	0.016	0.016
35	0.004	0.004	0.107	0.107	0.107	0.241	0.241	0.241	0.241

Table E-18

Adjusted Level of Effort in Blocks for Non-Airgun HRG Surveys for Renewable Energy Sites

	Years								
Modeled Area	2012	2013	2014	2015	2016	2017	2018	2019	2020
22	0.000	2.000	2.000	2.000	2.000	2.000	2.000	0.000	0.000
23	6.708	7.208	7.208	7.208	7.208	7.208	0.500	0.000	0.000
24	4.833	7.333	7.333	7.333	7.333	7.333	2.500	0.000	0.000
25	1.875	1.875	1.875	1.875	1.875	1.875	0.000	0.000	0.000
26	6.708	9.208	9.208	9.208	9.208	9.208	2.500	0.000	0.000
27	4.208	4.208	4.208	4.208	4.208	4.208	0.000	0.000	0.000
28	2.500	5.000	5.000	5.000	5.000	5.000	2.500	0.000	0.000
29	0.000	2.000	2.000	2.000	2.000	2.000	2.000	0.000	0.000
30	6.708	7.208	7.208	7.208	7.208	7.208	0.500	0.000	0.000
31	4.833	7.333	7.333	7.333	7.333	7.333	2.500	0.000	0.000
32	1.875	1.875	1.875	1.875	1.875	1.875	0.000	0.000	0.000
33	6.708	9.208	9.208	9.208	9.208	9.208	2.500	0.000	0.000
34	4.208	4.208	4.208	4.208	4.208	4.208	0.000	0.000	0.000
35	2.500	5.000	5.000	5.000	5.000	5.000	2.500	0.000	0.000

7.5. AIM RESULTS AND ADJUSTMENTS

7.5.1. Modeling Results

The output results from AIM provide the number of Level A and Level B harassment takes for each species, by season, modeled region, and survey type that exceeded the specific threshold considered. Following the AIM runs, typically the resulting “ping-histories” or the individual received level values (in pressure or SPL units) for each of the modeled animats are available to be examined and summed into energy (SEL) units as needed. For this analysis, the TL modeling provided to the AIM model included both SPL and SEL values, so the received levels in the correct units are readily available without additional calculations. The individual animat’s SEL ping histories are then examined and summed for each animat to determine its total received energy, which is what is required to be compared to the threshold criteria. Note that nowhere in these calculations are any mitigation (e.g., ramp-ups or stopping transmissions) assumed or applied to the calculation. Finally, these results were then corrected to adjust for two parameters which were programmed into the modeling: (1) the density of animats/animals in the modeled area; and (2) the actual number of blocks that the model examined in each modeled region. As discussed previously, the animal densities used in the AIM modeling were deliberately kept high to ensure that a statistically valid result was obtained. Typically, these “modeled” densities are at least an order of magnitude greater than the actual marine mammal density present in the region. Therefore, the modeling result is corrected or scaled by the ratio of the actual density divided by the modeled density. The result of applying these two corrections to the AIM modeling is a set of three tables for each type of survey. **Tables E-19** through **E-21** are a representative example of these tables for the 2D seismic airgun surveys. Each of these three tables captures the seasonal and spatial variability of the results in the 21 columns representing the 21 modeling regions, while providing the estimated impacts or takes for a specific threshold. The three tables, therefore, each represent one of the thresholds of interest. They are: (1) potential Level A impacts (takes) based on the Southall et al. (2007) criteria for one block of 2D survey effort; (2) potential Level A impacts (takes) based on the historic 180 dB (SPL) criterion for one block of 2D survey effort; and (3) the potential Level B impacts (takes) based on the historic 160 dB (SPL) criterion for one block of 2D survey effort.

Table E-19

Potential Level A Takes (number of individuals) for One Block of 2D Seismic Airgun Survey Effort, Based on the Southall et al (2007) Injury Criteria

Common Name	Modeled Sites																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
ORDER CETACEA																					
Suborder Mysticeti (Baleen Whales)																					
Common minke whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sei whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bryde’s whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Blue whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fin whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
North Atlantic right whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Humpback whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)																					
Short-beaked common dolphin	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pygmy killer whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Short-finned pilot whale	0.003	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001
Long-finned pilot whale	0.001	0.000	0.008	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
Risso’s dolphin	0.000	0.000	0.036	0.000	0.000	0.000	0.000	0.044	0.000	0.000	0.000	0.000	0.044	0.000	0.000	0.000	0.000	0.000	0.036	0.000	0.000
Northern bottlenose whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pygmy sperm whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dwarf sperm whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Atlantic white-sided dolphin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fraser's dolphin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sowerby’s beaked whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Blainville’s beaked whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Gervais’ beaked whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
True’s beaked whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Killer whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Melon-headed whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor porpoise	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sperm whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
False killer whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pantropical spotted dolphin	0.000	0.000	0.000	0.009	0.000	0.000	0.009	0.000	0.009	0.000	0.000	0.009	0.000	0.000	0.009	0.000	0.009	0.009	0.000	0.009	0.000
Clymene dolphin	0.000	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.004	0.004	0.000	0.004	0.000
Striped dolphin	0.000	0.000	0.000	0.011	0.000	0.000	0.084	0.000	0.011	0.000	0.000	0.022	0.000	0.000	0.020	0.000	0.011	0.011	0.000	0.011	0.000
Atlantic spotted dolphin	0.000	0.000	0.000	0.117	0.000	0.000	0.063	0.000	0.081	0.000	0.000	0.075	0.000	0.000	0.009	0.000	0.001	0.001	0.000	0.107	0.000
Spinner dolphin:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rough-toothed dolphin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bottlenose dolphin	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cuvier’s beaked whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000
ORDER SIRENIA																					
West Indian manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA																					
Suborder Pinnipedia																					
Hooded seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table E-20

Potential Level A Takes (number of individuals) for One Block of 2D Seismic Airgun Survey Effort, Based on the Historic NMFS Criterion (180 dB)

Common Name	Modeled Sites																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
ORDER CETACEA																					
Suborder Mysticeti (Baleen Whales)																					
Common minke whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sei whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bryde’s whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Blue whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fin whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
North Atlantic right whale	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Humpback whale	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)																					
Short-beaked common dolphin	0.012	0.019	0.245	0.036	0.142	0.011	0.016	0.243	0.300	0.049	0.008	0.012	0.250	0.215	0.010	0.033	0.010	0.018	0.073	0.293	0.046
Pygmy killer whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Short-finned pilot whale	0.002	0.037	0.247	0.003	0.001	0.001	0.020	0.244	0.033	0.002	0.000	0.017	0.150	0.034	0.019	0.005	0.001	0.029	0.160	0.000	0.001
Long-finned pilot whale	0.001	0.009	0.022	0.000	0.000	0.000	0.006	0.024	0.007	0.001	0.000	0.005	0.015	0.004	0.007	0.001	0.000	0.007	0.011	0.000	0.000
Risso’s dolphin	0.010	0.017	0.103	0.014	0.049	0.001	0.019	0.126	0.025	0.000	0.000	0.033	0.127	0.035	0.000	0.035	0.000	0.008	0.103	0.014	0.035
Northern bottlenose whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pygmy sperm whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dwarf sperm whale	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Atlantic white-sided dolphin	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fraser's dolphin	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sowerby’s beaked whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Blainville’s beaked whale	0.000	0.001	0.003	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.001	0.002	0.000	0.000
Gervais’ beaked whale	0.000	0.001	0.003	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.001	0.002	0.000	0.000
True’s beaked whale	0.000	0.001	0.003	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.001	0.002	0.000	0.000
Killer whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Melon-headed whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor porpoise	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sperm whale	0.000	0.005	0.014	0.000	0.000	0.000	0.006	0.007	0.000	0.000	0.000	0.007	0.007	0.000	0.003	0.007	0.000	0.000	0.000	0.000	0.000
False killer whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pantropical spotted dolphin	0.005	0.007	0.021	0.020	0.015	0.004	0.006	0.021	0.022	0.021	0.004	0.005	0.022	0.026	0.006	0.006	0.006	0.006	0.021	0.022	0.020
Clymene dolphin	0.002	0.003	0.010	0.009	0.007	0.002	0.003	0.010	0.011	0.010	0.002	0.002	0.010	0.008	0.003	0.003	0.003	0.003	0.010	0.011	0.010
Striped dolphin	0.006	0.072	0.221	0.024	0.022	0.005	0.052	0.025	0.027	0.025	0.004	0.012	0.203	0.026	0.013	0.075	0.008	0.007	0.025	0.027	0.025
Atlantic spotted dolphin	0.000	0.064	0.179	0.260	0.211	0.000	0.039	0.082	0.203	0.232	0.000	0.040	0.191	0.252	0.006	0.070	0.001	0.001	0.011	0.266	0.176
Spinner dolphin:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rough-toothed dolphin	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Bottlenose dolphin	0.005	0.017	0.350	0.353	0.049	0.005	0.083	0.356	0.035	0.033	0.004	0.074	0.464	0.274	0.010	0.107	0.007	0.110	0.417	0.217	0.261
Cuvier’s beaked whale	0.000	0.010	0.019	0.000	0.000	0.000	0.007	0.017	0.000	0.000	0.000	0.006	0.008	0.000	0.007	0.009	0.000	0.006	0.017	0.000	0.000
ORDER SIRENIA																					
West Indian manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA																					
Suborder Pinnipedia																					
Hooded seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table E-21

Potential Level B Takes (number of individuals) for One Block of 2D Seismic Airgun Survey Effort, Based on the Historic NMFS Criterion (160 dB)

Common Name	Modeled Sites																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
ORDER CETACEA																					
Suborder Mysticeti (Baleen Whales)																					
Common minke whale	0.001	0.001	0.000	0.000	0.003	0.001	0.001	0.000	0.000	0.004	0.001	0.001	0.000	0.004	0.000	0.000	0.000	0.001	0.000	0.000	0.003
Sei whale	0.002	0.003	0.010	0.009	0.007	0.002	0.002	0.010	0.010	0.010	0.002	0.001	0.010	0.007	0.003	0.003	0.002	0.003	0.010	0.010	0.009
Bryde’s whale	0.002	0.003	0.009	0.010	0.007	0.002	0.002	0.009	0.010	0.010	0.002	0.001	0.010	0.008	0.003	0.003	0.003	0.003	0.009	0.010	0.009
Blue whale	0.003	0.004	0.009	0.010	0.008	0.003	0.003	0.009	0.010	0.010	0.002	0.003	0.010	0.008	0.003	0.003	0.003	0.004	0.009	0.010	0.010
Fin whale	0.004	0.004	0.040	0.011	0.010	0.003	0.004	0.008	0.051	0.009	0.003	0.003	0.040	0.010	0.003	0.020	0.004	0.004	0.008	0.016	0.010
North Atlantic right whale	0.000	0.000	0.000	0.142	0.039	0.000	0.000	0.003	0.016	0.014	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.059	0.012
Humpback whale	0.015	0.024	0.058	0.033	0.059	0.012	0.016	0.059	0.052	0.088	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)																					
Short-beaked common dolphin	1.182	1.882	24.008	3.566	13.956	1.050	1.568	23.791	29.431	4.814	0.810	1.138	24.514	21.043	0.941	3.216	1.028	1.794	7.199	28.708	4.464
Pygmy killer whale	0.003	0.005	0.010	0.009	0.010	0.003	0.003	0.010	0.010	0.012	0.002	0.003	0.009	0.008	0.002	0.004	0.003	0.003	0.010	0.011	0.009
Short-finned pilot whale	0.240	3.668	24.254	0.324	0.125	0.062	1.962	23.899	3.197	0.156	0.025	1.666	14.658	3.365	1.875	0.482	0.076	2.886	15.713	0.047	0.138
Long-finned pilot whale	0.080	0.917	2.144	0.000	0.029	0.021	0.611	2.384	0.677	0.052	0.008	0.519	1.467	0.406	0.716	0.129	0.024	0.666	1.055	0.026	0.009
Risso’s dolphin	0.968	1.678	10.082	1.398	4.778	0.061	1.856	12.365	2.456	0.043	0.023	3.203	12.472	3.470	0.047	3.421	0.028	0.818	10.099	1.343	3.452
Northern bottlenose whale	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Pygmy sperm whale	0.008	0.010	0.000	0.000	0.014	0.008	0.011	0.000	0.000	0.015	0.008	0.010	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.014
Dwarf sperm whale	0.025	0.030	0.061	0.025	0.042	0.025	0.034	0.061	0.017	0.045	0.023	0.029	0.061	0.049	0.027	0.027	0.020	0.025	0.061	0.018	0.041
Atlantic white-sided dolphin	0.035	0.000	0.062	0.000	0.000	0.008	0.000	0.020	0.006	0.000	0.007	0.000	0.020	0.019	0.018	0.018	0.013	0.000	0.014	0.012	0.000
Fraser's dolphin	0.003	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000
Sowerby’s beaked whale	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001
Blainville’s beaked whale	0.001	0.138	0.260	0.000	0.001	0.001	0.100	0.231	0.000	0.001	0.001	0.084	0.115	0.001	0.097	0.124	0.000	0.090	0.237	0.000	0.001
Gervais’ beaked whale	0.001	0.138	0.260	0.000	0.001	0.001	0.100	0.231	0.000	0.001	0.001	0.084	0.115	0.001	0.097	0.124	0.000	0.090	0.237	0.000	0.001
True’s beaked whale	0.001	0.138	0.260	0.000	0.001	0.001	0.100	0.231	0.000	0.001	0.001	0.084	0.115	0.001	0.097	0.124	0.000	0.090	0.237	0.000	0.001
Killer whale	0.003	0.004	0.008	0.003	0.008	0.003	0.003	0.008	0.003	0.011	0.002	0.003	0.008	0.005	0.005	0.004	0.004	0.003	0.008	0.002	0.012
Melon-headed whale	0.003	0.005	0.012	0.012	0.010	0.003	0.003	0.012	0.012	0.012	0.002	0.003	0.011	0.010	0.004	0.004	0.003	0.003	0.012	0.013	0.009
Harbor porpoise	0.022	0.021	0.073	0.000	0.016	0.009	0.010	0.040	0.009	0.053	0.002	0.002	0.008	0.007	0.018	0.024	0.016	0.007	0.028	0.017	0.011
Sperm whale	0.008	0.502	1.384	0.003	0.005	0.006	0.553	0.708	0.002	0.005	0.005	0.696	0.696	0.003	0.340	0.700	0.008	0.009	0.014	0.002	0.005
False killer whale	0.003	0.005	0.016	0.018	0.010	0.003	0.003	0.016	0.004	0.012	0.002	0.003	0.016	0.006	0.004	0.005	0.003	0.003	0.016	0.003	0.009
Pantropical spotted dolphin	0.498	0.676	2.083	1.940	1.451	0.383	0.543	2.038	2.198	2.011	0.347	0.472	2.118	2.528	0.587	0.614	0.632	0.587	2.038	2.172	2.003
Clymene dolphin	0.238	0.323	0.995	0.927	0.693	0.183	0.259	0.974	1.050	0.961	0.166	0.225	1.012	0.829	0.281	0.293	0.302	0.281	0.974	1.037	0.957
Striped dolphin	0.603	7.028	21.640	2.346	2.164	0.463	5.105	2.464	2.658	2.432	0.420	1.170	19.917	2.589	1.307	7.335	0.764	0.710	2.464	2.625	2.421
Atlantic spotted dolphin	0.047	6.291	17.501	25.444	20.654	0.036	3.830	8.064	19.944	22.762	0.033	3.964	18.751	24.709	0.583	6.814	0.060	0.055	1.107	26.046	17.263
Spinner dolphin:	0.002	0.003	0.009	0.009	0.007	0.002	0.002	0.009	0.010	0.009	0.002	0.002	0.010	0.008	0.003	0.003	0.003	0.003	0.009	0.010	0.009
Rough-toothed dolphin	0.021	0.029	0.049	0.054	0.067	0.021	0.026	0.049	0.086	0.056	0.019	0.024	0.047	0.037	0.022	0.026	0.027	0.020	0.049	0.088	0.047
Bottlenose dolphin	0.501	1.684	34.290	34.629	4.811	0.473	8.098	34.882	3.385	3.267	0.394	7.267	45.474	26.882	0.982	10.488	0.680	10.751	40.828	21.279	25.572
Cuvier’s beaked whale	0.005	0.965	1.818	0.002	0.004	0.005	0.698	1.620	0.002	0.004	0.005	0.588	0.804	0.004	0.677	0.868	0.003	0.629	1.657	0.002	0.004
ORDER SIRENIA																					
West Indian manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA																					
Suborder Pinnipedia																					
Hooded seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Similar tables were produced for each of the seismic airgun surveys and non-airgun HRG surveys to be conducted including:

Seismic airgun surveys

- 2D seismic surveys;
- 3D seismic surveys;
- WAZ seismic surveys;
- VSP seismic surveys; and
- HRG surveys (90 in^3 airgun).

Non-airgun HRG surveys

- Boomer HRG marine mineral surveys;
- Boomer HRG renewable energy surveys;
- Side-scan sonar HRG marine mineral surveys;
- Side-scan sonar HRG renewable energy surveys;
- Chirp subbottom profiler HRG marine mineral surveys;
- Chirp subbottom profiler HRG renewable energy surveys;
- Multibeam HRG marine mineral surveys; and
- Multibeam HRG renewable energy surveys.

For the non-airgun HRG surveys, even though the individual surveys are typically conducted in roughly square nautical mile areas, all of the above tables were presented in a "per block" format to be consistent with the airgun surveys. Also, the LOE tables for these non-airgun surveys have been kept in that format.

Each of these "per block" survey results were multiplied by the appropriate LOE to estimate the number of incidental takes by species by modeled area for each year. Total annual takes are summarized in the following tables in the **Attachment** to this appendix:

All Surveys (seismic airgun and non-airgun HRG)

- Table Attachment E-1: Level A incidental take using Southall criteria
- Table Attachment E-2: Level A incidental take using historic NMFS criterion (180 dB SPL)
- Table Attachment E-3: Level B incidental take using historic NMFS criterion (160 dB SPL)

All seismic airgun surveys

- Table Attachment E-4: Level A incidental take using Southall criteria
- Table Attachment E-5: Level A incidental take using historic NMFS criterion (180 dB SPL)
- Table Attachment E-6: Level B incidental take using historic NMFS criterion (160 dB SPL)

All non-airgun HRG surveys

- Table Attachment E-7: Level A incidental take using Southall criteria
- Table Attachment E-8: Level A incidental take using historic NMFS criterion (180 dB SPL)
- Table Attachment E-9: Level B incidental take using historic NMFS criterion (160 dB SPL)

Supporting tables for each year and survey type are available on the BOEM website at: http://www.boem.gov/Oil-and-Gas-Energy-Program/GOMR/GandG.aspx.

In general, due to their significant LOE and strong transmission signal, for any given year the combination of 2D and 3D surveys, account for about 90-95 percent of all takes, while all of the non-airgun survey efforts result in less than about 5 percent of takes for any given year. This is due to their lower source levels, beam patterns, and significantly lower LOE.

7.5.2. Discussion of the Uncertainty of the Modeling Effort

This section briefly discusses the level of uncertainty or error that may be included in the calculations. This section addresses the issue in a general way and also discusses the limitations of any similar analysis based on the overall intent of the analysis and the safeguards used during its completion.

The analysis as described in this appendix and **Appendix D** used the best available state-of-the-art acoustic models and databases for determining acoustic propagation and source characteristics. Similarly, the marine mammal data (i.e., including density and distribution data, as well as all animal movement data) are the best currently available and are constantly being updated and improved as new material and data are published. The final computation or software component used was the AIM model. Essentially, AIM is a sophisticated and complex record keeping program, which uses correct statistical analyses and sampling to integrate the various components that constitute its input (i.e., source parameters, acoustic propagation parameters, and the animal distribution and movement parameters) and provide the estimates of the impacts to the modeled animals. Each of these analysis tools has been tested and verified against known scenarios and each has demonstrated reasonable levels of accuracy based on current theories and databases. In 2006, the Center for Independent Experts (CIE) conducted a review and assessment of AIM and concluded that AIM is a credible tool for developing application models (Independent System for Peer Review, 2006). Additionally, when multiple inputs parameters, data and techniques were available, the more conservative value was generally selected, with the result that the analysis overall produced a conservative (i.e., high) level of potential impacts based on the knowledge available.

The task for this analysis was to use the best science available to estimate the potential impacts to marine mammals for the proposed action. The goal is to predict potential impacts for a period out to 10 years, for a variety of sources, locations and times (i.e., seasons), which have only been identified generally, in an acoustic propagation environment that changes daily or more frequently depending on the weather, with a highly variable and mobile animal population. Currently, the only methodology capable of even beginning to capture the variability identified in this task is to use representative conditions or averages of these variables to estimate the ultimate impact levels. This was the approach used in this analysis and even so, tens and possible hundreds of millions calculations were needed to produce the results provided here. Ultimately, the accuracy of the task relies less on the accuracy of the models and more on the accuracy of the modeler's ability to estimate these representative or average conditions. To date, probably the best measurement of this need to estimate representative or average conditions is the annually reported level of impacts for any given year of operations; as compared to that year's take authorization number. To the best of our knowledge, this has not been done officially, but anecdotal information and experience with years of annual reports has shown that typically the number of animals observed at sea is less than predicted, and their potential impacts appear lower since they are seldom observed near the sources.

As an example of the difficulty of this process, the following example may provide insight. In this example, the only variable allowed to change is the actual local density or distribution near an airgun array which is performing a 2D survey of a typical dolphin species. This species may have an average density of about one animal per square nautical mile, but on a particular day a large pod of 500 of those dolphins has congregated due to a prey species and that pod approaches to about one kilometer from the operational airgun array. Obviously, this event could cause more impacts for that day than any average calculation would show. However, if the estimated average density of 1 animal per square nautical mile is correct, over the average of a season or a year the actual number of impacts would approach the estimate because that same pod on average over time would be farther away from the operational source for most if not all of the remaining days and the average estimate of impacts for those days would exceed reality.

Finally, it should be noted that the results of this Programmatic EIS are preliminary and more refined estimates could be made in the future during the MMPA Incidental Take Authorization (ITA) process for individual surveys. At that time, details about acoustic systems, planned tracks and testing periods would be better known and could be used to refine the analysis.

8. REFERENCES CITED

Aguilar Soto, N., M.P. Johnson, P.T. Madsen, F. Diaz, I. Domínguez, A. Brito, and P.L. Tyack. 2008. Cheetahs of the deep sea: Deep foraging sprints in short-finned pilot whales off Tenerife (Canary Islands). Journal of Animal Ecology 77:936–947.

Alves, F., A. Dinis, I. Cascão, and L. Freitas. 2010. Bryde's whale (*Balaenoptera brydei*) stable associations and dive profiles: New insights into foraging behavior. Marine Mammal Science 26:202-212.

Alves, F., L. Freitas, and A. Dinis. 2006. Occurrence and diving behaviour of false killer whale off Madeira archipelago (NE Atlantic). In: ECS 2006, Gydnia, Poland.

Amano, M. and M. Yoshioka. 2003. Sperm whale diving behavior monitored using a suction-cup-attached TDR tag. Marine Ecology Progress Series 258:291-295.

American National Standard Institute. 1984. American National Standard Institute—American national standard preferred frequencies, frequency levels and band numbers for acoustic measurements. S1.6. Acoustical Society of America, New York, New York.

American National Standard Institute. 1986. American National Standard Institute—American National Standard Method for Measurement of Impulsive Noise. S12.7. Acoustical Society of America. New York, New York.

American National Standard Institute. 2004. American National Standard Institute—American national standard acoustic terminology. S1.1.Acoustical Society of America. New York, New York.

Anderson, R.C., R. Clark, P.T. Madsen, C. Johnson, J. Kiszka, and O. Breysse. 2006. Observations of Longman's Beaked Whale (*Indopacetus pacificus*) in the Western Indian Ocean. Aquatic Mammals 32:223-231.

Aoki, K., M. Amano, M. Yoshioka, K. Mori, D. Tokuda, and N. Miyazaki. 2007. Diel diving behavior of sperm whales off Japan. MEPS 349:277-287.

Archer II, F.I. and W.F. Perrin. 1999. Stenella coeruleoalba. Mammalian Species 603:1-9.

Bain, D.E., J.C. Smith, R. Williams, and D. Lusseau. 2006. Effects of vessels on behavior of southern resident killer whales (*Orcinus* spp.). NMFS Contract Report No. AB133F03SE0959 and AB133F04CN0040. 61 pp. Internet website: http://www.grrescue.com/Research%20library%20files/nmfsrep2003_4final.pdf. Accessed October 31, 2011.

Baird, R.W. 1994. Foraging behavior and ecology of transient killer whales (*Orcinus orca*). Ph.D. Thesis, Simon Fraser University, Vancouver, Canada. 159 pp.

Baird, R.W. 2005. Sightings of dwarf (*Kogia sima*) and pygmy (*K. breviceps*) sperm whales from the main Hawaiian Islands. Pacific Science 59:461-466.

Baird, R.W., J.F. Borsani, M.B. Hanson, and P.L. Tyack. 2002. Diving and night-time behavior of long-finned pilot whales in the Ligurian Sea. Marine Ecology Progress Series 237:301-305.

Baird, R.W., M.B. Hanson, and L.M. Dill. 2005. Factors influencing the diving behaviour of fish-eating killer whales: Sex differences and diel and interannual variation in diving rates. Can. J. Zool. 83:257-267.

Baird, R.W., A.D. Ligon, S.K. Hooker, and A.M. Gorgone. 2001. Subsurface and nighttime behaviour of pantropical spotted dolphins in Hawai'i. Can. J. Zool. 79:988-996.

Baird, R.W., D.L. Webster, D.J. McSweeney, A.D. Ligon, G.S. Schorr, and J. Barlow. 2006. Diving behaviour of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawai'i. Can. J. Zool. 84:1120-1128.

Baird, R.W., D.L. Webster, G.S. Schorr, D.J. McSweeney, and J. Barlow. 2008. Diel variation in beaked whale diving behavior. Marine Mammal Science 24:630-642.

Baker, C.S. and L.M. Herman. 1989. The behavioral responses of summering humpback whales to vessel traffic: Experimental and opportunistic observations. In. Kewalo Basin Marine Mammal Laboratory, Honolulu. 84 pp.

Barlow, J. 1995. The abundance of cetaceans in California waters: Part I. Ship surveys in summer and fall of 1991. U.S. National Marine Fisheries Service Fishery Bulletin 93:1-14.

Baumgartner, M.F. and B.R. Mate. 2003. Summertime foraging ecology of North Atlantic right whales. Marine Ecology-Progress Series 264:123-135.

Baumgartner, M.F., K.D. Mullin, L.N. May, and T.D. Leming. 2001. Cetacean habitats in the northern Gulf of Mexico. Fishery Bulletin Seattle 99:219-239.

Benoit-Bird, K.J. and W.W.L. Au. 2003. Prey dynamics affect foraging by a pelagic predator (*Stenella longirostris*) over a range of spatial and temporal scales. Behavioral Ecology and Sociobiology 53:364-373.

Bishop, G.C., W.T. Ellison, and L.E. Mellberg. 1987. A simulation model for high-frequency under-ice reverberation. J. Acoust. Soc. Am. 82:275-285.

Blix, A.S. and L.P. Folkow. 1995. Daily energy expenditure in free living minke whales. Acta Physiologica Scandinavica 153:61-66.

Brown, S.G. 1977. Some results of sei whale marking in the southern hemisphere. Rep. Int. Whal. Comm. Si1:39-43.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to Distance Sampling: Estimating abundances of biological populations. Oxford University Press, New York, NY.

Calambokidis, J., G.S. Schorr, G.H. Steiger, J. Francis, M. Bakhtiari, G. Marshall, E.M. Oleson, D. Gendron, K. Robertson. 2008. Insights into the Underwater Diving, Feeding, and Calling Behavior of Blue Whales from a Suction-Cup-Attached Video-Imaging Tag (CRITTERCAM). Marine Technology Society Journal 41:19-29.

Caldwell, D.K., M.C. Caldwell, and R.V. Walker. 1976. First records for Fraser's dolphin (*Lagenodelphis hosei*) in the Atlantic and the melon-headed whale (*Peponocephala electra*) in the western Atlantic. Cetology 25:4.

Cañadas, A., R. Sagarminaga, and T.S. Garcia. 2002. Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. Deep Sea Research Part I: Oceanographic Research Papers 49:2053-2073.

Charif, R.A., D.K. Mellinger, K.J. Dunsmore, and C.W. Clark. 2002. Estimated source levels of fin whale *(Balaenoptera physalus)* vocalizations: Adjustments for surface interference. Marine Mammal Science 18:81-98.

Chaudry, F.A. 2006. A comparison of east Australian humpback whale migratory behaviour between the northern and southern migrations. In: ECS 2006, Gydnia, Poland.

Chittleborough, R.G. 1953. Aerial observations of the humpback whale (*Megaptera nodosa*). Aust. J. Mar. Freshw. Res. 4:219-226.

Chu, K.C. 1988. Dive times and ventilation patterns of singing humpback whales (*Megaptera novaeangliae*). Can. J. Zool. 66:1322-1327.

Clapham, P.J. 1993. Social organization of humpback whales on a North Atlantic feeding ground. Symp. Zool. Soc. Lond. 66:131-145.

Coakes, A.K. and H. Whitehead. 2004. Social structure and mating system of sperm whales off northern Chile. Can J. Zool. 82:1360-1369.

Croll, D.A., A. Acevedo-Gutierrez, B.R. Tershy, and J. Urban-Ramirez. 2001. The diving behavior of blue and fin whales: Is dive duration shorter than expected based on oxygen stores? Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology 129:797-809.

Croll, D.A., B.R. Tershy, R.P. Hewitt, D.A. Demer, P.C. Fiedler, S.E. Smith, W. Armstrong, J.M. Popp, T. Kiekhefer, V.R. Lopez, J. Urban, and D. Gendron. 1998. An integrated approach to the foraging ecology of marine birds and mammals. Deep Sea Research II 45:1353-1371.

Cummings, W.C. 1985. Bryde's whale *Balaenoptera edeni* Anderson, 1878, pp. 137-154. In: S.H. Ridgway and R. Harrison (eds), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London.

Curren, K., N. Bose, and J. Lien. 1994. Swimming kinematics of a harbor porpoise (*Phocoena phocoena*) and an Atlantic white-sided dolphin (*Lagenorhynchus acutus*). Marine Mammal Science 10:485-492.

Dahlheim, M.E. and R.G. Towell. 1994. Occurrence and distribution of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in southeastern Alaska, with notes on an attack by killer whales (*Orcinus orca*). Marine Mammal Science 10:458-464.

Dalla Rosa, L., E.R. Secchi, Y.G. Maia, A.N. Zerbini, and M.P. Heide-Jørgensen. 2008. Movements of satellite-monitored humpback whales on their feeding ground along the Antarctic Peninsula. Polar Biology 31(7):771-781.

Davis R.W., G.A.J. Worthy, B. Würsig, S.K. Lynn, and F.I. Townsend. 1996. Diving behavior and at-sea movements of an Atlantic spotted dolphin in the Gulf of Mexico. Mar. Mamm. Sci. 12:569-581.

Davis, R.W., G.S. Fargion, N. May, T.D. Leming, M. Baumgartner, W.E. Evans, L.J. Hansen, and K. Mullin. 1998. Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. Marine Mammal Science 14:490-507.

Davis, R.W., N. Jaquet, D. Gendron, U. Markaida, G. Bazzino, and W. Gilly. 2007. Diving behavior of sperm whales in relation to behavior of a major prey species, the jumbo squid, in the Gulf of California, Mexico. Mar. Ecol. Prog. Ser. 333:291-302.

de Haro, J.C. and M.A. Iniguez. 1997. Ecology and behaviour of the Peale's dolphin, *Lagenorhynchus australis* (Peale, 1848), at Cabo Virgenes (52° 30'S, 68° 28'W), in Patagonia, Argentina. Rep. Int. Whal. Comm. 47:723-727.

Doi, T. 1974. Further development of whale sighting theory. In: W.E. Schevill (ed.), The Whale Problem: A status report. Harvard University Press, Cambridge, MA, pp 359-368.

Dolar. L. and W. Perrin. 2003. Dwarf sperm whale (*Kogia sima*) habitats in the Philippines, pp 44. In: 15th Biennial conference on the biology of marine mammals, Greensboro, NC.

Dolar, M.L.L., W.A. Walker, G.L. Kooyman, W.F. Perrin. 2003. Comparative feeding ecology of spinner dolphins (*Stenella longirostris*) and Fraser's dolphins (*Lagenodelphis hosei*) in the Sulu Sea. Marine Mammal Science 19:1-19.

Dolphin, W.F. 1987a. Ventilation and dive patterns of humpback whales, *Megaptera novaeangliae*, on their Alaskan feeding grounds. Can. J. Zool. 65:83-90.

Dolphin, W.F. 1987b. Dive behavior and estimated energy expenditure of foraging humpback whales in southeast Alaska. Can. J. Zool. 65:354-362.

Dolphin, W.F. 1988. Foraging dive patterns of humpback whales *Megaptera novaeangliae* in Southeast Alaska USA: A cost-benefit analysis. Can J Zool 66:2432-2441.

Edwards, E.F. 2006. Duration of unassisted swimming activity for spotted dolphin (*Stenella attenuata*) calves: implications for mother-calf separation during tuna purse-seine sets. Fishery Bulletin 104:125-135.

Ellison, W.T., C.W. Clark, and G.C. Bishop. 1987. Potential use of surface reverberation by bowhead whales, Balaena mysticetus, in under-ice navigation: Preliminary considerations. Rep. Int. Whal. Comm. 37:329-332.

Ellison, W.T., B.L. Southall, C.W. Clark, and A.S. Frankel. 2011. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conservation Biology, online version published December 19, 2011. DOI: 10.1111/j.1523-1739.2011.01803.x.

Evans, W.E. 1994. Common Dolphin, white bellied porpoise (*Delphnis delphis*, Linnaeus, 1758), pp. 191-224. In : S. Ridgway and R. Harrison R (eds), Handbook of Marine Mammals, Vol. 5. Academic Press, San Diego, CA.

Fertl, D., T.A. Jefferson, I.B. Moreno, A.N. Zerbini, and K.D. Mullin. 2003. Distribution of the Clymene dolphin *Stenella clymene*. Mammal Review 33:253-271.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. Journal of the Acoustical Society of America 111:2929-2940.

Finneran, J.J., C.E. Schlundt, and S. Ridgway. 2005. Temporary Shift in bottlenose dolphins (*Tursiops truncates*) exposed to mid-frequency tones. Journal of the Acoustical Society of America 118(4):2696-2705.

Fish, F.E. and J.J. Rohr. 1999. Review of Dolphin Hydrodynamics and Swimming Performance. Spawar Systems Center, San Diego, CA. 136 pp. + apps.

Ford, J.K.B. G.A. Ellis, D.R. Matkin, K.C. Balcomb, D. Briggs, and A.B. Morton. 2005. Killer whale attacks on minke whales: Prey capture and antipredator tactics. Marine Mammal Science 21:603-618.

Frankel, A.S., C.W. Clark, L.M. Herman, and C.M. Gabriele. 1995. Spatial Distribution, Habitat Utilization, and Social Interactions of Humpback Whales, *Megaptera novaeangliae*, off Hawai'i, determined using Acoustic and Visual Techniques. Can. J. Zool. 73:1134-1146.

Frankel, A.S., W.T. Ellison, and J. Buchanan. 2002. Application of the Acoustic Integration Model (AIM) to predict and minimize environmental impacts. IEEE Oceans 2002:1438-1443.

Gabriele, C.M., J.M. Straley, L.M. Herman, and R.J. Coleman. 1996. Fastest documented migration of a North Pacific humpback whale. Mar. Mamm. Sci. 12:457-464.

Gill, P.C. 2002. A blue whale (*Balaenoptera musculus*) feeding ground in a southern Australian coastal upwelling zone. Journal of Cetacean Research and Management 4:179-184.

Goldbogen, J., J. Calambokidis, R.E. Shadwick, E.M. Oleson, M.A. McDonald, and J.A. Hildebrand. 2006. Kinematics of foraging dives and lunge-feeding in fin whales. J. Exp. Biol. 209:1231-1244.

Goldbogen, J.A., J. Calambokidis, D.A. Croll, J.T. Harvey, K.M. Newton, E.M. Oleson, G. Schorr, and R.E. Shadwick. 2008. Foraging behavior of humpback whales: kinematic and respiratory patterns suggest a high cost for a lunge. Journal of Experimental Biology 211:3712-3719.

Greene, C.R., Jr. 1997. Physical Acoustic Measurements. In W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996 (LGL Report 2121-2, Section 3). LGL Ltd. report for BP Exploration (Alaska) Inc., Anchorage, AK and the National Marine Fisheries Service, Silver Spring, MD. 245 pp.

Harzen, S.E. 2002. Use of an electronic theodolite in the study of movements of the bottlenose dolphin (*Tursiops truncatus*) in the Sado Estuary, Portugal. Aquatic Mammals 28:251-260.

Heide-Jørgensen, M.P., D. Bloch, E. Stefansson, B. Mikkelsen, L.H. Ofstad, and R. Dietz. 2002. Diving behaviour of long-finned pilot whales *Globicephala melas* around the Faroe Islands. Wildlife Biology 8:307-313.

Heyning J.E. and W.F. Perrin. 1994. Evidence for two species of common dolphins (genus *Delphinus*) from the eastern North Pacific. Contributions in Science 442:1-35.

Hobson R.P. and A.R. Martin. 1996. Behaviour and dive times of Arnoux's beaked whales, *Berardius arnuxii*, at narrow leads in fast ice. Canadian Journal of Zoology 74:388-393.

Hohn, A., M. Scott, A. Westgate, J. Nicolas, and B. Whitaker. 1995. Radiotracking of a rehabilitated pygmy sperm whale. In: Eleventh Biennial Conference on the Biology of Marine Mammals, Orlando, FL. 55 pp.

Hooker, S.K. and R.W. Baird. 1999a. Deep-diving behaviour of the northern bottlenose whale, *Hyperoodon ampullatus* (Cetacea: Ziphiidae). Proceedings of the Royal Society of Biological Sciences: Series B. 266:671-676.

Hooker, S.K. and R.W. Baird. 1999b. Observations of Sowerby's beaked whales, *Mesoplodon bidens*, in the Gully, Nova Scotia. Canadian Field-Naturalist 113:273-277.

Hui, C.A. 1987. Power and speed of swimming dolphins. Journal of Mammalogy 68:126-132.

Independent System for Peer Review. 2006. Summary report: Review of Acoustic Integration Model (AIM) 25-27 September, 2006. 134 pp. Internet Website: http://www.nmfs.noaa.gov/pr/pdfs/permits/lfa_aim_review.pdf. Accessed November 1, 2011.

Jaquet, N., S. Dawson, and E. Slooten. 2000. Seasonal distribution and diving behaviour of male sperm whales off Kaikoura: Foraging implications. Canadian Journal of Zoology 78:407-419.

Jaquet, N. and D. Gendron. 2002. Distribution and relative abundance of sperm whales in relation to key environmental features, squid landings and the distribution of other cetacean species in the Gulf of California, Mexico. Marine Biology 141:591-601.

Jaquet, N. and H. Whitehead. 1999. Movements, distribution and feeding success of sperm whales in the Pacific Ocean, over scales of days and tens of kilometers. Aquatic Mammals 25:1-13.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico, Synthesis Report. 341 pp.

Johnson, M, P.T. Madsen, W.M.X. Zimmer, N. Aguilar de Soto, and P.L.Tyack. 2004. Beaked whales echolocate on prey. Proceedings of the Royal Society of London Series B-Biological Sciences 271:S383-S386.

Joyce, G., N. Øien, J. Calmabokidis, and J.C. Cubbage. 1989. Surfacing rates of minke whales in Norwegian waters. Rep. Int. Whal. Comm. 39:431-434.

Kastak, D., B.L. Southall, R.J. Schusterman, and C.R. Kastak. 2005. Underwater temporary threshold shift in pinnipeds: Effects of noise level and duration. Journal of the Acoustical Society of America 118(5):3154-3163.

Kastak, D., R.J. Schusterman, B.L. Southall, and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. Journal of the Acoustical Society of America 106(2):1142-1148.

Kastelein, R.A. and N.M. Gerrits. 1991. Swimming, diving, and respiration patterns of a Northern bottlenose whale (*Hyperoodon ampullatus*, Forster, 1770). Aquatic Mammals 17:20-30.

Kenney, R.D. and H.E. Winn. 1986. Cetacean high-use habitats of the northeast United States continental shelf. Fish. Bull. 84:345-357.

Klatsky, L.J., R.S. Wells, and J.C. Sweeney. 2007. Offshore bottlenose dolphins (*Tursiops truncatus*): movement and dive behavior near the Bermuda pedestal. Journal of Mammalogy 88:59-66.

Kooyman, G.L. and H.T. Andersen. 1969. Deep diving, pp 65-94. In: H.T. Andersen (ed.), Biology of marine mammals. Academic Press, New York, xii + 511 pp.

Kopelman, A.H. and S.S. Sadove. 1995. Ventilatory rate differences between surface-feeding and non-surface-feeding fin whales (*Balaenoptera physalus*) in the waters off eastern Long Island, New York, U.S.A., 1981-1987. Marine Mammal Science 11:200-208.

Kriete, B. 2002. Bioenergetic changes from 1986 to 2001 in the southern resident killer whale population, *Orcinus orca*. Orca Relief Citizens' Alliance. 26 pp.

Lagerquist, B.A., K.M. Stafford, and B.R. Mate. 2000. Dive characteristics of satellite-monitored blue whales (*Balaenoptera musculus*) off the central California coast. Marine Mammal Science 16:375-391.

Laurie, A.H. 1933. Some aspects of respiration in fin and blue whales. Discovery Reports 7:365-406.

Leatherwood, S. and D.K. Ljungblad. 1979. Nighttime swimming and diving behavior of a radio tagged spotted dolphin *Stenella attenuata*. Cetology 34:1-6.

Leatherwood, S., W.F. Perrin, V.L. Kirby, C.L. Hubbs, and M. Dahlheim. 1980. Distribution and Movements of Risso's Dolphin *Grampus griseus* in the Eastern North Pacific. Fishery Bulletin 77:951-964.

Ligon, A.D. and R.W. Baird. 2001. Diving behaviour of false killer whales off Maui and Lana'i, Hawai'i. In: 14th Biennial Conference on the Biology of Marine Mammals, Vancouver, Canada.

Lockyer, C. 1976. Body Weights of Some Species of Large Whales. J. Cons. int. Explor. Mer. 36:259-273.

Lockyer, C. 1997. Diving behaviour of the sperm whale in relation to feeding. Bulletin de l'Institut Royal des Sciences Naturelles de Belgique Biologie 67:47-52.

Lockyer, C. and R.J. Morris. 1986. The history and behavior of a wild, sociable bottlenose dolphin (*Tursiops truncatus*) off the north coast of Cornwall (England, UK). Aquatic Mammals 12:3-16.

Lockyer, C. and R. Morris. 1987. Observations on diving behavior and swimming speeds in a wild juvenile *Tursiops truncatus*. Aquatic Mammals 13:31-35.

Loughlin, T.R. 1982. Observations of *Mesoplodon stejnegeri* in the central Aleutian Islands, Alaska. Journal of Mammalogy 63:697-700.

MacLeod, C.D. and A.F. Zuur. 2005. Habitat utilization by Blainville's beaked whales off Great Abaco, northern Bahamas, in relation to seabed topography. Marine Biology 147:1-11.

Madsen P.T. 2005. Marine mammals and noise: Problems with root-mean-squared sound pressure level for transients. Journal of the Acoustical Society of America 117:3952-3957.

Mate, B.R., R. Gisiner, and J. Mobley. 1998. Local and migratory movements of Hawaiian humpback whales tracked by satellite telemetry. Can. J. Zool. 76:863-868.

Mate, B.R., B.A. Lagerquist, and J. Calambokidis. 1999. Movements of North Pacific blue whales during the feeding season off southern California and their southern fall migration. Marine Mammal Science 15:1246-1257.

Mate, B.R., B.A. Lagerquist, M. Winsor, J. Geraci, and J.H. Prescott. 2005. Movements and dive habits of a satellite-monitored longfinned pilot whale (*Globicephala melas*) in the northwest Atlantic. Marine Mammal Science 21:136-144.

Mate, B.R., S.L. Nieukirk, and S.D. Kraus. 1997. Satellite-monitored movements of the northern right whale. Journal of Wildlife Management 61:1393-1405.

Mate, B.R., K.A. Rossbach, S.L. Nieukirk, R.S. Wells, A.B. Irvine, M.D. Scott, and A.J. Read. 1995. Satellite-monitored movements and dive behaviour of a bottlenose dolphin (*Tursiops truncatus*) in Tampa Bay, Florida. Mar. Mamm. Sci. 11:452-463.

Mate, B.R., K.M. Stafford, R. Nawojchik, and J.L Dunn. 1994. Movements and dive behavior of a satellite-monitored Atlantic white-sided dolphin (*Lagenorhynchus acutus*) in the Gulf of Maine. Marine Mammal Science 10:116-121.

May-Collado, L. and A.M. Ramirez. 2005. Occurrence and behavioral patterns of the spotted coastal dolphin *Stenella attenuata* (Cetacea : Delphinidae) in the Gulf of Papagayo, Costa Rica. Revista De Biologia Tropical 53:265-276.

May-Collado, L., T. Gerrodette, J. Calambokidis, K. Rasmussen,and I. Sereg. 2005. Patterns of cetacean sighting distribution in the Pacific Exclusive Economic Zone of Costa Rica based on data collected from 1979-2001. Revista De Biologia Tropical 53:249-263.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaengliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. APPEA J. 38:692-707.

Miller, P.J.O., M.P. Johnson, P.L. Tyack, and E.A. Terray. 2004. Swimming gaits, passive drag and buoyancy of diving sperm whales *Physeter macrocephalus*. Journal of Experimental Biology 207:1953-1967.

Miyazaki, N. and S. Wada. 1978. Frasers Dolphin *Lagenodelphis hosei* in the Western North Pacific. Scientific Reports of the Whales Research Institute Tokyo:231-244.

Morris, C. and U. Tscherter. 2006. Site fidelity of individual minke whales (*Balaenoptera acutorostrata*) in the St. Lawrence estuary. ECS 2006, Gydnia, Poland.

Mullin, K.D., W. Hoggard, and L.J. Hansen. 2004. Abundance and seasonal occurence of cetaceans in outer continental shelf and slope waters of the North-central and Northwestern Gulf of Mexico. Gulf of Mexico Science 1:62-73.

National Research Council. 2003. Ocean noise and marine mammals. National Academies Press, Washington, D.C.

National Research Council. 2005. Marine mammal populations and ocean noise: Determining when noise causes biologically significant effects. The National Academies Press, Washington, DC. 99 pp + apps. Internet website: http://www.nap.edu/openbook.php?record_id=11147&page=1 Accessed September 6, 2011.

Nawojchik, R., D.J. St. Aubin, and A. Johnson. 2003. Movements and dive behavior of two stranded, rehabilitated long-finned pilot whales (*Globicephala melas*) in the northwest Atlantic. Marine Mammal Science 19:232-239.

Norris, K.S. and J.H. Prescott. 1961. Observations on Pacific cetaceans of Californian and Mexican waters. University of California Publications in Zoology 63:291-402.

Norris, K.S. and T.P. Dohl. 1980. Behavior of the Hawaiian Spinner Dolphin, *Stenella longirostris*. Fish. Bull. 77:821-849.

Nøttestad, L., A. Ferno, and B.E.Axelsen. 2002. Digging in the deep: Killer whales' advanced hunting tactic. Polar Biology 25:939-941.

Nowacek, D.P., M.P. Johnson, and P.L. Tyack. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society of London Series B-Biological Sciences 271:227-231.

Øien, N., L. Folkow, and C. Lydersen. 1990. Dive Time Experiments on Minke Whales in Norwegian Waters During the 1988 Season. Rep. Int. Whal. Comm. 40:337-341.

Olavarria, C., L.A. Aguayo, and R. Bernal. 2001. Distribution of Risso's dolphin (*Grampus griseus*, Cuvier 1812) in Chilean waters. Revista de Biologia Marina y Oceanografia 36:111-116.

Olsen, E. and J.C. Holst. 2001. A note on common minke whale (*Balaenoptera acutorostrata*) diets in the Norwegian Sea and the North Sea. Journal of Cetacean Research and Management 3:179-183.

Olsen, E., W.P. Budgell, E. Head, L. Kleivane, L. Nottestad, R. Prieto, M.A. Silva, H. Skov, G.A. Vikingsson, G. Waring, and N. Oien. 2009. First Satellite-Tracked Long-Distance Movement of a Sei Whale (*Balaenoptera borealis*) in the North Atlantic. Aquatic Mammals 35:313-318.

Otani, S. 2000. Diving behavior and swimming speed of a free-ranging harbor porpoise, *Phocoena phocoena*. Marine Mammal Science 16:811-814.

Palka, D. and M. Johnson, (eds.). 2007. Cooperative research to study dive patterns of sperm whales in the Atlantic Ocean. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico Region, New Orleans, LA. OCS Study MMS2007-033. 49 pp.

Panigada, S., G. Nortarbartolo di Sciara, M. Panigada, S. Airoldi, J. Borsani, and M. Jahoda. 2005. Fin whales (*Balaenoptera physalus*) summering in the Ligurian Sea: Distribution, encounter rate, mean group size and relation to physiographic variables. Journal of Cetacean Research and Management 7:137-145.

Panigada, S., M. Zanardelli, S. Canese, and M. Jahoda. 1999. How Deep Can Baleen Whales Dive? Marine Ecology Progress Series 187:309-311.

Papastavrou, V., S.C. Smith, and H. Whitehead. 1989. Diving behavior of the sperm whale *Physeter macrocephalus* off the Galapagos Islands, Ecuador. Can. J. Zool. 67:839-846.

Parks, S.E. and P.L. Tyack. 2005. Sound production by North Atlantic right whales (*Eubalaena glacialis*) in surface active groups. Journal of the Acoustical Society of America 117:3297-3306.

Ramirez, N., D. Schulte, and J. Kennedy. 2006. Finback whale (*Balaenoptera physalus*) behavior on Jeffreys Ledge in the Gulf Of Maine. ECS 2006, Gydnia, Poland.

Reilly, S.B. and V.G. Thayer. 1990. Blue Whale *Balaenoptera musculus* Distribution in the Eastern Tropical Pacific. Marine Mammal Science 6:265-277.

Richardson, W.J., C.R. Greene Jr., C.I. Malme, and D.H. Thomson. 1995. Marine Mammals and Noise. Academic Press, San Diego, CA.

Ridoux, V., C. Guinet, C. Liret, P. Creton, R. Steenstrup, and G. Beauplet. 1997. A video sonar as a new tool to study marine mammals in the wild: Measurements of dolphin swimming speed. Mar. Mamm. Sci. 13:196-206.

Ritter, F. and B. Brederlau. 1999. Behavioural observations of dense beaked whales (*Mesoplodon densirostris*) off La Gomera, Canary Islands (1995-1997). Aquatic Mammals 25:55-61.

Robison, B.H. and J.E. Craddock. 1983. Mesopelagic Fishes Eaten by Frasers Dolphin *Lagenodelphis hosei*. Fishery Bulletin 81:283-290.

Rohr, J.J., F.E. Fish, and J.W. Gilpatrick. 2002. Maximum swim speeds of captive and free-ranging delphinids: Critical analysis of extraordinary performance. Marine Mammal Science 18:1-19.

Schilling, M.R., I. Seipt, M.T. Weinrich, A.E. Kuhlberg, and P.J. Clapham. 1992. Behavior of individually-identified sei whales *Balaenoptera borealis* during an episodic influx into the southern gulf of maine in 1986. Fish. Bull. 90:749-755.

Scott, M.D., A.A. Hohn, A.J. Westgate, J.R. Nicolas, B.R. Whitaker, and W.B. Campbell. 2001. A note on the release and tracking of a rehabilitated pygmy sperm whale (*Kogia breviceps*). Journal of Cetacean Research and Management 3:87-94.

Scott, T.M. and S.S. Sadove. 1997. Sperm Whale, *Physeter macrocephalus*, sightings in the shallow shelf waters off Long Island, New York. Mar. Mamm. Sci. 13:317-320.

Selzer, L.A. and P.M. Payne. 1988. The distribution of white-sided (*Lagenorhynchus acutus*) and common dolphins (*Delphinus delphis*) vs. environmental features of the continental shelf of the northeastern United States. Mar. Mamm. Sci. 4:141-153.

Shane, S.H. 1995. Behavior patterns of pilot whales and Risso's dolphins off Santa Catalina Island, California. Aquatic Mammals 21:195-197.

Silber, G.K., M.W. Newcomer, and H.M. Pérez-Cortés. 1990. Killer Whales (*Ornicus orca*) attack and kill a Bryde's whale (*Balaenoptera edeni*). Can. J. Zool. 68:1603-1606.

Silber, G.K., M.W. Newcomer, P.C. Silber, M.H. Pérez-Cortés, and G.M. Ellis. 1994. Cetaceans of the northern Gulf of California: Distribution, occurrence, and relative abundance. Marine Mammal Science 10:283-298.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33:411-521.

Stern, S.J. 1992. Surfacing rates and surfacing patterns of minke whales (*Balaenoptera acutorostrata*) off central California, and the probability of a whale surfacing within visual range. The distribution of white-sided (*Lagenorhynchus acutus*) and common dolphins (*Delphinus delphis*) vs. environmental features of the continental shelf of the northeastern United States 42:379-385.

Stockin, K.A., R.S. Fairbairns, E.C.M. Parsons, D.W. Sims. 2001. Effects of diel and seasonal cycles on the dive duration of the minke whale (*Balaenoptera acutorostrata*). Journal of the Marine Biological Association of the United Kingdom 81:189-190.

Stone, G.S., S.K. Katona, M. Mainwaring, J.M. Allen, H.D. Corbett. 1992. Respiration and surfacing rates of fin whales (*Balaenoptera physalus*) observed from a lighthouse tower. Rep. Int. Whal. Comm. 42:739-745.

Teloni ,V., J.P. Mark, M.J.O. Patrick, and M.T. Peter. 2008. Shallow food for deep divers: Dynamic foraging behavior of male sperm whales in a high latitude habitat. Journal of Experimental Marine Biology and Ecology 354:119-131.

University of Washington Applied Physics Laboratory. 1994. APL UW High Frequency Ocean Environmental Acoustic Models Handbook. APL UW Technical Report 9407. Internet website: http://staff.washington.edu/dushaw/epubs/APLTM9407.pdf

U.S. Dept. of the Navy. 2001. Final Overseas Environmental Impact Statement and Environmental Impact Statement for SURTASS/LFA. Dept. of the Navy, Southern Division, Naval Facilities Engineering Command, North Charleston, SC.

U.S. Dept. of the Navy. 2007a. Final Supplemental Environmental Impact Statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS/LFA) Sonar.

U.S. Dept. of the Navy. 2007b. Navy OPAREA Density Estimates (NODE) for the GOMEX OPAREA. Dept. of the Navy, Naval Facilities Engineering Command, Atlantic: Norfolk, VA. Contract N62470-02-D-9997, Task Order 0046. Prepared by GeoMarine Inc., August 2007.

U.S. Dept. of the Navy. 2008. Final Atlantic Fleet Active Sonar Training Environmental Impact Statement/ Overseas Environmental Impact Statement. Dept. of the Navy, December 2008.

Wahlberg, M. 2002. The acoustic behaviour of diving sperm whales observed with a hydrophone array. Journal of Experimental Marine Biology and Ecology 281:53-62.

Watkins, W.A. 1981. Activities and Underwater Sounds of Fin Whales. The Scientific Reports of the Whales Research Institute:83-117.

Watkins, W.A., M.A. Daher, N.A. DiMarzio, A. Samuels, D. Wartzok, K.M. Fristrup, D.P. Gannon, P.W. Howey, R.R. Maiefski, and T.R. Spradlin. 1999. Sperm whale surface activity from tracking by radio and satellite tags. Marine Mammal Science 15:1158-1180.

Watkins, W.A., M.A. Daher, N.A. DiMarzio, A. Samuels, D. Wartzok, K.M. Fristrup, P.W. Howey, and R.R. Maiefski. 2002. Sperm whale dives tracked by radio tag telemetry. Marine Mammal Science 18:55-68.

Watkins, W.A., M.A. Daher, K. Fristrup, and G. Notarbartolo di Sciara. 1994. Fishing and Acoustic Behavior of Fraser's Dolphin (*Lagenodelphis hosei*) near Dominica, Southeast Caribbean. Caribbean Journal of Science 30:76-82.

Weinrich, M.T., C.R. Belt, and D. Morin. 2001. Behavior and ecology of the Atlantic white-sided dolphin (*Lagenorhynchus acutus*) in coastal New England waters. Marine Mammal Science 17:231-248.

Weir, C.R. 2000. Sightings of beaked whales species (Cetacea: Ziphiidae) in the waters to the north and west of Scotland and the Faroe Islands. Eur. Res. Cet. 14:239-243.

Wells, R.S., H.L. Rhinehart, P. Cunningham, J. Whaley, M. Baran, C. Koberna, and D.P. Costa. 1999. Long distance offshore movements of bottlenose dolphins. Mar. Mamm. Sci. 15:1098-1114.

Westgate, A.J., A.J.Read, P. Berggren, H.N. Koopman, and D.E. Gaskin. 1995. Diving behaviour of harbour porpoises, *Phocoena phocoena*. Canadian Journal of Fisheries and Aquatic Sciences 52:1064-1073.

Whitehead, H., S.C. Smith, and V. Papastavrou. 1989. Diving behavior of the sperm whales, (*Physeter macrocephalus*), off the Galapagos Islands. Can. J. Zool. 67:839-846.

Whitehead, H., S. Brennan, and D. Grover. 1992. Distribution and Behavior of Male Sperm Whales on the Scotian Shelf, Canada. Canadian Journal of Zoology 70:912-918.

Williams, R., D.E. Bain, J.K.B. Ford, and A.W. Trites. 2002. Behavioural responses of male killer whales to a 'leapfrogging' vessel. Journal of Cetacean Research and Management 4:305-310.

Williams, T.M., R.W. Davis, L.A. Fuiman, J. Francis, B.B.J. Le, M. Horning, J. Calambokidis, D.A. Croll. 2000. Sink or swim: Strategies for cost-efficient diving by marine mammals. Science 288:133-136.

Winn, H.E., J.D. Goodyear, R.D. Kenney, and R.O. Petricig. 1995. Dive patterns of tagged right whales in the Great South Channel. Cont. Shelf. Res. 15:593-611.

Witteveen, B.H., R.J. Foy, K.M. Wynne, and Y. Tremblay. 2008. Investigation of foraging habits and prey selection by humpback whales (*Megaptera novaeangliae*) using acoustic tags and concurrent fish surveys. Marine Mammal Science 24:516-534.

Woodley, T.H. and D.E. Gaskin. 1996. Environmental characteristics of North Atlantic right and fin whale habitat in the lower Bay of Fundy, Canada. Can. J. Zool. 74:75-84.

Würsig, B. and M. Würsig. 1979. Behavior and Ecology of the bottlenose dolphin, (*Tursiops truncatus*) in the South Atlantic. Fish. Bull. 77:399-412.

Yin, S.E. 1999. Movement patterns, behaviors, and whistle sounds of dolphin groups off Kaikoura, New Zealand. Ph.D. Thesis, Texas A&M University, College Station, TX. 107 pp.

ATTACHMENT: SUMMARY TABLES OF TOTAL ANNUAL TAKE ESTIMATES

Table Attachment E-1

All Surveys (airgun and non-airgun) – Total Annual Level A Takes (number of individuals) Using Southall Criteria

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.000	0.084	0.161	0.013	0.069	0.045	0.021	0.022	0.009
Sei Whale	0.002	0.211	0.405	0.035	0.178	0.115	0.057	0.060	0.030
Bryde's Whale	0.002	0.635	1.240	0.131	0.724	0.529	0.360	0.166	0.040
Blue Whale	0.000	0.831	1.623	0.164	0.915	0.664	0.439	0.208	0.043
Fin Whale	0.015	0.021	0.021	0.021	0.021	0.018	0.005	0.000	0.000
North Atlantic Right Whale	0.002	0.039	0.074	0.011	0.047	0.036	0.025	0.009	0.001
Humpback Whale	0.000	3.046	5.931	0.567	3.153	2.226	1.402	0.779	0.235
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	4.094	121.807	230.677	24.072	101.335	68.641	29.844	23.101	1.241
Pygmy Killer Whale	0.000	0.162	0.313	0.028	0.176	0.114	0.082	0.067	0.060
Short-Finned Pilot Whale	0.005	11.627	22.508	1.950	82.506	51.948	90.213	122.188	151.359
Long-Finned Pilot Whale	0.000	59.577	117.528	13.877	79.694	61.037	45.681	14.788	1.264
Risso’s Dolphin	1.863	372.779	733.668	89.369	503.809	387.135	290.469	92.466	7.868
Northern Bottlenose Whale	0.000	0.004	0.007	0.001	0.003	0.002	0.001	0.001	0.000
Pygmy Sperm Whale	0.005	0.006	0.006	0.006	0.087	0.047	0.081	0.083	0.138
Dwarf Sperm Whale	0.014	2.838	5.583	0.681	4.493	3.333	2.957	1.670	1.367
Atlantic White-sided Dolphin	0.000	1.347	2.659	0.319	2.039	1.540	1.315	0.685	0.460
Fraser's Dolphin	0.000	0.209	0.403	0.033	0.162	0.105	0.041	0.040	0.002
Sowerby's Beaked Whale	0.000	0.000	0.000	0.000	0.006	0.004	0.007	0.009	0.012
Blainville's Beaked Whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
Gervais' Beaked Whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
True's Beaked Whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
Killer Whale	0.003	0.058	0.106	0.014	0.071	0.045	0.040	0.040	0.046
Melon-Headed Whale	0.000	0.161	0.313	0.027	0.175	0.113	0.081	0.067	0.060
Harbor Porpoise	0.001	2.065	3.995	0.339	2.051	1.344	0.886	0.834	0.623
Sperm Whale	0.001	0.096	0.185	0.016	0.077	0.051	0.021	0.019	0.001
False Killer Whale	0.000	0.155	0.300	0.027	0.237	0.151	0.158	0.170	0.194
Pantropical Spotted Dolphin	0.448	136.524	264.052	23.606	132.347	89.822	56.072	48.734	27.819
Clymene Dolphin	0.214	65.225	126.151	11.278	63.229	42.913	26.789	23.283	13.291
Striped Dolphin	0.595	528.183	1021.267	87.032	514.183	342.274	224.183	227.108	157.395
Atlantic Spotted Dolphin	5.399	778.265	1503.662	140.710	773.775	531.263	338.099	275.677	154.355
Spinner Dolphin	0.002	0.614	1.187	0.106	0.595	0.404	0.252	0.219	0.125
Rough-Toothed Dolphin	0.010	0.015	0.015	0.015	0.050	0.036	0.048	0.061	0.075
Bottlenose Dolphin	1.298	16.917	31.297	5.417	37.973	26.119	31.803	34.150	39.172
Cuvier's Beaked Whale	0.001	10.214	19.711	1.578	7.885	5.120	1.972	1.972	0.098
ORDER SIRENIA									
West Indian Manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table Attachment E-2

All Surveys (airgun and non-airgun) – Total Annual Level A Takes (number of individuals) Using Historic NMFS Criterion (180 dB)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.000	0.342	0.666	0.064	0.381	0.266	0.187	0.124	0.076
Sei Whale	0.000	1.966	3.855	0.417	2.565	1.881	1.477	0.819	0.504
Bryde's Whale	0.000	1.948	3.820	0.413	2.536	1.858	1.458	0.813	0.501
Blue Whale	0.001	2.183	4.275	0.452	2.754	2.002	1.541	0.883	0.540
Fin Whale	0.001	4.401	8.639	0.951	5.898	4.344	3.478	1.926	1.228
North Atlantic Right Whale	0.002	1.164	2.293	0.271	1.885	1.397	1.299	0.877	0.604
Humpback Whale	0.003	5.900	11.546	1.210	7.336	5.318	4.047	2.321	1.392
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	1.219	3122.842	6148.048	708.337	4438.213	3318.065	2735.485	1435.926	917.571
Pygmy Killer Whale	0.000	2.253	4.410	0.463	2.807	2.037	1.551	0.879	0.523
Short-Finned Pilot Whale	0.013	2354.316	4631.150	524.173	3290.560	2446.252	2005.847	1085.159	705.747
Long-Finned Pilot Whale	0.003	297.403	582.364	61.352	376.214	273.197	211.259	122.617	76.973
Risso’s Dolphin	0.091	1619.783	3180.578	350.478	2173.534	1603.414	1283.210	705.875	445.801
Northern Bottlenose Whale	0.000	0.127	0.250	0.029	0.179	0.134	0.110	0.055	0.033
Pygmy Sperm Whale	0.001	2.372	4.594	0.399	2.217	1.483	0.852	0.667	0.319
Dwarf Sperm Whale	0.003	14.849	29.009	2.951	17.497	12.585	9.151	5.272	2.864
Atlantic White-sided Dolphin	0.000	4.668	9.152	0.985	5.987	4.389	3.390	1.831	1.064
Fraser's Dolphin	0.000	0.243	0.469	0.040	0.218	0.144	0.078	0.066	0.031
Sowerby's Beaked Whale	0.000	0.203	0.397	0.040	0.242	0.174	0.128	0.075	0.042
Blainville's Beaked Whale	0.000	39.568	77.313	7.855	47.099	33.812	24.918	14.709	8.543
Gervais' Beaked Whale	0.000	39.568	77.313	7.855	47.099	33.812	24.918	14.709	8.543
True's Beaked Whale	0.000	39.568	77.313	7.855	47.099	33.812	24.918	14.709	8.543
Killer Whale	0.001	1.966	3.844	0.397	2.394	1.727	1.294	0.749	0.442
Melon-Headed Whale	0.000	2.523	4.943	0.525	3.216	2.343	1.816	1.031	0.633
Harbor Porpoise	0.002	7.056	13.800	1.430	8.707	6.285	4.780	2.833	1.760
Sperm Whale	0.000	158.828	309.724	30.401	179.051	126.960	89.385	54.767	29.976
False Killer Whale	0.000	2.802	5.492	0.590	3.636	2.658	2.087	1.180	0.736
Pantropical Spotted Dolphin	0.304	447.186	876.533	94.964	580.693	425.651	333.075	184.484	112.454
Clymene Dolphin	0.145	207.397	406.406	43.850	267.772	195.992	152.835	85.080	51.779
Striped Dolphin	0.396	2039.424	3993.807	422.639	2575.840	1874.396	1442.044	818.428	496.874
Atlantic Spotted Dolphin	3.461	2983.891	5852.577	645.633	3954.207	2914.067	2306.571	1254.103	762.825
Spinner Dolphin	0.001	1.951	3.823	0.412	2.519	1.844	1.438	0.800	0.487
Rough-Toothed Dolphin	0.006	13.762	26.895	2.760	16.679	11.993	8.993	5.364	3.256
Bottlenose Dolphin	0.938	5978.445	11749.675	1315.320	8208.500	6081.036	4934.402	2686.431	1715.054
Cuvier's Beaked Whale	0.000	276.973	541.189	54.986	329.696	236.682	174.425	102.965	59.798
ORDER SIRENIA									
West Indian Manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table Attachment E-3

All Surveys (airgun and non-airgun) – Total Annual Level B Takes (number of individuals) Using Historic NMFS Criterion (160 dB)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.022	33.550	65.312	6.287	37.298	26.088	18.339	12.125	7.407
Sei Whale	0.036	192.672	377.852	40.901	251.373	184.310	144.793	80.298	49.415
Bryde's Whale	0.036	190.943	374.409	40.440	248.542	182.095	142.935	79.681	49.131
Blue Whale	0.066	213.999	418.979	44.264	269.881	196.170	150.994	86.495	52.877
Fin Whale	0.115	431.364	846.749	93.167	578.072	425.755	340.840	188.785	120.395
North Atlantic Right Whale	0.194	114.092	224.739	26.592	184.766	136.944	127.334	85.913	59.169
Humpback Whale	0.245	578.293	1131.575	118.608	718.954	521.193	396.647	227.499	136.417
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	119.444	306069.739	602570.182	69424.082	434989.253	325203.591	268104.901	140735.079	89931.144
Pygmy Killer Whale	0.034	220.825	432.243	45.365	275.139	199.673	151.972	86.180	51.211
Short-Finned Pilot Whale	1.292	230746.558	453899.015	51374.206	322507.797	239757.144	196593.075	106356.459	69170.223
Long-Finned Pilot Whale	0.262	29148.473	57077.465	6013.098	36872.714	26775.994	20705.467	12017.687	7544.143
Risso’s Dolphin	8.944	158754.967	311728.435	34350.388	213028.049	157150.561	125767.385	69182.833	43692.995
Northern Bottlenose Whale	0.000	12.462	24.544	2.829	17.568	13.169	10.740	5.422	3.226
Pygmy Sperm Whale	0.112	232.504	450.223	39.071	217.329	145.381	83.499	65.368	31.298
Dwarf Sperm Whale	0.336	1455.336	2843.191	289.246	1714.850	1233.490	896.926	516.700	280.721
Atlantic White-sided Dolphin	0.003	457.486	896.992	96.503	586.760	430.138	332.240	179.465	104.325
Fraser's Dolphin	0.035	23.774	45.946	3.929	21.400	14.120	7.671	6.446	3.024
Sowerby's Beaked Whale	0.002	19.913	38.908	3.959	23.676	17.011	12.506	7.323	4.161
Blainville's Beaked Whale	0.002	3878.018	7577.417	769.886	4616.214	3313.885	2442.204	1441.662	837.260
Gervais' Beaked Whale	0.002	3878.018	7577.417	769.886	4616.214	3313.885	2442.204	1441.662	837.260
True's Beaked Whale	0.003	3878.019	7577.418	769.887	4616.214	3313.886	2442.205	1441.662	837.260
Killer Whale	0.051	192.653	376.717	38.928	234.603	169.297	126.828	73.362	43.349
Melon-Headed Whale	0.036	247.292	484.433	51.498	315.189	229.642	177.968	101.038	62.004
Harbor Porpoise	0.154	691.538	1352.566	140.176	853.358	615.982	468.490	277.676	172.453
Sperm Whale	0.018	15566.727	30356.018	2979.633	17548.762	12443.391	8760.616	5367.671	2937.989
False Killer Whale	0.039	274.585	538.272	57.864	356.340	260.532	204.520	115.616	72.104
Pantropical Spotted Dolphin	29.753	43828.703	85909.037	9307.463	56913.689	41718.028	32644.651	18081.229	11021.618
Clymene Dolphin	14.215	20326.942	39831.854	4297.704	26244.328	19209.194	14979.406	8338.682	5074.879
Striped Dolphin	38.853	199883.937	391433.034	41422.836	252458.092	183709.544	141334.709	80214.088	48698.652
Atlantic Spotted Dolphin	339.182	292451.134	573611.088	63278.489	387551.801	285607.693	226067.062	122914.597	74764.470
Spinner Dolphin	0.131	191.216	374.705	40.424	246.883	180.701	140.913	78.445	47.741
Rough-Toothed Dolphin	0.555	1348.832	2636.003	270.481	1634.722	1175.421	881.440	525.689	319.159
Bottlenose Dolphin	91.950	585947.347	1151585.614	128914.529	804515.124	596002.320	483620.734	263297.116	168092.427
Cuvier's Beaked Whale	0.016	27146.128	53041.920	5389.204	32313.495	23197.195	17095.430	10091.631	5860.820
ORDER SIRENIA									
West Indian Manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table Attachment E-4

All Seismic Airgun Surveys – Total Annual Level A Takes (number of individuals) Using Southall Criteria

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.000	0.083	0.161	0.013	0.069	0.044	0.021	0.022	0.009
Sei Whale	0.000	0.208	0.402	0.032	0.176	0.113	0.057	0.060	0.030
Bryde's Whale	0.000	0.632	1.237	0.128	0.721	0.526	0.359	0.166	0.040
Blue Whale	0.000	0.831	1.622	0.164	0.915	0.663	0.439	0.208	0.043
Fin Whale	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
North Atlantic Right Whale	0.000	0.036	0.071	0.008	0.045	0.034	0.024	0.009	0.001
Humpback Whale	0.000	3.046	5.931	0.567	3.153	2.226	1.402	0.779	0.235
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	0.000	116.584	225.454	18.848	96.111	64.095	28.714	23.101	1.241
Pygmy Killer Whale	0.000	0.161	0.312	0.027	0.175	0.113	0.081	0.067	0.060
Short-Finned Pilot Whale	0.000	11.616	22.498	1.939	82.495	51.938	90.208	122.188	151.359
Long-Finned Pilot Whale	0.000	59.577	117.528	13.877	79.694	61.037	45.681	14.788	1.264
Risso’s Dolphin	0.000	370.550	731.439	87.140	501.580	385.115	290.103	92.466	7.868
Northern Bottlenose Whale	0.000	0.004	0.007	0.001	0.003	0.002	0.001	0.001	0.000
Pygmy Sperm Whale	0.000	0.000	0.000	0.000	0.081	0.041	0.080	0.083	0.138
Dwarf Sperm Whale	0.000	2.819	5.564	0.662	4.474	3.315	2.953	1.670	1.367
Atlantic White-sided Dolphin	0.000	1.347	2.659	0.319	2.039	1.540	1.315	0.685	0.460
Fraser's Dolphin	0.000	0.208	0.402	0.032	0.161	0.105	0.041	0.040	0.002
Sowerby's Beaked Whale	0.000	0.000	0.000	0.000	0.006	0.004	0.007	0.009	0.012
Blainville's Beaked Whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
Gervais' Beaked Whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
True's Beaked Whale	0.000	1.459	2.816	0.225	1.126	0.731	0.282	0.282	0.014
Killer Whale	0.000	0.052	0.100	0.008	0.065	0.040	0.036	0.040	0.046
Melon-Headed Whale	0.000	0.161	0.312	0.027	0.175	0.113	0.081	0.067	0.060
Harbor Porpoise	0.000	2.064	3.995	0.338	2.051	1.344	0.886	0.834	0.623
Sperm Whale	0.000	0.095	0.184	0.015	0.076	0.050	0.021	0.019	0.001
False Killer Whale	0.000	0.155	0.300	0.026	0.236	0.151	0.158	0.170	0.194
Pantropical Spotted Dolphin	0.000	135.938	263.432	22.986	131.727	89.279	55.904	48.705	27.790
Clymene Dolphin	0.000	64.945	125.855	10.982	62.933	42.653	26.708	23.269	13.277
Striped Dolphin	0.000	527.416	1020.455	86.220	513.371	341.562	223.973	227.070	157.357
Atlantic Spotted Dolphin	0.000	771.308	1496.301	133.348	766.414	524.822	336.201	275.338	154.015
Spinner Dolphin	0.000	0.611	1.184	0.103	0.592	0.401	0.251	0.219	0.125
Rough-Toothed Dolphin	0.000	0.000	0.000	0.000	0.036	0.023	0.043	0.061	0.075
Bottlenose Dolphin	0.000	14.775	28.936	3.056	35.612	24.127	30.763	33.955	38.977
Cuvier's Beaked Whale	0.000	10.213	19.709	1.577	7.883	5.119	1.972	1.972	0.098
ORDER SIRENIA									
West Indian Manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table Attachment E-5

All Seismic Airgun Surveys – Total Annual Level A Takes (number of individuals) Using Historic NMFS Criterion (180 dB)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.000	0.342	0.666	0.064	0.380	0.266	0.187	0.124	0.075
Sei Whale	0.000	1.965	3.855	0.417	2.564	1.880	1.476	0.818	0.502
Bryde's Whale	0.000	1.948	3.820	0.412	2.535	1.857	1.457	0.812	0.499
Blue Whale	0.000	2.182	4.274	0.451	2.753	2.000	1.539	0.882	0.537
Fin Whale	0.000	4.400	8.638	0.949	5.896	4.342	3.474	1.924	1.223
North Atlantic Right Whale	0.000	1.162	2.290	0.269	1.883	1.395	1.294	0.874	0.595
Humpback Whale	0.000	5.897	11.542	1.207	7.332	5.314	4.043	2.319	1.385
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	0.000	3121.383	6146.553	706.842	4436.718	3316.557	2733.398	1434.611	913.703
Pygmy Killer Whale	0.000	2.253	4.410	0.462	2.807	2.037	1.549	0.879	0.520
Short-Finned Pilot Whale	0.000	2354.300	4631.133	524.156	3290.543	2446.116	2004.600	1084.354	703.430
Long-Finned Pilot Whale	0.000	297.400	582.360	61.349	376.210	273.181	211.129	122.524	76.692
Risso's Dolphin	0.000	1619.672	3180.466	350.367	2173.422	1603.231	1282.343	705.289	444.065
Northern Bottlenose Whale	0.000	0.127	0.250	0.029	0.179	0.134	0.110	0.055	0.033
Pygmy Sperm Whale	0.000	2.371	4.592	0.397	2.216	1.482	0.851	0.666	0.318
Dwarf Sperm Whale	0.000	14.844	29.005	2.947	17.492	12.581	9.146	5.268	2.852
Atlantic White-sided Dolphin	0.000	4.668	9.152	0.985	5.987	4.389	3.388	1.830	1.060
Fraser's Dolphin	0.000	0.242	0.468	0.039	0.218	0.143	0.078	0.066	0.031
Sowerby's Beaked Whale	0.000	0.203	0.397	0.040	0.242	0.174	0.128	0.075	0.042
Blainville's Beaked Whale	0.000	39.568	77.313	7.855	47.099	33.810	24.904	14.699	8.511
Gervais' Beaked Whale	0.000	39.568	77.313	7.855	47.099	33.810	24.904	14.699	8.511
True's Beaked Whale	0.000	39.568	77.313	7.855	47.099	33.810	24.904	14.699	8.511
Killer Whale	0.000	1.965	3.843	0.396	2.393	1.727	1.293	0.748	0.440
Melon-Headed Whale	0.000	2.523	4.942	0.525	3.215	2.342	1.814	1.030	0.630
Harbor Porpoise	0.000	7.054	13.798	1.428	8.705	6.283	4.777	2.831	1.753
Sperm Whale	0.000	158.828	309.723	30.401	179.051	126.956	89.342	54.729	29.855
False Killer Whale	0.000	2.801	5.491	0.590	3.635	2.658	2.085	1.179	0.733
Pantropical Spotted Dolphin	0.000	446.741	876.082	94.513	580.242	425.213	332.719	184.322	111.974
Clymene Dolphin	0.000	207.184	406.191	43.634	267.556	195.783	152.671	85.007	51.562
Striped Dolphin	0.000	2038.848	3993.224	422.056	2575.257	1873.787	1441.135	817.898	495.292
Atlantic Spotted Dolphin	0.000	2978.964	5847.582	640.637	3949.211	2909.316	2303.489	1252.888	759.259
Spinner Dolphin	0.000	1.949	3.821	0.410	2.517	1.842	1.436	0.800	0.485
Rough-Toothed Dolphin	0.000	13.755	26.888	2.752	16.672	11.986	8.985	5.358	3.240
Bottlenose Dolphin	0.000	5977.039	11748.210	1313.855	8207.035	6079.369	4930.570	2684.179	1708.610
Cuvier's Beaked Whale	0.000	276.973	541.189	54.986	329.696	236.673	174.331	102.893	59.574
ORDER SIRENIA									
West Indian Manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table Attachment E-6

All Seismic Airgun Surveys – Total Annual Level B Takes (number of individuals) Using Historic NMFS Criterion (160 dB)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.000	33.522	65.282	6.257	37.268	26.060	18.319	12.111	7.365
Sei Whale	0.000	192.625	377.801	40.850	251.322	184.255	144.677	80.219	49.182
Bryde's Whale	0.000	190.896	374.359	40.389	248.492	182.040	142.818	79.602	48.897
Blue Whale	0.000	213.901	418.875	44.161	269.778	196.066	150.850	86.408	52.620
Fin Whale	0.000	431.204	846.583	93.001	577.905	425.583	340.531	188.601	119.857
North Atlantic Right Whale	0.000	240.877	475.584	56.846	361.004	272.896	230.884	117.752	61.087
Humpback Whale	0.000	577.964	1131.230	118.264	718.609	520.862	396.288	227.280	135.768
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	0.000	305926.755	602423.698	69277.598	434842.769	325055.721	267900.300	140606.264	89552.017
Pygmy Killer Whale	0.000	220.776	432.193	45.316	275.090	199.618	151.862	86.104	50.974
Short-Finned Pilot Whale	0.000	230744.930	453897.344	51372.535	322506.126	239743.839	196470.811	106277.564	68943.198
Long-Finned Pilot Whale	0.000	29148.152	57077.138	6012.771	36872.388	26774.497	20692.778	12008.551	7516.617
Risso’s Dolphin	0.000	158744.009	311717.478	34339.430	213017.091	157132.663	125682.450	69125.392	43522.784
Northern Bottlenose Whale	0.000	12.462	24.544	2.829	17.568	13.169	10.733	5.418	3.214
Pygmy Sperm Whale	0.000	232.353	450.073	38.920	217.178	145.240	83.426	65.321	31.130
Dwarf Sperm Whale	0.000	1454.885	2842.740	288.795	1714.399	1233.034	896.367	516.331	279.556
Atlantic White-sided Dolphin	0.000	457.481	896.987	96.497	586.754	430.117	332.072	179.330	103.897
Fraser's Dolphin	0.000	23.717	45.882	3.865	21.337	14.063	7.641	6.436	3.006
Sowerby's Beaked Whale	0.000	19.910	38.905	3.957	23.674	17.008	12.499	7.317	4.143
Blainville's Beaked Whale	0.000	3878.016	7577.415	769.884	4616.211	3313.759	2440.889	1440.645	834.120
Gervais' Beaked Whale	0.000	3878.016	7577.415	769.884	4616.211	3313.759	2440.889	1440.645	834.120
True's Beaked Whale	0.000	3878.016	7577.415	769.884	4616.211	3313.759	2440.889	1440.645	834.120
Killer Whale	0.000	192.589	376.649	38.861	234.535	169.229	126.733	73.295	43.147
Melon-Headed Whale	0.000	247.240	484.381	51.446	315.137	229.581	177.832	100.945	61.720
Harbor Porpoise	0.000	691.367	1352.385	139.995	853.177	615.792	468.191	277.456	171.788
Sperm Whale	0.000	15566.706	30355.996	2979.611	17548.740	12442.986	8756.403	5363.975	2926.098
False Killer Whale	0.000	274.527	538.213	57.806	356.282	260.465	204.367	115.520	71.815
Pantropical Spotted Dolphin	0.000	43785.058	85864.840	9263.266	56869.492	41675.091	32609.770	18065.447	10974.596
Clymene Dolphin	0.000	20306.091	39810.739	4276.589	26223.212	19188.734	14963.300	8331.541	5053.608
Striped Dolphin	0.000	199827.536	391375.882	41365.683	252400.939	183649.880	141245.653	80162.157	48543.554
Atlantic Spotted Dolphin	0.000	291968.246	573121.475	62788.875	387062.188	285142.042	225764.925	122795.508	74414.994
Spinner Dolphin	0.000	191.026	374.513	40.231	246.691	180.515	140.765	78.378	47.541
Rough-Toothed Dolphin	0.000	1348.103	2635.268	269.746	1633.987	1174.707	880.655	525.176	317.548
Bottlenose Dolphin	0.000	585809.587	1151442.029	128770.944	804371.539	595838.922	483245.127	263076.392	167460.910
Cuvier's Beaked Whale	0.000	27146.110	53041.902	5389.186	32313.477	23196.314	17086.222	10084.514	5838.840
ORDER SIRENIA									
West Indian Manatee	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Harbor Seal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table Attachment E-7

All Non-Airgun HRG Surveys – Total Annual Level A Takes (number of individuals) Using Southall Criteria

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.0003	0.0004	0.0004	0.0004	0.0004	0.0003	0.0000	0.0000	0.0000
Sei Whale	0.0020	0.0024	0.0024	0.0024	0.0024	0.0021	0.0004	0.0000	0.0000
Bryde's Whale	0.0023	0.0030	0.0030	0.0030	0.0030	0.0027	0.0007	0.0000	0.0000
Blue Whale	0.0002	0.0005	0.0005	0.0005	0.0005	0.0005	0.0003	0.0000	0.0000
Fin Whale	0.0155	0.0208	0.0208	0.0208	0.0208	0.0185	0.0053	0.0000	0.0000
North Atlantic Right Whale	0.0021	0.0026	0.0026	0.0026	0.0026	0.0022	0.0005	0.0000	0.0000
Humpback Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	4.0936	5.2235	5.2235	5.2235	5.2235	4.5460	1.1299	0.0000	0.0000
Pygmy Killer Whale	0.0004	0.0010	0.0010	0.0010	0.0010	0.0009	0.0006	0.0000	0.0000
Short-Finned Pilot Whale	0.0053	0.0106	0.0106	0.0106	0.0106	0.0106	0.0053	0.0000	0.0000
Long-Finned Pilot Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Risso’s Dolphin	1.8630	2.2287	2.2287	2.2287	2.2287	2.0205	0.3658	0.0000	0.0000
Northern Bottlenose Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pygmy Sperm Whale	0.0048	0.0064	0.0064	0.0064	0.0064	0.0059	0.0016	0.0000	0.0000
Dwarf Sperm Whale	0.0145	0.0192	0.0192	0.0192	0.0192	0.0178	0.0047	0.0000	0.0000
Atlantic White-sided Dolphin	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Fraser's Dolphin	0.0001	0.0003	0.0004	0.0004	0.0004	0.0003	0.0003	0.0000	0.0000
Sowerby's Beaked Whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
Blainville's Beaked Whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
Gervais' Beaked Whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
True's Beaked Whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000
Killer Whale	0.0025	0.0061	0.0061	0.0061	0.0061	0.0058	0.0036	0.0000	0.0000
Melon-Headed Whale	0.0001	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0000	0.0000
Harbor Porpoise	0.0005	0.0007	0.0007	0.0007	0.0007	0.0006	0.0002	0.0000	0.0000
Sperm Whale	0.0008	0.0009	0.0009	0.0009	0.0009	0.0008	0.0001	0.0000	0.0000
False Killer Whale	0.0001	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0000	0.0000
Pantropical Spotted Dolphin	0.4477	0.5868	0.6200	0.6200	0.6200	0.5432	0.1677	0.0287	0.0287
Clymene Dolphin	0.2139	0.2803	0.2962	0.2962	0.2962	0.2595	0.0801	0.0137	0.0137
Striped Dolphin	0.5954	0.7674	0.8121	0.8121	0.8121	0.7114	0.2107	0.0386	0.0386
Atlantic Spotted Dolphin	5.3991	6.9574	7.3614	7.3614	7.3614	6.4414	1.8980	0.3397	0.3397
Spinner Dolphin	0.0020	0.0026	0.0028	0.0028	0.0028	0.0024	0.0008	0.0001	0.0001
Rough-Toothed Dolphin	0.0099	0.0145	0.0145	0.0145	0.0145	0.0134	0.0047	0.0000	0.0000
Bottlenose Dolphin	1.2977	2.1422	2.3608	2.3608	2.3608	1.9922	1.0400	0.1955	0.1955
Cuvier's Beaked Whale	0.0013	0.0015	0.0015	0.0015	0.0015	0.0013	0.0003	0.0000	0.0000
ORDER SIRENIA									
West Indian Manatee	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gray Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Harbor Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table Attachment E-8

All Non-Airgun HRG Surveys – Total Annual Level A Takes (number of individuals) Using Historic NMFS Criterion (180 dB)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0001	0.0004
Sei Whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0012	0.0008	0.0024
Bryde's Whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0012	0.0008	0.0024
Blue Whale	0.0007	0.0010	0.0011	0.0011	0.0011	0.0011	0.0015	0.0009	0.0026
Fin Whale	0.0012	0.0016	0.0017	0.0017	0.0017	0.0018	0.0031	0.0019	0.0055
North Atlantic Right Whale	0.0020	0.0025	0.0025	0.0025	0.0025	0.0027	0.0051	0.0031	0.0089
Humpback Whale	0.0025	0.0034	0.0035	0.0035	0.0035	0.0034	0.0037	0.0022	0.0066
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	1.2187	1.4589	1.4946	1.4946	1.4946	1.5087	2.0876	1.3143	3.8682
Pygmy Killer Whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0011	0.0008	0.0024
Short-Finned Pilot Whale	0.0132	0.0166	0.0171	0.0171	0.0171	0.1358	1.2475	0.8050	2.3163
Long-Finned Pilot Whale	0.0027	0.0033	0.0033	0.0033	0.0033	0.0153	0.1295	0.0932	0.2808
Risso’s Dolphin	0.0913	0.1118	0.1118	0.1118	0.1118	0.1826	0.8666	0.5861	1.7367
Northern Bottlenose Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
Pygmy Sperm Whale	0.0011	0.0015	0.0015	0.0015	0.0015	0.0014	0.0007	0.0005	0.0017
Dwarf Sperm Whale	0.0034	0.0046	0.0046	0.0046	0.0046	0.0046	0.0057	0.0038	0.0119
Atlantic White-sided Dolphin	0.0000	0.0001	0.0001	0.0001	0.0001	0.0002	0.0017	0.0014	0.0044
Fraser's Dolphin	0.0004	0.0006	0.0007	0.0007	0.0007	0.0006	0.0003	0.0001	0.0002
Sowerby's Beaked Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002
Blainville's Beaked Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0134	0.0104	0.0320
Gervais' Beaked Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0134	0.0104	0.0320
True's Beaked Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0134	0.0104	0.0320
Killer Whale	0.0005	0.0007	0.0007	0.0007	0.0007	0.0007	0.0010	0.0007	0.0021
Melon-Headed Whale	0.0004	0.0005	0.0005	0.0005	0.0005	0.0006	0.0014	0.0009	0.0029
Harbor Porpoise	0.0016	0.0018	0.0018	0.0018	0.0018	0.0019	0.0031	0.0023	0.0068
Sperm Whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0041	0.0430	0.0377	0.1213
False Killer Whale	0.0004	0.0006	0.0006	0.0006	0.0006	0.0007	0.0016	0.0010	0.0029
Pantropical Spotted Dolphin	0.3036	0.4453	0.4509	0.4509	0.4509	0.4381	0.3559	0.1610	0.4798
Clymene Dolphin	0.1450	0.2127	0.2154	0.2154	0.2154	0.2088	0.1643	0.0729	0.2170
Striped Dolphin	0.3964	0.5755	0.5831	0.5831	0.5831	0.6088	0.9086	0.5299	1.5825
Atlantic Spotted Dolphin	3.4607	4.9269	4.9955	4.9955	4.9955	4.7511	3.0827	1.2151	3.5657
Spinner Dolphin	0.0013	0.0019	0.0020	0.0020	0.0020	0.0019	0.0015	0.0007	0.0020
Rough-Toothed Dolphin	0.0057	0.0074	0.0075	0.0075	0.0075	0.0073	0.0080	0.0052	0.0164
Bottlenose Dolphin	0.9382	1.4056	1.4650	1.4650	1.4650	1.6672	3.8323	2.2521	6.4434
Cuvier's Beaked Whale	0.0002	0.0002	0.0002	0.0002	0.0002	0.0090	0.0939	0.0726	0.2243
ORDER SIRENIA									
West Indian Manatee	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gray Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Harbor Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table Attachment E-9

All Non-Airgun HRG Surveys – Total Annual Level B Takes (number of individuals) Using Historic NMFS Criterion (160 dB)

Marine Mammal	Year								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
ORDER CETACEA									
Suborder Mysticeti (Baleen Whales)									
Common Minke Whale	0.0225	0.0287	0.0300	0.0300	0.0300	0.0282	0.0200	0.0135	0.0419
Sei Whale	0.0358	0.0476	0.0511	0.0511	0.0511	0.0557	0.1152	0.0784	0.2328
Bryde's Whale	0.0355	0.0470	0.0505	0.0505	0.0505	0.0553	0.1169	0.0790	0.2338
Blue Whale	0.0659	0.0980	0.1037	0.1037	0.1037	0.1048	0.1448	0.0871	0.2568
Fin Whale	0.1153	0.1598	0.1665	0.1665	0.1665	0.1722	0.3083	0.1847	0.5384
North Atlantic Right Whale	0.1945	0.2461	0.2491	0.2491	0.2491	0.2690	0.5016	0.3002	0.8702
Humpback Whale	0.2454	0.3285	0.3444	0.3444	0.3444	0.3313	0.3597	0.2189	0.6492
Suborder Odontoceti (Toothed Whales, Dolphins, and Porpoises)									
Short-beaked Common Dolphin	119.4440	142.9833	146.4839	146.4839	146.4839	147.8699	204.6009	128.8144	379.1270
Pygmy Killer Whale	0.0345	0.0494	0.0494	0.0494	0.0494	0.0549	0.1097	0.0759	0.2370
Short-Finned Pilot Whale	1.2920	1.6287	1.6711	1.6711	1.6711	13.3054	122.2637	78.8942	227.0254
Long-Finned Pilot Whale	0.2621	0.3201	0.3267	0.3267	0.3267	1.4975	12.6893	9.1359	27.5252
Risso’s Dolphin	8.9444	10.9577	10.9577	10.9577	10.9577	17.8981	84.9354	57.4417	170.2112
Northern Bottlenose Whale	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0063	0.0041	0.0118
Pygmy Sperm Whale	0.1119	0.1503	0.1503	0.1503	0.1503	0.1410	0.0732	0.0472	0.1675
Dwarf Sperm Whale	0.3358	0.4508	0.4508	0.4508	0.4508	0.4557	0.5592	0.3686	1.1655
Atlantic White-sided Dolphin	0.0027	0.0055	0.0055	0.0055	0.0055	0.0208	0.1680	0.1357	0.4275
Fraser's Dolphin	0.0345	0.0568	0.0637	0.0637	0.0637	0.0575	0.0304	0.0098	0.0183
Sowerby's Beaked Whale	0.0023	0.0026	0.0026	0.0026	0.0026	0.0030	0.0073	0.0056	0.0175
Blainville's Beaked Whale	0.0023	0.0026	0.0026	0.0026	0.0026	0.1259	1.3153	1.0167	3.1400
Gervais' Beaked Whale	0.0023	0.0026	0.0026	0.0026	0.0026	0.1259	1.3153	1.0167	3.1400
True's Beaked Whale	0.0026	0.0032	0.0032	0.0032	0.0032	0.1265	1.3156	1.0167	3.1400
Killer Whale	0.0509	0.0642	0.0678	0.0678	0.0678	0.0680	0.0952	0.0667	0.2021
Melon-Headed Whale	0.0361	0.0525	0.0525	0.0525	0.0525	0.0604	0.1362	0.0921	0.2839
Harbor Porpoise	0.1543	0.1717	0.1812	0.1812	0.1812	0.1894	0.2990	0.2206	0.6643
Sperm Whale	0.0182	0.0215	0.0215	0.0215	0.0215	0.4051	4.2127	3.6965	11.8913
False Killer Whale	0.0389	0.0582	0.0582	0.0582	0.0582	0.0674	0.1524	0.0959	0.2885
Pantropical Spotted Dolphin	29.7529	43.6445	44.1968	44.1968	44.1968	42.9366	34.8805	15.7818	47.0220
Clymene Dolphin	14.2145	20.8513	21.1152	21.1152	21.1152	20.4600	16.1068	7.1416	21.2706
Striped Dolphin	38.8529	56.4013	57.1529	57.1529	57.1529	59.6638	89.0555	51.9312	155.0979
Atlantic Spotted Dolphin	339.1818	482.8880	489.6133	489.6133	489.6133	465.6510	302.1377	119.0890	349.4761
Spinner Dolphin	0.1306	0.1899	0.1924	0.1924	0.1924	0.1862	0.1484	0.0672	0.2001
Rough-Toothed Dolphin	0.5554	0.7281	0.7355	0.7355	0.7355	0.7138	0.7853	0.5128	1.6114
Bottlenose Dolphin	91.9501	137.7600	143.5851	143.5851	143.5851	163.3981	375.6071	220.7238	631.5169
Cuvier's Beaked Whale	0.0158	0.0181	0.0181	0.0181	0.0181	0.8810	9.2072	7.1172	21.9798
ORDER SIRENIA									
West Indian Manatee	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ORDER CARNIVORA									
Suborder Pinnipedia									
Hooded Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Gray Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Harbor Seal	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

APPENDIX F

PHYSICAL AND ENVIRONMENTAL SETTINGS

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1. GEOGRAPHY AND GEOLOGY

This section provides a regional geologic description of the Area of Interest (AOI). Additional geological background information is provided in a literature synthesis by White (2011).

1.1. REGIONAL GEOLOGIC DESCRIPTION

The AOI encompasses Atlantic waters from the shoreline (excluding estuaries) to 350 nmi (648 km) offshore and from the mouth of Delaware Bay (38°51' N) to Cape Canaveral, Florida (28°N). The region has a mix of depositional and erosional environments and is greatly influenced by a prominent ocean current system, the Gulf Stream. Physiographically, the AOI includes the southern portion of the Mid-Atlantic Bight (MAB) from the mouth of Delaware Bay south to Cape Hatteras, North Carolina, plus all of the South Atlantic Bight (SAB) extending from Cape Hatteras to just south of Cape Canaveral, Florida (**Figure F-1**). The MAB and SAB differ physiographically; the MAB has a classic continental shelf-slope-rise sequence, while the SAB has a terrace-like sequence with several prominent features as discussed below and shown in **Figure F-1**.

The MAB has a broad continental shelf, with the 100-m (330-ft) water-depth contour generally coinciding with the shelf break. Offshore Norfolk, Virginia, the continental shelf is approximately 55-125 km (30-68 nmi) wide, with the change from gradual to steep topographic relief at the shelf break generally occurring at depths of 40-160 m (130-525 ft) (Tucholke, 1987). Bathymetry in the AOI is shown in **Figure F-2**. The continental slope, which has an average gradient between 4° and 11°, begins seaward of the shelf break (Heezen et al., 1959). The continental rise begins at a depth of approximately 2,000 m (6,560 ft). The MAB shelf is incised with deep canyons and valleys. Some canyons were eroded by rivers during lower stands of sea level, but most were formed via other erosional processes, such as slides, debris flows, and turbidity currents (Uchupi, 1968; Malahoff et al., 1980; Tucholke, 1987). There are three major canyons in the AOI (Baltimore, Washington, and Norfolk) and several minor canyons (Warr, Accomac, Hull, Keller, Hatteras, and Pamlico) (**Figure F-1**).

The seafloor in the SAB is divided into two distinct bathymetric areas: the Florida-Hatteras Shelf and the Blake Plateau (**Figure F-1**), which are connected by the gently dipping Florida-Hatteras Slope (Popenoe, 1981; Shor and McClennen, 1988). The Florida-Hatteras Shelf is a shallow, extremely flat inner shelf with water depths less than 100 m (330 ft) and a gradient less than 1:1,000 (Heezen et al., 1959; Shepard, 1973). Off Cape Hatteras, the shelf is narrow (~45 km [~24 nmi]), then broadens to over 105 km (57 nmi) offshore Cape Fear (**Figure F-1**) (Newton et al., 1971). Off the Georgia coast, the Florida-Hatteras Shelf extends nearly 150 km (81 nmi) at its greatest width before narrowing again to less than 60 km (32 nmi) off Cape Canaveral (**Figure F-1**). The shelf break generally occurs in water depths of approximately 40-80 m (130-260 ft) offshore northeastern Florida (Macintyre and Milliman, 1970).

From the edge of the shallow shelf, the Florida-Hatteras Slope gently transitions down about 60 m (200 ft) onto the Blake Plateau, a broad, flat sedimentary basin. The slope is smooth and uniform with a seaward slope of approximately 1° (Tucholke, 1987). Shelf-edge ridges, or reefs, occur near the top of the slope, and the upper slope is smooth and largely devoid of submarine canyons. Blake Plateau is an intermediate depth outer shelf where water depths range from approximately 700-1,100 m (2,300-3,600 ft). There are numerous terrace-like features and elongated depressions (some with deepwater coral mounds) along the base of the Florida-Hatteras slope, although the Blake Plateau generally has a smooth surface (Stetson et al., 1962, 1969; Milliman et al., 1967). The western and northern portions of the Plateau have a series of deep elongated and flat-bottomed erosional depressions caused by scouring by the Gulf Stream and other currents. The Florida-Hatteras slope and the terraces and depressions on the Blake Plateau are attributed to Gulf Stream erosion (Tucholke, 1987).

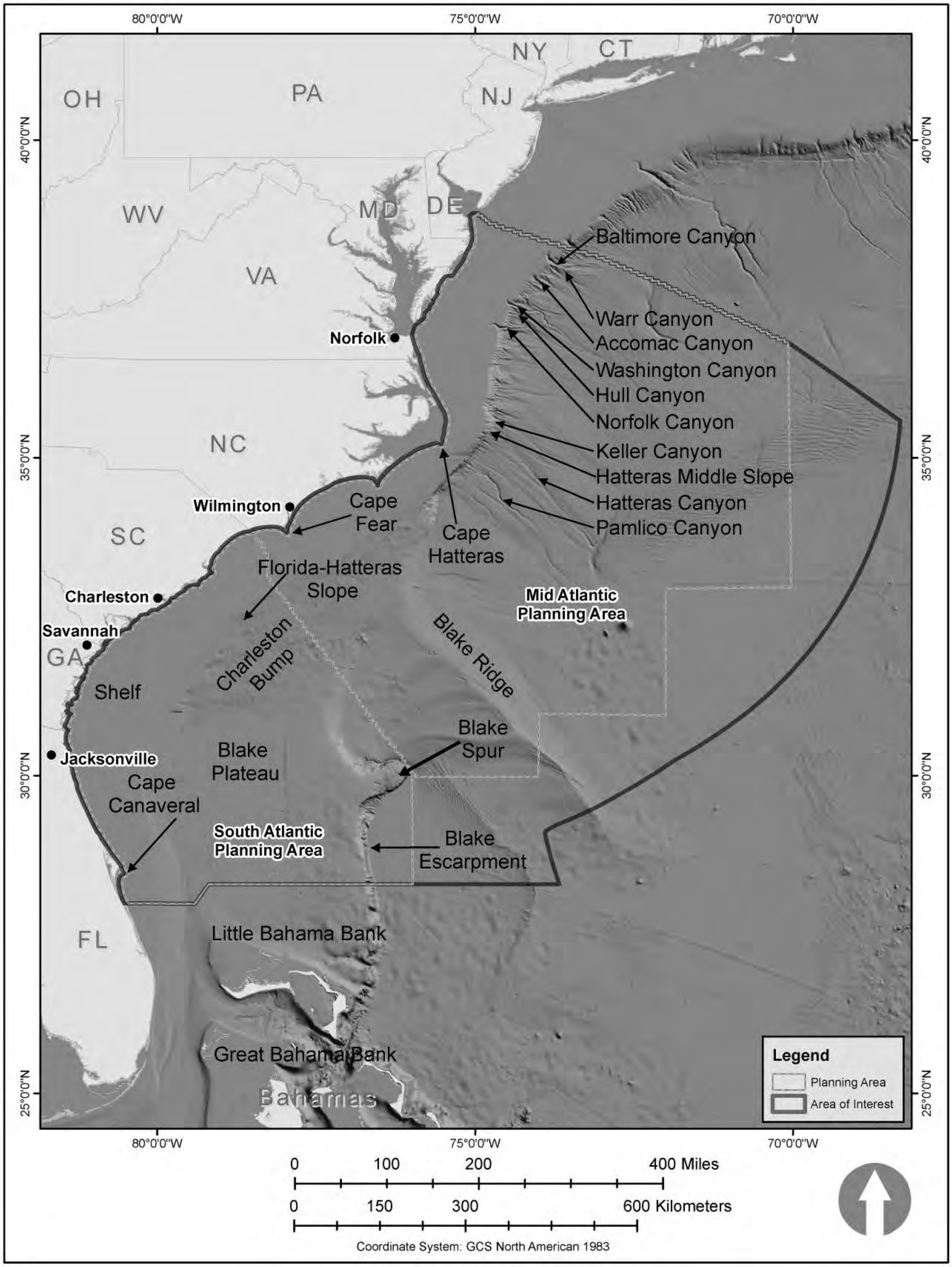


Figure F-1. Submarine Physiographic Features in the Area of Interest.

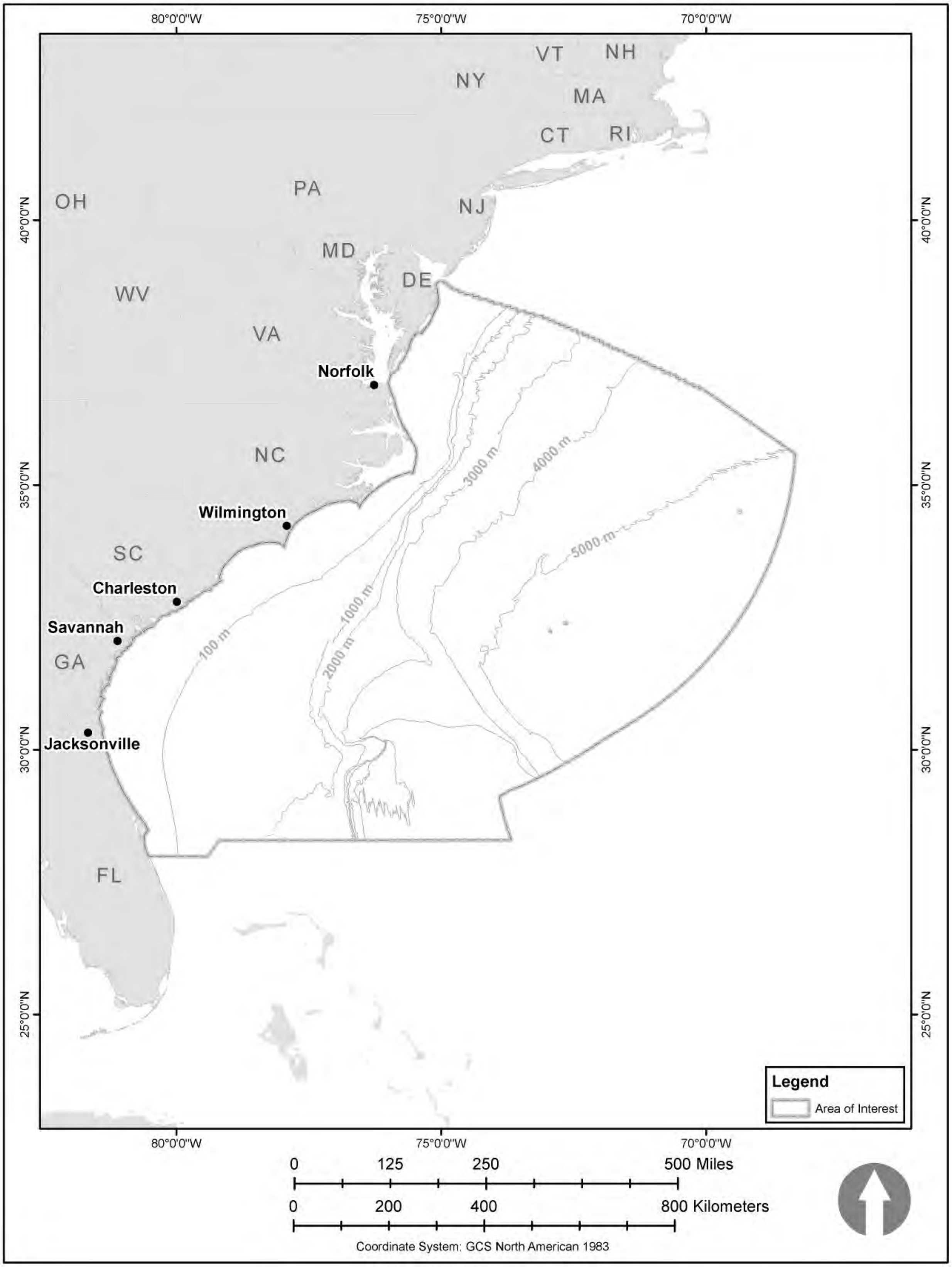
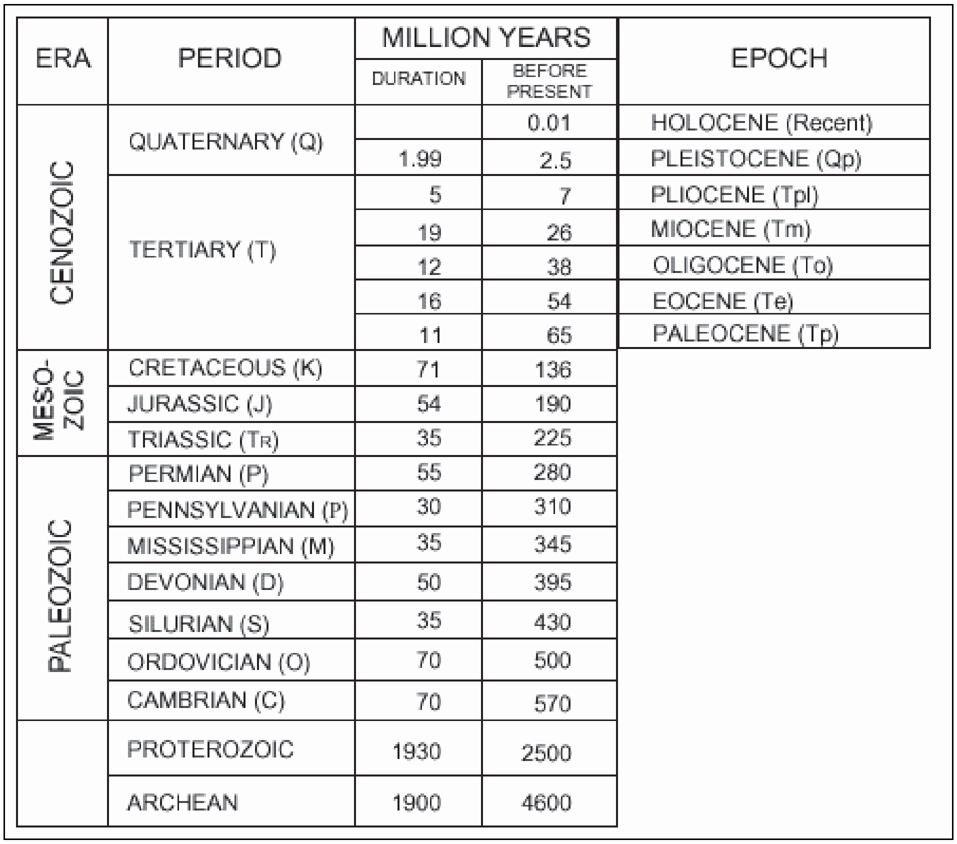


Figure F-2. Bathymetry in the Area of Interest.

The Charleston Bump, located offshore Charleston, South Carolina (**Figure F-1**) and identified by the recurving 500-600 m (1,640-1,969 ft) isobaths (Bane and Brooks, 1979), is a distinctive feature of the SAB. It presents prominent bottom relief on a flat seafloor located in 400-700 m (1,312-2,297 ft) water depth, causing an offshore deflection of the Gulf Stream's path and producing meanders, eddies, and upwelling over the continental shelf in this area (Bane, 1983; Sedberry et al., 2001).

1.2. GEOLOGIC HISTORY AND SEDIMENTARY BASINS

The Atlantic and Gulf coasts of North America are situated along a passive continental margin formed by the break up and pull-apart of the supercontinent Pangea during the Triassic-Jurassic periods during formation of the incipient Atlantic basin (**Figure F-3**). Continental rifting was accompanied by the deposition of red beds and volcanic rocks during the Triassic period followed by marine incursions into rift basins during the middle and late Jurassic period when deposition of evaporates took place along the Atlantic margin from Newfoundland to the SAB (**Figure F-4**).



ERA	PERIOD	MILLION YEARS		EPOCH
		DURATION	BEFORE PRESENT	
CENOZOIC	QUATERNARY (Q)		0.01	HOLOCENE (Recent)
		1.99	2.5	PLEISTOCENE (Qp)
	TERTIARY (T)	5	7	PLIOCENE (Tpl)
		19	26	MIOCENE (Tm)
		12	38	OLIGOCENE (To)
		16	54	EOCENE (Te)
		11	65	PALEOCENE (Tp)
MESO-ZOIC	CRETACEOUS (K)	71	136	
	JURASSIC (J)	54	190	
	TRIASSIC (TR)	35	225	
PALEOZOIC	PERMIAN (P)	55	280	
	PENNSYLVANIAN (P)	30	310	
	MISSISSIPPIAN (M)	35	345	
	DEVONIAN (D)	50	395	
	SILURIAN (S)	35	430	
	ORDOVICIAN (O)	70	500	
	CAMBRIAN (C)	70	570	
	PROTEROZOIC	1930	2500	
	ARCHEAN	1900	4600	

Figure F-3. Geologic Time Scale (Guccione and Zachary, 2000).

A passive continental margin is one where the continent and adjacent ocean floor are on the same tectonic plate. Passive continental margins are characterized by subsidence, erosion, and thick sediment accumulations leading to the development of the characteristic continental margin sequence: continental shelf, continental slope, and continental rise (Kennett, 1982). This type of margin experiences little, if any, volcanic or earthquake activity after initial formation of the basin. Because these margins are found along the east coasts of North and South America and the west coasts of Europe and Africa, they are also known as "Atlantic-type" margins.

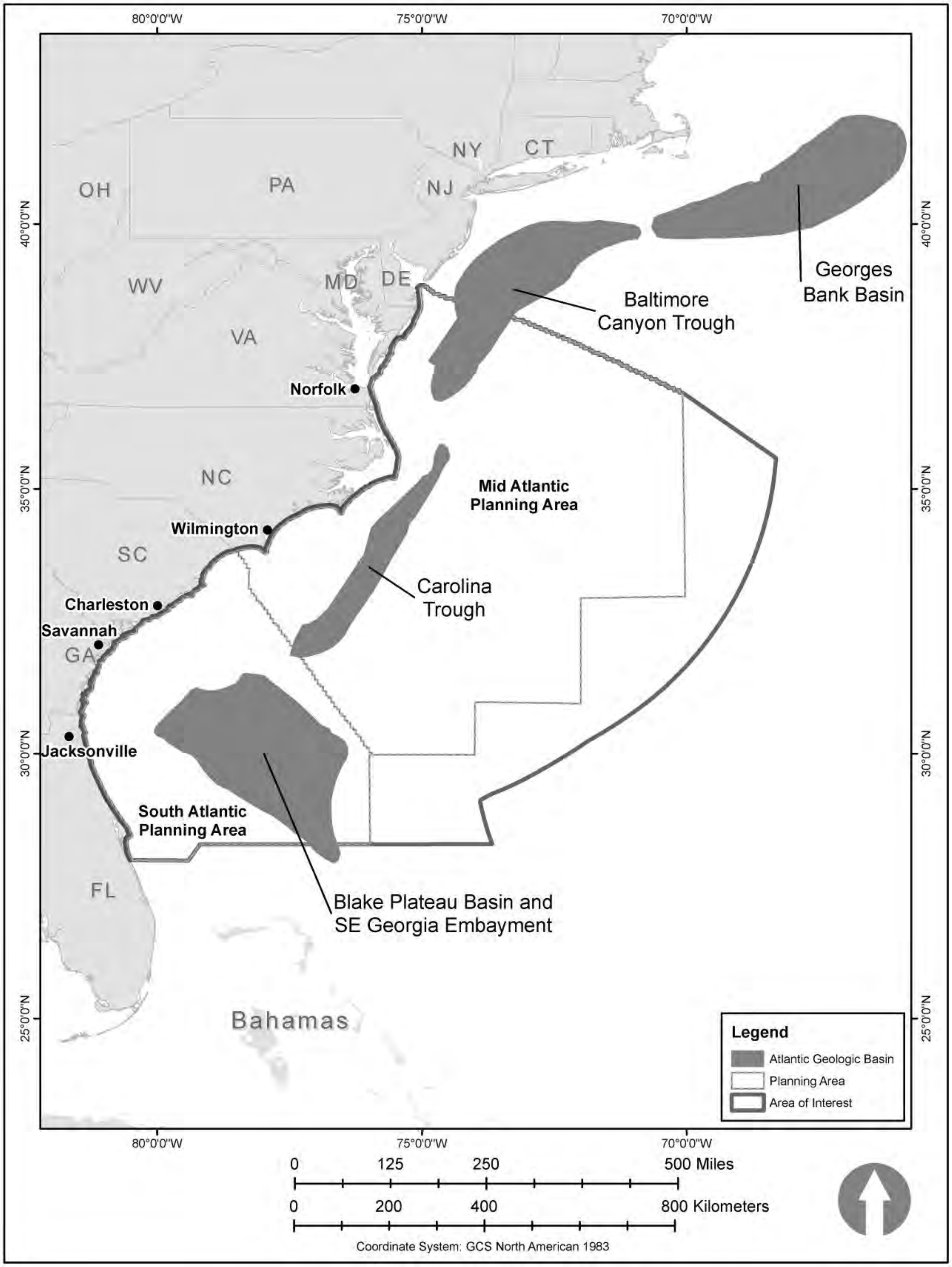


Figure F-4. Major Geologic Basins along the Atlantic Coast.

Sedimentary basins are areas of the Earth's crust with a history of subsidence and within which sediments accumulate forming stratigraphic successions. The stratigraphy of each basin is controlled primarily by large-scale events, such as tectonic activity, climate changes, and eustatic sea-level change. The mechanisms that produce sedimentary basins are lithospheric stretching, flexuring of the oceanic-continental lithosphere, and strike-slip faulting. Sedimentary basins develop within plates (*intraplate basins*) or at their edges (*interplate basins*). Intraplate basins can develop on both continental and oceanic crust; interplate basins can form at passive margins where new oceanic crust is being created, as well as destructive and conservative margins.

Figure F-4 illustrates major geologic basins along the Atlantic coast that are defined by seismic surveys. Underlying the Blake Plateau are two deep sedimentary basins with sediment accumulations up to 13 km (8 mi) thick that have no surface physiographic expression: the Carolina Trough and the Blake Plateau Basin (**Figure F-4**). The Carolina Trough exhibits salt diapirism and is located below the continental slope and upper rise off North and South Carolina. The Blake Plateau Basin is located below the southern portion of Blake Plateau to the east of Georgia and northern Florida. The Southeast Georgia Embayment is a deep sedimentary basin located beneath the Blake Plateau where sediment thickness can be as much as 3.4 km (2.1 mi); it also has no surface physiographic expression.

1.3. SEDIMENTS

Unconsolidated sediment, primarily sand, silt, clay, and some gravel, covers much of the continental shelf and slope of both the MAB and SAB (**Figure F-5**). The MAB shelf is overlain by a mantle of sand approximately 20 m (65 ft) thick, with some areas characterized by linear sand ridges and swales. Rivers draining into the MAB carry little sediment offshore because of sediment being trapped in estuaries or coastal marshes, resulting in coarse sediments on the shelf (Milliman and Meade, 1983). Tucholke (1987) attributes the coarse sediments on the shelf to the winnowing out of fine-grained materials and their transport either shoreward into estuaries or off the shelf via submarine canyons onto the continental slope. On the Mid-Atlantic continental slope, sediments tend to be silt and clay mixtures with interspersed, localized sandy areas (Milliman et al., 1972; Ray et al., 1980). Slope sediments are highly variable, consisting mainly of sandy silts on the upper slope and silts and clays on the lower slope (McGregor, 1983). Fine-grained biogenic calcareous sediments predominate seaward of the 3,000-m (9,843-ft) isobath (Amato, 1994).

Late Jurassic (approximately 190 million years ago) carbonate sediments and reefs of the Florida Platform form the shelf off the northern Florida coast and the Carolina Platform off the North Carolina coast (**Figure F-5**). Terrigenous clastic sediments of Tertiary age prograded across the Florida-Hatteras shelf (**Figure F-4**) to form a thick sedimentary wedge over these platforms that are truncated by the Gulf Stream, which scours the inner part of the Blake Plateau nearly clean of sediments. The distribution of continental shelf and slope bottom sediments in the SAB are much more complex than those found in other areas (Amato, 1994). A thick layer of phosphoritic sediment, whose thickness varies widely, is covered by a thin layer of carbonate sand over much of the Blake Plateau. The thin layer of sand, generally less than 5 m (15 ft) thick, covers most of the shelf surface. Hard substrate, such as cemented sand, that can range from smooth outcrops to rough bottoms with relief up to 15 m (50 ft) occurs in places where the sand cover is absent. Accumulation of sediment on the Blake Plateau has not kept pace with the rate of subsidence because the Plateau lies beneath and east of the Gulf Stream along the east side on the inner shelf, so deposition of coastal sediments is precluded (Amato, 1994).

Sand and gravel layers in the SAB are much thinner than those found north of Cape Hatteras, and rock outcrops are common. The northern areas are characterized by quartz sands while the southern areas of the SAB have higher carbonate content. Continental shelf sands are remnants of delta and riverine sediments. Sediments on the outer shelf of the SAB tend to be medium to coarse-grained sand (Pilkey et al., 1979). Sediments on the continental slope are primarily composed of silt and clay (Tucholke, 1987).

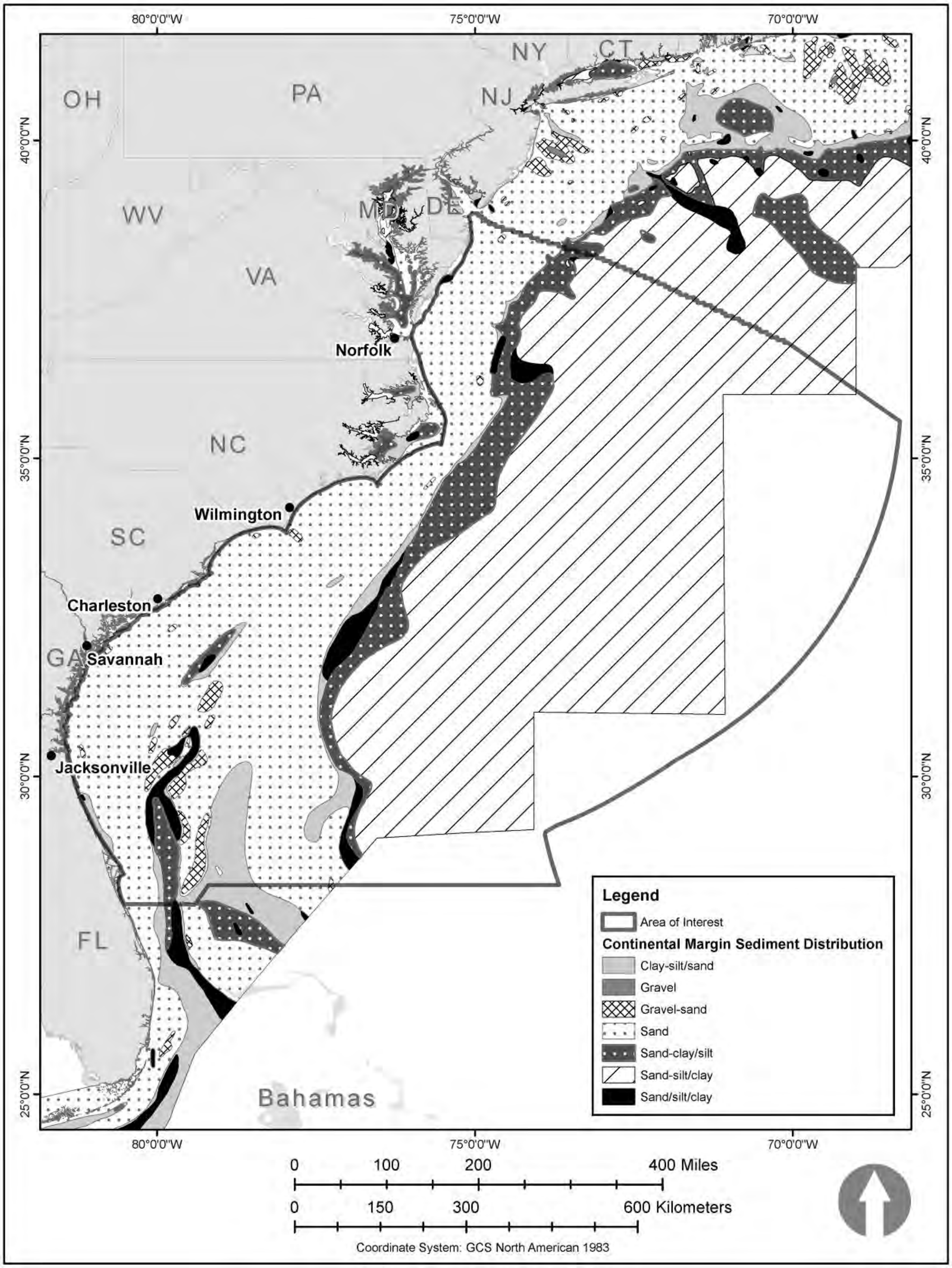


Figure F-5. Distribution of Surficial Sediment Types in the Area of Interest (Poppe et al., 2005).

2. PHYSICAL OCEANOGRAPHY

This section provides a regional description of the physical oceanography in the AOI. Additional background information is provided in a literature synthesis by Voulgaris (2011).

The major currents along the Atlantic coast are the Gulf Stream system flowing northward and the Labrador Current flowing southward. The Gulf Stream is the western boundary current of the North Atlantic Subtropical Gyre that strongly influences the physical oceanography of the MAB and SAB (Pickard and Emery, 1990; Verity et al., 1993). Offshore southeastern Florida, the Gulf Stream begins in the Florida Straits as the Florida Current, a continuation of the Loop Current from the Gulf of Mexico. The Florida Current is that section of the Gulf Stream that stretches from the Florida Straits north to Cape Hatteras, North Carolina. A composite of the Loop Current, Florida Current, and Gulf Stream positions from satellite imagery is shown in **Figure F-6**.

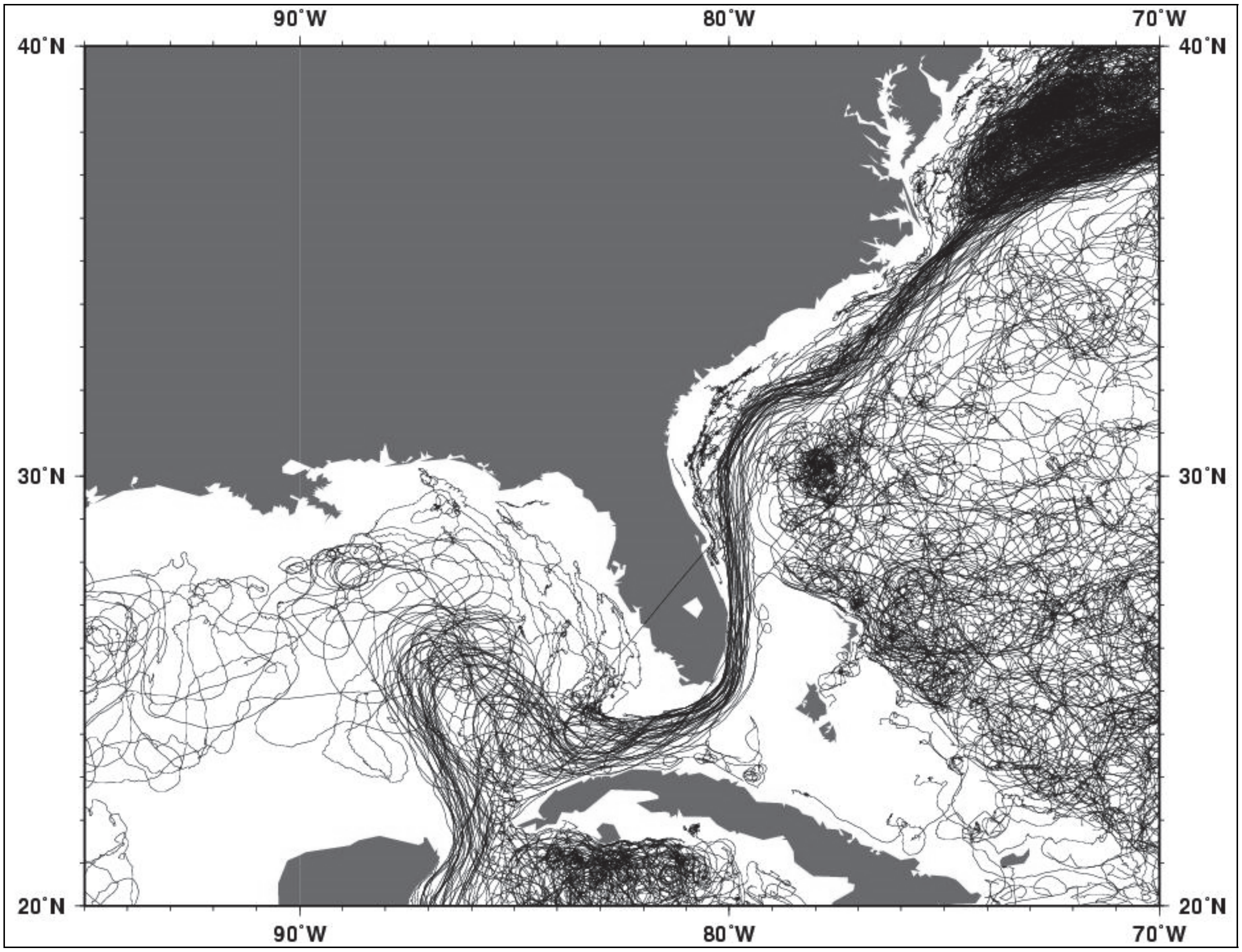


Figure F-6. Loop Current (Gulf of Mexico) and Gulf Stream (Atlantic Coast) Locations Based on Trajectories of Near-surface Drifting Buoys from 1978-2003 (Cooperative Institute for Marine and Atmospheric Studies, 2008).

The Gulf Stream is a powerful, warm, and swiftly flowing current that flows northward, generally along the shelf edge, carrying warm equatorial waters into the cooler North Atlantic (Pickard and Emery, 1990; Verity et al., 1993). It generally follows the shelf edge up the southeast coast until it reaches Cape Hatteras, where it begins its northeastward flow across the Atlantic Ocean toward Europe (Pickard and Emery, 1990). The Antilles Current, which originates from the North Equatorial Current and flows northwestward along the eastern edge of the Bahamas, contributes to the Gulf Stream when it joins the Florida Current off the east coast of Florida.

About 30 million m^3/s (1,060 million ft^3/s) of water is transported through the Florida Straits by the Florida Current; transport volume increases progressively to the northeast to about 85 million m^3/s (3,000 million ft^3/s) near Cape Hatteras (Pickard and Emery 1990). Surface current speed is high, at times exceeding 2.5 m/s (8.2 ft/s) with a mean surface velocity of about 1.8 m/s (5.9 ft/s) (Von Arx et al., 1974; Tomczak and Godfrey, 2003). Current flow in the Florida Straits is greatest within about 200 m (656 ft) of the surface, with velocity decreasing with depth. Current speed is about 10 cm/s (0.3 ft/s) at depths greater than about 1,000 m (3,280 ft) (Tomczak and Godfrey, 2003). The Gulf Stream is typically 80-150 km (50-93 mi) wide and 800-1,200 m (2,600-4,000 ft) deep and has a slightly lower flow rate after passing Cape Hatteras (80 million m^3/s [2.8 billion ft^3/s]) where the velocity of the current also is fastest near the surface with a maximum speed of about 2.5 m/s (8 ft/s) (Pickard and Emery, 1990; Tomczak and Godfrey, 2003).

In addition to the Gulf Stream, features such as rings, meanders, and filaments can form and affect shelf waters in the SAB (Science Applications International Corporation, 1984; Florida Institute of Oceanography, 1986). South of Cape Hatteras, meanders diverging from the Gulf Stream typically form frontal eddies that remain attached to the Gulf Stream. North of Cape Hatteras, meanders pinch off to form small gyre features that become separated from the Gulf Stream as either warm or cold core rings (Mann and Lazier, 1996).

Off northeastern Florida, the Gulf Stream flows consistently northward. Although its position remains fairly stable off northeastern Florida, lateral meandering does occur (Bane et al., 1981; Lee et al., 1981; Dept. of the Navy, 1995). Frontal eddies, filaments, and warm and cold core rings may form during development of a meander and move across the shelf. Over the SAB shelf, there is a broad, slow, northerly flow with frequent intrusions of the Gulf Stream. Currents and water masses on the SAB shelf are mainly influenced by the Gulf Stream's deflections, meanders, and flow with mean current speeds on the shelf ranging from 1.8 m/sec (3.5 kn) near the surface to 0.40 m/sec (0.8 kn) near the bottom (Lee and Waddell, 1983). Surface velocities within the Gulf Stream offshore northeastern Florida are higher, ranging from 1.03 to 2.57 m/sec (2 to 5 kn) (Mann and Lazier, 1996) with a difference in current speeds reported for December (0.30 m/sec [0.6 kn]) and July (0.50 m/sec [1 kt]) (Dept. of the Navy, 1986).

Anticyclonic meanders that pinch off from the Gulf Stream form a separated deep pool of warm Sargasso Sea water rotating clockwise known as warm core rings (Brooks, 1996). Warm core rings span 100 km (~54 nmi) in diameter (García-Moliner and Yoder, 1994) with vertical dimensions of about 1 km (0.6 nmi) and may persist for several weeks to more than a year, drift in a south-to-southwesterly direction, and either dissipate or merge with the Gulf Stream (Pickard and Emery, 1990; Mann and Lazier, 1996; García-Moliner and Yoder, 1994); on average, 22 warm-core rings are formed per year, each measuring approximately 100 km (54 nmi) in diameter and 1,000 m (3,280 ft) in the vertical dimension (Gyory et al., 2005). When a cyclonic meander pinches off the Gulf Stream, cold core rings form, a counterclockwise rotating ring of cool continental slope water surrounded by the warmer waters of the Sargasso Sea (Pickard and Emery, 1990). Cold core rings form twice as frequently as warm core rings. On average, 35 cold-core rings are shed by the Gulf Stream per year (Gyory et al., 2005). Cold core rings are larger (100-300 km [54-162 nmi] in diameter) and last longer, persisting from months to years. Cold core rings form to the south of the Gulf Stream, drift in a south-to-southwest direction, and eventually dissipate or merge with the Gulf Stream in a similar fashion to their warm core ring counterparts (Pickard and Emery, 1990). Frontal eddies are distinct features from the larger cold and warm core rings that pinch off the Gulf Stream after it is deflected from the U.S. coastline. Frontal eddies often take the form of finger-like extensions and protrude onto the shelf, folding back to enclose a cold, nutrient-rich core of water upwelled from deep within the Gulf Stream (Mann and Lazier, 1996). The transient upwelling associated with frontal eddies results in more localized areas of high surface primary productivity. The formation of warm and cold core rings does not appear to be correlated with seasonality, but rather appears to be driven by localized flow dynamics of the Gulf Stream.

Upwelling along the Atlantic coast is both wind-driven and a result of dynamic uplift (Shen et al., 2000; Lentz et al., 2003). Upwelling can occur along the area of the MAB from New Jersey to Virginia during summer months when southwesterly winds prevail (Cook, 1988). In some areas of the upper MAB, upwelling occurs in stratified waters (spring and summer) after the passing of storms (Cook, 1988).

In addition to the Gulf Stream, currents originating from the outflow of both Chesapeake and Delaware Bays influence the surface circulation in the MAB. The Chesapeake Bay plume flows seaward from the mouth of the Bay and then turns south to form a coastal jet that can extend as far as Cape Hatteras. Similarly, the Delaware Coastal Current begins in Delaware Bay and flows southward along the Delmarva Peninsula before being entrained into the Chesapeake Bay plume.

3. WATER QUALITY

This section provides a regional description of water quality in the AOI. Additional information on chemical oceanography and water quality is provided in a literature synthesis by Windom (2011).

Water quality is typically gauged by measuring a series of parameters such as dissolved oxygen, transparency (i.e., water clarity, turbidity, or suspended matter), chlorophyll content, nutrient concentrations, and contaminant concentrations (heavy metals and hydrocarbons). Offshore water quality in the AOI is expected to be generally good to excellent, with low water column stratification, nitrogen and phosphorus concentrations, and chlorophyll concentrations. Additionally, observations of high water clarity, dissolved oxygen concentrations at or near saturation, and low concentrations of suspended matter and trace metal and hydrocarbon contaminants indicate good water quality (U.S. Environmental Protection Agency [USEPA], 1998). Concentrations of suspended matter (turbidity) are typically low in Mid-Atlantic marine waters, generally <1 mg/L (Louis Berger Group, Inc., 1999). Suspended matter and turbidity vary locally between surface and bottom waters, vary seasonally (because of rainfall and riverine discharge), are located in different areas because of differing sources and grain sizes, and increase naturally during storm events. Turbidity may be temporarily affected by dredging activities, in offshore waters this would be limited primarily to disposal at approved offshore disposal sites. These sites are located, designed, and operated under permit guidelines of the Clean Water Act (CWA) and the Marine Protection, Research, and Sanctuaries Act (MPRSA) to ensure any changes in turbidity would be localized and short-term (USEPA, 2011a).

The overall condition of coastal waters is rated as fair. This assessment is based on an evaluation of five indices: water quality, sediment, benthic, coastal habitat, and fish tissue contaminants. The southeast coast is rated as fair with an index score of 3.6 while for the northeast coast is rated fair to poor with a score of 2.2 (based on a scale from 1 to 5) (USEPA, 2008).

Some areas of the Atlantic have heavy shipping traffic and may experience localized impacts from ships, especially from bilge water, domestic wastewater, and tank washings. Ship discharges are regulated under USEPA's National Pollution Discharge Elimination System (NPDES) vessels program. The primary means of regulation is the Vessel General Permit, which applies to discharges incidental to the normal operation of all non-recreational, non-military vessels of 79 feet or greater in length which discharge in waters of the U.S. (USEPA, 2011b).

Pelagic tar is probably the most common form of hydrocarbon contamination present in the offshore environment (Farrington, 1987). Higher tar concentrations tend to be associated with the Loop Current and the Gulf Stream while only trace concentrations are found over the continental shelf. Van Vleet (1984) indicated that tanker operations may be the major source of pelagic tar.

Hydrocarbon and metal concentrations in MAB and SAB sediments vary with sediment texture, but with the exception of disposal sites, are not indicative of significant contamination (Lee, 1979; Smith et al., 1979; Windom and Betzer, 1979). Metal and hydrocarbon concentrations on the continental slope tend to be higher than on the shelf because of the greater proportions of silt and clay in slope sediments. Trace metals include elements that are generally present in minute amounts in the sediment. With the exception of dump sites, trace metal concentrations nearshore and offshore rarely approach toxicity limits defined by the USEPA. To assist in understanding applicable limits, the National Oceanic and Atmospheric Administration (NOAA) has recently upgraded its Screening Quick Reference Tables (SQuiRTs) to include an expanded list of analytes for which benchmarks are presented (U.S. Dept. of Commerce [USDOC], NOAA, 2011). Elevated lead concentrations have been detected, decreasing with depth in the sediment column, suggesting an anthropogenic source (U.S. Dept. of the Interior [USDOI], Minerals Management Service [MMS], 1992). On the Mid-Atlantic slope and rise, sediment samples indicated that hydrocarbons found were either mainly biogenic in origin or were contaminants derived from the burning of fossil fuels. Biogenic gas is found in all marine sediments, but no evidence of petroleum contamination was reported in sediments from the South Atlantic slope and rise (USDOI, MMS, 1992).

In coastal waters, water quality is controlled primarily by the anthropogenic inputs of land runoff, land point source discharges, and atmospheric deposition. With increasing distance from shore, oceanic circulation patterns play an increasingly larger role in dispersing and diluting anthropogenic contaminants and determining water quality. Due primarily to the influence of tidal plumes leaving estuaries, areas of the Atlantic closer to shore will show major local variations (USDOI, MMS, 1992). While the overall quality of U.S. coastal waters has been rated fair in all three National Coastal Condition Reports issued by USEPA, the overall condition of U.S. coastal waters has improved slightly since the 1990s (USEPA, 2008).

Most threats to marine water quality originate on land. Immediately along the coastline water quality is influenced by cities and other large nearby populations with associated non-point pollution sources: urban runoff containing oil, greases, and nutrients; domestic and sanitary wastes; and large expanses of agricultural land where fertilizers and biocides are applied. In less populated areas networks of wetlands, estuaries, and bays can be subject to effluents from distributed septic systems. Plumes from the two prominent estuaries in the MAB, Chesapeake and Delaware Bays, affect coastal water quality. These estuaries have extensive watersheds that funnel nutrients, sediment, and organic material into secluded, poorly flushed estuaries that are much more susceptible to eutrophication, the pattern of which also closely reflects the distribution of population density (USEPA, 2008). Hypoxia, the condition of having low dissolved oxygen concentration in the water, is caused by excessive nutrients and other oxygen-demanding contaminants. Hypoxia often forms when the water column becomes vertically stratified, and mixing between oxygenated surface waters and bottom waters cannot occur. Hypoxia is not a widespread phenomenon in the AOI. However, it does occur, most notably during the summer in the deeper waters of Chesapeake Bay (Hagy et al., 2004).

Between 1980 and 2003, coastal counties of the Southeast Coast region showed the largest rate of population increase (58 percent) of any coastal region in the conterminous U.S. In 2003, the coastal population of the Northeast Coast region was the largest in the country, with 52.6 million people, representing 34 percent of the nation's total coastal population. Although coastal counties along the Northeast Coast showed the slowest rate of population increase between 1980 and 2003, the region gained the second-largest number of people (almost 8 million) of all U.S. regions during this period (USEPA, 2008).

4. METEOROLOGY AND AIR QUALITY

Oceanographic and atmospheric phenomena combine to create the long-term climate and short-term weather patterns that characterize the AOI. The regional climate is influenced by several factors, including oscillating atmospheric pressure systems, prevailing winds, and warm Gulf Stream waters. Three atmospheric pressure systems govern the wind patterns and climate in this region: the Icelandic Low, the Bermuda-Azores High, and the Ohio Valley High (Blanton et al., 1985). The Bermuda-Azores High is a semi-permanent, high-pressure system centered over the island of Bermuda in summer and fall and over the Azores in the eastern North Atlantic in winter and spring. The anticyclonic (clockwise) circulation associated with the Bermuda-Azores High dominates the climate from approximately May through August, producing southeasterly winds (<6 m/s [<20 ft/s]) and hot, humid weather over much of the southeastern U.S. In winter (approximately November through March), the Icelandic Low and weak Ohio Valley High combine to generate west-northwesterly winds (8-10 m/s [26-33 ft/s]) and drier weather conditions in the region (Adams et al., 1993). Wind velocities offshore of Cape Canaveral exhibited similar trends, but with slightly lower average speeds at 4.6 m/s (15.1 ft/s) in summer and 6.7 m/s (22 ft/s) in winter (USDOC, NOAA, National Data Buoy Center [NDBC], 2011a). Weather systems pass rapidly through the southeastern U.S. (approximately every 2-5 days) throughout the year, and their effects are superimposed on the seasonal cycling of the Bermuda-Azores High (Joyce, 1987). While there is a large range of changes in air temperature, wind, and barometric pressure between seasons, fluctuations associated with the passage of weather systems may exceed seasonal changes.

A long-term record of atmospheric and oceanographic conditions is available from oceanographic buoys maintained by the USDOC, NOAA, NDBC (2011b). Air temperature measured over a 17-year period at an oceanographic buoy 48 km (26 nmi) southeast of Cape May, New Jersey, averaged 23.3 °C

(73.9 °F) in August and 3.6 °C (38.5 °F) in February, the warmest and coldest months, respectively (USDOC, NOAA, NDBC, 2011c). In contrast, a buoy located 278 km (150 nmi) east of Cape Hatteras recorded mean monthly air temperatures of 26.1 °C (79.0 °F) in August and 14.9 °C (58.8 °F) in January over a concurrent 25-year period (USDOC, NOAA, NDBC, 2011d), illustrating the warming influence of the Gulf Stream.

Prevailing westerly winds result in a tropical/subtropical climate south of Cape Hatteras (Joyce, 1987). Air temperature measured in southeast Onslow Bay averages 26 °C (78.8 °F) in summer (June through August) and 13 °C (55.4 °F) in winter (December through February), with annual extremes of 31 °C (87.8 °F) and -12 °C (10.4 °F) (Coastal Ocean Research and Monitoring Program, 2011). By contrast, air temperatures recorded from a NOAA oceanographic buoy located approximately 37 km (20 nmi) off Cape Canaveral averaged 27.1 °C (80.8 °F) in summer and 19.8 °C (67.6 °F) in winter between 1988 and 2001 (USDOC, NOAA, NDBC, 2011a). Warmer average temperatures and temperature extremes of 31.8 °C (89.2 °F) and 0 °C (32.0 °F) are almost certainly a result of the moderating influence of the warm Gulf Stream waters.

Over the past 50 years, total annual precipitation has averaged about 115 cm (45 in) in Lewes, Delaware and 145 cm (57 in) at Cape Hatteras, North Carolina (Southeast Regional Climate Center, 2011a,b). Precipitation in the form of snow or freezing rain occurs more frequently in the north. Average annual precipitation ranges between 109 and 142 cm (43 and 56 in) along the coastlines of the Carolinas, Georgia, and northern Florida (Boyles et al., 2004). Maximum rainfall occurs in late summer; however, maximum discharge of freshwater from local rivers into the SAB occurs in March or April as water drains from inland mountain and piedmont areas, which receive their maximum rainfall in the early spring (Blanton et al., 1985).

The proximity of the Gulf Stream to the southeast U.S. coast has a strong effect in the generation of cyclonic, extra-tropical storms in winter as cold, dry continental air meets the warm, moist air over Gulf Stream waters (Adams et al., 1993). Thunderstorms and major storm systems occur in the region most often during summer and fall as hot, humid air masses collide with passing fronts (Joyce, 1987).

Tropical and extra-tropical cyclones are significant influences on weather and sea state conditions in the AOI. Tropical cyclones, which occur during summer and fall, are severe but infrequent. Extra-tropical cyclones occur frequently during winter and may produce unfavorable conditions during winter and spring. Most major storms, including hurricanes, occur during the North Atlantic hurricane season, which occurs from June through November. Tropical cyclones form in warm, equatorial waters of the North Atlantic Ocean and Caribbean Sea and often move northward along the southeastern U.S. coast following the path of the Gulf Stream (Adams et al., 1993; Buchan, 2000). Since 1944, when reliable data on storm systems began being recorded, 655 named storms have occurred over the North Atlantic; 162 of these storms were major hurricanes (USDOC, NOAA, National Climatic Data Center [NCDC], 2011a). From 1950 through 2005, 27 hurricanes made first landfall between Cape Canaveral, Florida and Cape Hatteras, with just two hurricanes striking the coast between Cape Hatteras and Long Island, New York (USDOC, NOAA, NCDC, 2011b).

Air quality typically is defined by the concentration of criteria pollutants established by USEPA under the National Ambient Air Quality Standards (NAAQS)—a listing that identifies those pollutants considered harmful to public health and the environment. The Clean Air Act (CAA) establishes two types of national air quality standards: (1) primary standards, which set limits to protect public health, including the health of "sensitive" populations (e.g., asthmatics, children, and the elderly); and (2) secondary standards, which set limits to protect public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. The NAAQS have been established for six principal pollutants (called “criteria” pollutants): carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter (PM_{10} and $PM_{2.5}$), and sulfur oxides.

Outer continental shelf (OCS) waters are not classified as to the presence of criteria pollutants under NAAQS and the CAA. Ambient air quality offshore is expected to range from good to excellent because of the distance from significant emission sources (e.g., large urban areas or concentrated offshore development). Most of the coastal counties adjacent to the AOI have all criteria pollutants present. However, Sussex County, Delaware at the mouth of Delaware Bay is part of the Philadelphia-Wilmington-Atlantic City moderate nonattainment area for 8-h ozone. The Norfolk-Virginia Beach-Newport News-Hampton Roads area in Virginia is a maintenance area for 8-h ozone. A maintenance area is an area that has been redesignated to attainment for the 8-hour ozone standard. There are no other coastal nonattainment or maintenance areas adjacent to the AOI (USEPA, 2011c).

5. ACOUSTIC ENVIRONMENT

Various activities and processes, both natural and anthropogenic, combine to form the sound profile within the ocean, generally referred to as ambient ocean noise (Richardson et al., 1995). Most ambient noise is broadband (composed of a spectrum of numerous frequencies without a differentiating pitch) and encompasses virtually the entire frequency spectrum. Vessel traffic is a major contributor to ocean noise between 5 and 500 Hz (National Research Council [NRC], 2003). Spray and bubbles associated with breaking waves are the major contributions to ambient noise in the 500-to-100,000-Hz range. At frequencies greater than 100,000 Hz, "thermal noise" caused by the random motion of water molecules is the primary source. Ambient noise sources, especially noise from wave and tidal action, can cause coastal environments to have particularly high ambient noise levels.

A large portion of the noise from vessel traffic comes from vessel engines and propellers, and those sounds occupy the low frequencies used by most large whales (Richardson et al., 1995). In the open water, ship traffic can influence ambient background noise at distances of thousands of kilometers; however, the effects of ship traffic sounds in shallow coastal waters are much less far reaching, most likely because a large portion of the sound's intensity is absorbed by soft, nonreflective, unconsolidated materials (sands and mud) on the seafloor. Other anthropogenic sources include dredging, nearshore construction activities, and sonar signals (especially those used by the military). Offshore oil and gas operations contribute to the ambient noise in other regions, but are not currently occurring in the AOI.

Long-term data analyzed by McDonald et al. (2006) offshore California show an increase in ambient noise of approximately 10-12 dB in the frequency range 30-50 Hz over a 40-year period, suggesting an average noise increase rate of 2.5-3 dB per decade. The authors attributed the change to increased levels of shipping traffic. While comparable long-term data for the AOI have not been published, it is assumed that underwater noise from vessel traffic and other anthropogenic sources is increasing and will continue to increase incrementally over the next decade.

6. REFERENCES CITED

Adams, C.E., T.J. Berger, W.C. Boicourt, J.C. Churchill, M.D. Earle, P. Hamilton, F.M. Vukovich, R.J. Wayland, and R.D. Watts. 1993. A review of the physical oceanography of the Cape Hatteras, North Carolina region: Volume I Literature Synthesis. Prepared by Science Applications International Corporation. OCS Study MMS 93/0031. 152 pp. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4821.pdf. Accessed August 19, 2011.

Amato, R.V. 1994. Sand and gravel maps of the Atlantic continental shelf with explanatory text. U.S. Dept. of the Interior, Minerals Management Service. OCS Monograph MMS 93-0037.

Bane, J.M., Jr. 1983. Initial observations of the subsurface structure and short-term variability of the seaward deflection of the gulf stream off Charleston, South Carolina. Journal of Geophysical Research 88 C(8):4673-4684.

Bane, J.M., Jr. and D.A. Brooks. 1979. Gulf Stream Meanders along the continental margin from the Florida Straights to Cape Hatteras. Geophysical Research Letters 6:280-282.

Bane, J.M., Jr., D.A. Brooks, and K.R. Lorenson. 1981. Synoptic observations of the three dimensional structure and propagation of Gulf Stream meanders along the Carolina continental margin. Journal of Geophysical Research 86:6411-6425.

Blanton, J.O., F.B. Schwing, A.H. Weber, L.J. Pietrafesa, and D.W. Hayes. 1985. Wind stress climatology in the South Atlantic Bight. In: Atkinson, L.P., D.W. Menzel, and K.A. Bush, eds. Oceanography of the southeastern U.S. continental shelf, Washington, D.C. American Geophysical Union. Pp. 10-22.

Boyles, R.P., C. Holder, and S. Raman. 2004. North Carolina climate: A summary of climate normals and averages at 18 agricultural research stations. North Carolina Agricultural Research Service, College of Agricultural and Life Sciences, North Carolina State University, Raleigh, NC. Technical Bulletin 322.

Brooks, D.A. 1996. Physical oceanography of the shelf and slope seas from Cape Hatteras to George's Bank: A brief review. In: Sherman, K., N.A. Jaworski, and T.J. Smayda, eds. The northeast shelf ecosystem: Assessment, sustainability, and management. Cambridge, MA: Blackwell Science, Inc. Pp. 47-74.

Buchan, K.C. 2000. The Bahamas. Marine Pollution Bulletin 41:94-111.

Cook, S.K. 1988. Physical oceanography of the Middle Atlantic Bight. In: Pacheco, A.L., ed. Characterization of the Middle Atlantic Water Management Unit of the Northeast Regional Action Plan. Northeast Fisheries Science Center, NMFS, Woods Hole, MA. NOAA Tech. Memo. NMFS-F/NEC-56. Pp. 1-49.

Cooperative Institute for Marine and Atmospheric Studies. 2008. Surface currents in the Atlantic Ocean: Drifting buoy spaghetti maps. Available at: http://oceancurrents.rsmas.miami.edu/atlantic/spaghetti-bw/florida.jpg. Accessed September 13, 2011. Last updated 2008.

Coastal Ocean Research and Monitoring Program. 2011. Description of Onslow Bay coastal climatology. Available at: http://www.cormp.org/climate/OB_climatology.html. Accessed August 19, 2011.

Dept. of the Navy. 1986. U.S. Navy climatic study of the Caribbean Sea and Gulf of Mexico, Volume 3. Florida coastal waters and southwest Atlantic. Naval Oceanography Command Detachment, Asheville, NC. NAVAIR 50-1C-545. 198 pp.

Dept. of the Navy. 1995. Environmental documentation for candidate site analysis for SEAWOLF shock test program, Mayport, Florida and Norfolk, Virginia. Prepared by Ecology and Environment, Inc. for the U.S. Dept. of the Navy, Southern Division, Naval Facilities Engineering Command.

Farrington, J.W. 1987. Hydrocarbons. In: Milliman, J.D. and W.R. Wright, eds. The marine environment of the U.S. Atlantic continental slope and rise. Boston/Woods Hole, MA: Jones and Bartlett Publ., Inc. Pp. 130-139.

Florida Institute of Oceanography. 1986. Physical oceanographic study of Florida's Atlantic coast region - Florida Atlantic Coast Study (FACTS). Volume 2 Technical Report. Prepared for U.S. Dept. of the Interior, Minerals Management Service. MMS Contract Number 14-12-0001-30082. OCS Study MMS 86-0079.

García-Moliner, G. and J.A. Yoder. 1994. Variability in pigment concentration in warm-core rings as determined by coastal zone color scanner satellite imagery from the Mid-Atlantic Bight. J. Geophys. Res. 99(C7):14277–14290.

Guccione J. and D.L. Zachary. 2000. Geologic history of the southeastern United States and its effects on soils of the region. In: Scott, H.D., ed. Water and chemical transport in soils of the southeastern USA. Electronic Document for the SAAESD, Southern Cooperative Series Bulletin #395.

Gyory, J., A.J. Mariano, and E.H. Ryan. 2005. The Gulf Stream. Surface currents in the Atlantic Ocean. Available at: http://oceancurrents.rsmas.miami.edu/atlantic/gulf-stream.html. Accessed August 19, 2011.

Hagy, J.D., W.R. Boynton, C.W. Keefe, and K.V. Wood. 2004. Hypoxia in Chesapeake Bay, 1950-2001: Long-term change in relation to nutrient loading. Estuaries 27:634–658.

Heezen, B.C., M. Tharp, and M. Ewing. 1959. The floors of the oceans, 1: The North Atlantic. The Geological Society of America Special Paper 65. 122 pp.

Joyce, T.M. 1987. Meteorology and air-sea interactions. In: Milliman, J.D. and W.R. Wright, eds. The marine environment of the U.S. Atlantic continental slope and rise. Boston/Woods Hole, MA: Jones and Bartlett Publishers, Inc. Pp. 5-26.

Kennett, J.P. 1982. Marine geology. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Lee, R.F. 1979. Chapter 3: Hydrocarbons in water, sediment, zooplankton, benthic fauna, and demersal fishes of South Atlantic/Georgia Bight. In: Texas Instruments, Inc., South Atlantic Benchmark Program, Outer Continental Shelf (OCS) Environmental Studies. Volume 3. Results of Studies of Georgia Bight of North Atlantic Ocean. Prepared for Bureau of Land Management. Contract No. AA551-CT7-2. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4453.pdf. Accessed August 19, 2011.

Lee, T.N. and E. Waddell. 1983. On Gulf Stream variability and meanders over the Blake Plateau at 30ºN. Journal of Geophysical Research 88:4617-4632.

Lee, T.N., L.P. Atkinson, and R. Legeckis. 1981. Observations of a Gulf Stream frontal eddy on the Georgia continental shelf, April 1977. Deep-Sea Research 28:347-348.

Lentz, S.J., S. Elgar, and R.T. Guza. 2003. Observations of the flow field near the nose of a buoyant coastal current. Journal of Physical Oceanography 33:933-943.

Louis Berger Group, Inc. 1999. Environmental Report: Use of Federal offshore sand resources for beach and coastal restoration in New Jersey, Maryland, Delaware, and Virginia. Prepared by Louis Berger Group for U.S. Dept. of the Interior, Minerals Management Service, Herndon, VA. OCS Study MMS 99-0036,

Macintyre, I.G. and J.D. Milliman. 1970. Physiographic features on the outer shelf and upper continental slope, Atlantic continental margin, southeastern United States. Bulletin of the American Geological Society 81:2577-2598.

Malahoff, A., R.W. Embley, R.B. Perry, and C. Fefe. 1980. Submarine mass-wasting of sediments on the continental slope and upper rise south of Baltimore Canyon. Earth and Planetary Science Letters 49:1-7.

Mann, K.H. and J.R.N. Lazier. 1996. Dynamics of marine ecosystems: Biological-physical interactions in the sea. Second edition. Boston, MA: Blackwell Scientific Publications. 394 pp.

McDonald, M.A., J.A. Hildebrand, and S.M. Wiggins. 2006. Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. J. Acoust. Soc. Am. 120(2):711-718. Available at: http://www.awionline.org/ht/a/GetDocumentAction/i/10168. Accessed September 6, 2011.

McGregor, B.A. 1983. Environmental geologic studies on the United States Mid- and North Atlantic Outer Continental Shelf area 1980–1982. U.S. Geological Survey Open File Report 83-824.

Milliman, J.D. and R.H. Meade. 1983. World-wide delivery of river sediment to the oceans. J. Geology 91:1-21.

Milliman, J.D., F.T. Manheim, R.M. Pratt, and E.F.K. Zarudski. 1967. Alvin dives on the continental margin off the southeastern United States, July 2-13, 1967. Woods Hole Oceanographic Institution Ref. No. 67-80. 64 pp.

Milliman, J.D., O.H. Pilkey, and D.A. Ross. 1972. Sediments of the continental margin of the eastern United States. Geological Society of America Bulletin 83:1315-1334.

National Research Council. 2003. Ocean noise and marine mammals. Washington, DC: National Academies Press. 151 pp. + app. Available at: http://www.nap.edu/openbook.php?isbn=0309085365. Accessed September 2, 2011.

Newton, J.G., O.H. Pilkey, and O.H. Blanton. 1971. An oceanographic atlas of the Carolina continental margin. Division of Mineral Resources, North Carolina Dept. of Conservation and Development, Raleigh, NC. 57 pp.

Pickard, G.L. and W.J. Emery. 1990. Descriptive physical oceanography, an introduction. 5th Edition. Elsevier, Woburn, MA.

Pilkey, O.H., F. Keer, and S. Keer. 1979. Surficial sediments of the U.S. Atlantic southeastern United States continental shelf, Chapter 5. In: South Atlantic OCS geological studies: Final report FY 1976. Prepared for the U.S. Dept. of the Interior, Bureau of Land Management by the U.S. Geological Survey, Office of Marine Geology, Washington, DC.

Popenoe, P. 1981. A summary of environmental geologic studies on the southeastern United States Atlantic Outer Continental Shelf, 1977–1978. U.S. Dept. of the Interior, U.S. Bureau of Land Management. U.S. Geological Survey Open File Report 81-583. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/1/1157.pdf. Accessed August 19, 2011.

Poppe, L.J., S.J. Williams, and V.F. Paskevich. 2005. U.S. Geological Survey east-coast sediment analysis: Procedures, database, and GIS data. U.S. Geological Survey Open-File Report 2005-1001. Available at: http://woodshole.er.usgs.gov/openfile/of2005-1001/. Accessed August 19, 2011.

Ray, G.C., M.G. McCormick-Ray, J.A. Dobbin, C.N. Ehler, and D.J. Basta. 1980. Eastern United States coastal and ocean zones data atlas. Council on Environmental Quality, Executive Office of the President and the Office of Coastal Zone Management, National Oceanic and Atmospheric Administration.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. San Diego, CA: Academic Press. 576 pp.

Science Applications International Corporation. 1984. South Atlantic OCS Physical Oceanography, Final report (Year five). U.S. Dept. of the Interior, Minerals Management Service, Atlantic OCS Region, Vienna, VA. Contract No. 14-12-0001-29201.

Sedberry, G.R., J.C. McGovern, and O. Pahuk. 2001. The Charleston Bump: An island of essential fish habitat in the Gulf Stream. In: Island in the stream: Oceanography and fisheries of the Charleston Bump. American Fisheries Society Symposium 25:3-24.

Shen, C.Y. R.A. Fusina, and L.K. Shay. 2000. An assessment of local coastal dynamics observed with high-frequency radar. Journal of Geophysical Research 105(C3):6517-6530.

Shepard, F.P. 1973. Submarine geology, 3rd Edition. New York: Harper and Row.

Shor, A.N. and C.E. McClennen. 1988. Marine physiography of the U.S. Atlantic Margin. In: Sheridan, R.E. and J.A. Grow, eds. The Atlantic continental margin. Volume I-2. The Decade of North American Geology Project. Geological Society of America, Boulder, CO.

Smith, C.L., W.G. MacIntyre, and C.W. Wu. 1979. Chapter 9: Hydrocarbons. In: Middle Atlantic Outer Continental Shelf environmental studies. Volume 2-B. Chemical and biological benchmark studies. Contract No. AA550-CT6-62. Prepared by the Virginia Institute of Marine Science for the Bureau of Land Management, Washington, DC. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4479.pdf. Accessed August 19, 2011.

Southeast Regional Climate Center. 2011a. Lewes, Delaware (075320): Period of record monthly climate summary. Available at: http://www.sercc.com/cgi-bin/sercc/cliMAIN.pl?de5320. Accessed August 19, 2011.

Southeast Regional Climate Center. 2011b. Cape Hatteras WSO, North Carolina (311458): Period of record monthly climate summary. Available at: http://www.sercc.com/cgi-bin/sercc/cliMAIN.pl?nc1458. Accessed August 19, 2011.

Stetson, T.R., D.F. Squires, and R.M. Pratt. 1962. Coral banks occurring in deep water on the Blake Plateau. American Museum Novitates 2114:1-39.

Stetson T.R., E. Uchupi, and J.D. Milliman. 1969. Surface and subsurface morphology of two small areas of the Blake Plateau. Trans.Gulf Coast Assoc.Geol.Soc. 19:131-142.

Tomczak, M. and J.S. Godfrey. 2003. Regional oceanography: An introduction. 2nd edition. 390 pp. Available at: http://www.es.flinders.edu.au/~mattom/regoc/pdfversion.html. Accessed August 19, 2011.

Tucholke, B.E. 1987. Submarine geology. In: Milliman, J.D. and W.R. Wright, eds. The marine environment of the U.S. Atlantic continental slope and rise. Boston/Woods Hole, MA: Jones and Bartlett Publishers, Inc. Pp. 56-113.

Uchupi, E. 1968. Atlantic continental shelf and slope of the United States – Physiography. U.S. Geological Survey, Professional Paper 529-D. 30 pp.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration. 2011. Assessing risk to ecological resources. Pollutants in the environment. Posted November 13, 2008. Available at: http://response.restoration.noaa.gov/topic_subtopic_entry.php?RECORD_KEY%28entry_subtopic_topic%29=entry_id,subtopic_id,topic_id&entry_id%28entry_subtopic_topic%29=783&subtopic_id%28entry_subtopic_topic%29=5&topic_id%28entry_subtopic_topic%29=2. Posted November 13, 2008. Accessed August 19, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center. 2011a. State of the climate. Hurricanes & tropical storms, 2005. Available at: http://www.ncdc.noaa.gov/sotc/tropical-cyclones/2005. Accessed August 19, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center. 2011b. Hurricanes. Available at: http://www.ncdc.noaa.gov/oa/climate/severeweather/hurricanes.html. Updated March 1, 2011. Accessed August 19, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Data Buoy Center. 2011a. Station 41009 (LLNR 840) - Canaveral 20 nm east of Cape Canaveral, FL: Element Air Temperature. Available at: http://www.ndbc.noaa.gov/station_history.php?station=41009. Updated September 15, 2010. Accessed August 19, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Data Buoy Center. 2011b. Moored Buoy Program. Available at: http://www.ndbc.noaa.gov/mooredbuoy.shtml. Updated February 4, 2008. Accessed August 19, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Data Buoy Center. 2011c. Station 44009 (LLNR 168) - Delaware Bay 26 nm Southeast of Cape May, NJ: Element Air Temperature. Available at: http://www.ndbc.noaa.gov/station_history.php?station=44009. Updated September 15, 2010. Accessed August 19, 2011.

U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Data Buoy Center. 2011d. Station 41001 (LLNR 635) - 150 nm east of Cape Hatteras: Element Air Temperature. Available at: http://www.ndbc.noaa.gov/station_history.php?station=41001. Updated September 15, 2010. Accessed August 19, 2011.

U.S. Dept. of the Interior, Minerals Management Service. 1992. Outer Continental Shelf Natural Gas and Oil Resource Management Comprehensive Program, 1992−1997, Final Environmental Impact Statement. U.S. Dept. of the Interior, Minerals Management Service, Environmental Projects Coordination Branch, Herndon, VA. OCS/EA MMS 92-0004.

U.S. Environmental Protection Agency. 1998. Conditions of the Mid-Atlantic estuaries. Office of Research and Development, Washington, DC. EPA-600-R-98-147,

U.S. Environmental Protection Agency. 2008. National Coastal Condition Report III. Office of Research and Development, Office of Water, Washington, DC. EPA-842/R-08/002. Available at: http://water.epa.gov/type/oceb/assessmonitor/downloads.cfm. Updated February 15, 2011. Accessed August 19, 2011.

U.S. Environmental Protection Agency. 2011a. Dredged material management. Available at: http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/dredgemgmt.cfm. Updated March 24, 2011. Accessed August 19, 2011.

U.S. Environmental Protection Agency. 2011b. National Pollutant Discharge Elimination System; Vessel discharges. Available at: http://cfpub.epa.gov/npdes/home.cfm?program_id=350. Updated January 04, 2011. Accessed August 19, 2011.

U.S. Environmental Protection Agency. 2011c. Mid-Atlantic air protection: Mid-Atlantic Region 8-hour ozone nonattainment & maintenance areas. Available at: http://www.epa.gov/reg3artd/airquality/ozone8hrmaintareas_2.htm. Updated August 3, 2011. Accessed August 19, 2011.

Van Vleet, E.S. 1984. Fingerprinting oil spills in the marine environment. Marine Technology Society Journal 18(3):11-23.

Verity, P.G., T.N. Lee, J.A. Yoder, G.A. Paffenhöfer, J.O. Blanton and C.R. Alexander. 1993. Outer shelf processes. In: Menzel, D.W., ed. Ocean processes: U.S. Southeast Continental Shelf: A summary of research conducted in the South Atlantic Bight under the auspices of the U.S. Dept. of Energy from 1977 to 1991. U.S. Dept. of Energy, Washington, DC. Pp. 45-74.

Von Arx, W.S., H.B. Stewart, and J.R. Apel. 1974. The Florida Current as a potential source of useable energy. In: Proceedings of the McArthur Workshop on the Feasibility of Extracting Useable Energy from the Florida Current.

Voulgaris, G. 2011. Chapter 3, Physical oceanography and air-sea interactions. In: Michel, J., ed. South Atlantic Information Resources: Data Search and Literature Synthesis. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2011-xxx.

White, S.M. 2011. Chapter 2, Geological Oceanography. In: Michel, J., ed. South Atlantic Information Resources: Data Search and Literature Synthesis. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2011-xxx.

Windom, H.L. 2011. Chapter 4, Chemical Oceanography. In: Michel, J., ed. South Atlantic Information Resources: Data Search and Literature Synthesis. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2011-xxx.

Windom, H.L and P.R. Betzer. 1979. Chapter 4: Trace metal chemistry of South Atlantic/Georgia Bight. In: Texas Instruments, Inc., South Atlantic Benchmark Program, Outer Continental Shelf (OCS) Environmental Studies. Volume 3. Results of studies of Georgia Bight of North Atlantic Ocean. Prepared for Bureau of Land Management. Contract No. AA551-CT7-2. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4453.pdf. Accessed August 19, 2011.

APPENDIX G

RECENT PUBLICATIONS OF THE ENVIRONMENTAL STUDIES PROGRAM, ATLANTIC REGION, 2006 TO PRESENT

The Bureau of Ocean Energy Management (BOEM) funds ocean research through the Environmental Studies Program to provide science in support of management decisions. This Appendix lists Environmental Studies Program publications issued from 2006-2011 that are relevant to the Atlantic Outer Continental Shelf (OCS). Older Atlantic OCS publications are listed on the BOEM website (U.S. Dept. of the Interior [USDOI], BOEM, 2011a), and most Environmental Studies Program publications are available online through the Environmental Studies Program Information System (ESPIS) (USDOI, BOEM, 2011b).

Study Number	Title
2011	
BOEMRE 2011-037	*Commercial Wind Lease Issuance and Site Characterization Activities on the Atlantic Outer Continental Shelf Offshore New Jersey, Delaware, Maryland, and Virginia* http://www.boemre.gov/offshore/renewableenergy/PDFs/MidAtlanticWEAs_DraftEA.pdf
BOEMRE 2011-019	*A Comparison of Marine Productivity Among Outer Continental Shelf Planning Areas* http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/5/5121.pdf
2010	
BOEMRE TA&R 648	*Offshore Wind Energy Installation and Decommissioning Cost Estimation in the U.S. Outer Continental Shelf* http://www.boemre.gov/tarprojects/648/aa.pdf
2009	
MMS 2009-020	*Determining Night-time Distribution of Long-tailed Ducks Using Satellite Telemetry* http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4823.pdf
MMS 2009-011	*Workshop on Environmental Research Needs in Support of Potential Virginia Offshore Oil and Gas Activities* http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4723.pdf
2008	
MMS 2008-060	*Final Biological Characterization and Numerical Wave Model Analysis within Borrow Sites Offshore of Florida's Northeast Coast Report Volume I No. 1435-01-05-CT-39075-M05PC00005* http://www.boemre.gov/sandandgravel/PDF/2008-060_Volume1.pdf
2007	
MMS 2007-057	*Workshop to Identify Alternative Energy Environmental Information Needs* http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4291.pdf
MMS 2007-048	*Examination of the Physical and Biological Implications of Using Buried Channel Deposits and Other Non-topographic Offshore Features as Beach Nourishment Material* http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4274.pdf
MMS-2007-038	*Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Evergy Uses on the Outer Continental Shelf* http://www.boemre.gov/itd/pubs/2007/2007-038.pdf
MMS 2007-033	*Cooperative Research to Study Dive Patterns of Sperm Whales in the Atlantic Ocean* http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/4247.pdf
2006	
MMS 2006-065	*Investigation of Dredging Impacts on Commercial and Recreational Fisheries and Analysis of Available Mitigation Measures to Protect and Preserve Resources* http://www.boemre.gov/sandandgravel/PDF/FloridaStudyReport/Studies/2006-065.pdf

REFERENCES CITED

U.S. Dept. of the Interior, Bureau of Ocean Energy Management. 2011a. Available at: http://www.gomr.boemre.gov/homepg/whatsnew/publicat/atlantic/atlantic.html. Accessed November 29, 2011.

U.S. Dept. of the Interior, Bureau of Ocean Energy Management. 2011b. Environmental Studies Program Information System. Available at: https://www.gomr.boemre.gov/homepg/espis/espisfront.asp. Accessed November 29, 2011.

APPENDIX H

MARINE MAMMAL HEARING AND SENSITIVITY TO ACOUSTIC IMPACTS

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1. INTRODUCTION/OVERVIEW

Marine animals critically depend on sound to live, making and listening to it in various ways to perform various life functions. The ocean is a naturally noisy place, but humans make a host of sounds that are increasingly impinging on the ocean acoustic environment. There is clear evidence that some of these sounds can negatively impact marine life, but the types and magnitudes of impacts as they relate to different species and sound types remain poorly understood in all but a few conditions. However, there has been significant progress in the last decade, particularly in scientific knowledge in these areas, for some species and conditions, both in terms of hearing impacts and behavioral responses to various kinds of noise. From this evolution in understanding has emerged new ways of assessing and mitigating potential impacts. While much of the focus and discussion have been on potential injurious types of sound impacts (driven by concerns over hearing/tissue damage and the isolated mass strandings of beaked whales exposed to military sonar), more focus recently has been on the impacts of human noise on biologically significant behaviors and the overall acoustic ecology of marine life. There is a realization that the footprints within which direct harm may occur are relatively small, and the conditions in which marine mammals will become stranded appear to be restricted. However, the areas over which animals may be disturbed in significant ways that may impact vital life functions can be significantly larger. These considerations and the underlying complexity of understanding and assessing their probability of occurrence, as well as mitigation, have become more critical in noise exposure criteria and other means of assessment. Many of these issues and the underlying science are considered in detail in a major comprehensive review and application of science in the context of noise exposure criteria (Southall et al., 2007). That assessment forms the current basis for much of this appendix, but subsequent studies have provided additional important findings that are also summarized here.

This appendix summarizes the current state of scientific knowledge about the importance of sound and effects of noise on marine animals, with particular attention to marine mammals. It considers separately the effects of noise on physiology, hearing, communication, and behavior from a range of different impulsive and continuous sound sources. It also considers historical and emerging noise exposure criteria and operational mitigation measures, with attention to the types of acoustic sources present in the proposed geological and geophysical (G&G) operations off the U.S. East Coast. Finally, noise impacts for endangered/threatened species most likely to be present in these areas are considered.

2. ROLE OF ACOUSTICS IN MARINE MAMMAL ECOLOGY

The underwater acoustic environment can be a noisy place, receiving sound from a host of natural and anthropogenic sources. Some natural sounds are biological (e.g., fishes, marine mammals, some invertebrates), and others are environmental (e.g., waves, earthquakes, rain). Among the anthropogenic sources, many produce noise as a by-product of their normal operations (e.g., shipping, drilling, tidal turbines), whereas others (e.g., sonars, airguns) are produced for a specific remote sensing purpose (see Hildebrand [2009] for a recent review). Detailed measurements have been made for many of these sources, but their degree of overlap with and impacts on acoustically-oriented marine life remains generally poorly understood.

For most marine vertebrates, the production and reception of sound serves critical biological functions, including communication, foraging, navigation, and predator-avoidance (e.g., Schusterman, 1981; Watkins and Wartzok, 1985; Richardson et al., 1995; Tyack, 1998; Wartzok and Ketten, 1999; National Research Council [NRC], 2003; 2005; Clark and Ellison, 2004; Southall et al., 2007). As a general statement, all studied marine mammals produce sounds in a variety of inter- and intra-individual contexts, most associated with vital life functions as identified by the NRC (2005). As described below and shown in **Figure H-1** in comparison with some of the major human noise sources, each species group utilizes different frequency ranges.

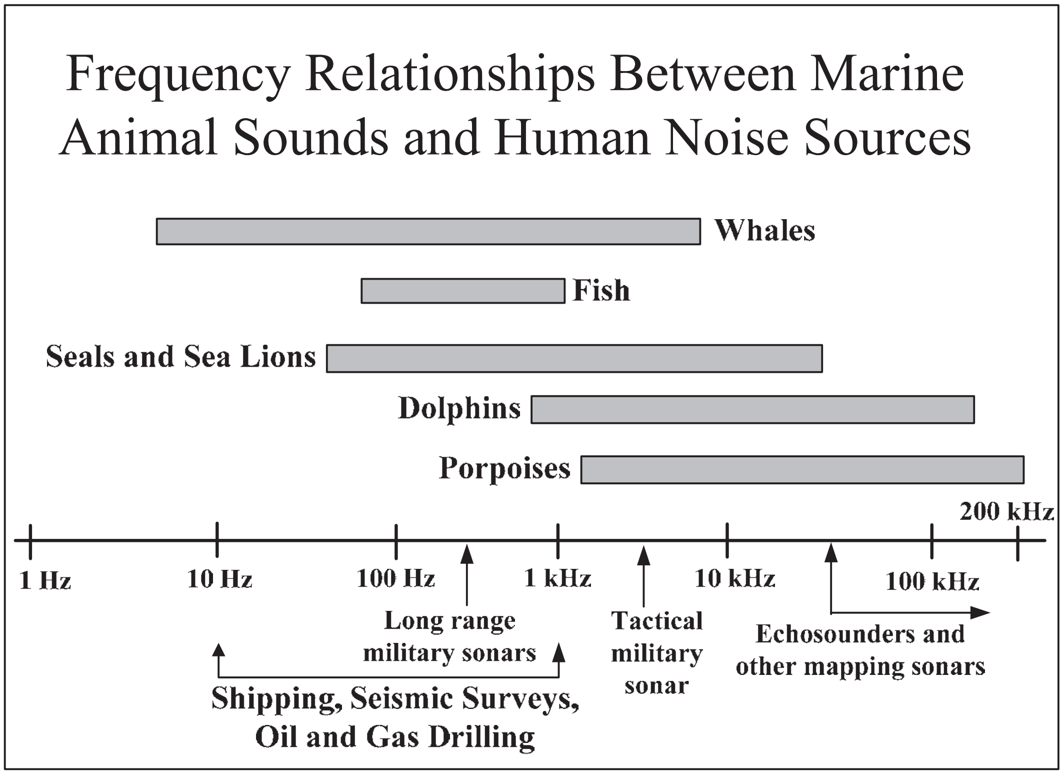


Figure H-1. Frequency Range of Sounds Generally Produced by Different Marine Animal Groups Shown Relative to Major Human Noise Sources.

Dolphins, porpoises, and other toothed whales (odontocete cetaceans) have developed sophisticated biosonar capabilities involving high frequency impulsive clicks to feed and navigate (Au, 1993) and use a variety of whistles and other calls to communicate in social interactions. These animals make sounds across some of the widest frequency bands that have been measured in any animal group. Communicative sounds generally range from a few hundreds of hertz to several tens of kilohertz, but echolocation clicks can extend above 100 kHz.

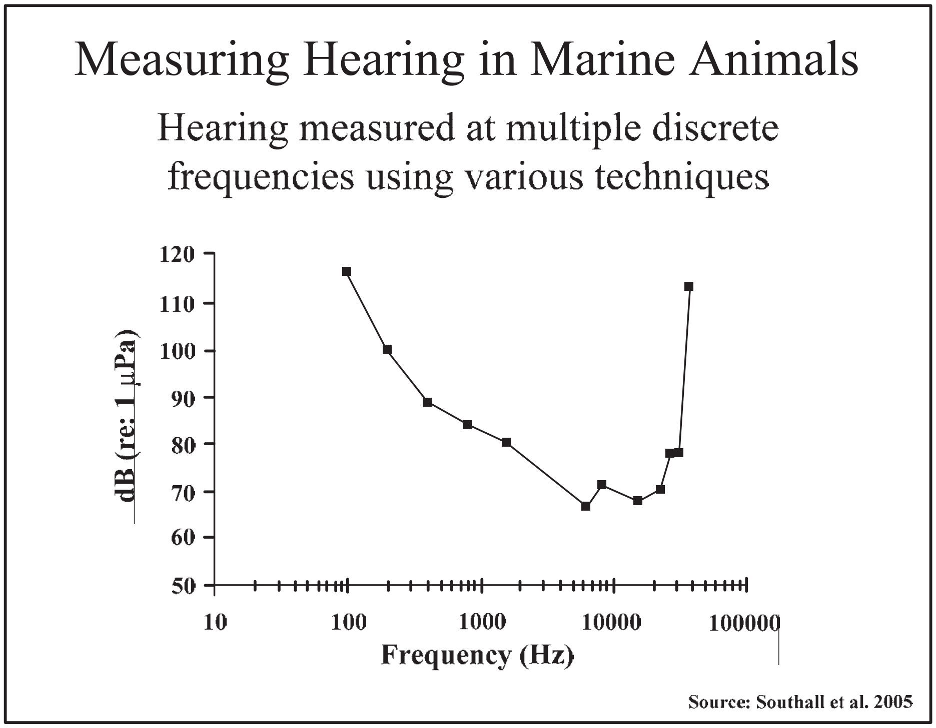
Baleen whales (mysticete cetaceans) have developed moderate to long-range communication capabilities for reproductive and social interactions and to orient themselves in the underwater world (e.g., Clark, 1990; Popper and Edds-Walton, 1997). Large whales generally produce low-frequency sounds in the tens of hertz to the several kilohertz band, with a few signals extending above 10 kHz.

Other marine mammals such as pinnipeds, manatees, and polar bears make and listen to sounds for a variety of communicative and spatial orientation functions, but like the large whales they appear to lack specialized echolocation capabilities (Schusterman, 1981; Schusterman et al., 2000). These sounds can extend above those used by mysticetes but occur over a narrower frequency band than those used by odontocetes, generally from ~100 Hz to several tens of kilohertz. Pinnipeds and polar bears spend time both at sea and on land, however, and thus rely on sounds both above and below the water.

Finally, many fishes make and listen to sounds in mating and other social interactions (Kaatz, 2002). Most of these sounds are generally low-frequency in nature, although some fishes produce more impulsive sounds as well. Aside from some simple hissing and other sounds produced in air, marine turtles generally do not appear to produce sounds in water for communicative or foraging purposes, but may rely on sound in a general orienting sense.

3. HEARING IN MARINE MAMMALS

Hearing has been measured using behavioral and/or electrophysiological methods in about a quarter of the known marine mammal species, although with a disproportional representation of species commonly found in captivity, and some entire groups (e.g., mysticete cetaceans) remain untested. For a detailed review, see Southall et al. (2007); key findings obtained since then are discussed below. Hearing sensitivity is generally quantified by determining the quietest possible sound that is detectable by an animal (either via a behavioral response or by quantifying an electrical response) on some signal presentations. By testing such responses across a range of test frequencies, a measure of the animal's overall hearing capability (typically called an "audiogram") may be obtained; an example is given in **Figure H-2**.



Source: Southall et al. 2005

Figure H-2. Typical Hearing Curve or "Audiogram" Obtained from a California Sea Lion with a Behavioral Testing Technique.

Where detection threshold levels are lower, hearing sensitivity is greater (the animal can hear well), and vice versa. This sensitivity usually follows a U-shaped curve with regions of relatively good sensitivity that drop off on the low and high ends. The region of lowest overall average hearing is called the range of "best hearing sensitivity." Similarly, the region where hearing thresholds are within some range from the lowest overall threshold (e.g., 80 dB in Southall et al., 2007) is often referred to as the overall range of functional hearing.

Given the available direct measurements of hearing, extrapolations based on taxonomy, and predictions based on auditory morphology, vocalizations, or behavior, it is clear that not all marine taxa have equal hearing frequency ranges or absolute hearing sensitivity (Richardson et al., 1995; Wartzok and Ketten, 1999; Southall et al., 2007).

As shown in **Figure H-3**, most marine taxa have measured or estimated (in the case of baleen whales) functional hearing capabilities across similar frequencies to those where their vocalizations occur, although perception may be slightly broader than the frequency range of vocalizations (Luther and Wiley, 2009). Fishes generally hear in a relatively narrow frequency band up to just a few kilohertz, while marine mammals as a whole cover a very wide band, with baleen whales likely hearing down into very low frequencies, pinnipeds at low to intermediate frequencies (relatively), and odontocete cetaceans hearing over a very broad range extending well into the ultrasonic (for humans) range. Recently, functional hearing has been demonstrated in a marine invertebrate as well (longfin squid; see Mooney et al., 2010). Specific hearing characteristics for different marine mammal groups are described below.

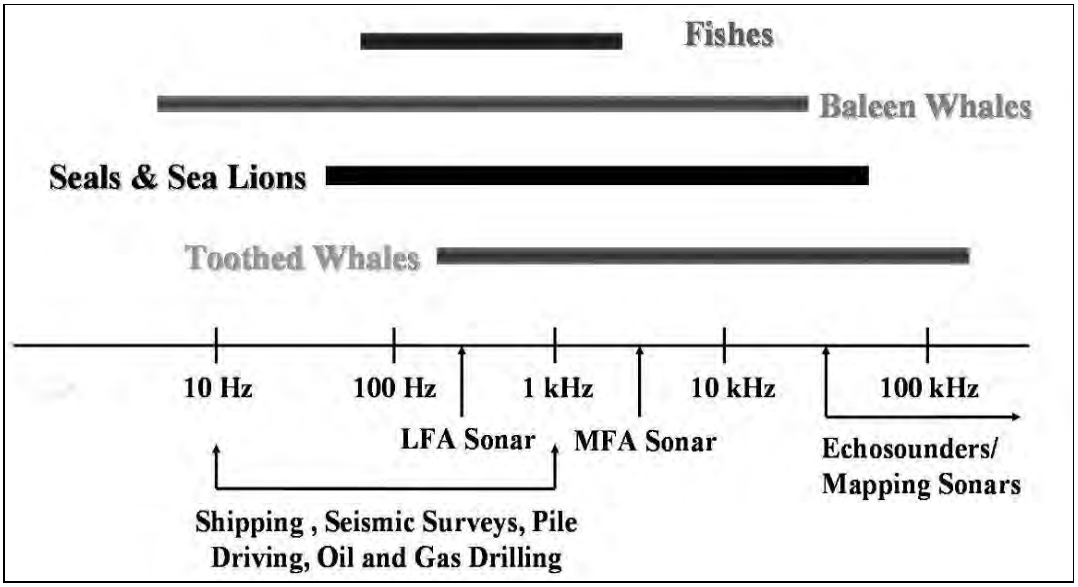


Figure H-3. Measured or Estimated Functional Hearing Ranges for Different Marine Vertebrate Groups Shown Relative to Various Human Noise Sources.

3.1. HEARING IN MYSTICETE CETACEANS

Because of the lack of captive subjects and logistical challenges of bringing experimental subjects into the laboratory, direct measurements of mysticete hearing are unavailable, although there was an unsuccessful attempt to directly measure hearing in a stranded gray whale calf by Ridgway and Carder (2001). Consequently, hearing in mysticetes is estimated based on other means such as vocalizations (Wartzok and Ketten, 1999), anatomy (Houser et al., 2001; Parks et al., 2007), behavioral responses to sound (Frankel, 2005; Reichmuth, 2007), and nominal natural background noise conditions in the likely frequency ranges of hearing (Clark and Ellison, 2004).

The combined information from these and other sources strongly suggests that mysticetes are likely most sensitive to sound from perhaps tens of hertz to ~10 kHz. However, humpback whales (*Megaptera novaeangliae*) produce sounds with harmonics extending above 24 kHz (Au et al., 2006), and Ketten et al. (2007) suggested, based on anatomical data, that some mysticetes could hear frequencies up to 30 kHz. Southall et al. (2007) estimated the lower and upper frequencies for functional hearing in mysticetes, collectively, to be 7 Hz and 22 kHz, respectively, but based on the above information this may be a slight underestimate on the high frequency cutoff. Nevertheless, there appears to be little doubt that mysticetes operate primarily in the very low and low frequency ranges.

3.2. HEARING IN ODONTOCETE CETACEANS

Because of the presence of specialized, high frequency biosonar and lower frequency communication systems in odontocete cetaceans, it is almost certain that they hear over an extremely wide frequency range, spanning some 12 octaves in some species. Hearing has been directly measured in controlled conditions for over a dozen odontocete species with either behavioral or electrophysiological techniques. Southall et al. (2007) reviewed the available literature and (like Wartzok and Ketten [1999]) identified two functional hearing groups within the odontocetes, which they referred to as mid-frequency cetaceans (with functional hearing between 150 Hz and 160 kHz) and high-frequency specialists (functional hearing estimated between 200 Hz and 180 kHz). Subsequent to the Southall et al. (2007) publication, additional data have been obtained on several species that had been previously tested (such as harbor porpoise) and measurements or anatomical modeling results have been obtained for several new species – e.g., Cuvier's beaked whales (Cranford et al., 2008a,b) and false killer whales (Montie et al., 2011) suggesting that these additional species have similar basic hearing ranges and functional capabilities to other cetaceans. These and other studies have contributed to an increased understanding of hearing in odontocete cetaceans, but they are fundamentally consistent for these species with the Southall et al. (2007) assessment for these species in terms of the broad range and high-frequency extension of functional hearing in odontocete cetaceans.

3.3. HEARING IN PINNIPEDS AND MANATEES

Pinnipeds are amphibious mammals and have functional hearing both above and below the water, although they have broader functional hearing ranges in water (Kastak and Schusterman, 1998 for a discussion). Direct measurements of hearing using behavioral and electrophysiological methods have been obtained in nearly 10 different species (Southall et al., 2007; Mulsow and Reichmuth, 2010). Southall et al. (2007) estimated functional hearing across all pinnipeds as extending between 75 Hz and 75 kHz under water and between 75 Hz and 30 kHz in air. However, they also noted that, as in the odontocete cetaceans, there appears to be a segregation in functional hearing within pinniped taxa, with phocids (seals lacking external ear pinnae that are less mobile on land, such as harbor seals) extending to much higher frequencies, especially in water, than otariids (seal lions and fur seals that have distinct external ear pinnae and are more agile on land). This would be a logical additional segregation in terms of functional hearing within marine mammals.

Hearing has also been tested both in terms of absolute and masked hearing capabilities in manatees (Gerstein et al., 1999; Mann et al., 2005). The combined data suggest that manatees have hearing capabilities that are generally similar to phocid pinnipeds except perhaps at the lowest frequencies, with functional hearing between about 250 Hz and ~80 kHz. Based on these data, the extrapolation of pinniped data to manatees, where information is lacking, would seem reasonable.

3.4. MARINE MAMMAL HEARING WEIGHTING FUNCTIONS

Because animals including marine mammals do not hear equally well at all frequencies, frequency-weighting functions are often used as a means of quantitatively compensating for differential frequency responses for different species. These are commonly applied in assessing the potential for the detection of a sound at a specific frequency and, more commonly, for assessing potential noise impacts. Noise exposure criteria are discussed in greater detail in **Section 4.0**. However, as they are related to the above generalizations regarding basic hearing in different marine mammal groups, the frequency weighting functions derived by Southall et al. (2007) are described briefly here.

Table H-1 shows the five functional hearing groups and estimated functional hearing ranges for marine mammals proposed in the Southall et al. (2007) noise exposure criteria.

Using the estimated lower and upper frequency cut-off limits as 6-dB down points on an exponential roll-off for the frequency-weighting functions (as is done in human C-weighting), Southall et al. (2007) developed frequency-weighting filters for each of the five functional hearing groups as shown in **Figure H-4**.

Table H-1

Marine Mammal Functional Hearing Groups and Estimated Functional Hearing Ranges Proposed by Southall et al. (2007)

Functional Hearing Group	Estimated Auditory Bandwidth	Genera Represented (Number Species/Subspecies)	Frequency-Weighting Network
Low-frequency cetaceans	7 Hz to 22 kHz	*Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera* (13 species/subspecies)	M_{lf} (lf: low-frequency cetaceans)
Mid-frequency cetaceans	150 Hz to 160 kHz	*Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcacella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon* (57 species/subspecies)	M_{mf} (mf: mid-frequency cetaceans)
High-frequency cetaceans	200 Hz to 180 kHz	*Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus* (19 species/subspecies)	M_{hf} (hf: high-frequency cetaceans)
Pinnipeds in water	75 Hz to 75 kHz	*Arctocephalus, Callorhinus, Zalophus, Eumetopias, Neophoca, Phocarctos, Otaria, Erignathus, Phoca, Pusa, Halichoerus, Histriophoca, Pagophilus, Cystophora, Monachus, Mirounga, Leptonychotes, Ommatophoca, Lobodon, Hydrurga, Odobenus* (41 species/subspecies)	M_{pw} (pw: pinnipeds in water)
Pinnipeds in air	75 Hz to 30 kHz	Same species as pinnipeds in water (41 species/subspecies)	M_{pa} (pa: pinnipeds in air)

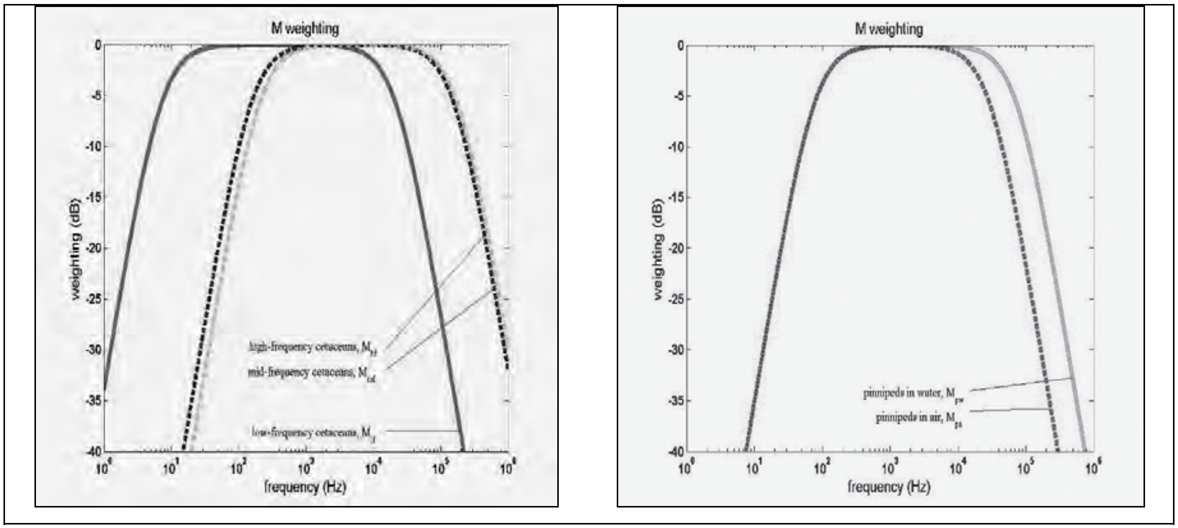


Figure H-4. Frequency-Weighting Functions for Cetaceans (left) and Pinnipeds in Air and Water (right) Proposed by Southall et al. (2007).

4. EFFECTS OF NOISE ON MARINE MAMMAL HEARING AND BEHAVIOR

Where there is an overlap between noise sources and the frequencies of sound used by marine life, there may be concerns related to how such sound may interfere with important biological functions. Noise, either natural or anthropogenic, can adversely affect marine life in various ways, inducing alteration of behavior, reduction of communication ranges or orientation capability, temporary or permanent damage to the auditory or other systems; and/or, in extreme cases, habitat avoidance or even death (e.g., Richardson et al., 1995; NRC, 2003, 2005; Nowacek et al., 2007; Southall et al., 2007). Noise impacts may also be additive or synergistic to those of other human stressors. While determining the biological significance of noise exposure impacts remains challenging (NRC, 2005), significant strides have been made in quantifying the effects of noise on marine mammals. The potential and measured effects of noise on physiology, hearing, and behavior are reviewed here, with attention to findings subsequent to the Southall et al. (2007) review and assessment of noise impacts on marine mammals.

4.1. EFFECTS OF NOISE ON MARINE MAMMAL PHYSIOLOGY

Noise can result in direct, physiological impacts on marine mammals, even in cases where hearing impacts or even behavioral responses may be lacking. These may include stress responses and direct physical injury (e.g., tissue damage). Stress responses can vary from an acute startle response to more chronic effects and can vary widely across individuals in type and magnitude according to a host of factors (Busch and Hayward [2009] for a recent review). Stress reactions in humans and other vertebrates include various physiological changes to pulmonary, respiratory cardiac, metabolic, neuro-endocrine, immune, and reproductive functions; these can vary from relatively benign to very detrimental or fatal in some conditions.

Direct measurements of physical stress responses in marine mammals from sound exposure are relatively limited (Thomas et al., 1990; Miksis et al., 2001; Romano et al., 2004), although the larger body of data for terrestrial mammals and other animals is available and, in some cases, may be useful where direct information is lacking (Wright et al., 2007a,b). The available literature for marine mammals indicates endocrine secretions of glucocorticoids and altered cardiovascular function in some conditions following relatively intense noise exposure.

Direct physical injury can occur from exposure to high levels of sound or, more commonly, to shock wave pulses associated with high intensity events such as explosions. These pulses are typically short, peak pressures that may damage internal organs or air-filled body cavities, such as lungs (Yelverton et al., 1973; Goertner, 1982; Young, 1991). Direct data on direct physical injury are limited to anecdotal or forensic investigations after accidental events because ethical considerations prevent direct empirical methods to measure such impacts in marine mammals. However, such observations (e.g., Todd et al., 1996) and modeling based on impact data for the human vestibular system as well as other organs (e.g., lungs) for underwater sound exposures (Cudahy and Ellison, 2002) suggest that marine mammals can be susceptible to direct physical injury to particular organ systems and tissues following intense exposure, particularly where high particle motion events occur.

Other forms of physiological damage that have been investigated and in some cases shown in marine mammals include the formation of gas bubble lesions and fat emboli, similar to those associated with human decompression sickness; these have been observed in some beaked whale species that stranded around naval mid-frequency sonar training exercises (Jepson et al., 2003; Fernández et al., 2005). Currently, these tissue impacts are thought to result from a behavioral response that changes diving patterns in some way and subsequently causes lesion/emboli formation, rather than as a direct physical effect of sound exposure (Cox et al., 2006; Zimmer and Tyack, 2007). These kinds of emboli have not been definitively shown in other marine mammals exposed to natural or anthropogenic sound to date.

4.2. EFFECTS OF NOISE ON MARINE MAMMAL HEARING

Much of the scientific and regulatory attention on the impacts of noise on marine life has centered on the issue of how sound affects hearing in marine mammals. While the available literature on the underlying issues remains quite limited compared to that available for some terrestrial species, considerable progress has been made in these areas, particularly in the last decade, for marine mammals. There have been numerous reviews of the available data on these issues (Richardson et al., 1995; Wartzok and Ketten, 1999; NRC, 2003, 2005), the most recent comprehensive assessment being the Southall et al. (2007) review and application of the available science in the context of proposing noise exposure criteria (see below). A summary description of temporary and permanent hearing losses and auditory masking is given here with reference to these reviews generally, and some discussion of more recent relevant literature on each issue.

4.2.1. Temporary and Permanent Threshold Shift in Marine Mammals

Noise-induced threshold shifts are increases in hearing thresholds within a certain frequency range (Yost, 2000). Following exposure, the magnitude of the threshold shift normally decreases over time following cessation of noise exposure. Threshold shifts can be temporary (TTS) or permanent (PTS) and can consist of both temporary and permanent components. Several important factors relate to the type and magnitude of hearing loss, including exposure level, frequency content, duration, and temporal pattern of exposure. A range of mechanical stress or damage (e.g., supporting cell structure fatigue) and metabolic (e.g., inner ear hair cell metabolism, such as energy production, protein synthesis, and ion transport) processes within the auditory system underlie both TTS and PTS (Yost, 2000; Kryter, 1994; Ward, 1997). Intense sound exposure more often results in mechanical processes, whereas prolonged exposure more typically results in metabolic changes (e.g., Saunders et al., 1985).

Temporary threshold shift is a relatively short-term reversible loss of hearing, often resulting from cellular fatigue and metabolic changes. Based on data from cetacean TTS studies (Southall et al., 2007), a threshold shift of 6 dB is generally considered the minimum threshold shift that is statistically larger than typical day-to-day or session-to-session variation in a subject's baseline threshold at a particular frequency. Conversely, PTS is an irreversible loss of hearing (permanent damage) that commonly results from inner ear hair cell loss and/or severe damage or other structural damage to auditory tissues (e.g., Saunders et al., 1985; Henderson et al., 2008). Permanent threshold shift data are typically not collected in marine mammals owing to ethical and permitting reasons, but a recent TTS experiment was found to unintentionally induce PTS in a harbor seal (Kastak et al., 2008). Southall et al. (2007) reviewed the available terrestrial literature and concluded that 40 dB of TTS was a reasonable and conservative approximation of PTS onset for marine mammals (Henderson et al., 2008 for a consideration of the human literature in this regard).

Temporary threshold shift has been measured in three cetacean and three pinniped species using both impulsive and continuous noise; many of these data were reviewed in detail by Southall et al. (2007), but there are some notable new data that change some of the conclusions reached in that assessment. In general, it appears that marine mammal auditory systems are relatively resilient to noise exposure and that relatively intense sounds are required to cause TTS and, given some simplifying assumptions to extrapolate to 40 dB TTS, PTS as well. However, there are clear differences in terms of the sound exposure types and some major differences between species as well. As in terrestrial mammals, marine mammals experience TTS at relatively lower onset levels for impulsive noise than for non-impulsive noise. The relative TTS onset levels for different marine mammal groups from the Southall et al. (2007) criteria are discussed in the section below regarding exposure criteria. However, some modifications to these criteria would now be in order, as expected, based on subsequent information.

New data are available demonstrating much lower (>20 dB) TTS-onset exposure levels for harbor porpoises exposed to impulse noise (airguns) than has been measured in other odontocetes (Lucke et al., 2009). These data are significant because they are the only TTS measurements available for any individual in the high-frequency cetacean functional hearing group and would arguably be used as the representative value for these species rather than using the extrapolated (though much more expansive) data for mid-frequency cetaceans in predicting auditory fatigue. In addition, several studies have contributed to an expanded understanding of TTS onset and growth at a range of sound frequencies in odontocete cetaceans. Mooney et al. (2009a,b) demonstrate conditions where equal energy assumptions about exposure of different durations and levels fail to accurately predict TTS onset and growth. Finneran and Schlundt (2010) and Finneran et al. (2010a,b) provide additional TTS data for bottlenose dolphins, demonstrating a greater sensitivity (10-20 dB) to noise exposure (lower absolute TTS onset levels) and a more rapid growth of TTS with increasing noise exposure level at higher frequencies within their region of best sensitivity than had been tested when the Southall et al. (2007) criteria were published. These data suggest that the exposure level relative to the subject's absolute hearing sensitivity (referred to as the sensation level) is particularly important in determining TTS onset. They also suggest that exposure levels in the region of best hearing sensitivity should be used as generic TTS-onset values against which frequency weighting functions could be applied to correct for frequency-specific hearing. These findings are significant for mysticetes despite being made with odontocete cetaceans, as they affect the selection of the appropriate TTS-onset values to apply for mysticetes from the odontocete literature (since no mysticete TTS values are or for the foreseeable future will be available).

4.2.2. Auditory Masking

In addition to potential effects on hearing from relatively high levels of sound exposure that would generally occur relatively close to anthropogenic sound sources in the field, noise interference ("masking") effects can occur, and likely do over much greater footprints around real sound sources. Noise can affect hearing and partially or completely reduce an individual's ability to effectively communicate, detect important predator, prey, and/or conspecific signals, and/or detect important environmental features associated with spatial orientation (Clark et al., 2009 for a review). Spectral, temporal, and spatial overlap between the masking noise and the sender/receiver determine the extent of interference; the greater the spectral and temporal overlap, the greater the potential for masking.

Southall et al. (2007) considered auditory masking issues and realized the much greater relative areas over which this phenomena occurs relative to TTS and PTS, but did not propose explicit exposure criteria for marine mammals, owing in part to the very divergent conditions in which masking can occur and a lack of clear understanding about defining an "onset" for masking that would be statistically definable and biologically meaningful. Largely for the same reasons, masking effects have generally been considered only qualitatively in planning of activities and regulatory decisions over noise impacts. Subsequent data have demonstrated vocal modifications in marine mammals exposed to noise that are presumably the result of anthropogenic masking noise (e.g., Holt et al., 2009). Additionally, Clark et al. (2009) provided a quantitative means of determining the relative loss of acoustic communication range for marine mammals using specific calls in conditions where they are exposed to specific anthropogenic noise sources.

There is particular concern that low-frequency anthropogenic noise may mask communication in baleen whales, which can communicate over long distances and within the same frequency band (e.g., Payne and Webb, 1971; Clark et al., 2009). An example of baleen whale calling behavior that is increasingly masked by nearby ship noise is shown in **Figure H-5**.

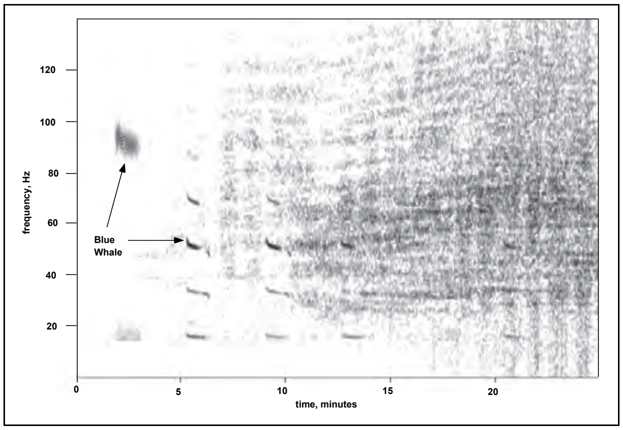


Figure H-5. Time Series Plot Showing a Calling Blue Whale and the Increasing Noise (and Masking) in the Same Low-Frequency Band from an Approaching Vessel (courtesy of C. Clark).

4.3. EFFECTS OF NOISE ON MARINE MAMMAL BEHAVIOR

Behavioral responses to sound are highly variable and critically depend on the context of sound exposure, as much or more than the level-duration-frequency characteristics that determine the probability of auditory effects (Wartzok et al., 2004, Southall et al., 2007). There is a very wide range of possible behavioral responses to sound exposure, given that the sound is audible to the particular animal, including, in approximate order of increasing severity but decreasing likelihood:

- none observable – animals can become less sensitive over repeated exposures;
- looking or increased alertness;
- minor behavioral responses such as vocal modifications associated with masking;
- cessation of feeding or social interactions;
- temporary avoidance behavior (emerging as one of the more common responses);
- modification of group structure or activity state;
- habitat abandonment; and/or
- injury and/or death via direct response or possibly exacerbated by physiological factors.

These effects clearly have differing probabilities to affect marine mammal vital rates (NRC, 2005), but it has proven (and remains) exceedingly difficult to establish a generally accepted definition and criterion for biologically meaningful behavioral disturbance. Assessing the severity of behavioral effects of anthropogenic sound exposure on marine mammals presents unique challenges associated with the inherent complexity of behavioral responses and the contextual factors affecting them, both within and between individuals and species. Severity of responses can vary depending on characteristics of the sound source (e.g., moving or stationary, number and spatial distribution of sound source[s], similarity to predator sounds, and other relevant factors) (Richardson et al., 1995; NRC, 2005; Southall et al., 2007; Wirsing et al., 2008; Bejder et al., 2009; Barber et al., 2010).

Southall et al. (2007) reviewed the considerable available literature on the effects of noise on marine mammal hearing in extensive detail, but (other than for single impulse exposures where TTS-onset was used as a threshold value for behavioral disturbance) did not find a single metric or identifiable exposure level that was broadly applicable as a benchmark for behavioral effects. Several general observations were made, including that many of the responses observed across taxa were temporary avoidance behavior. Additionally, certain species (e.g., harbor porpoises, beaked whales) appear to be categorically more sensitive to noise than other species observed, and certain behavioral states (e.g., migrating) can make species such as bowhead whales more sensitive to exposure. Subsequent data have demonstrated and quantified behavioral responses of various species, including some of the Endangered Species Act-listed marine mammals being considered in this Programmatic Environmental Impact Statement (Programmatic EIS), to seismic exploration using airguns (Weir, 2008a,b; Miller et al., 2009). Additional data have demonstrated behavioral responses of cetaceans to vessels associated with whale-watching activities (e.g., Bejder and Lusseau, 2008; Visser et al., 2010) and to the construction of offshore energy installations (Thompson et al., 2010). Finally, there has been considerable new information, using both controlled exposure experiments and opportunistic observations of anthropogenic noise source operations, on the behavioral responses of particularly sensitive marine mammals, including harbor porpoises (Kastelein et al., 2008a,b; Gilles et al., 2009) and beaked whales (Caretta et al., 2008; McCarthy et al., 2011; Southall et al., 2011; Tyack et al., 2011). These studies amplify the conclusions of Southall et al. (2007) that these are particularly sensitive species, although it remains unclear whether any additional species should be added to this general category.

5. MARINE MAMMAL NOISE EXPOSURE CRITERIA

Beginning in the 1980's with regulations on oil and gas exploration, sound-producing entities and regulatory agencies have been grappling with how to quantitatively predict and operationally mitigate the effects of human noise from industrial activities on marine life. While the marine noise issue is an increasingly global one, many of the developments on exposure criteria for marine mammals have involved U.S. regulatory processes.

In June 1997, the High Energy Seismic Survey team (HESS, 1999) convened a panel of experts to assess existing data on marine mammals exposed to seismic pulses and to predict exposures at which physical injury could occur. With the limited available data at that time, exposure to airgun pulses with received levels above 180 dB *re:* 1µPa (root-mean-square [RMS] – averaged over the pulse duration) was determined to have a high potential for "serious behavioral, physiological, and hearing effects."

Based on the HESS (1999) panel conclusions, the National Marine Fisheries Service (NMFS) established a 180 dB_{rms} (received level) threshold criterion for injury from sound exposure for cetaceans and a 190 dB_{rms} threshold criterion for pinnipeds (*Federal Register*, 2003). Additionally, behavioral response criteria were developed as step-function (all-or-none) thresholds based solely on the RMS value of received levels, and have been used by NMFS, although not entirely consistently. Thresholds for behavioral response from impulse sounds are 160 dB_{rms} (received level) for all marine mammals, based on behavioral response data for marine mammals exposed to seismic airgun operations (Malme et al., 1983, 1984; Richardson et al., 1986). Thresholds for behavioral response for "continuous" (non-impulsive) sounds have been 120 dB_{rms} (for some but not all sound sources) based on the results of Malme et al. (1984) and Richardson et al. (1990).

Recognizing that the available data on hearing and noise impacts were rapidly evolving and that a more comprehensive and scientifically robust method of assessment would be required than these simplistic threshold estimates, NMFS supported an expert working group to develop more comprehensive and current marine mammal noise exposure criteria. This process ultimately resulted in the Southall et al. (2007) marine mammal noise exposure criteria. Within this process, several important segregations were made. First, the marine mammals were segregated into the functional hearing groups (not entirely taxonomy-based), as described above. Second, sound sources were categorized into functional categories, based on their acoustic and repetitive properties (**Table H-2**).

Table H-2

Sound Source Categories, Acoustic Characteristics, and Examples, as Proposed by Southall et al. (2007)

Sound Type	Acoustic Characteristics (at source)	Examples
Single Pulse	Single acoustic event; >3 dB difference between received level using impulse versus equivalent continuous time constant	Single explosion; sonic boom; single airgun, watergun, pile strike, or sparker pulse; single ping of certain sonars, depth sounders, and pingers
Multiple Pulse	Multiple discrete acoustic events within 24 hr; >3 dB difference between received level using impulse versus equivalent continuous time constant	Serial explosions; sequential airgun, watergun, pile strikes, or sparker pulses; certain active sonar (IMAPS); some depth sounder signals
Non-Pulse	Single or multiple discrete acoustic events within 24 h; <3 dB difference between received level using impulse versus equivalent continuous time constant	Vessel/aircraft passes, drilling; many construction or other industrial operations; certain sonar systems (LFA; tactical mid-frequency); acoustic harassment/deterrent devises; acoustic tomography sources (ATOC); some depth sounder signals

IMAPS = Integrated Marine Mammal Monitoring and Protection System.
LFA = Low-Frequency Active.
ATOC = Acoustic Thermometry of Ocean Climate.

Additionally, the potential for hearing and behavioral effects for noise exposures of these different categories was assessed for each of the different functional hearing groups according to a wider and more applicable set of acoustic exposure metrics. For hearing impacts, this included the sound energy (sound exposure level), which accounts for amplitude level and duration, as well as peak sound pressure. For behavioral effects, the conventional RMS levels for sound exposure were considered, in part because this is typically all of the information available regarding available studies.

As described briefly above, Southall et al. (2007) proposed explicit and numerical exposure level values for injury from sound exposure for each of the marine mammal functional hearing groups. Using measured onset-TTS levels where possible (or extrapolating them from related species where not) and a series of extrapolation procedures to estimate the growth of TTS and a reasonably conservative estimate of physical injury (40 dB TTS as described above), received level threshold values were determined. For sound exposure level values, the frequency weighting functions described above would be applied to the received sound to account for differential frequency sensitivity among the different marine mammal groups. The resulting thresholds for injury from sound exposure for different marine mammal groups, via these general methods and using all available relevant data as proposed by Southall et al. (2007), are summarized in **Table H-3**.

Table H-3

Marine Mammal Noise Exposure Criteria for Injury for Different Marine Mammal Functional Hearing Groups Proposed by Southall et al. (2007)

Marine Mammal Group	Sound Type		
	Single Pulses	Multiple Pulses	Non-Pulses
Low-frequency Cetaceans	**Cell 1**	**Cell 2**	**Cell 3**
Sound Pressure Level	230 dB$_{peak}$ re: 1μPa (flat)	230 dB$_{peak}$ re: 1μPa (flat)	230 dB$_{peak}$ re: 1μPa (flat)
Sound Exposure Level	198 dB re: 1μPa^2-s (M$_{lf}$)	198 dB re: 1μPa^2-s (M$_{lf}$)	215 dB re: 1μPa^2-s (M$_{lf}$)
Mid-frequency Cetaceans	**Cell 4**	**Cell 5**	**Cell 6**
Sound Pressure Level	230 dB$_{peak}$ re: 1μPa (flat)	230 dB$_{peak}$ re: 1μPa (flat)	230 dB$_{peak}$ re: 1μPa (flat)
Sound Exposure Level	198 dB re: 1μPa^2-s (M$_{mf}$)	198 dB re: 1μPa^2-s (M$_{mf}$)	215 dB re: 1μPa^2-s (M$_{mf}$)
High-frequency Cetaceans	**Cell 7**	**Cell 8**	**Cell 9**
Sound Pressure Level	230 dB$_{peak}$ re: 1μPa (flat)	230 dB$_{peak}$ re: 1μPa (flat)	230 dB$_{peak}$ re: 1μPa (flat)
Sound Exposure Level	198 dB re: 1μPa^2-s (M$_{hf}$)	198 dB re: 1μPa^2-s (M$_{hf}$)	215 dB re: 1μPa^2-s (M$_{hf}$)
Pinnipeds (in water)	**Cell 10**	**Cell 11**	**Cell 12**
Sound Pressure Level	218 dB$_{peak}$ re: 1μPa (flat)	218 dB$_{peak}$ re: 1μPa (flat)	218 dB$_{peak}$ re: 1μPa (flat)
Sound Exposure Level	186 dB re: 1μPa^2-s (M$_{pw}$)	186 dB re: 1μPa^2-s (M$_{pw}$)	203 dB re: 1μPa^2-s (M$_{pw}$)
Pinnipeds (in air)	**Cell 13**	**Cell 14**	**Cell 15**
Sound Pressure Level	149 dB$_{peak}$ re: 20μPa (flat)	149 dB$_{peak}$ re: 20μPa (flat)	149 dB$_{peak}$ re: 20μPa (flat)
Sound Exposure Level	144 dB re: (20μPa)^2-s (M$_{pa}$)	144 dB re: (20μPa)^2-s (M$_{pa}$)	144.5 dB re: (20μPa)^2-s (M$_{pa}$)

Several notable features of these criteria are the relatively high received level values predicted necessary to induce injury and that all of the cetaceans have numerically-identical threshold values, with the exception of the frequency-weighting functions. The former is simply a function of the relatively high TTS-onset values in the marine mammal species tested thus far. The latter is the case because at the time of the Southall et al. (2007) criteria paper, there were no direct data on auditory fatigue in low- or high-frequency cetaceans, and the mid-frequency cetacean TTS-onset levels were used for these other groups. Subsequently, the Lucke et al. (2009) results have shown significantly lower onset values for TTS in high-frequency cetaceans; these will presumably be applied for these species. For low-frequency cetaceans, some of the subsequent TTS data for mid-frequency cetaceans in regions of best sensitivity (Finneran and Schlundt, 2010) may be applicable in considering the appropriate TTS-onset value to extrapolate to the mysticetes, which are highly unlikely to test in a controlled hearing study to measure auditory fatigure. Finally, these newer TTS measurements in mid-frequency cetaceans (Finneran and Schlundt, 2010; Finneran et al., 2010a,b) will require reanalysis of the appropriate TTS-onset (and thus injury onset) point for this category as well. Such improvements based on additional data were envisioned, and in most cases specifically called for in terms of experimental approaches and priorities, and the conclusions and threshold values will continue to evolve over time. Despite the expected requisite re-thinking based on new data, the Southall et al. (2007) approach to marine mammal noise exposure represented a major evolution in the complexity and scientific basis for predicting the effects of noise on hearing in marine mammals over the extremely simplistic historical NMFS thresholds for injury.

In terms of behavioral impacts, the Southall et al. (2007) noise exposure criteria took a dual approach depending on the sound type. For exposure to single impulses (e.g., explosion), the acoustic component of the event was considered sufficiently intense to constitute behavioral harassment at levels consistent with TTS onset (**Table H-4**). The logic for this was that since these events are so brief and transient that any responses other than those affecting hearing would likely be similarly transient in nature and thus not affect the long-term health or fitness of animals. It was noted, however, that startle responses can trigger stress and other physiological responses, the biological significance of which remains poorly understood.

Table H-4

Marine Mammal Noise Exposure Criteria for Behavior for Different Marine Mammal Functional Hearing Groups Proposed by Southall et al. (2007)

Marine Mammal Group	Sound Type		
	Single Pulses	Multiple Pulses	Non-Pulses
Low-frequency Cetaceans	**Cell 1**	**Cell 2**	**Cell 3**
Sound Pressure Level	224 dB$_{peak}$ re: 1μPa (flat)	see Tables 6 & 7 in Southall et al., 2007	see Tables 14 & 15 in Southall et al., 2007
Sound Exposure Level	183 dB re: 1μPa^2-s (M$_{lf}$)	Not applicable	Not applicable
Mid-frequency Cetaceans	**Cell 4**	**Cell 5**	**Cell 6**
Sound Pressure Level	224 dB$_{peak}$ re: 1μPa (flat)	see Tables 8 & 9 in Southall et al., 2007	see Tables 16 & 17 in Southall et al., 2007
Sound Exposure Level	183 dB re: 1μPa^2-s (M$_{mf}$)	Not applicable	Not applicable
High-frequency Cetaceans	**Cell 7**	**Cell 8**	**Cell 9**
Sound Pressure Level	224 dB$_{peak}$ re: 1μPa (flat)	see Tables 18 & 19 in Southall et al., 2007	see Tables 18 & 19 in Southall et al., 2007
Sound Exposure Level	183 dB re: 1μPa^2-s (M$_{hf}$)	Not applicable	Not applicable
Pinnipeds (in water)	**Cell 10**	**Cell 11**	**Cell 12**
Sound Pressure Level	212 dB$_{peak}$ re: 1μPa (flat)	see Tables 10 & 11 in Southall et al., 2007	see Tables 20 & 21 in Southall et al., 2007
Sound Exposure Level	171 dB re: 1μPa^2-s (M$_{pw}$)	Not applicable	Not applicable
Pinnipeds (in air)	**Cell 13**	**Cell 14**	**Cell 15**
Sound Pressure Level	109 dB$_{peak}$ re: 20μPa (flat)	see Tables 12 & 13 in Southall et al., 2007	see Tables 22 & 23 in Southall et al., 2007
Sound Exposure Level	100 dB re: (20μPa)^2-s (M$_{pa}$)	Not applicable	Not applicable

For all other sound types (which are the majority), Southall et al. (2007) did not propose explicit threshold criteria, for the reasons of context-dependence and other complexities in the nature of behavioral responses and available literature described above. It was concluded that significant behavioral effects would likely occur at exposure levels below those required for TTS and PTS, but that simple step-function thresholds for behavior (such as the historical NMFS values) were simply inconsistent with the best available science. While an overarching exposure level approach for behavior as seems reasonable for injury is perhaps more convenient from an assessment standpoint, the underlying reasons behind the type and magnitude of behavioral response involve a multitude of factors and require a multivariate assessment method to adequately describe.

To begin addressing some of these issues Southall et al. (2007) derived a severity scaling to attempt for the first time to put some reasonable bounds on the likely significance of observed responses, highlighting the importance of responses with the potential to affect vital rates and survivorship (as in NRC, 2005). An ordinal ranking of behavioral response severity (see Table 4 in Southall et al., 2007) was developed, the intent being to delineate behaviors that are relatively minor and/or brief from those considered more likely to affect these vital rates. The observed behavioral responses in all 10 conditions for multiple pulses and continuous noise for each of the five functional hearing groups were reviewed in detail, and individual responses were assessed according to this severity scaling and measured or reasonably estimated exposure levels. An example of this severity scaling of the observed behavioral literature in one of these conditions (low-frequency cetaceans exposed to impulse noise, predominantly airguns) that may be particularly relevant to this assessment is shown in **Table H-5**. Blank cells in this table indicate the lack of measured responses for these received sound levels and response categories; an overarching conclusion of Southall et al. (2007) was the striking lack of data in most exposure conditions for marine mammals.

This severity scaling, as evident in **Table H-5**, did not reveal broadly applicable patterns of response in most cases – i.e., where no response occurs below some specific received level and a high probability of response occurs above some point (as step-functions would presume). Certain observations were made, including the behavioral context-dependence of response for different received levels in migrating bowhead whales and the particular sensitivity of harbor porpoises both in field and laboratory experiments. But the primary advances made in the Southall et al. (2007) criteria in terms of behavioral response were to very clearly demonstrate that step-function thresholds for response using a single received level and no other considerations related to behavioral context are overly simplistic and outdated and to develop at least a qualitative means of addressing behavioral response severity issues.

Table H-5

Southall et al. (2007) Assessment of Individual Behavioral Responses of Low-Frequency Cetaceans to Multiple-Pulse Exposure for Various Received Levels

(Individual observations are weighted to account for statistical considerations, and source data are indicated by parenthetical subscript: Malme et al. (1983)[1]; Malme et al. (1984)[2]; Richardson et al. (1986)[3]; Ljungblad et al. (1988)[4]; Todd et al. (1996)[5]; McCauley et al. (1998)[6]; Richardson et al. (1999)[7]; and Miller et al. (2005)[8]

Response Score	Received Exposure Level (dB_{RMS} re: 1μPa)											
	80 to <90	90 to <100	100 to <110	110 to <120	120 to <130	130 to <140	140 to <150	150 to <160	160 to <170	170 to <180	180 to <190	190 to <200
9												
8												
7										1 (6)		
6				9.5 (3,7)	47.4 (3,7)	2.2 (3,7)	1.4 (4)	2 (1,2)	5.5 (1,2,4,6)	9.3 (1,2,4,6,8)		
5					1 (3,7)		1 (4)	1 (1,2)				
4												
3									1 (1,2)	1 (1,2)		
2												
1				5 (3,7)	6 (3,7)	1 (3,7)	2 (1,2)	3 (5)				
0				59.8 (3,7)	17.7 (3,7)	1.1 (3,7,8)	0.1 (8)	0.1 (8)	6.8 (1,2,8)	6.3 (1,2,8)		

Clearly, the Southall et al. (2007) criteria for behavior are a starting point to develop a rudimentary framework in moving toward a more multivariate and biologically-meaningful way of assessing the type and magnitude of behavioral responses of marine mammals to noise than historical thresholds. As evidenced by the absence of data in many exposure level and response types above, significant data gaps exist in almost all areas, and many of the available studies lack key information about the nature of exposure in which behavioral responses were observed (which is why many studies were excluded from the Southall et al. [2007] analysis). This is an active area of research, and subsequent studies (some described above) have begun to report additional information on background noise, various exposure metrics, and behavioral contexts.

Broad application of the Southall et al. (2007) criteria for both injury and behavior has been relatively slow in evolving, in part due to the increased complexity of the recommendations over the previous simplistic approaches, such as step-functions used by NMFS. However, NMFS has used exposure criteria consistent with the Southall et al. (2007) thresholds for injury from sound exposure for assessing potential impacts of Navy active sonar operations (*Federal Register*, 2009a,b) for a host of species, including large whales and pinnipeds. In fact, these regulations actually include higher exposure values for certain species for which higher TTS onset values were directly measured than the more conservative values used in Southall et al. (2007). Additionally, recent NMFS regulations (*Federal Register*, 2009a,b) have also begun to use a more graduated dose-function based approach to behavioral response rather than the historical step-function thresholds. NMFS is preparing acoustic exposure guidelines that are expected to increasingly consider the increased complexity and context-dependence of responses of marine mammals to sound.

6. ASSESSMENT OF HEARING INFORMATION FOR SPECIES/GROUPS IN THE AREA OF INTEREST

Specific sound sources that will be used in G&G exploration activities off the U.S. East Coast, as discussed in **Chapter 3** of the Programmatic EIS, include both impulsive (e.g., 2D and 3D seismic exploration surveys using conventional airguns) and continuous noise sources such as side-scan sonars, sediment sampling, electromagnetic surveys, and various vessel activities.

Most of the marine mammals likely to be present in the Area of Interest (AOI), as discussed in Programmatic EIS **Chapter 4.2.2**, are cetaceans, with some pinnipeds possibly present at very low densities in the northern extent of the area and manatees potentially present in southern, near-coastal waters. For some of these species (e.g., bottlenose dolphins), relatively good information exists about hearing and behavioral responses to some types of sounds (e.g., Nowacek et al., 2001), though not particularly for seismic exploration specifically. For most of the mid-frequency cetacean species, including the endangered sperm whale, the injury criteria proposed by Southall et al. (2007) and general conclusions on behavioral response would be expected to be applicable; direct recent information on behavioral responses in sperm whales to seismic airguns are available as well (e.g., Miller et al., 2009).

For West Indian manatees, direct measurements of hearing are available (Gerstein et al., 1999; Mann et al., 2005), as well as responses to vessel presence and noise (Nowacek et al., 2004a). From the perspective of hearing injury, the use of pinniped exposure criteria from the Southall et al. (2007) criteria would seem reasonable, as described above. These animals are generally very coastal-oriented, which would likely mean they would encounter G&G activities only in nearshore waters.

For the endangered mysticetes that occur in the area (north Atlantic right whale, blue whale, fin whale, humpback whale, and sei whale), as for all low-frequency cetaceans, no direct information regarding hearing is available. As described above, the Southall et al., 2007 exposure criteria for injury are based on assumptions and extrapolations from mid-frequency cetacean data that may need to be reassessed to some degree based on the subsequent measurements of lower onset TTS levels in bottlenose dolphins within their range of best hearing sensitivity (Finneran and Schlundt, 2010). In terms of behavioral response, substantial effort has been made and data are available for impulse noise (seismic airguns specifically) for mysticetes, though not for all of the species present in the AOI. Nowacek et al. (2004b) showed that north Atlantic right whales may be particularly responsive to alarm-like non-impulsive noise in controlled exposure studies. Similarly and more recently, Southall et al. (2011) demonstrated behavioral responses, and an apparent context-dependence in response based on behavioral state, in some blue and fin whales exposed to simulated sonar sounds off the coast of California. The fact that many of the mysticetes in the AOI may be engaged in migratory behavior during the course of operations, the increased sensitivity of some other mysticetes (e.g., bowhead and gray whales) during migrations should be considered in assessing potential responses of species where no direct data on responses to certain sound types (airguns) are available (e.g., blue, fin, and sei whales).

7. REFERENCES CITED

Au, W.W.L. 1993. The sonar of dolphins. Springer-Verlag, New York.

Au, W.W.L., A.A. Pack, M.O. Lammers, L.M. Herman, M.H. Deakos, and K. Andrews. 2006. Acoustic properties of humpback whale songs. Journal of the Acoustical Society of America 120:1103-1110.

Barber, J.R., K.R. Crooks, and K.M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25:180-189.

Bejder, L. and D. Lusseau. 2008. Valuable lessons from studies evaluating impacts of cetacean watch tourism. Bioacoustics 17:158-161.

Bejder, L., A. Samuels, H. Whitehead, H. Finn, and S. Allen. 2009. Impact assessment research: use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. Marine Ecology Progress Series 395:177-185. Available at: http://www.int-res.com/articles/theme/m395p177.pdf. Accessed August 5, 2011.

Busch, D.S. and L.S. Hayward. 2009. Stress in a conservation context: A discussion of glucocorticoid actions and how levels change with conservation-relevant variables. Biological Conservation 142:2844-2853.

Carretta, J.V., J. Barlow, and L. Enriquez. 2008. Acoustic pingers eliminate beaked whale bycatch in a gill net fishery. Marine Mammal Science 24:956-961.

Clark, C.W. 1990. Acoustic behavior of mysticete whales, pp. 571-583. In: J. Thomas and R. Kastelein, (eds.), Sensory Abilities of Cetaceans. Plenum Press.

Clark, C.W. and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements, pp. 564-582. In: J. Thomas, C. Moss and M. Vater (eds.), Echolocation in Bats and Dolphins. The University of Chicago Press.

Clark, C.W., W.T. Ellison, B.L. Southall, L. Hatch, S.M. Van Parijs, A. Frankel, and D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Marine Ecology Progress Series 395:201-222. Available at: http://www.int-res.com/articles/theme/m395p201.pdf. Accessed August 5, 2011.

Cox, T.M., T.J. Ragen, A.J. Read, E. Vos, R.W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernández, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houser, T. Hullar, P.D. Jepson, D. Ketten, C.D. MacLeod, P. Miller, S. Moore, D.C. Mountain, D. Palka, P. Ponganis, S. Rommel, R. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Mead, and L. Benner. 2006. Understanding the impacts of anthropogenic sound on beaked whales. Journal of Cetacean Research and Management 7:177-187.

Cranford, T.W., M.F. McKenna, M.S. Soldevilla, S.M. Wiggins, J.A. Goldbogen, R.E. Shadwick, P. Krysl, J.A. St. Leger, and J.A. Hildebrand. 2008a. Anatomic geometry of sound transmission and reception in Cuvier's beaked whale (*Ziphius cavirostris*). Anat. Rec. 291:353-378.

Cranford, T. W.P. Krysl, and J.A. Hildebrand. 2008b. Acoustic pathways revealed: simulated sound transmission and reception in Cuvier's beaked whale (*Ziphius cavirostris*). Bioinsp. Biomim. 3:016001 (10pp). Available at: http://spermwhale.org/SDSU/My%20Work/Cranford_et_al_Sound_Paths_FEM_BB_2008.pdf. Accessed August 5, 2011.

Cudahy, E. and W. Ellison. 2002. A review of the potential for in vivo tissue damage by exposure to underwater sound. Groton, CT: Naval Submarine Medical Research Library.

Federal Register. 2003. Small takes of marine mammals incidental to specified activities; Oceanographic surveys in the Hess Deep, Eastern Equatorial Pacific Ocean. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. July 11, 2003. 68 FR 133, pp. 41314-41321. Available at: http://www.gpo.gov/fdsys/pkg/FR-2003-07-11/pdf/03-17622.pdf.

Federal Register. 2009a. Taking and Importing Marine Mammals; U.S. Navy Training in the Hawaii Range Complex. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. January 12, 2009. 74 FR 7 pp. 1456-1491. Available at: http://www.gpo.gov/fdsys/pkg/FR-2009-01-12/pdf/E9-37.pdf

Federal Register. 2009b. Taking and Importing Marine Mammals; U.S. Navy Training in the Southern California Range Complex. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. January 21, 2009. 74 FR 12 pp. 3882-3918. Available at: http://www.gpo.gov/fdsys/pkg/FR-2009-01-21/pdf/E9-1073.pdf

Fernández, A., J.F. Edwards, F. Rodríguez, A. Espinosa De Los Monteros, P. Herráez, P. Castor, J.R. Jaber, V. Martín, and M. Arbelo. 2005. "Gas and Fat Embolic Syndrome'' involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. Veterinary Pathology 42:446–457.

Finneran, J.J. and C.E. Schlundt. 2010. Frequency-dependent and longitudinal changes in noise-induced hearing loss in a bottlenose dolphin (*Tursiops truncatus*). Journal of the Acoustical Society of America 128:567-570.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and R.L. Dear. 2010a. Growth and recovery of temporary threshold shift at 3 kHz in bottlenose dolphins: Experimental data and mathematical models. Journal of the Acoustical Society of America 127:3256-3266.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and R.L. Dear. 2010b. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. Journal of the Acoustical Society of America 127:3267-3272.

Frankel, A.S. 2005. Gray whales hear and respond to a 21-25 kHz high-frequency whale-finding sonar, p. 97. In: Proceedings 16th Biennial Conference on the Biology of Marine Mammals, San Diego, California, 12-16 December 2005.

Gerstein, E.R., L. Gerstein, S.E. Forsythe, and J.E. Blue. 1999. The underwater audiogram of the West Indian manatee (*Trichechus manatus*). Journal of the Acoustical Society of America 105:3575-3583.

Gilles, A., M. Scheidat, and U. Siebert. 2009. Seasonal distribution of harbour porpoises and possible interference of offshore wind farms in the German North Sea. Marine Ecology Progress Series 383:295-307.

Goertner, J.F. 1982. Prediction of underwater explosion safe ranges for sea mammals. Naval Surface Weapons Center, Silver Spring, MD. Available at: http://www.dtic.mil/dtic/tr/fulltext/u2/a139823.pdf. Accessed August 5, 2011.

Henderson, D., B. Hu, and E. Bielefeld. 2008. Patterns and mechanisms of noise-induced cochlear pathology, pp. 195-217. In: Schacht, J., A.N. Popper, and R.R Fay (eds.), Auditory Trauma, Protection, and Repair. Springer, New York.

High Energy Seismic Survey (HESS). 1999. High energy seismic survey review process and interim operational guidelines for marine surveys offshore Southern California. Prepared for The California State Lands Commission and the Minerals Management Service Pacific Outer Continental Shelf Region. Camarillo, California: High Energy Seismic Survey Team.

Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. Marine Ecology Progress Series 139:5-20. Available at: http://www.int-res.com/articles/theme/m395p005.pdf. Accessed August 5, 2011.

Holt, M.M., D.P. Noren, V. Veirs, C.K. Emmons, and S. Veirs. 2009. Speaking up: Killer whales (*Orcinus orca*) increase their call amplitude in response to vessel noise. J. Acoust. Soc. Amer. 125:EL27-EL32. Available at: http://www.beamreach.org/wiki/images/d/d2/JAS00EL27.pdf. Accessed August 5, 2011.

Houser, D.S., D.A. Helweg, and P.W.B. Moore. 2001. A bandpass filter-bank model of auditory sensitivity in the humpback whale. Aquatic Mammals 27:82-91.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. Nature 425:575-576.

Kaatz, I.M. 2002. Multiple sound producing mechanisms in teleost fishes and hypotheses regarding their behavioural significance. Bioacoustics 12:230-233.

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise, and ecology. Journal of the Acoustical Society of America 103:2216-2228.

Kastak, D., J. Mulsow, A. Ghoul, and C. Reichmuth. 2008. Noise-induced permanent threshold shift in a harbor seal. Journal of the Acoustical Society of America 123:2986.

Kastelein, R.A., W.C. Verboom, N. Jennings, and D. de Haan. 2008a. Behavioral avoidance threshold level of a harbor porpoise (*Phocoena phocoena*) for a continuous 50 kHz pure tone. J. Acoust. Soc. Amer. 123:1858-1861.

Kastelein, R.A., L. Hoek, and C.A.F. de Jong. 2008b. Hearing thresholds of a harbor porpoise (*Phocoena phocoena*) for sweeps (1–2 kHz and 6–7 kHz bands) mimicking naval sonar signals. J. Acoust. Soc. Amer. 129:3393-3399.

Ketten, D.R., S. Cramer, and J. Arruda. 2007. A manual for the removal, fixation, and preservation of cetacean ears. Woods Hole Oceanographic Institution, Woods Hole, MA.

Kryter, K.D. 1994. The handbook of hearing and the effects of noise. New York: Academic Press. 673 pp.

Ljungblad, D.K., B. Würsig, S.L. Swartz, and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41:183-194. Available at: http://arctic.synergiesprairies.ca/arctic/index.php/arctic/article/download/1717/1696. Accessed August 5, 2011.

Lucke, K., U. Siebert, P.A. Lepper, and M-A. Blachet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America 125:4060-4070. Available at: http://www.thecre.com/pdf/Lucke%20et%20al%20%202009.pdf. Accessed August 5, 2011.

Luther, D.A. and R.H. Wiley. 2009. Production and perception of communicatory signals in a noisy environment. Biology Letters 5:183-187. Available at: http://www.unc.edu/home/rhwiley/pdfs/LutherWiley2009.pdf. Accessed August 5, 2011.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1983. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Bolt Beranek and Newman Inc., Cambridge, MA: BBN Rep. 5366. Prepared for U.S. Dept. of the Interior, Minerals Management Service, Anchorage, AK. NTIS PB86-174174.

Malme, C. I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Phase II: January 1984 migration. Bolt Beranek and Newman Inc., Cambridge, MA: BBN Report No. 5586. Prepared for U.S. Dept. of the Interior, Minerals Management Service. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/1/1086.pdf. Accessed August 5, 2011.

Mann, D.A., D.E. Colbert, J.C. Gaspard, B.M. Casper, M.L.H. Cook, R.L. Reep, and G.B. Bauer. 2005. Temporal resolution of the Florida manatee (*Trichechus manatus latirostris*) auditory system. J. Comparative Physiology 191(10):903-908.

McCarthy, E., D. Moretti, L. Thomas, N. DiMarzio, R. Morrissey, S. Jarvis, J. Ward, A. Izzi, and A. Dilley. 2011. Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multiship exercises with mid-frequency sonar. Mar. Mamm. Sci. 27(3):E206-E226.

McCauley, R.D., M-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: Preliminary results of observations about a working seismic vessel and experimental exposures. Australian Petroleum Production and Exploration Association Journal 38:692-707.

Miksis, J.L., R.C. Connor, M.D. Grund, D.P. Nowacek, A.R. Solow, and P.L. Tyack. 2001. Cardiac response to acoustic playback experiments in the captive bottlenose dolphin (*Tursiops truncatus*). Journal of Comparative Psychology 115:227-232.

Miller, G.W., J.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillvray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals – southeastern Beaufort Sea, 2001-2002, pp. 511-542. In: S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore oil and gas environmental effects monitoring/Approaches and technologies. Battelle Press, Columbus, OH.

Miller, P.J.O., M.P. Johnson, P.T. Madsen, N. Biassoni, M. Quero, and P.L. Tyack. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. Deep-Sea Research 56:1168-1181. Available at: http://www.marinebioacoustics.com/files/2009/Miller_et_al_2009.pdf. Accessed August 5, 2011.

Montie, E.W., C.A. Manire, and D.A. Mann. 2011. Live CT imaging of sound reception anatomy and hearing measurements in the pygmy killer whale, *Feresa attenuata*. The Journal of Experimental Biology 214:945-955.

Mooney, T.A., P.E. Nachtigall, and S. Vlachos. 2009a. Sonar-induced temporary hearing loss in dolphins. Biology Letters 5:565-567.

Mooney, T.A., P.E. Nachtigall, M. Breese, S. Vlachos, and W.W.L. Au. 2009b. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): the effects of noise level and duration. J. Acoust. Soc. Amer. 125(3):1816-1826.

Mooney, T.A., R.T. Hanlon, J. Christensen-Dalsgaard, P.T. Madsen, D.R. Ketten, and P.E. Nachtigall. 2010. Sound detection by the longfin squid (*Loligo pealeii*) studied with auditory evoked potentials: sensitivity to low-frequency particle motion and not pressure. The Journal of Experimental Biology 213:3748-3759. Available at: http://jeb.biologists.org/content/213/21/3748.full.pdf. Accessed August 5, 2011.

Mulsow, J. and C. Reichmuth. 2010. Psychophysical and electrophysiological aerial audiograms of a Steller sea lion (*Eumetopias jubatus*). Journal of the Acoustical Society of America 127:2692–2701.

National Research Council. 2003. Ocean noise and marine mammals. The National Academies Press, Washington, DC.

National Research Council. 2005. Marine mammal populations and ocean noise: Determining when noise causes biologically significant events. The National Academies Press, Washington, DC.

Nowacek, S.M., R.S. Wells, and A.R. Solow. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal Science 17(4):673-688.

Nowacek, S.M., R.S. Wells, E.C.G. Owen, T.R. Speakman, R.O. Flamm, and D.P. Nowacek. 2004a. Florida manatees, *Trichechus manatus latirostris*, respond to approaching vessels. Biological Conservation 119:517-523. Available at: http://ocean.fsu.edu/faculty/nowacek/nowacek_biocons.pdf. Accessed August 5, 2011.

Nowacek, D., M.P. Johnson and P.L. Tyack. 2004b. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society of London. Series B. Biological Sciences 271:227-231. Available at: http://rspb.royalsocietypublishing.org/content/271/1536/227.full.pdf+html. Accessed August 5, 2011.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. Mammal Review 37(2):81–115.

Parks, S., D.R. Ketten, J.T. O'Malley, and J. Arruda. 2007. Anatomical Predictions of Hearing in the North Atlantic Right Whale. The Anatomical Record 290:734-744. Available at: http://adcp.whoi.edu/csi/images/Parksetal2007.pdf. Accessed August 5, 2011.

Payne, R. and D. Webb. 1971. Orientation by means of long range acoustic signaling in baleen whales. Annals of the New York Academy of Sciences 188:110-141.

Popper, A.N. and P.L. Edds-Walton. 1997. Bioacoustics of marine vertebrates, pp. 1831-1836. In: M.J. Crocker (ed.), Encyclopedia of Acoustics, Vol. IV. Wiley-Interscience, New York.

Reichmuth, C. 2007. Assessing the hearing capabilities of mysticete whales. A proposed research strategy for the Joint Industry Programme on Sound and Marine Life on 12 September. Available at: http://www.soundandmarinelife.org/Site/Products/MysticeteHearingWhitePaper-Reichmuth.pdf. Accessed August 5, 2011.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. Journal of the Acoustical Society of America 79:1117-1128.

Richardson, W.J., B. Würsig, and C.R. Greene, Jr. 1990. Reactions of bowhead whales, *Balaena mysticetus*, to drilling and dredging noise in the Canadian Beaufort Sea. Marine Environmental Research 29:135-160.

Richardson, W.J., C.R. Greene, Jr., J.S. Hanna, W.R. Koski, G.W. Miller, N.J. Patenaude, and M.A. Smultea. 1995. Acoustic effects of oil production activities on bowhead and white whales visible during spring migration near Pt. Barrow, Alaska-1991 and 1994 phases: Sound propagation and whale responses to playbacks of icebreaker noise. OCS Study MMS 95-0051.

Richardson, W.J., G.W. Miller, and C.R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. Journal of the Acoustical Society of America 106(4):2281.

Ridgway, S. and D.A. Carder. 2001. Assessing hearing and sound production in cetacean species not available for behavioral audiograms: experiences with sperm, pygmy sperm, and gray whales. Aquatic Mammals 27:267-276. Available at: http://www.aquaticmammalsjournal.org/share/AquaticMammalsIssueArchives/2001/AquaticMammals_27-03/27-03_Ridgway.pdf. Accessed August 5, 2011.

Romano, T.A., M.J. Keogh, C. Kelly, P. Feng, L. Berk, L., C.E. Schlundt, D.A. Carder, and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: Measures of the nervous and immune systems before and after intense sound exposure. Canadian Journal of Fisheries and Aquatic Sciences 61:1124-1134. Available at: http://www.awionline.org/ht/a/GetDocumentAction/i/10174. Accessed August 5, 2011.

Saunders, J.C., S.P. Dear, and M.E. Schneider. 1985. The anatomical consequences of acoustic injury: A review and tutorial. Journal of the Acoustical Society of America 78:833-860.

Schusterman, R.J. 1981. Behavioral capabilities of seals and sea lions: A review of their hearing, visual, learning, and diving skills. Psychological Record 31:125-143.

Schusterman, R.J., D. Kastak, D.H. Levenson, C.J. Reichmuth, and B.L. Southall. 2000. Why pinnipeds don't echolocate. Journal of the Acoustical Society of America 107:2256-2264.

Southall, B.L., R.J. Schusterman, D. Kastak, and C.R. Kastak. 2005. Reliability of underwater hearing thresholds in pinnipeds. Acoustic Research Letters Online 6(4):243-249. Available at: http://www.sea-inc.net/resources/lrni_Southalletal_ARLO_hearingreliability_2005.pdf. Accessed August 5, 2011.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33:411-521. Available at: http://www.pinnipedlab.org/publications/pub_131_2007.pdf. Accessed August 5, 2011.

Southall, B.L., J. Calambokidis, P. Tyack, D. Moretti, J. Hildebrand, C. Kyburg, R. Carlson, A. Friedlaender, E. Falcone, G. Schorr, A. Douglas, S. DeRuiter, J. Goldbogen, and J. Barlow. 2011. Project report: Biological and Behavioral Response Studies of Marine Mammals in Southern California, 2010 (SOCAL-10).

Thomas, J.A., R.A. Kastelein, and F.T. Awbrey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. Zoo Biology 9:393-402.

Thompson, P.M., D. Lusseau, T. Barton. D. Simmons, J. Rustin, and H. Bailey. 2010. Assessing the responses of coastal cetaceans to construction of offshore wind turbines. Marine Pollution Bulletin, 60:1200-1208.

Todd, S., P. Stevick, J. Lien, F. Marques, and D. Ketten. 1996. Behavioral effects of exposure to underwater explosions in humpback whales (*Megaptera novaeangliae*). Canadian Journal of Zoology 74:1661-1672. Available at: http://csi.whoi.edu/sites/default/files/literature/Full%20Text_30.pdf. Accessed August 5, 2011.

Tyack, P.L. 1998. Acoustic communication under the sea, pp. 163-220. In: S.L. Hopp, M.J. Owren, and C.S. Evans (eds.), Animal Acoustic Communication. Springer-Verlag, Berlin.

Tyack, P.L., W.M.X. Zimmer, D. Moretti, B.L. Southall, D.E. Claridge, J.W. Durban, C.W. Clark, A. D'Amico, N. DiMarzio, S. Jarvis, E. McCarthy, R. Morrissey, J. Ward, and I.L. Boyd. 2011. Beaked whales respond to simulated and actual navy sonar. PLoS ONE 6(3):e17009. Available at: http://www.plosone.org/article/info:doi/10.1371/journal.pone.0017009. Accessed August 5, 2011.

Visser, F., K.L. Hartman, E.J.J. Rood, A.J.E. Hendriks, D.B. Zult, W.J. Wolff, J. Huisman, and G.J. Pierce. 2010. Risso's dolphins alter daily resting pattern in response to whale watching at the Azores. Marine Mammal Science 27:366-381.

Ward, W.D. 1997. Effects of high-intensity sound, pp. 1497-1507. In: M.J. Crocker (ed.), Encyclopedia of Acoustics Vol. III. New York: John Wiley & Sons, Inc.

Wartzok, D. and D.R. Ketten. 1999. Marine mammal sensory systems, pp. 117-175. In: J.E. Reynolds, II and S.A. Rommel (eds.), Biology of marine mammals. Smithsonian Institute Press: Washington D.C.

Wartzok, D., A.N. Popper, J. Gordon, and J. Merrill. 2004. Factors affecting the responses of marine mammals to acoustic disturbance. Marine Technology Society Journal 37:6-15. Available at: http://www.ingentaconnect.com/content/mts/mtsj/2003/00000037/00000004/art00002. Accessed August 5, 2011.

Watkins, W.A. and D. Wartzok. 1985. Sensory biophysics of marine mammals. Marine Mammal Science 1:219-260.

Weir, C.R. 2008a. Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. Aquatic Mammals 34(1):71-83. Available at: http://www.ketosecology.co.uk/Weir%282008%29_Seismic.pdf. Accessed August 5, 2011.

Weir, C.R. 2008b. Short-finned pilot whales (*Globicephala macrorhynchus*) respond to an airgun ramp-up procedure off Gabon. Aquatic Mammals 34(3):349-354. Available at: http://www.ketosecology.co.uk/Weir%282008%29_SoftStart.pdf. Accessed August 5, 2011.

Wirsing, A.J., M.R. Heithaus, A. Frid, and L.M. Dill. 2008. Seascapes of fear: evaluating sublethal predator effects experienced and generated by marine mammals. Marine Mammal Science 24:1-15.

Wright, A.J., N.A. Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A Wintle, G. Notarbartolo-di-Sciara, and V. Martin. 2007a. Anthropogenic noise as a stressor in animals: A multidisciplinary perspective. International Journal of Comparative Psychology 20:250-273. Available at: http://www.comparativepsychology.org/ijcp-vol20-2-3-2007/14.Wright_etal_A_PDF.pdf. Accessed August 5, 2011.

Wright, A.J., N.A. Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A Wintle, G. Notarbartolo-di-Sciara, and V. Martin. 2007b. Do marine mammals experience stress related to anthropogenic noise? International Journal of Comparative Psychology 20:274-316. Available at: http://www.comparativepsychology.org/ijcp-vol20-2-3-2007/15.Wright_etal_B_PDF.pdf. Accessed August 5, 2011.

Yelverton, J.T., D.R. Richmond, E.R. Fletcher, and R.K. Jones. 1973. Safe distances from underwater explosions for mammals and birds. AD-766 952. Prepared for Defense Nuclear Agency, Washington, DC. Available at: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=AD766952&Location=U2&doc=GetTRDoc.pdf. Accessed August 5, 2011.

Yost, W.A. 2000. Fundamentals of Hearing: An Introduction. New York: Academic Press.

Young, G.A. 1991. Concise methods for predicting the effects of underwater explosions on marine life. AD-A241-310. Naval Surface Warfare Center, Silver Spring, MD. Available at: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA241310&Location=U2&doc=GetTRDoc.pdf. Accessed August 5, 2011.

Zimmer, W.M.X. and P.L. Tyack. 2007. Repetitive shallow dives pose decompression risk in deep-diving beaked whales. Marine Mammal Science 23(4):888-925.

APPENDIX I

SEA TURTLE HEARING AND SENSITIVITY TO ACOUSTIC IMPACTS

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1. INTRODUCTION

There is growing concern over anthropogenic sound in the world's oceans and its potentially harmful effects on protected marine organisms, including sea turtles. Similar to other migratory marine species, sea turtles occupy different ecological niches throughout ontogeny, each characterized by unique acoustic conditions. Sea turtles spend the majority of their lives in the ocean; their only land-linked behaviors are egg deposition and hatching. Like many marine fishes and mammals, sea turtles use a range of habitats for each developmental stage (see review by Bolton, 2003). Once hatchlings reach the sea, they are pelagic, moving primarily with ocean currents. After a period of years, which varies both among species and populations, a critical ontogenetic habitat shift occurs whereby most sea turtles actively recruit to a demersal, neritic habitat and are considered juveniles. Finally, upon reaching maturity, all sea turtles maintain a discrete foraging area (this region frequently overlaps with the juveniles), migrating only to return to their natal nesting beach. The exception to this life history model in North Atlantic populations is the leatherback turtle (*Dermochelys coriacea*). Leatherbacks remain pelagic as both juveniles and adults and return to the neritic zone only for reproduction (Bolton, 2003).

Few studies have examined the role acoustic cues play in the ecology of sea turtles (Mrosovsky, 1972; Samuel et al., 2005; Nunny et al., 2008). There is evidence that sea turtles may use sound to communicate; the few vocalizations described for sea turtles are restricted to the "grunts" of nesting females (Mrosovsky, 1972). These sounds are low frequency and relatively loud, thus leading to speculation that nesting females use sounds to communicate with conspecifics (Mrosovsky, 1972). We know very little about the extent to which sea turtles use their auditory environment ("soundscape"). However, the passive acoustic environment for sea turtles changes with each ontogenetic habitat shift. In the inshore environment where juvenile and adult sea turtles generally reside, the ambient environment is noisier than the open ocean environment of the hatchlings; this inshore environment is dominated by low frequency sound (Hawkins and Myrberg, 1983), and, in highly trafficked areas, virtually constant low frequency noises from shipping, recreational boating, and seismic surveys compound the potential for acoustic impact (Hildebrand, 2005).

2. MORPHOLOGY

Much of the research on the hearing capacity of sea turtles is limited to gross morphological dissections (Wever, 1978; Lenhardt et al., 1985). The tympanum is a continuation of the facial tissue and is distinguishable only by palpitation of the area. Beneath the tympanum is a thick layer of subtympanal fat (**Figure I-1**), a feature that distinguishes sea turtles from both terrestrial and semi-aquatic turtles. Recent imaging data suggests that this layer of fat is similar to the fats found in the jaws of odontocete whales and functions as a low-impedance channel for sounds to the ear (Ketten et al., 1999). The middle ear cavity lies posterior to the tympanum; the Eustachian tube connects the middle ear with the throat (Wever, 1978; Lenhardt et al., 1985). As with most turtles, the middle ear is small and encased by bone. The ossicular mechanism consists of two elements: the extracolumella and the columella (stapes). The extracolumella is a cartilaginous disk under the tympanic membrane attached to the columella by ligaments. The columella, a long rod with the majority of its mass concentrated at each end, extends medially from the middle ear cavity through a narrow bony channel and expands within the oval window to form a funnel shaped end. The columella is free to move only longitudinally within this channel so when the tympanum is depressed directly above the middle of the extracolumella, the columella moves readily in and out of the oval window, without any flexion of the columella. The stapes and oval window are connected to the saccular wall by fibrous strands. It is thought that these stapedo-saccular strands relay vibrational energy of the stapes to the saccule (Wever and Vernon, 1956; Wever, 1978; Lenhardt et al., 1985). For semi-aquatic turtles, the columella is the main pathway for sound input to the inner ear; when the columella is clipped while leaving the tympanum intact, the animal displayed an extreme decrease of sensitivity of hearing (Wever and Vernon, 1956).

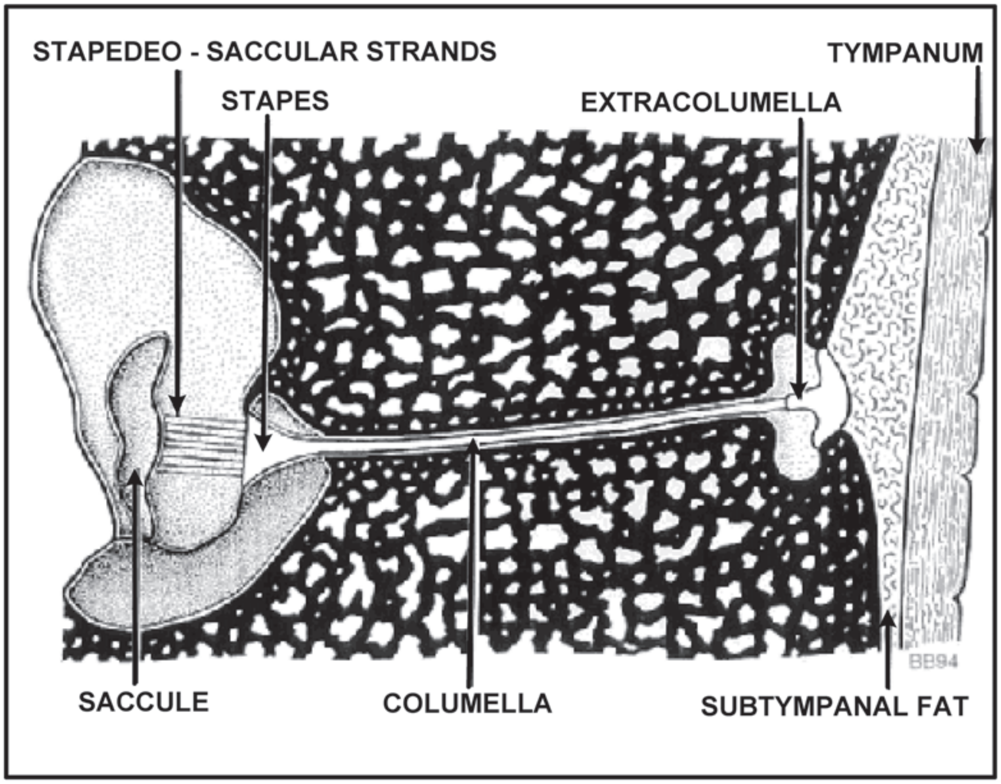

Figure I-1. Middle Ear Anatomy of the Juvenile Loggerhead Sea Turtle (Moein, 1994).

The auditory sense organ within the inner ear of the sea turtle cochlea is the basilar papilla (basilar membrane). This membrane is large and composed of dense connective tissue in sea turtles (rather than a thin basilar membrane found in terrestrial turtles) (Wever, 1978; Hetherington, 2008). This basilar papilla is positioned opposite the round window and lies within the pathway of fluid displacement due to columella motion. In most reptiles, and presumably in sea turtles as well, the tectorial membrane lays over the hair cells of the basilar papilla. For sea turtles, the innervations of the hair cells may be accomplished through the movement of the overlying tectorial membrane rather than the movement of the papillae (Hetherington, 2008).

Based on the functional morphology of the ear, it appears that sea turtles receive sound through the standard vertebrate tympanic middle ear path. This ear, however, is adapted to underwater sound, not aerial. For the terrestrial vertebrate, the middle ear is an impedance transformer between sound in air (environment) and sound in fluid (inner ear). This impedance mismatch can be overcome by having a high convergence ratio between the tympanic membrane and oval window (thus amplifying the force acting on the inner ear) and by having a multiple bone ossicular mechanism that acts as a lever system to amplify force. The convergence ratio of the tympanic membrane to oval window in sea turtles is reported to be lower than other semi-aquatic turtles (Lenhardt et al., 1985), and sea turtles lack an osscicular mechanism that acts as a lever (having only a single straight columella). Thus, the sea turtle ear appears to be a poor receptor for aerial sounds. However, this ear is well adapted to water conduction sound. The dense layer of fat under the tympanum acts as a low-impedance channel for underwater sound (similar to that pathway found in odontocetes [Ketten et al., 1999]). Furthermore, the retention of air in the middle ear of these sea turtles suggests that they are able to detect sound pressures.

3. ELECTROPHYSIOLOGICAL RESPONSE TO SOUND

Electrophysiological studies on hearing have been conducted on juvenile green turtles (*Chelonia mydas*) (Ridgway et al., 1969; Bartol and Ketten, 2006), juvenile Kemp's ridley turtles (*Lepidochelys kempii*) (Bartol and Ketten, 2006), and juvenile loggerhead turtles (*Caretta caretta*) (Bartol et al., 1999;

Lavender et al., 2010, 2011). Electrophysiological responses, specifically auditory evoked potentials (AEPs), are the most widely accepted technique for measuring hearing in situations in which normal behavioral testing is impractical. The AEPs reflect the synchronous discharge of large populations of neurons within the auditory pathway and, thus, are useful monitors of the functioning of the throughput of the auditory system. Most AEP research has concentrated on the use of responses occurring within the first 10 ms following presentation of click or brief tone burst stimuli. This response has been termed the auditory brainstem response (ABR) and consists of a series of 5-7 patterned and identifiable waves. Corwin et al. (1982) recorded AEPs from five classes of non-mammalian vertebrates (including the red eared turtle, *Pseudemys scripta elegans*) and found the response, recorded outside the brain, to be congruous with the criteria for "conventional" ABRs. Furthermore, these techniques are noninvasive and can be performed on conscious subject animals (Bullock, 1981; Corwin et al., 1982).

Ridgway et al. (1969) measured auditory cochlear potentials of green turtles using both aerial and vibrational stimuli. Thresholds were not measured; instead, cochlear response curves of 0.1 μV potential were plotted for frequencies ranging from 50 to 2,000 Hz. Green turtles detect a limited frequency range (200-700 Hz) with best sensitivity at the low tone region of about 400 Hz. Though this investigation examined two separate modes of sound reception (i.e., air and bone conduction), sensitivity curves were relatively similar, suggesting that the inner ear is the main structure for determining frequency sensitivity. To measure electrophysiological responses to sound stimuli, Bartol et al. (1999) collected ABRs from juvenile loggerhead turtles. Vibratory stimuli were delivered directly to the dermal plates over the loggerhead turtle's tympanum. Thresholds were recorded for both tonal and click stimuli. Best sensitivity was found in the low frequency region of 250-1000 Hz. The decline in sensitivity was rapid after 1,000 Hz, and the most sensitive threshold tested was at 250 Hz. More recently, Bartol and Ketten (2006) collected underwater ABRs from hatchling and juvenile loggerhead and juvenile green turtles. For these experiments, the speaker was suspended in air while the turtle's tympanum remained submerged underwater. All turtles tested responded to sounds in the low frequency range, from at least 100 Hz (lowest frequency tested) to no greater than 900 Hz. Interestingly, the smallest turtles tested, hatchling loggerheads, had the greatest range of hearing (100-900 Hz) while the larger juveniles responded to a much narrower range (100-400 Hz). Hearing sensitivity of green turtles also varied with size; smaller greens had a broader range of hearing (100-800 Hz) than that detected in larger subjects (100-500 Hz). Lavender et al. (2010, 2011) have recorded underwater AEPs using a Navy J9 underwater speaker from loggerhead turtles, their ages ranging from yearlings to subadults. Under these conditions, loggerheads were found to respond to frequencies between 50-1000 Hz.

4. BEHAVIORAL RESPONSES TO SOUND

Multiple studies have attempted to examine the behavioral responses of juvenile loggerheads to sound in their natural environment, both in controlled settings (O'Hara and Wilcox, 1990; Moein et al., 1995; McCauley et al., 2000; Lavender et al., 2011) and as observed *in situ* (Holst et al., 2007; Weir, 2007; DeRuitter and Doukara, 2010). Behavioral audiograms have been collected from multiple size classes of loggerhead turtles (Lavender et al., 2011). Behavioral audiograms require the animal to perform a task in the presence of auditory stimuli; though time consuming (it can take months to train a turtle to sound), behavioral audiograms are a more sensitive measure of hearing threshold than electrophysiological responses and ascribe a critical behavioral component to hearing trials. Lavender et al. (2011) recorded audiograms using a two-response, forced-choice approach, whereby the turtles were required to vary behavior according to presence or absence of sound, permitting a behavioral measure of acoustic sensitivity. Lavender et al. (2011) have found that while loggerheads respond to similar frequencies as previous studies (50-1,000 Hz), their threshold levels are actually more sensitive than reported using electrophysiological methods.

Several sea turtle behavioral studies have been initiated to assist in the development of an acoustic repelling device for sea turtles. O'Hara and Wilcox (1990) attempted to create a sound barrier for loggerhead turtles at the end of a canal using seismic airguns. The test results indicated that airguns were effective as a deterrent for a distance of about 30 m when the sound output of this system was approximately 220 dB re 1 μPa at 1 m in the 25-1,000 Hz range. However, this study did not account for the reflection of sound by the canal walls, and the stimulus frequency and intensity levels are ambiguous. Moein et al. (1995) investigated the use of airguns to repel juvenile loggerhead turtles from hopper dredges. A net enclosure was erected in the York River, Virginia to contain the turtles, and an airgun was stationed at each end of the net. Sound frequencies of the airguns ranged from 100 to 1,000 Hz at three decibel levels (175, 177, and 179 dB re 1 μPa at 1 m). Avoidance of the airguns was observed upon first exposure. However, after three separate exposures to the airguns, the turtles habituated to the stimuli. McCauley et al. (2000) examined the response of sea turtles (one green and one loggerhead turtle) to an airgun signal. For these trials, the turtles were placed in cages, and behavior was monitored as a single airgun approached and departed. During these trials, the turtles showed a noticeable increase in swimming behavior when the airgun level was above 166 dB re 1 μPa at 1 m and became erratic and increasingly agitated above 175 dB. Because these animals were caged, avoidance behavior could not be monitored. However, the researchers speculated that avoidance would occur at 175 dB re 1 μPa at 1 m, the point at which the animals were acutely agitated (McCauley et al., 2000).

Researchers have also attempted to monitor sea turtle avoidance to sound during an active seismic survey (Weir, 2007; DeRuiter and Doukara, 2010). Weir (2007) observed 240 animals during a 10-month seismic survey off the coast of Angola. Behaviors were recorded at time of first sighting and as the vessel and towed equipment moved in relation to the turtle. Fewer turtles were observed near the airguns as they were firing (as opposed to the "gun-off" state). However, the source of agitation for the turtle could not be identified; the turtle could have reacted to the ship and towed equipment rather than specifically to the airgun (Weir, 2007). DeRuiter and Doukara (2010) observed turtles during active operation of an airgun array as well and found a startle response (rapid dive) to the airgun. However, again, these authors could not distinguish the stimulus source of the startle response as they did not perform a control with the airguns off (DeRuiter and Doukara, 2010).

5. EFFECTS OF ANTHROPOGENIC NOISE

There is growing concern over anthropogenic sound in the world's oceans and the potentially harmful effect it has on protected marine organisms. Anthropogenic noises can originate from a multitude of sources, including (but not limited to) shipping traffic, seismic surveys for petroleum exploration, military sonar operations, pile driving, etc. These sounds have the potential to impact an animal in several ways: trauma to hearing (temporary or permanent), trauma to non-hearing tissue (barotraumas), alteration of behavior, and masking of biologically significant sounds (McCarthy, 2004).

Hearing damage is usually categorized as either a temporary or permanent injury. Temporary threshold shifts (TTS) are recoverable injuries to the hearing structure and can vary in intensity and duration. Normal hearing abilities return over time; however, animals often lack the ability to detect prey and predators and assess their environment during the recovery period. In contrast, permanent threshold shifts (PTS) are permanent loss of hearing through loss of sensory hair cells (Clark, 1991). Few studies have looked at hair cell damage in reptiles, and it is still unknown if sea turtles are able to regenerate hair cells (Warchol, 2011). There are almost no data on the effects of intense sounds on marine turtles and, thus, it is difficult to predict the level of damage to hearing structures. Clear avoidance reactions to seismic signals at levels between 166-179 dB re 1μPa have been observed (Moein et al., 1995; McCauley et al., 2000); however, both of these studies were done in a caged environment, so the extent of avoidance could not be monitored. Moein et al. (1995) did observe a habituation effect to the airguns; the animals stopped responding to the signal after three presentations. This lack of behavioral response could be a result of TTS or PTS.

The BOEM concludes that there is incomplete or unavailable information (40 CFR 1502.22) about sea turtles that use the AOI with respect to their physiology and behavioral response to intense sounds. The available data and information about sea turtles using the AOI is reported to the best of our ability in this document. The BOEM has used what scientifically credible information is available and applied it using accepted scientific methodologies. What is known about representative species, however, in combination with observation and interpretation of behavioral response to stimuli does allow some inferences to be drawn that allow reasonably foreseeable significant adverse impacts on sea turtles to be understood well enough so that mitigations can be designed to avoid or reduce them.

The BOEM has determined that incomplete or unavailable data or information on sea turtle physiology and behavioral response to intense sounds is adequate to understand reasonably foreseeable adverse impacts and is not essential to a reasoned choice among the alternatives, including the No Action alternative.

Anthropogenic noises below injury level have the potential to mask relevant sounds in the animals' environment. Masking sounds can interfere with the acquisition of prey or mate, the avoidance of predators, and, particularly in the case of sea turtles, identification of an appropriate nesting site (Nunny et al., 2008). Sea turtles appear to be low frequency specialists and, thus, the potential masking noises would fall within at least 50-1,000 Hz. These maskers could have diverse origins, ranging from natural to anthropogenic sounds (Hildebrand, 2005). The overall behavioral changes that can occur due to obscuration of sound scenery can have major ecological consequences for sea turtles. However, there are no quantitative data demonstrating masking effects for sea turtles.

Clearly, more research on the behavioral and physiological responses to sounds needs to be conducted on sea turtles before appropriate noise exposure criteria can be developed for reduced fitness, injury, and death. While the research community is making progress in the frequency range of hearing for sea turtles, there are few data on hearing loss/damage, hair cell regeneration, masking, and behavioral responses. Inner ear research on hair cell population needs to be conducted on multiple species and multiple age classes by using histology/imaging techniques to analyze variations in auditory anatomy among stages and species. The critical point that noise disrupts scene analysis and masks signals should be explored and quantitative data on masking needs to be collected for sea turtles. When looking at behavioral responses, research beyond the "startle response" must be conducted. Controlled experiments in the natural environment need to be conducted to document and classify reactions to sound as either nuisance (i.e., causing the animal to move away, changing the animals' behavior to another acceptable consequence) or injurious (i.e., preventing the animal from completing essential behavior). The results of these research studies could provide new data on the hearing ability and response to sound for sea turtles and a quantitative base for assessing potential impact of man-made sound sources on multiple species of sea turtles across habitats and developmental stages.

6. REFERENCES CITED

Bartol, S.M. and D.R. Ketten. 2006. Turtle and tuna hearing. In: Y. Swimmer and R. Brill (eds.), Sea turtle and pelagic fish sensory biology: Developing techniques to reduce sea turtle bycatch in longline fisheries. Pp. 98-105. NOAA Tech. Mem. NMFS-PIFSC-7. Internet website: http://www.pifsc.noaa.gov/tech/NOAA_Tech_Memo_PIFSC_7.pdf. Accessed August 5, 2011.

Bartol, S.M., J.A. Musick, and M. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Copeia 3:836-840.

Bolton, A.B. 2003. Variation in sea turtle life history patterns: neritic vs. oceanic developmental stages, pp. 243-257. In: P.L. Lutz, J.A. Musick, and J. Wyneken (eds.), The Biology of Sea Turtles Vol. 2. Boca Raton: CRC Press. Internet website: http://books.google.com/books?id=IBwouTV8VEwC&printsec=frontcover&dq=lutz+The+Biology+of+Sea+Turtles+volume+2&hl=en&ei=DJo5TpjKKu240AHhtIDuAw&sa=X&oi=book_result&ct=book-thumbnail&resnum=1&ved=0CC0Q6wEwAA#v=onepage&q&f=false. Accessed August 5, 2011.

Bullock, T.H. 1981. Neuroethology deserves more study of evoked responses. Neuroscience 6:1203-1215.

Clark, W.W. 1991. Recent studies of temporary threshold shift (TTS) and permanent threshold shift (PTS) in animals. J. Acoust. Soc. Am. 90(1):155-163.

Corwin, J.T., T.H. Bullock, and J. Schweitzer. 1982. The auditory brain stem response in five vertebrate classes. Electroenceph. Clin. Neurophysiol. 54(6):629-641.

DeRuitter, S.L. and K.L. Doukara. 2010. Loggerhead turtles dive in response to airgun sound exposure. J. Acoust. Soc. Am. 127(3):1726.

Hawkins, A.D. and A.A. Myrberg, Jr. 1983. Hearing and sound communication under water, pp. 347-405. In: B. Lewis (ed.), Bioacoustics: A Comparative Approach. Academic Press: London.

Hetherington, T. 2008. Comparative anatomy and function of hearing in aquatic amphibians, reptiles, and birds, pp. 183-210. In: J.G.M. Thewissen and S. Nummela (eds.), Sensory Evolution on the Threshold: Adaptations in Secondarily Aquatic Vertebrates. UC Press: Berkeley.

Hildebrand, J.A. 2005. Impacts of anthropogenic sound, pp. 101-158. In: Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson (eds.), Marine Mammals and Noise. San Diego: Academic Press.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2007. Effects of large and small-source seismic surveys on marine mammals and sea turtles. American Geophysical Union, abstract #OS42A-01. Internet website: http://adsabs.harvard.edu/abs/2006AGUSMOS42A..01H. Accessed August 5, 2011.

Ketten, D.R., C. Merigo, E. Chiddick, and H. Krum. 1999. Acoustic fatheads: parallel evolution of underwater sound reception mechanisms in dolphins, seals, turtles, and sea birds. J. Acoust. Soc. Am. 105:1110.

Lavender, A.L., S.M. Bartol, and I.K. Bartol. 2010. Hearing capabilities of loggerhead sea turtles (*Caretta caretta*) throughout ontogeny. Proceedings of the Second International Conference on the Effects of Noise on Aquatic Life, Cork, Ireland.

Lavender, A.L., S.M. Bartol, and I.K. Bartol. 2011. A two-method approach for investigating the hearing capabilities of loggerhead sea turtles (*Caretta caretta*). Proceedings of 31st Annual Symposium on Sea Turtle Biology and Conservation, San Diego, CA.

Lenhardt, M.L., R.C. Klinger, and J.A. Musick. 1985. Marine turtle middle-ear anatomy. J. Aud. Res. 25(1):66-72.

McCarthy, E. 2004. International Regulation of Underwater Sound: Establishing Rules and Standards to Address Ocean Noise Pollution. Kluwer Academic Publishers, Norwell, MA. 287 pp.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000. Marine seismic surveys – a study of environmental implications. APPEA Journal 692-708. Internet website: http://www.anp.gov.br/meio/guias/sismica/biblio/McCauleye2000.PDF. Accessed August 5, 2011.

Moein, S.M. 1994. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Master's thesis, College of William and Mary, Williamsburg, Virginia. Internet website: http://el.erdc.usace.army.mil/tessp/pdfs/Auditory%20Evoked%20Potentials_Thesis.pdf. Accessed August 5, 2011.

Moein, S.E., J.A. Musick, J.A. Keinath, D.E. Barnard, M.L. Lenhardt, and R. George. 1995. Evaluation of seismic sources for repelling sea turtles from hopper dredges, pp. 90-93. In: L.Z. Hales (ed.), Sea Turtle Research Program: Summary Report. Technical Report CERC-95.

Mrosovsky, N. 1972. S pectographs of the sounds of leatherback turtles. Herpetologica 29(3):256-258.

Nunny, R., E. Graham, and S. Bass. 2008. Do sea turtles use acoustic cues when nesting? NOAA Tech. Mem. NMFS SEFSC No. 582:83. Internet website: http://www.nmfs.noaa.gov/pr/pdfs/species/turtlesymposium2005.pdf. Accessed August 5, 2011.

O'Hara, J. and J.R. Wilcox. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. Copeia 2:564-567.

Ridgway, S.H., E.G. Wever, J.G. McCormick, J. Palin, and J.H. Anderson. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. Proc. Nat. Acad. Sci. 64:884-890. Internet website: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC223317/pdf/pnas00113-0080.pdf. Accessed August 5, 2011.

Samuel, Y., S.J. Morreale, C.H. Greene, and M.E. Richmond. 2005. Underwater, low-frequency noise in coastal sea turtle habitat. J. Acoust. Soc. Am. 117(3):1465-1472.

Warchol, M.E. 2011. Sensory regeneration in the vertebrate inner ear: Differences at the levels of cells and species. Hearing Research 273:72-79

Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. Marine Turtle Newsletter 116:17-20. Internet website: http://www.seaturtle.org/mtn/archives/mtn116/mtn116p17.shtml. Accessed August 5, 2011.

Wever, E.G. 1978. The reptile ear: Its structure and function. Princeton University Press, Princeton.

Wever, E.G. and J.A. Vernon. 1956. The sensitivity of the turtle's ear as shown by its electrical potentials. Proc. Nat. Acad. Sci. 42:213-220. Internet website: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC528254/pdf/pnas00707-0043.pdf. Accessed August 5, 2011.

APPENDIX J

FISH HEARING AND SENSITIVITY TO ACOUSTIC IMPACTS

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1. INTRODUCTION

This report considers the effects of human-generated (anthropogenic) sound on fishes, with particular reference to seismic airguns and sonars. However, since there are few data on the effects of any anthropogenic sources on fishes, much of the discussion will be based upon a wider range of sound sources, with a goal of some extrapolation to help inform potential effects from airguns and sonars. Emphasis will be placed upon peer-reviewed studies in the scientific literature. However, gray literature reports of high scientific quality will be cited as appropriate.

It should be noted that this review will not be comprehensive. Readers interested in more extensive analysis of the effects of anthropogenic sounds on animals are referred to Popper (2003), Hastings (2008), Popper and Hastings (2009a), and Slabbekoorn et al. (2010) for general reviews and to Popper and Hastings (2009b) and the papers in Popper and Hawkins (2011) for a more detailed overview.

1.1. WHAT IS INJURY FOR FISHES?

A fundamental issue of concern with regard to fishes is what constitutes "injury" in the sense of the marine mammal literature (see Southall et al. [2007]) and the Marine Mammal Protection Act. For marine mammals, permanent hearing loss (or permanent threshold shift [PTS]) is considered injury. But, as discussed below, PTS is not likely to occur in fishes, and all evidence for temporary hearing loss (or temporary threshold shift [TTS]) shows that fishes recover quickly from this loss. Thus, for the sake of this discussion, "injury" would not include effects on hearing.

So, a question of importance is when "injury" starts in fishes and the nature of physiological effects that can lead to injury. In the very limited literature on interim criteria for regulation of exposure of fishes to pile driving sound (regulations have not be promulgated for other sound sources), the concern is for the onset of physiological effects, but this is not clearly defined. In a recent study by Halvorsen et al. (2011a,b) on effects of pile driving sounds on Chinook salmon (and similar studies by Casper et al., 2011a on striped bass and tilapia), it has become clear that there are some effects that have the potential for impacting the survival of fishes (e.g., burst swim bladder, massive internal bleeding), whereas other effects have no more impact on survival than does a small cut on the arm of a human (e.g., external bleeding at the base of fins).

Therefore, until a better definition of "injury" is available and agreed upon for fishes, an injury will be defined as an effect on the physiology of the animal that leads to immediate or potential death for the purposes of this report. In contrast, behavioral effects, such as moving from a site of feeding, would not be considered an injury.

At the same time, it might ultimately be possible and worthwhile to attempt to define criteria for behavioral impacts. However, as discussed in the body of this report, there are no data currently available that provide guidance on this topic.

1.2. FISH

The term "fish" generally refers to three groups of vertebrates: (a) the Agnatha or jawless vertebrates; (b) the cartilaginous fishes; and (c) the bony fishes (see Nelson [2006]). The Agnatha are a small group of very ancient vertebrates that primarily includes lamprey, and they will not be considered further. See Nelson (2006) for a complete review of fishes and their evolutionary relationships and www.fishbase.org for a listing of the more than 32,000 known living species.

The cartilaginous fishes, or elasmobranchs, include sharks and rays and their relatives. Virtually nothing is known about effects of human-generated sound on cartilaginous fishes, but there is concern about potential effects since these animals are integral to the ecosystem in many parts of the marine environment (Casper et al., 2011b).

Bony fishes include most of the species of aquatic vertebrates, including the majority of the species of fishes that are consumed by humans[1]. Unless otherwise stated, the term "fishes" in this report will refer to bony fishes. By convention, the word "fish" refers to one or more members of the same species, whereas "fishes" refers to multiple species.

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[1] E.g., tuna, salmon, cod, herring, pollack, and many others.

1.3. FISH BIOACOUSTICS – OVERVIEW

Sound plays a major role in the lives of all fishes (e.g., Zelick et al., 1999; Fay and Popper, 2000). This is particularly the case since sound travels much further in water than other potential signals, and it is not impeded by darkness, currents, or obstacles in the environment. Thus, fishes can glean a great deal of information about biotic (living) and abiotic (environmental) sources and get a good "image" of the environment to a very substantial distance from the animal (e.g., Fay and Popper, 2000; Popper et al., 2003; Slabbekoorn et al., 2010).

In addition to listening to the overall environment and being able to detect sounds of biological relevance (e.g., the presence of a reef, the sounds produced by swimming predators), many species of bony fishes (but not elasmobranchs) communicate with sounds and use sounds in a wide range of behaviors including, but not limited to, mating and territorial interactions (see Zelick et al. [1999] for review). Consequently, anything that impedes the ability of a fishes to hear biologically relevant sounds, such as those produced by anthropogenic sound sources, could interfere with the normal behaviors and even the survival of individuals, populations, or a species. Much more detailed discussions of all aspects of fish bioacoustics can be found in the papers in Webb et al. (2008) and in papers by Fay and Megela-Simmons (1999), Zelick et al. (1999), and Popper et al. (2003). A broad discussion of interactions of anthropogenic sounds and fishes can be found in Popper and Hastings (2009a,b) and in the papers in Popper and Hawkins (2011).

1.4. METRICS OF SOUND EXPOSURE

Before discussing effects of anthropogenic sound on fishes, it is important to understand that, to date, it has not been possible to easily compare results from the studies with different anthropogenic sources. In part, this is because while different sources are reasonably similar in maximum intensity, they have different spectral characteristics and rise times. In particular, rise time, which is the time from the onset of the signal to when it reaches a high level, can impact effects. Signals with slow rise times will affect air bubbles in the body (e.g., swim bladder) slowly, and so the bubbles will change size slowly and let the surrounding tissues adjust to the changes. In contrast, a signal with a fast rise time will cause rapid changes of the air bubbles, and the walls of the expanding and contracting bubble will "knock into" the surrounding tissues, which are, in effect, rigid next to the moving bubble. This causes damage to the nearby tissues. An analogy might be the effect on a nail being pounded through hard wood by a weak versus strong hammer strike.

The second issue in comparing results arises from the spectrum and time course of the signal and how these are described and calibrated. Until recently, most sound sources were described in terms of peak pressure and root-mean-square (rms) pressure. Peak pressure represents the maximum point of the energy in a signal whereas rms describes the average level of energy in the signal. The problem with both measures is that they do not give a good representation of the total energy in the signal over time – and it is this total energy that is likely to be the critical factor in determining potential effects on a receiver (Popper and Hastings, 2009b).

In comparing sounds such as sonars, seismic airguns, and pile driving, there may be similarities in both peak and rms, but neither measure shows the actual differences in the total energy to which a receiver is exposed. More recently, investigators have started to use a third measure, the Sound Exposure Level (SEL). The SEL is the integration over time of the square of the acoustic pressure (Popper and Hastings, 2009b) and is an indication of the total acoustic energy received by an organism, representing the total energy in a signal over time – most often in one second of exposure (see Popper and Hastings [2009b] for discussion of SEL and how it is calculated). SEL allows for a comparison between signals since it provides a measure of all energy present in a signal, and it has, accordingly, been more and more accepted by investigators (e.g., Popper et al., 2005, 2007; Hastings et al., 2008; Hastings and Miskis-Olds, 2011; Halvorsen et al., 2011a,b).

There are two uses of SEL. One is referred to as single-strike SEL (SEL_{ss}), and the other is cumulative SEL (SEL_{cum})[2]. The SEL_{ss} is the energy in a single signal, such as a single pile driving strike

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[2] Note, abbreviations for single strike and cumulative SEL has not been standardized and is adopted here from Halvorsen et al. (2011b).

or a single blast from a seismic airgun. The SEL_{cum} is the energy in all of the signals presented, such as in all of the strikes during a pile driving operation or seismic study[3].

2. BACKGROUND ON FISH HEARING

2.1. SOUND IN WATER

The basic physical principles of sound in water are the same as sound in air. Any sound source produces both pressure waves and actual motion of the medium particles. However, whereas the actual particle motion in air is inconsequential even a few centimeters from a sound source, particle motion travels (propagates) much further in water because of the density of water compared to air[4]. For a more extensive discussion of underwater acoustics, see Urick (1983) and Rogers and Cox (1988).

All fishes, including elasmobranchs, detect particle motion since it directly stimulates the inner ear (Popper et al., 2003). Bony fishes with an air bubble (most often the swim bladder) are also likely to detect pressure signals that are reradiated to the inner ear as particle motion. Species detecting pressure hear a wider range of frequencies and sounds of lower intensity than fishes without an air bubble since the bubble re-radiates the received signal, which is then detectable by the ear as a secondary sound source (Popper et al., 2003; Popper and Fay, 2010).

Exactly how well fishes with an air bubble hear depends on the relative position of the air bubble and ear. When the two structures are close together or when there is some kind of physical coupling between them the bandwidth of hearing and sensitivity is greater than it is in fishes where the air bubble and ear are further apart or not coupled. In the latter case, the signal that is re-radiated from the air bubble attenuates (decreases) over the distance between the structures, whereas in the other species the proximity of the structures, or the coupling, ensures that most of the energy re-radiated from the bubble gets to the ear[5].

2.2. HEARING SENSITIVITY

Basic data on hearing provides information about the range of frequencies that a fish can detect and the lowest sound level that an animal is able to detect at a particular frequency (**Figure J-1**). This level is often called the "threshold."[6] Sounds that are above threshold are detectable by fishes.

Hearing thresholds have been determined for perhaps 100 species (**Figure J-1**) (for data on hearing thresholds, see Fay [1988], Popper et al. [2003], Ladich and Popper [2004], Nedwell et al. [2004], Ramcharitar et al. [2006], and Popper and Schilt [2008]). These data demonstrate that, with few exceptions, fishes cannot hear sounds above about 3-4 kHz, and the majority of species are only able to detect sounds to 1 kHz or below[7]. There have also been studies on a few species of cartilaginous fishes, with results suggesting that they detect sounds to no more than 600 or 800 Hz (e.g., Myrberg et al., 1976; Myrberg, 2001; Casper et al., 2003; Casper and Mann, 2006).

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[3] As discussed below, there is some indication that if there is sufficient time (e.g., more than 12 hrs) between an accumulation period for SEL, then the accumulation for the next exposure period starts again at 0.

[4] The wavelength of a sound in water is about 1,500 m/sec (it varies depending on salinity, depth, temperature, etc.). The wavelength is defined as 1500/frequency which means for a 500 Hz signal the wavelength is 3 m. For a 100 Hz signal the wavelength is 15 m and the near field transition point would be 15/6.28 = ~2.8 m.

[5] Until recently the literature talked about hearing "generalists" and "specialists." However, these terms are no longer in use. See Popper and Fay (2010) for explanation and discussion.

[6] Very often, for fish, hearing thresholds are the lowest levels at which sound is detected 50% of the time. In other words, whereas a fish will detect a particular signal 50% of the time, it will not detect the same signal 50% of the time. Variation in threshold is well known and reflects momentary changes in the detecting structure, in the motivation of the animal, and innumerable other factors.

[7] The lowest detectable frequency is often hard to determine since the limiting factor in experiments trying to measure this is often the equipment. In many cases, the equipment does not work well at frequencies below 50-100 Hz, making it hard to determine if fishes can detect lower frequencies. However, recent studies using specialized equipment have demonstrated that some species can detect sounds below 50 Hz (called infrasound), but it is still not clear if this is done by the ear or by the lateral line (Karlsen, 1992; Knudsen et al., 1994).

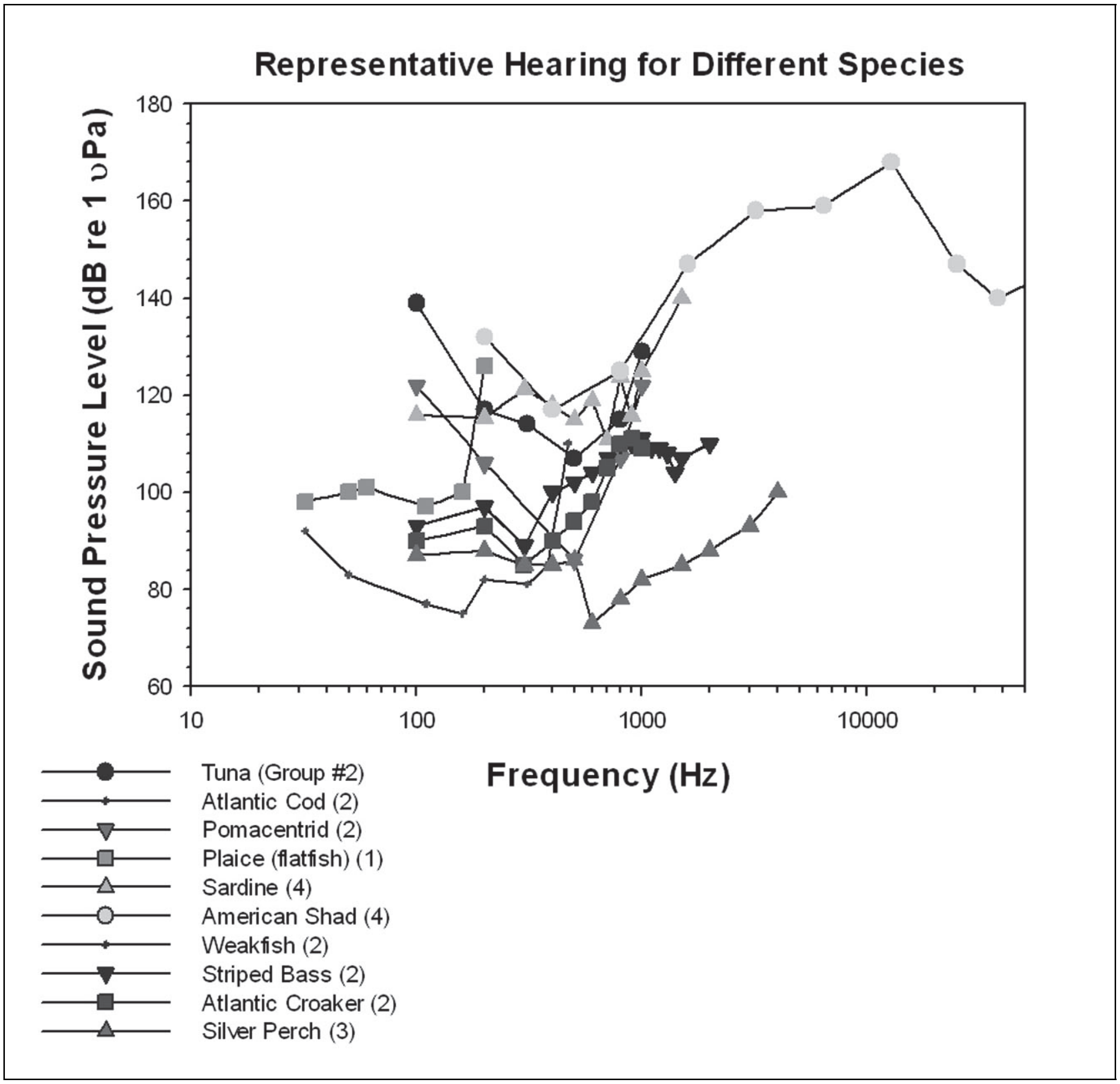

Figure J-1. Hearing Curves (Audiograms) for Select Bony Fishes (see Fay [1988], Nedwell et al. [2004], and Ramcharitar [2006] for data). Each data point indicates the lowest sound level the species could detect at a particular frequency (see text for caveats on data). Group number given in the legend refers to the discussion within the text. Data for American shad are truncated at 50 kHz to keep the size of the graph reasonable, but it should be noted that this species can hear sounds to at least 180 kHz (Mann et al., 1997).

The data available, while very limited, suggest that the majority of marine species do not have specializations to enhance hearing and probably rely on both particle motion and sound pressure for hearing. Most importantly, it should be noted that hearing capabilities vary considerably between different bony fish species (**Figure J-1**; **Table J-1**), and there is no clear correlation between hearing capability and environment. There is also broad variability in hearing capabilities within a single fish group. As just one example, there is broad diversity in hearing capabilities and hearing structures within the family Sciaenidae (drumfish, weakfish, croakers) (**Figure J-1**; data reviewed in Ramcharitar et al. [2006]; see also Popper and Schilt [2008]).

Table J-1

Marine Fish Hearing Sensitivity

Family	Common Name of Taxa	Highest Frequency Detected (Hz)[a]	Hearing Category[b]	Reference	Notes
Asceripensidae	Sturgeon	800	2	Lovell, et al., 2005; Meyer et al., 2010	Several different species tested. Relatively poor sensitivity
Anguillidae	Eels	300	2	Jerkø et al., 1989	Poor sensitivity
Batrachoididae	Toadfishes	400	2	Fish and Offutt, 1972; Vasconcelos and Ladich, 2008	
Clupeidae	Shad, menhden	>120,000	4	Mann et al., 1997, 2001	Ultrasound detecting, but sensitivity relatively poor
	Anchovy, sardines, herrings	4,000	4	Mann et al., 2001	Not detect ultrasound, and relativley poor sensitivitiy
Chondrichthyes [Class]	Rays, sharks, skates	1,000	1	Casper et al., 2003	Low-frequency hearing, not very sensitive to sound
Gadidae	Atlantic cod, haddock, pollack, hake	500	2	Chapman and Hawkins, 1973; Sand and Karlsen, 1986	Probably detect infrasound (below 40 Hz). Best hearing 100-300 Hz
	Grenadiers		3?	Deng et al., 2011	Deep sea, highly specialized ear structures suggesting good hearing, but no measures of hearing
Gobidae	Gobies	400	1 or 2	Lu and Xu, 2009	
Labridae	Wrasses	1,300	2	Tavolga and Wodinksy, 1963	
Lutjanidae	Snappers	1,000	2	Tavolga and Wodinksy, 1963	
Malacanthidae	Tilefish		2	NA	No data
Moronidae	Striped bass	1,000	2	Ramcharitar unpublished	
Pomacentridae	Damselfish	1,500 – 2,000	2	Myrberg and Spires, 1980	
Pomadasyidae	Grunts	1,000	2	Tavolga and Wodinsky, 1963	
Polyprionidae	Wreckfish		2	NA	No data
Sciaenidae	Drums, weakfish, croakers	1,000	2	Ramcharitar et al., 2006	Hear poorly
	Silver perch	3,000	3	Ramcharitar et al., 2004, 2006	
Serranidae	Groupers		2	NA	No data
Scombridae	Yellowfin tuna	1,100	2	Iversen, 1967	With swim bladder
	Tuna	1,000	1	Iversen, 1969	Without swim bladder
	Bluefin tuna	1,000	2	Song et al., 2006	Based only on ear anatomy

[a] Lower frequency of hearing is not given since, in most studies, the lower end of the hearing bandwidth is more a function of the equipment used than determination of actual lowest hearing threshold. In all cases, fish hear below 100 Hz, and there are some species studied, such as Atlantic cod, Atlantic salmon, and plaice, where fish have been shown to detect infrasound, or sounds below 40 Hz.

[b] See text for explanation.

Notes: See text for important caveats about the data. For a number of additional species, hearing capabilities can only be surmised from morphological data. These data are shown shaded in gray

Sources: Data compiled from reviews in Fay (1988) and Nedwell et al. (2004). Updated names: www.fishbase.org.

Table J-1 and **Figure J-1** provide data on a number of fish groups of potential interest for this report. The data in **Table J-1** are presented in terms of fish taxa (family level) since data are often not available for specific species of interest. However, it is possible to extrapolate between broad groups of fishes in most cases. Where that is not the case, as in the sciaenids (reviewed in Ramcharitar et al., 2006), several different sets of data are shown. Moreover, this is also done when species within a group differ substantially in hearing structures. Thus, in the case of tuna, there are some species with a swim bladder (involved in pressure detection) and others that do not have a swim bladder (Iversen, 1967, 1969). Indeed, in the case of tuna, while the hearing range of the species with and without swim bladders is quite similar, it is likely that the sensitivity is poorer in the species without this structure.

It should also be noted that **Table J-1** only gives the likely highest frequency of hearing for a fish and leaves out the low frequency end of the hearing bandwidth. This is done because what is known about low frequency hearing is often a function of the equipment used in the study and not what the fish actually hears. Thus, if the sound source used to study hearing is only good to 100 Hz, then that might be the lowest frequency that investigators report. As a consequence, the low frequency range, with a few exceptions, must be viewed with caution, even as presented in **Figure J-1**. However, it is accurate to state that most, if not all, fishes can detect sounds to below 100 Hz and likely to below 50 Hz.

Another point to note is that **Table J-1** does not show hearing sensitivity, and the data in **Figure J-1** are not presented as thresholds but as relative levels of hearing within a single fish's hearing capabilities. Thus, **Table J-1** does not show the lowest sound levels that a fish can hear, nor does it indicate at what frequency best hearing occurs. The table is presented as it is because there is wide variation in data even for a single species (e.g., see Fay [1988] for a demonstration of different data on hearing for goldfish). The variation is likely a result of experimental design. It is often the case that the investigators did not use the right stimulus parameter (pressure or particle motion) to test a species. Thus, investigators have often presented hearing sensitivity data for fishes in terms of pressure sensitivity, even when the fish is likely not to detect sound pressure as it primarily detects particle motion (something that, until recently, has been very hard to measure).

With these caveats, it is possible to make some useful generalizations with regard to fish hearing that remove some of the "variability" in the data and help focus understanding of fish hearing capabilities. Such generalizations also make it possible to "predict" hearing range and sensitivity of some species for which there are data on the structure of the ear and auditory system but no hearing data. Indeed, such is the case for bluefin tuna, where, despite lack of hearing data, it is possible to predict that the hearing range for this species is similar to that of other tuna based on similarities in ear structure (Song et al., 2006). Similarly, morphological data on the ears of deep-sea grenadiers leads to the suggestion that these species have inner ear specializations that are often associated with fishes that hear to 2,500-4,000 Hz and have good hearing sensitivity (Deng et al., 2011); a similar observation has been made for myctophids (Popper, 1980).

Based on this kind of analysis, it is possible to "categorize" fish groups as to their hearing capabilities. This is presented in **Table J-1** where a column provides the categories of each species represented, which are defined as follows:

- *Group 1*: Fishes that do not have a swim bladder (e.g., Plaice in **Figure J-1**). These fishes are likely to use only particle motion for sound detection. The highest frequency of hearing is likely to be no greater than 400 Hz, with poor sensitivity compared to fishes with a swim bladder. Fishes within this group would include flatfish, some gobies, some tunas, and all sharks and rays (and relatives).
- *Group 2*: Fishes that detect sounds from below 50 Hz to perhaps 800-1,000 Hz (though several probably only detect sounds to 600-800 Hz). These fishes have a swim bladder but no known structures in the auditory system that would enhance hearing, and sensitivity (lowest sound detectable at any frequency) is not very great. Sounds would have to be more intense to be detected when compared to fishes in Group 3. These species detect both particle motion and pressure, and the differences between species are related to how well the species can use the pressure signal. A wide range of species fall into this category, including tuna with swim bladders, sturgeons, salmonids, etc.

- *Group 3*: Fishes that have some kind of structure that mechanically couples the inner ear to the swim bladder (or other gas bubble), thereby resulting in detection of a wider bandwidth of sounds and lower intensities than fishes in other groups (e.g., silver perch in **Figure J-1**). These fishes detect sounds to 3,000 Hz or more, and their hearing sensitivity, which is pressure driven, is better than in fishes of Groups 1 and 2. There are not many marine species known to fit within Group 3, but this group may include some species of sciaenids (Ramcharitar et al., 2006). It is also possible that a number of deep-sea species fall within this category, but that is only predicted based on morphology of the auditory system (e.g., Popper, 1980; Deng et al., 2011). Other members of this group would include all of the Otophysan fishes, though few of these species other than catfishes are found in marine waters.
- *Group 4*: All of these fishes are members of the herring family and relatives (Clupeiformes). Their hearing below 1,000 Hz is generally similar to fishes in Group 1, but their hearing range extends to at least 4,000 Hz (e.g., sardine in **Figure J-1**), and some species (e.g., American shad) are able to detect sounds to over 180 kHz (Mann et al., 2001).

2.3. OTHER ASPECTS OF FISH HEARING

Besides being able to detect sounds, a critical role for hearing is to be able to discriminate between different sounds (e.g., frequency and intensity), detect biologically relevant sounds in the presence of background noises (called maskers, see below), and determine the direction and location of a sound source in the space around the animal. While actual data are available on these tasks for only a few fish species, all species are likely to have similar capabilities (reviewed in Fay and Megela-Simmons, 1999; Popper et al., 2003; Fay, 2005).

Only a few points about the hearing structure in fishes is critical for this report, and readers interested in more detail can find reviews by Popper et al. (2003) and Popper and Schilt (2008). The fundamental structure for hearing by fishes is the inner ear. This is, in many ways, very similar in structure and function to the ear found in all other vertebrates. The inner ear has three otolith organs – the saccule, lagena, and utricle – each containing a dense structure called an otolith. The otolith lies in close proximity to a sensory surface called the sensory epithelium. Each epithelium contains sensory hair cells that are very similar to those found in the mammalian ear. On their top surfaces, sensory hair cells have hair-like projections, called cilia, that are bent when the epithelium and otolith move out of phase from one another – something that takes place when sound stimulates the ear. The sensory cells respond physiologically to the bending of the cilia and send signals on to the brain via the eighth cranial nerve – the same nerve involved in hearing in humans.

Germane to issues of effects of loud sounds on fishes is that the sensory hair cells in fishes, as in mammals (including humans), can be damaged or actually killed by exposure to very loud sounds (Le Prell et al., 2011). However, whereas in humans once sensory cells die they are not replaced, resulting in deafness, fishes are able to repair and replace cells that die (e.g., Lombarte et al., 1993; Smith et al., 2006). Moreover, whereas in humans the ear has its full complement of sensory hair cells at birth, fishes continue to produce (proliferate) sensory hair cells for much of their lives, which results in fishes having more and more sensory hair cells as they age (Popper and Hoxter, 1984; Lombarte and Popper, 1994). Indeed, large Mediterranean hake (*Merluccius merluccius*) have been shown to have a million or more sensory hair cells in a single saccule (Lombarte and Popper, 1994), as compared to humans which have, at birth, no more than 20,000 sensory cells in the auditory part of the ear.

Because fishes have the ability to repair damaged sensory hair cells and continuously add to their number, fishes are not likely to ever become deaf permanently. As discussed below, there is some chance of temporary hearing loss, but this is quickly repaired (Smith et al., 2006), and there is no evidence in fishes for permanent hearing loss.

3. EFFECTS OF HUMAN-GENERATED SOUND ON FISHES – OVERVIEW

There is a wide range of potential outcomes of exposing fishes to sound, from no effect to immediate death. Data on effects of sounds are limited, and broad extrapolations about effects on different species (or on the same species at different ages or sizes) is not yet possible (see discussion in Popper and Hastings [2009b] and Popper and Hawkins [2011]). Moreover, while there are some (albeit limited) data on effects on physiology, far less is known about effects on behavior.

The actual effects will vary based on a large number of factors. In particular, other than for physiological damage, which does not depend on hearing per se, the likelihood of TTS, masking, and/or behavioral change will depend on whether the fish hears the sound. **Figure J-2** illustrates the idea that there is a likelihood of any number of different potential effects close to the source and that the range of potential effects declines with increased distance from the source.

The actual effects are also likely to depend on the nature of the sound source itself. One may divide sounds into two very overlapping "classes": intermittent (or acute) and long-term (or chronic) (Popper and Løkkeborg, 2008). Intermittent sounds usually are of short duration and high intensity, and they are only present in a particular area for a short period of time. These include sounds produced by seismic airguns, sonars, and similar sources. Pile driving would also fit into this category, although it may last for hours, days, or even weeks. But, ultimately, pile driving ends. Loud intermittent sounds have the potential to cause death and physiological effects if the animal is close to the source. They could also produce hearing loss, masking, and behavioral effects to distances beyond those that would result in death or damage (**Figure J-2**).

Long-term (chronic) sources are generally lower in intensity than acute signals, may extend over a broad area, and, in general, raise the ambient noise level from a few to many decibels. In essence, chronic noise sources raise the overall background ambient level of the environment similar to what might be encountered when new machinery is added to a factory. In the case of the aquatic environment, perhaps the most dominant changes in the chronic noise environment come from boats which, is more likely to occur in a harbor, major shipping lanes, and similar areas. Long-term rises in sound level are not likely to result in death or physiological effects (though it is possible that there may be long-term changes in stress levels and immune response), but they could also produce hearing loss, masking, and/or behavioral effects (**Figure J-2**).

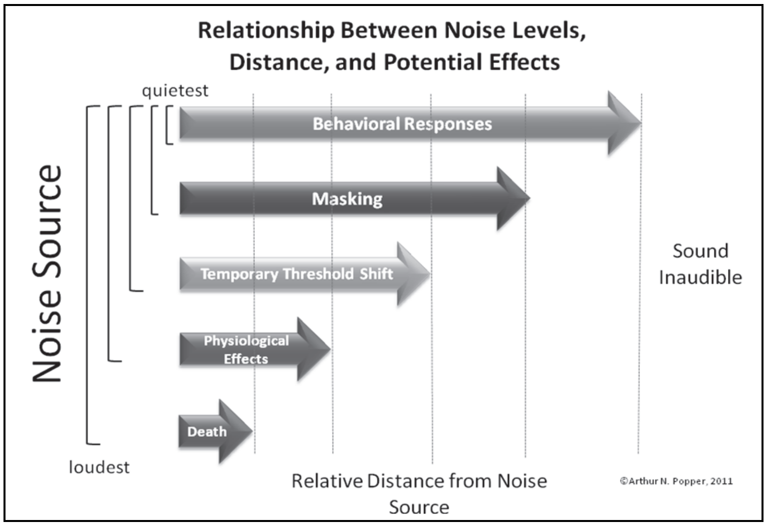

Figure J-2. Relationship between Noise Levels, Distance, and Potential Effects. (Note that close to the source, there is a range of potential effects, but as the distance from the source increases and sound levels get lower, the likelihood of some potential effects decreases. The actual effects will vary depending on the source. If the source is very intensive, then mortality may occur. But, if the source is less intensive, mortality and physiological effects may mot be an issue. At the lowest source levels, such as with increases in ambient sounds, behavioral responses and/or masking may be the only issues of concern.)

4. EFFECTS OF ANTHROPOGENIC SOUNDS ON HEARING

While there are few data on behavioral effects of sounds on fishes in the wild (**Section 6.0**), there are substantial data on effects of such sounds on the ability of fishes to hear. If hearing is impaired, even temporarily, a fish may not be able to find food or detect predators as successfully. Such impairment may be by auditory masking or temporary loss of hearing.

4.1. AUDITORY MASKING

Masking is a key issue for potential effects of human-generated sound on all vertebrates, including fishes (reviewed in Fay and Megela-Simmons, 1999; Popper et al., 2003). Masking occurs when there are sounds in the environment that are in the same frequency range as the sound of biological relevance to the animal and/or within the hearing range of the fishes. Thus, if a fish has a particular threshold for a biologically relevant sound in a quiet environment and a background noise in the same frequency range is introduced, this will decrease the ability of the fish to detect the biologically relevant signal. In effect, the threshold for the biologically relevant signal will become poorer. Thus, if background noise increases, it may be harder for a fish to detect the biologically relevant sounds that it needs to survive. Specifically, if the ambient noise (or masker) is raised by 10 dB, the threshold of the fish will increase by about 10 dB in the frequency range of the masker.

The actual concern with regard to masking is that fishes will not be able to hear sounds of biological relevance as well as they would without the masking sound. Thus, if a fish uses sounds to detect predators, the presence of the increased ambient sound would keep the fish from hearing the predator until it was much closer. Similarly, if male fishes use sounds to attract females, as occurs in toadfish (reviewed in Zelick et al., 1999), sciaenids (reviewed in Ramcharitar et al., 2006), and many other species, the female would have to be much closer to the males before they could hear the sound. In other words, the effectiveness of a male's call would decline in the presence of masking sounds since the females would be less likely to detect the sounds unless they are closer to the source (where the source is louder in the presence of the masker). Indeed, this effect is well known and has been described for a wide range of other vertebrates, including birds and amphibians (reviewed in Slabbekoorn et al., 2010).

More recently, it has been suggested that at least some larval fishes find the reefs upon which they will settle using sounds from the reef (e.g., Leis et al., 2003; Wright et al., 2005). These studies have suggested that if there is an increase in ambient (masking) noise, the larval fish would be less likely to hear the sounds of the reef and, thus, less likely find a place to settle. The reef sounds could be produced by a variety of sources, including snapping shrimp, water moving over reefs, other fishes, etc. and would be subject to masking by anthropogenic sounds within the hearing range of fishes. Clearly, if this observation is correct, then the presence of masking sounds could have a significant impact on long-term survival of populations of reef fishes.

4.2. TEMPORARY THRESHOLD SHIFT

A second concern is that exposure to sounds can result in a temporary loss of hearing sensitivity, or TTS. Temporary threshold shift recovers after some period of time following the termination of the noise and results from temporary, but recoverable, damage to the sensory cells of the inner ear that are involved with for hearing (Smith et al., 2006). Permanent hearing loss (i.e., PTS), resulting from exposure to very loud sounds, occurs in humans and other mammals. Permanent threshold shift is not, however, known to occur in fishes, since unlike mammals, they can repair and regenerate the sensory cells of the ear that are damaged (e.g., Lombarte et al., 1993; Smith et al., 2006)[8].

Data on TTS in fishes are reviewed in Popper and Hastings (2009b) and are only briefly summarized here. The data suggest that TTS occurs after long-term exposure to sounds that are as high as 170-180 dB re 1 μPa (rms), but only in species that have specializations that result in their having relatively wide hearing bandwidths (to over 2 kHz) and lower hearing thresholds than fishes without specializations. For example, TTS of 10-20 dB has been demonstrated in goldfish (*Carassius auratus*) and lined Raphael catfish (*Platydoras costatus*) (e.g., Scholik and Yan, 2002; Smith et al., 2004a, 2006;

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[8] Interesting, the sensory cells in the mammalian and fish ear responsible for hearing are the same. The difference between fishes and mammals is that fishes retain a regenerative mechanism in the ear for when cells are lost, whereas no such capacity is found in mammals.

Wysocki and Ladich, 2005), but little or no TTS has been found in fishes such as cichlids, sunfishes, and perch (e.g., Scholik and Yan, 2001; Amoser and Ladich, 2003; Smith et al., 2004a,b; Wysocki and Ladich, 2005). Moreover, studies of the effects of exposure to 150 dB re 1 µPa (rms, received level) for 9 months showed no effect on hearing or on survival and growth of young rainbow trout (*Oncorhynchus mykiss*) (Wysocki et al., 2007). Significantly, in those species where TTS was found, hearing returned to normal starting well within 24 hrs after the end of exposure (e.g., Smith et al., 2004b, 2006).

While TTS is not as likely to be particularly irrelevant with regard to repetitive sound sources, concerns have still arisen that fishes may temporarily have impaired hearing as a result of exposure to loud sounds (e.g., Popper et al., 2005, 2007; reviewed in Popper and Hastings, 2009b). Several studies show varying results, but overall, if TTS occurs as a result of exposure to loud sounds, it is not necessarily very great and recovery seems to be within 24 hrs in most cases (Popper et al., 2005, 2007; Hastings et al., 2008; Hastings and Miskis-Olds, 2011).

The potential effects of TTS are similar to those of masking (**Section 4.1**). If the hearing ability of an affected fish decreases, then the likelihood of detecting predators, prey, or mates (or a reef) decline, thus decreasing the potential fitness of the receiver until normal hearing returns.

4.3. EFFECTS OF HIGH INTENSITY SOURCES ON HEARING

Several studies have examined the effects of very high intensity sources on hearing and demonstrate little or no effect on a diverse group of species. Popper et al. (2005) and Song et al. (2008) examined the effects of exposure to a seismic airgun array on three species of fishes found in the Mackenzie River Delta near Inuvik, Northwest Territories, Canada. One species, the lake chub (*Couesius plumbeus*), has hearing specializations, whereas the northern pike (*Esox lucius*) and the broad whitefish (*Coregonus nasus*) (a salmonid) do not. Fishes were exposed to 5 or 20 shots from a 730-in^3 (12,000 cc) calibrated airgun array. And unlike earlier studies, the received exposure levels were not only determined for rms sound pressure level, but also for peak sound levels and SELs (e.g., average mean peak SPL 207 dB re 1 µPa RL; mean rms sound level 197 dB e 1 µPa RL; mean SEL 177 dB re 1 µPa^{2}s).

For both the 5 and 20 airgun shots, the results showed a temporary hearing loss for both lake chub and northern pike but not for broad whitefish. Hearing loss was on the order of 20-25 dB at some frequencies for both the northern pike and lake chub; full hearing recovery occurred within 18 hrs after sound exposure.

Popper et al. (2007) studied the effect of the Surveillance Towed Array Sensor System (SURTASS) low-frequency active (LFA) sonar on hearing, the structure of the ear, and select non-auditory systems in the rainbow trout and channel catfish (*Ictalurus punctatus*) (also Halvorsen et al., 2006). Fishes were exposed to LFA sonar for 324 or 648 seconds, an exposure duration that is far greater than any fishes in the wild would get since, in the wild, the sound source is on a vessel moving past the far slower swimming fishes. The maximum received level was approximately 193 dB re 1 µPa at 196 Hz. Analysis of hearing showed that channel catfish and some specimens of rainbow trout showed 10-20 dB of hearing loss immediately after exposure to the LFA sonar when compared to baseline and control animals; however, another group of rainbow trout showed no hearing loss. Recovery in trout took at least 48 hrs, and channel catfish recovered with 24 hrs. Similar studies on several other species, including hybrid sunfish and black perch, showed no TTS to the same signals (Halvorsen et al., 2006).

Finally, Hastings et al. (2008) studied TTS in Indian Ocean reef fishes during a seismic survey with a full airgun array. They found no hearing loss following sound exposures up to 190 dB re 1 µPa^2-s cumulative SEL in a species that hears well, in the pinecone soldierfish (*Myripristis murdjan*), and in three species that do not have hearing specializations: the blue green damselfish (*Chromis viridis*), sabre squirrelfish (*Sargocentron spiniferum*), and bluestripe seaperch (*Lutjanus kasmira*).

In summary, it is clear that if hearing loss occurs after exposure to intense sounds (and it does not always occur), it primarily shows up in fishes with hearing specializations and is not permanent (i.e., there is full recovery). More importantly, TTS is less likely to show up in fishes without hearing specializations. The only time that TTS has been documented as a response to high intensity sources has been when the exposure duration has substantially exceeded the amount of time that an animal would normally be exposed to such sounds in the wild (Popper et al., 2007).

5. EFFECTS OF HIGH INTENSITY SOURCES

Intensive sources are generally short (measured in parts of a second to several seconds) and are highly intensive at the source (attenuation follows normal attenuation characteristics of sound in water). Also, exposure time to the sound for an animal may be rather short. For example, a fish exposed to high intensity sonar may only hear a few sonar sounds since the source, on a boat, is moving. In the case of seismic devices, the source is constantly moving, although the sounds may increase the overall ambient noise for the duration of a 3D seismic study. Sounds from pile driving may last for as long as the pile driving operation, but there frequently are periods of pile driving followed by longer periods of silence as new piles are added, hammers moved or repaired, etc.

The concerns associated with intensive sources range from immediate mortality to delayed mortality to behavioral effects (**Figure J-2**). Behavioral effects are varied and less likely to involve masking or TTS, as found in long-term exposures, because of the short periods of the intense sounds. However, there are concerns, as discussed below, that an extended seismic survey could result in fishes leaving their feeding or spawning areas for extended periods of time, or even permanently, which could impact survival of populations as well as catchability for fishers (e.g., Engås et al., 1996; Slotte et al., 2004; Løkkeborg et al., 2011).

At the same time, while much concern about intensive sources rests on immediate mortality, the limited data suggest that the circumstances under which immediate mortality occurs are very limited. Indeed, there are no data to suggest mortality associated with high intensity sources other than pile driving[9].

The only data on mortality associated with sound (as compared to explosives) come from driving very large piles. For example, the California Department of Transportation (Caltrans, 2001) showed some mortality for several different species of wild fishes exposed to driving of steel pipe piles 2.4 m (8 ft) in diameter. However, no mortality seems to occur at distances of more than approximately 10 m (32.8 ft) from the source.

5.1. NON-AUDITORY PHYSIOLOGICAL EFFECTS OF EXPOSURE TO INTENSE SOUNDS

Non-auditory physiological effects from exposure to intense sounds generally result from rapid and substantial expansion and contraction of the air bubble walls within fishes (such as the swim bladder or air bubbles in the blood) that strike against nearby tissues or from air bubbles within the blood bursting or expanding and damaging tissues (Stephenson et al., 2010). The actual nature of non-auditory physiological effects may range from a very small amount of external bleeding to small internal bleeding to substantial hemorrhage of tissues (such as kidney or liver) to rupture of the swim bladder (see Stephenson et al. [2010] and Halvorsen et al. [2011a,b] for a discussion of the range of potential effects).

There are several potential (and overlapping) consequences of non-auditory physiological effects. One possibility is that the effects heal, and there is no lasting consequence. Alternatively, even if the physiological effect has no direct consequences per se, it is possible that it leads to temporary decreased fitness of the animal until the damage is healed. This could result in the animal being subject to predation, less able to find food, or other consequences that result in death.

Secondly, the effect could result in delayed mortality from events such as continuous bleeding or disruption of tissues (e.g., spleen or liver). Or, the tissue damage itself may not be life threatening, but it may become infected and potentially result in death.

There are few quantified and reliable data on effects of exposure to high intensity sound on body tissues. There are a number of studies showing no tissue damage as a result of exposure of several different species to sonar (Kane et al., 2010), seismic devices (Song et al., 2008), and pile driving (Caltrans, 2010a,b). However, in each of these studies, the swim bladder in the fishes may not have been filled with air, and this could have resulted in less likelihood of damage as compared to situations where the swim bladder is filled to its normal density of air (Halvorsen et al., 2011a,b).

The only quantifiable study documenting a range of physiological effects on fishes comes from exposure of Chinook salmon to 960 or 1,920 strikes of simulated pile driving sounds (Halvorsen et al.,

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[9] Note, there is mortality associated with explosive devices, but this is outside the purview of this appendix. A discussion of the effects of explosives can be found in Hastings and Popper (2005) and Popper and Hastings (2009b).

2011a,b; Casper et al., 2011a). This study demonstrates that effects are graded, with what is likely to be minimal peripheral bleeding at the lowest (but still very intense) sound exposures (210 dB re 1 $\mu Pa^2 \cdot s$ SEL_{cum}) to significant bleeding and tissue rupture at the very highest levels presented in the study (219 dB re 1 $\mu Pa^2 \cdot s$ SEL_{cum}). Importantly, fish held for a period of time post-exposure showed complete recovery from most of the effects, although the investigators are very careful to point out that recovery took place in a lab tank where fish with slightly lowered fitness would not be subject to predation or disease as may happen in the wild (Casper et al., 2011a).

Indeed, the overall impact on fishes in an ecosystem is low, as only a very small fraction of the fish population will likely be close enough to an intense source to be subject to immediate mortality. The open issues may be (a) injury that can lead to delayed mortality and (b) behavioral effects that lower fitness (e.g., move from migratory routes, leave food sites, and masking of biologically important sounds).

5.2. AUDITORY EFFECTS OF EXPOSURE TO INTENSE SOUNDS

Several studies have examined effects of high intensity sounds on the ear. While there was no effect on ear tissue in either the SURTASS LFA study (Popper et al., 2007) or in the study of effects of seismic airguns on hearing (Popper et al., 2005; Song et al., 2008), three earlier studies suggested that there may be some loss of sensory hair cells resulting from exposure to high intensity sources. However, none of these studies concurrently investigated effects on hearing. Enger (1981) showed some loss of sensory cells after exposure to pure tones in the Atlantic cod (*Gadus morhua*). A similar result was shown for the lagena of the oscar (*Astronotus oscellatus*), a cichlid fish, after an hour of continuous exposure (Hastings et al., 1996). In neither study was the hair cell loss more than a relatively small percentage of the total sensory hair cells in the hearing organs. And, in neither case was the sound anything like the high intensity sources of concern today.

Most recently, McCauley et al. (2003) showed loss of a small percentage of sensory hair cells in the saccule (the only end organ studied) of the pink snapper (*Pagrus auratus*), and this loss continued to increase (but never to become a major proportion of sensory cells) for up to at least 53 days post-exposure. This hair cell loss or the ones in the Atlantic cod or oscar would not necessarily have resulted in hearing loss since fishes have tens or even hundreds of thousands of sensory hair cells in each otolithic organ (Popper and Hoxter, 1984; Lombarte and Popper, 1994), and only a small portion were affected by the sound. The question remains as to why McCauley et al. (2003) found damage to sensory hair cells while Popper et al. (2005) did not. The difference in results may very well be associated with differences in species, precise sound source, spectrum of the sound, and sound propagation effects. For example, the Popper et al. (2005) study was in relatively shallow water with poor low-frequency propagation, therefore, the spectrum of sound is likely to have been very different than in the McCauley et al. (2003) study (Hastings, 2009).

One question that arises in the McCauley study is the continued damage to sensory cells after 53 days and whether this would indicate that there was permanent hair cell damage and hearing loss. Since the tissue sampled at each time interval in this study were from different fish, it is impossible to know if the dead cells on Day 53 had been replaced by newly formed cells and what was seen as damage was scar tissue or if the cells that died post-exposure were not replaced. However, based on the considerable data demonstrating hair cell replacement and addition in many fish species, it is likely that even if the cells that were damaged did not get replaced, the high rate of sensory cell proliferation in fishes would have compensated for the small number of lost hair cells (e.g., Corwin, 1981; Popper and Hoxter, 1984; Lombarte and Popper, 1994, 2004).

6. EFFECTS OF ANTHROPOGENIC SOUNDS ON BEHAVIOR

Perhaps the biggest issue with regard to effects of anthropogenic sound is the potential effects on fish behavior. Some potential effects can be suggested based on studies of masking and TTS (**Section 4.0**). However, whether TTS or masking actually impacts behavior or whether other behaviors are affected by anthropogenic sound (e.g., leaving a feeding area, changes in migratory paths) is very difficult to study and can only be studied using wild animals in the open water. While investigators have, from time to time, suggested that behavior can be predicted based on responses to sound in tanks, small cages, or larger enclosures, there is always the question as to whether these behaviors are the same as would be encountered in fishes in the wild whose responses were restricted by only their being able to move limited distances. As will be discussed below, there are a few studies that give some suggestion as to the potential responses of wild fishes to sound sources.

However, before discussing those results, it is critical to appreciate the complexities associated with understanding responses of fishes to increased ambient noise and/or the presence of intense sound sources. In fact, fishes may (or may not) show behavioral responses to a sound, and, if a response occurs, the nature of the response may vary widely. It is equally important to note that the nature of a response (or whether there is a response at all) varies depending on the type of signal heard as well as on the motivation of the fishes to respond, the experience of the fishes in the presence of a particular sound or to sounds in general, the age of a fish, and many other factors. Thus, predicting behavior is not simply correlating sound level or type with a behavior and assuming this behavior will show up every time that sound occurs. Instead, a fish may respond to a sound at one time but not at another and the response may be predicated on what the fish is otherwise doing when the sound is presented. Therefore, a fish that is mating may be less likely to respond to an anthropogenic sound than a fish that is simply swimming around, and a fish that has heard the same sound multiple times and does not associate danger with it may not respond, whereas a fish that hears the sound for the first time may respond.

The difficulty of predicting behavior is documented not only in the data on fishes but also from data on hearing for amphibians, birds, and mammals (including humans). These data show, in general, that as sound levels in the environment increase, animals tend to respond in different ways, which often vary depending on the nature of the sound source and sound level as well as on the behavioral state of the animal (e.g., what it is doing) when the sound level changes. Responses of animals vary widely (reviewed in Brumm and Slabbekoorn [2005]). These may include movement from the area of maximum sound level, as shown for several fish species (Engås et al., 1996; Slotte et al., 2004), to changing the intensity of calls so they can be heard over the background sounds (Bee and Swanson, 2007) or changing the spectrum of the emitted sounds so they are no longer masked, as has been shown in a variety of species (Brumm and Slabbekoorn, 2005; Dooling et al., 2009; Parris et al., 2009; Laiolo, 2010; Slabbekoorn et al., 2010).

It is also critical to note that animals (and humans) generally do not respond to sounds when the sounds are just detectable (whether there is background sound or not). Sounds generally have to be well above the minimal detectable level in order to elicit behavioral responses[10]. At the lowest sound levels, the animal may simply ignore the sound since it is deemed “not important” or from too distant of a source. It is only at higher levels where the animal becomes “aware” of the sound and may make a decision that it is important or not to behaviorally respond. To put it into terms of masking, it is possible that the sound has to be sufficiently above the masked threshold of detection for the animal to be able to resolve the signal within the noise and recognize the signal as being of biological relevance.

By way of example, in an experiment on responses of American shad to sounds produced by their predators (dolphins), it was found that if the predator sound is detectable but not very loud the shad will not respond (Plachta and Popper, 2003). But, if the sound level is raised by about 8 or 10 dB, the American shad will turn and move away from the sound source. Finally, if the sound is made even louder, as if a predator were nearby, the American shad go into a frenzied set of motions that probably helps them avoid being caught. It was speculated by the researchers that the lowest sound levels were recognized by the American shad as being from very distant predators and, thus, not worth a response. At somewhat higher levels, the American shad recognized that the predator was closer and started to swim away. Finally, the loudest sound was thought to resemble a very nearby predator, eliciting maximum response to avoid predation.

At the same time, there is evidence from a recent study in Norway (Doksaeter et al., 2009) that fishes will only respond to sounds that are of biological relevance to them. Doksaeter et al. (2009) showed no responses at all from free-swimming herring (*Clupea*) when exposed to sonars produced by naval vessels. Similarly, sounds at the same received level that had been produced by major predators of the herring (killer whales) elicited strong flight responses.

Significantly, the sound levels received by the fishes from the sonar in this experiment were from 197-209 dB (rms) re 1 μPa at 1-2 kHz. In this frequency range, the hearing threshold for herring that are most closely related to those used in the Doksaeter et al. (2009) study is about 125-135 dB re 1 μPa

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[10] Of course, there are exceptions. A parent will respond to the lowest sound produced by their newborn child, and a person walking down a very dark street at night will probably respond to sounds of scraping feet even if they are very quiet.

(Mann et al., 2005). This means that the fish showed no reactions to a sound that is biologically irrelevant even though the sound was up to 84 dB above the fish's hearing threshold (209 dB sonar versus 120 dB threshold).

It is likely that responses from fishes to any noise source, including pile driving, will show gradations in responses similar to the American shad. Therefore, fish responses can be seen as being in several sequential steps (see also **Figure J-2**):

- Fishes do not hear the sound (it is too low and/or masked).
- The sound is at a higher level detectable to the fish, but it is sufficiently low that the sound is "dismissed" as not being biologically relevant or important.
- The sound is somewhat higher above threshold, but the fish cannot discriminate it from the ambient sounds and so still does not respond (e.g., informational masking).
- The sound is clearly audible to the fish and recognizable, but the fish does not respond or makes only an initial, small response (e.g., startle) and then returns to whatever it was doing. In addition, after multiple presentations of the sound, the fish may decide that the sound is not biologically important, and the animal habituates and no longer shows a startle response.
- Sound is even louder, and the fish recognizes it as something that may be biologically relevant and may change behavior (e.g., swim away or change swimming course). But, when the sound ends or after the fish habituates to the sound, the animal returns to what it was doing.
- The fish may totally avoid the very loudest signals if they perceive it as being potentially "harmful" and permanently change location or migratory pattern.

6.1. FISH CATCH AND ANTHROPOGENIC SOUND

Several studies have demonstrated that human-generated sounds may affect the behavior of at least a few species of fishes. Engås et al. (1996) examined movement of fishes during and after a seismic airgun study by determining catch rate of haddock (*Melanogrammus aeglefinus*) and Atlantic cod as an indicator of fish behavior. These investigators found a significant decline in catch rate of both species that lasted for several days after termination of airgun use. Catch rate subsequently returned to normal. The conclusion was that the decline in catch rate resulted from the fish moving away from the fishing site as a result of the airgun sounds. However, the investigators did not actually observe behavior, and it is possible that the fish just changed depth. Another alternative explanation is that the airguns actually killed the fish in the area, and the return to normal catch rate occurred because of other fishes entering the fishing areas.

More recent work from the same group (Slotte et al., 2004) showed parallel results for several additional pelagic species, including blue whiting and Norwegian spring spawning herring[11]. However, unlike earlier studies from this group, the authors used fishing sonar to observe behavior of the local fish schools. They reported that fishes in the area of the airguns appeared to go to greater depths after the airgun exposure. Moreover, the abundance of animals approximately 30-50 km (18.6-31.1 mi) away from the ensonification increased, suggesting that migrating fish would not enter the zone of seismic activity.

Similarly, Skalski et al. (1992) showed a 52 percent decrease in rockfish (*Sebastes* sp.) catch when the area of catch was exposed to a single airgun emission at 186-191 dB re 1 μPa (mean peak level) (see also Pearson et al. [1987, 1992]). They also demonstrated that fishes would show a startle response to sounds as low as 160 dB, but this level of sound did not appear to elicit a decline in catch.

Culik et al. (2001) conducted a very limited number of experiments to determine catch rate of herring (*Clupea harengus*) in the presence of pingers producing sounds that overlapped with the frequency range of herring hearing (2.7-160 kHz). They found no change in catch rate in gill nets with or without the higher frequency sounds (>20 kHz) present, although there was an increase in catch rate with the signals from 2.7 to 19 kHz (a different source than that of the higher frequency). The results could mean that the fish did not "pay attention" to the higher frequency sound or that they did not hear it, or that lower

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[11] Scientific names for neither species was given in publication.

frequency sounds may be attractive to fish. There were no behavioral observations to document how the fish actually responded when they detected the sound.

Most recently, Løkkeborg et al. (2011) repeated the earlier study using a somewhat different approach, and the results were different from those found initially. There was some suggestion that the fish in this study did not respond to the seismic sounds in these studies, but comparisons are hard to make because of substantial experimental differences. However, what these results do suggest is that understanding and predicting effects of sound on fishes will not be simple, and that there are many factors that come into play in trying to understand fish behavior.

6.2. OTHER BEHAVIORAL STUDIES

There have been a variety of other behavioral studies, none of which provide conclusive evidence that fishes will or will not respond to a particular sound source. For example, Wardle et al. (2001) used a video system to examine the behaviors of fishes and invertebrates on a coral reef in response to emissions from seismic airguns that were carefully calibrated and measured to have a peak level of 210 dB re 1 µPa at 16 m (164 ft) from the source and 195 dB re 1 µPa at 109 m (357.6 ft) from the source. They found no substantial or permanent changes in the behavior of the fishes or invertebrates on the reef throughout the course of the study, and no animals appeared to leave the reef. There was no indication of any observed damage to the animals.

Mueller-Blenkle et al. (2010) examined responses of several penned Atlantic Ocean species to sounds recorded from pile driving, but results were equivocal and could not be used to predict responses of fishes to pile driving. Indeed, responses levels were low, and fishes showed some acclimation to the sounds, suggesting (though not proving) that fishes might learn to ignore high levels of anthropogenic sound over time.

A study by Jorgenson and Gyselman (2009) may provide some insight into how fishes would behave in response to intense anthropogenic sounds[12]. The authors exposed fishes in the Mackenzie River (Northwest Territories, Canada) to seismic airguns and using sonar observed the movements of the fishes. The goal was to determine if a seismic survey, using high intensity sounds for long periods of time, could impact behavior by changing migratory patterns of fishes.

The investigators could not determine the species observed by sonar, but based on known river inhabitants, they suggest that there were a variety of species present, including those used by Popper et al. (2005)[13]. While results may be limited to one or two species, the investigators found that free-swimming fishes observed with sonar showed no response to the airguns with respect to changes in swimming direction or speed, even when sound exposure levels (single discharge) were on the order of 175 dB re 1 $\mu Pa^2 \cdot s$ and peak levels of over 200 dB re 1 µPa.

Finally, Sarà et al. (2007) used divers to observe the behavioral responses of bluefin tuna (*Thunnus thynnus*) in large in-ocean cages (approximately 70 m [229.6 ft] square opening and 30 m [98.4 ft] deep) to noise from passing boats. The results showed that the tuna schools would change depth and some swimming patterns in the presence of sounds from approaching ferries and hydrofoils (normal transport in the region of the cages) and exhibit various other types of behavior in response to sounds from small boats. While these results are potentially of interest in suggesting that at least bluefin tuna may be disturbed by vessel noise, the authors did not provide sound levels received at the fish. Moreover, the fish used are a large oceanic pelagic schooling species (weight of 40-54 kg [88-119 lbs] in this study) and the results may not necessarily apply to other species.

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[12] It should be noted that this study was done on fish in a river, and it is not clear how applicable results would be to fishes in a marine environment and, thus, in a much larger expanse of water in which they can move around.

[13] The Jorgenson and Gyselman study was conducted just after the Popper et al. (2005) investigation and so it is highly likely that the same species, plus additional species, were in the Mackenzie River at the time.

7. OTHER ISSUES WITH REGARD TO EFFECTS OF ANTHROPOGENIC SOUNDS

7.1. STRESS

Although an increase in background sound may cause stress in humans[14], there have been few studies on fishes (e.g., Smith et al., 2004b; Remage-Healey et al., 2006; Wysocki et al., 2006, 2007). There is some indication of physiological effects on fishes, such as a change in hormone levels and altered behavior, in some (Pickering, 1981; Smith et al., 2004a,b) but not all species tested to date (e.g., Wysocki et al., 2007). Sverdrup et al., 1994 found that Atlantic salmon subjected to up to 10 explosions to simulate seismic airguns released primary stress hormones, adrenaline and cortisol, as a biochemical response. There was no mortality. All experimental subjects returned to their normal physiological levels within 72 hrs of exposure. Since stress affects human health, it seems reasonable that stress from loud sound may impact fish health, but available information is too limited to adequately address the issue.

7.2. EGGS AND LARVAE

An additional area of concern is whether high intensity sounds may have an impact on eggs and larvae of fishes. Eggs and larvae do not move very much and so must be considered as a stationary object with regard to a moving sound source. Thus, the time for impact of sound is relatively small since there is no movement relative to the vessel.

There have been a few studies on effects of sound on eggs and larvae (reviewed extensively in Popper and Hastings, 2009b), and there are no definitive conclusions to be reached. At the same time, many of the studies have used non-acoustic mechanical signals such as dropping the eggs and larvae or subjecting them to explosions (e.g., Lagardère, 1982; Jensen and Alderdice, 1983, 1989; Dwyer et al., 1993). Other studies have placed the eggs and/or larvae in very small chambers (e.g., Banner and Hyatt, 1973) where the acoustics are not suitable for comparison with what might happen in a free sound field (and even in the small chambers, results are highly equivocal). A few studies of the effects of high energy sounds on eggs and larvae of invertebrates also provided no definitive evidence of damage, but, like for vertebrates, there are insufficient studies to reach firm conclusions as to the effects of sounds on invertebrates (Lagardère and Régnault, 1980).

Several studies did examine effects of sounds on fish eggs and larvae, and, in all cases, there were no observed effects on normal survival or hatching, including with the use of sounds that mimic those produced by seismic airguns (e.g., Kostyuchenko, 1972). In contrast, Booman et al. (1996) investigated the effects of seismic airguns on eggs, larvae, and fry of different larval stages of cod (*Gadus morhua*), saithe (*Pollachius virens*), herring (*Clupea harengus*), turbot (*Psetta maximus*), and plaice (*Pleuronectes platessa*) in field experiments. They exposed fishes to sound source with peak sound pressure levels, 220-242 dB re 1 μPa^2, and found significant mortality, but only when the specimens were within about 5 m (16.4 ft) of the source. The most substantial effects were to fishes that were within 1.4 m (4.6 ft) of the source. While the authors suggested damage to some cells, such as those of the lateral line, few data were reported, and the study is in need of replication. Moreover, it should be noted that the eggs and larvae were very close to the airgun array; at such close distances, the particle velocity of the signal would be exceedingly large. However, the received sound pressure and particle velocity were not measured in this study.

Jørgensen et al. (2005) examined effects of high intensity pure tones from 1.5 to 6.5 kHz on the survival and behavior of larval and juvenile fishes of several species placed in small plastic bags. The study used herring (*Clupea harengus*) (standard lengths 2-5 cm [0.8-1.9 in]), Atlantic cod (*Gadus morhua*) (standard length 2-6 cm [0.8-2.4 in]), saithe (*Pollachius virens*) (4 cm [1.6 in]), and spotted wolffish (*Anarhichas minor*) (4 cm [1.6 in]) at different developmental stages. Both tissue pathology and survival were studied in response to sounds from 150 to 189 dB, and the only effects found were 20-30 percent mortality in one group of herring larvae at the highest sound levels, but this was not replicated.

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[14] The data here are very complex, and there are many variables in understanding how sound may stress humans or any animal. The variables include sound level, duration, frequency spectrum, physiological state of the animal, and innumerable other factors. Thus, extrapolation from human stress effects to other organisms is highly problematic and should be done with only the most extreme caution.

In a follow-up unpublished analysis of these data, Kvadsheim and Sevaldsen (2005) sought to understand whether the mid-frequency continuous wave (CW) signals used by Jørgensen et al. (2005) would have a significant impact on larvae and juveniles exposed to this sonar in the wild. The investigators concluded that the extent of damage/death induced by the sonar would be below the level of loss of larval and juvenile fishes from natural causes, and so no concerns should be raised. The only issue they did suggest that needs to be considered is when the CW signal is at the resonance frequency of the swim bladders of small clupeids. If this is the case, the investigators predict (based on minimal data that are in need of replication) that such sounds might increase the mortality of small clupeids that have swim bladders that would resonate.

Most recently, a group in the Netherlands exposed larvae of common sole (*Solea solea*) to simulated pile driving sounds in an apparatus that is very similar to that used by Halvorsen et al. (2011a,b) for larger fish (de Jong et al., 2011; L.J. Bolle, pers. comm.[15]). The larvae of different stages were exposed to sound with SEL_{cum} of up to 206 dB re 1 $\mu Pa^2 \cdot s$ without any affect on fish mortality. In other words, there were no differences in mortality between fish exposed to the simulated pile driving sound and fish that served as controls. The authors did not, however, look at effects on fish tissue or larval growth, and it is possible that either or both of these would have shown an effect of sound exposure.

7.3. INVERTEBRATES

One question that is difficult to answer is the potential effect of high intensity sounds on invertebrates (e.g., crabs and cephalopods). There are almost no data on hearing by aquatic invertebrates, and the few suggestions of hearing indicates that it is for low frequencies and only to the particle motion component of the sound field (e.g., Mooney et al., 2010). There are few data indicating if and how invertebrates may use sound in behavior, although a number of species make sounds and so, presumably, use such sounds for communication (e.g., Budelmann, 1992; Popper et al., 2001). However, there are no data that indicate whether masking occurs in invertebrates or suggest whether sounds from construction would have any impact on invertebrate behavior. The one available study on effects of seismic exploration on shrimp suggests no behavioral effects at sound levels with a source level of about 196 dB re 1 μPa rms at 1 m (3.3 ft) (Andriguetto-Filho et al., 2005).

There are also no substantive data on whether the high sound levels of any anthropogenic sound would have physiological effects on invertebrates. The only potentially relevant data are from a study on the effects of seismic exploration on snow crabs on the east coast of Canada (Boudreau et al., 2009). The preponderance of evidence from this study showed no short-term or long-term effects of seismic exposure in adult or juvenile animals or on eggs.

Two other studies are important to mention, but only because the results are likely to be referenced. It is important to note that both have substantial problems that make them scientifically unsound. An unpublished study by Guerra et al. (2004) suggested that there was damage to body tissues in squid that had possibly been exposed to high intensity naval sonars. However, there is no evidence that the animals were exposed to sonar (only an inference). Moreover, there were no controls for the tissues, and all of the animals had died well before they were accessed by the investigators. During this time, it is highly likely that the tissue went through normal degenerative processes, therefore, it is impossible to know if the damage suggested was from anything other than normal tissue decay. It is also important to note that this work, while in the news, was never published in the scientific literature and that the histological analysis of the tissue has not been made available for examination by other experts.

The second study by André et al. (2011) exposed four cephalopod species (*Loligo vulgaris*, *Sepia officinalis*, *Octopus vulgaris,* and *Illex coindetii*) in a tank to sounds and then, after sacrifice of the animals, examined the statocysts (which are the ears of cephalopods). The authors show that there is some tissue degeneration, and they suggested that the sounds to which the animals were exposed caused the damage. However, there are very substantial problems with this study that open the results, and conclusions, to serious question.

First, the only controls provided were never subject to the same handling as the experimental animals. The only controls should be animals and tissues exposed to precisely the same conditions and procedures

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[15] Personal communication on May 22, 2011 to Dr. Arthur N. Popper. The full report from this study should be released in July 2011 and submitted for publication soon thereafter. Dr. Popper reviewed the report at the request of the Dutch regulatory authority and found it to be an excellent study.

as the experimental other than for the variable in question, in this case the sound. However, this was not done in this study, and so it is very reasonable to suggest that the overall treatment of the experimental animals, including handling, being placed and maintained in the test tank, etc. could have been the cause of any effects noted.

Second, cephalopods, even as indicated by the authors, are detectors of particle motion (just like fishes that do not have specializations to couple an air bubble to the ear). The signals to which the cephalopods were exposed were measured in pressure (something that the animals do not detect), and there was no calibration of the particle motion. Since the exposure was done in a tank with relatively flexible walls, it is impossible to predict the particle motion from pressure measurements. Thus, nothing in this experiment can relate the sound levels and any damage to the statocysts, even if the damage seen was related to the sounds.

Third, to generalize about invertebrates, it is important to note that the lack of any air bubbles (such as the fish swim bladder) that would be set in motion by high intensity sounds leads to the suggestion that there would be little or no impact of high intensity sounds on invertebrates (although, like fishes, if the invertebrates are very close to the source, the shock wave from the source might have a general impact on survival).

Finally, the authors exposed the animals to sound for 2 hrs, which is far longer than any exposure in the wild where the anthropogenic sources of concern, such as sonar and seismic airguns. These are generally moving sources, thus they would expose a slower moving (or stationary) animal for just a few minutes (if not less) rather than 2 hrs.

7.4. VESSEL NOISE AND FISH

A growing concern with regard to increases in anthropogenic noise comes from the increasing number of commercial ships that are found over large geographic areas as well inshore and the increasing number of small pleasure craft found inshore and in harbors. All vessels produce sound as a by-product of their operation, which is generally below 1 kHz. Source levels of vessels can range from <150 dB re 1 µPa to over 190 dB for the largest commercial vessels (Richardson et al., 1995; Hildebrand, 2009).

Vessel noise produces sounds in the general hearing range of fishes (Amoser et al., 2004). Continuous exposure (30 minutes) to boat noise has been shown to increase fish cortisol levels (stress response) (Wysocki et al., 2006). Temporary threshold shift has been associated with long-term, continuous exposure (2 hrs), and masked hearing thresholds have also been recorded for fishes exposed to noise from small boats and ferries (Scholik and Yan, 2001; Vasconcelos et al., 2007). Additionally, vessels (i.e., trawlers, ferries, small boats) can change fish behavior (e.g., induce avoidance, alter swimming speed and direction, and alter schooling behavior) (Sarà et al., 2007). Studies do not indicate precisely which of these kinds of physical or behavioral effects may result from a single ship or from an aggregation of shipping activity, although it is important to bear in mind that the large number of commercial vessels, their nearly continuous presence in many nearshore areas, and projected increases in shipping trends. One of the most serious implications of this increase in shipping noise is the impact it may have in terms of masking sounds of biological origin and affecting communication between fishes.

The sounds produced by motor-driven ships causes herring to dive and swim away from the vessel (Mitson and Knudsen, 2003). Paradoxically, research vessels specially designed to reduce noise can result in an even greater behavioral reaction (Ona et al., 2007). Sand et al. (2008) have pointed out that passing ships produce high levels of infrasonic and low-frequency noise (>10-1,000 Hz), and that infrasonic frequencies may be responsible for the observed avoidance reactions.

8. GENERAL CONCLUSIONS – EFFECTS

The data obtained to date on effects of sound on fishes are very limited both in terms of the number of well-controlled studies and in the number of species tested. Moreover, there are significant limits in the range of data available for any particular type of sound source. While new data have become available on physiological effects of very intense pile driving (Casper et al., 2011a; Halvorsen et al., 2011a,b) and these data may be carefully extrapolated to other sound sources and species, the data are still very limited and comparable data are needed for other sources and species.

At the same time, physiological effects are probably not the major issue with regard to anthropogenic sound since most fishes will not be close enough to a sound source to show such effects. Instead, the biggest issues are related to effects on behavior since anthropogenic sources could, potentially, impact behavior of fishes over broad areas. Yet, despite this clear need for understanding of behavioral effects, the extent of data is exceedingly limited and equivocal; it is not yet possible to make clear statements about effects of any particular sound source on the behavior of any species.

The following sections briefly review and comment on the effects discussed earlier in this report. At the same time, it should be noted that after examining the complete literature on effects of sound on fishes (and turtles), an international panel of experts reached the conclusion that there are insufficient data to reach conclusions for most any sound source[16].

The BOEM concludes that there is incomplete or unavailable information (40 CFR 1502.22) about the effects of sound on fish, in particular how loud sound may stress fish and influence their health. At issue also is our ability to understand what fish experience when we observe or interpret fish response to stimuli, such as airguns. While there will never be complete scientific information on the fish species that live in OCS waters of the AOI, a body of biological and physiological data and information about the effects of sound on fish is available to us. We report where limited data and insufficient knowledge challenge our ability to understand these effects. The acquisition of a much more complete knowledge base for fish using the AOI cannot be acquired without exhorbitant cost. It certainly cannot be acquired in a time frame to make it available for this evaluation.

The BOEM has therefore determined that data or information on the effects of sound on fish identified as incomplete or unavailable is not essential to a reasoned choice among the alternatives, including the No Action alternative. We are able to draw basic conclusions despite incomplete or unavailable information, discuss results using available scientifically credible information, and apply that information using accepted scientific methodologies.

8.1. PHYSIOLOGICAL EFFECTS

Several general points can be made with reference to effects on fish physiology and mortality of intense sounds.

1. There is little evidence for immediate mortality other than when fishes are very close to intense sound sources, such as pile driving for very large piles. There are no data on any other sound source. Substantial study needs to be put into questions of immediate mortality.
2. Physiological effects that are sufficient to potentially kill fishes over time appears to have some correlation with the total amount of sound exposure. A few non-quantified studies have shown no damage to non-auditory tissues as a result of seismic airgun exposure (Popper et al., 2005; Song et al., 2008) or to any tissue after exposure to high intensity low-frequency and mid-frequency sonars (Halvorsen et al., 2006; Popper et al., 2007). A quantified study of pile driving (Halvorsen et al., 2011a,b) demonstrates a range of effects that increase in likely impact on the animals, but the fishes seem to recover from these effects in a few days (Casper et al., 2011a). There are some data that suggest that some seismic airgun signals, under certain acoustic conditions, may damage sensory cells of the ears (McCauley et al., 2003), but that there is no effect on other species under different acoustic conditions (Song et al., 2008).
3. There are very few data documenting effects of any intense sound source on eggs and larvae. Far more data are needed before any preliminary conclusions can be reached on the effects of sound on eggs and larvae, and studies need to include, in addition to mortality, effects on growth and body tissues.
4. It is possible that exposure to loud sounds or increased background noise can result in increased stress levels and effects on the immune system. However, such effects have never been documented for fishes, and the only long-term study (Wysocki et al., 2007) of

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[16] This panel was co-chaired by Drs. Arthur Popper and Richard Fay, and a report is in preparation. The work was done under the auspices of the Standards Group of the Acoustical Society of America and was funded by several U.S. and international agencies and organizations. The report cannot be provided at this point, but will be provided as soon as possible.

increased ambient noise showed no effect. It is critical to note that lack of effect may be more a function of not enough study rather than being the actual result. Future studies are needed to ask questions of such effects.

8.2. EFFECTS ON FISH BEHAVIOR

The more critical issue for effects of anthropogenic sound on fishes, however, is the effect on the behavior of wild animals and whether sound exposure will alter the behavior of a fish in a manner that will affect its way of living – such as where it tries to find food or how well it can find a mate. With the exception of just a few field studies, there are no data on behavioral effects, and most of these studies are very limited in scope and all are related to seismic airguns. Because of the limited ways in which behavior of fishes in these studies were "observed" (often by doing catch rates, which tell nothing about how fishes really react to a sound), there really are no data on the most critical questions regarding behavior.

Indeed, the fundamental questions are how fishes behave during and after exposure to a sound as compared to their "normal" pre-exposure behavior. This requires observations of a great number of animals over a large area for a considerable period of time before and after exposure to sound sources as well as during exposure. Only with such data is it possible to tell how sounds affect overall behavior (including movement) of animals. These experiments are very difficult to do, require a large amount of resources, and are very expensive to conduct.

8.3. INCREASED BACKGROUND SOUND

In addition to questions about how fish movements change in response to sounds, there are also questions as to whether any increase in background sound has an effect on more subtle aspects of behavior, such as the ability of a fish to hear a potential mate or predator or to glean information about its general environment. There is a body of literature that shows that the sound detection ability of fishes can be "masked" by the presence of other sounds within the hearing range of the fishes (reviewed in Fay and Megela-Simmons, 1999; Popper et al., 2003). Just as a human has trouble hearing another person as the room they are in gets noisier, it is likely that the same effect occurs for fishes (as well as all other animals). In effect, acoustic communication and orientation of fishes may potentially be restricted by noise regimes in their environment that are within the hearing range of the fishes. Perhaps this is the single most important area for future study since the masking effects of anthropogenic sounds could have a direct impact on the ability of fishes to hear sounds relevant to survival.

9. CURRENT CRITERIA

There is considerable national and international concern about effects of anthropogenic sound on marine organisms, including fishes (see Popper and Hawkins [2011]). However, despite the concerns, there is actually very little in the way of recommendations for regulatory levels of sound. In fact, the only known criteria, which are clearly labeled "interim," arose on the U.S. West Coast out of concern about effects of pile driving on fishes (reviewed in Woodbury and Stadler, 2008; Stadler and Woodbury, 2009). These criteria are for the onset of physiological effects and say nothing about behavior.

The current interim criteria are dual in nature. That is, they state that physiological onset may occur if the peak sound level of a pile driving strike is 206 dB re 1 µPa or have an $\mathrm{SEL}_{\mathrm{cum}}$ of 187 dB re $1\mu\mathrm{Pa}^2$-s for fishes above 2 g (0.07 oz) or 183 dB re $1\mu\mathrm{Pa}^2$-s for fishes below 2 g (0.07 oz) (for explanation of these criteria, see also Popper et al. [2006] and Carlson et al. [2007]).

The levels for the current interim criteria were substantially criticized as not being based on the best available science at the time of their implementation (see Carlson et al. [2007] for detailed recommendations that were not used in setting the current interim criteria). Presently, based on a wide range of data that arose concurrent or subsequent to the current interim criteria, it is clear that the set levels, at least for cumulative exposure, are far too low and unrealistic for onset of physiological effects.

The inadequacy of the interim criteria has now been documented in a recent quantified study on the effects of pile driving on the onset of physiological effects in Chinook salmon (Halvorsen et al., 2011a,b) and several other species (Casper et al., 2011a). These studies, which demonstrated that an $\mathrm{SEL}_{\mathrm{cum}}$ below approximately 207 dB re $1\mu\mathrm{Pa}^2\cdot$s will not result in the onset of injury and that $\mathrm{SEL}_{\mathrm{cum}}$ as high as

210 dB re 1μPa^2·s produces physiological effects that are inconsequential (e.g., minor external bleeding). While these data need to be replicated for other species and other sounds, they have been shown to be appropriate for three very different species, suggesting that there may be reasonably broad applicability of these values for setting future interim criteria.

At the same time, these results are only for pile driving. It is not clear which aspect(s) of intense sounds result in physiological onset, but it is likely that the rise time (onset time) of the signal may be of consequence. Thus, signals with slower rise times than pile driving may have even higher onset levels whereas sounds with faster rise times (e.g., from explosives) may have somewhat lower criteria.

One other factor that must be recognized with these criteria is recovery time, which is built into the West Coast interim criteria (Stadler and Woodbury, 2009). That is, all tissues, when damaged, start to recover as soon as the stimulus is removed. This has been documented in mammals exposed to intense sounds (reviewed in Popper and Hastings, 2009b), and it is more than likely that the same thing happens for fishes. Indeed, Popper et al. (2005) showed recovery of hearing loss resulting from exposure to seismic airguns within 18 hrs of the termination of exposure. Thus, if a fish is exposed to pile driving, the accumulation of exposure (the SEL_{cum}) is returned to zero (0) after 12 hrs without exposure (Carlson et al., 2007; Stadler and Woodbury, 2009).

This same restart of accumulation is important for any sound exposure condition. Thus, no matter whether a fish is exposed to pile driving, seismic airguns, sonars, etc., accumulated energy returns to zero after some period of non-exposure.

10. REFERENCES CITED

Amoser, S. and F. Ladich. 2003. Diversity in noise-induced temporary hearing loss in otophysine fishes. J. Acoust. Soc. Am. 113(4):2170-2179.

Amoser, S., E.L. Wysocki, and F. Ladich. 2004. Noise emission during the first powerboat race in an Alpine lake and potential impact on fish communities. J. Acoust. Soc. Am. 116:3789-3797.

André, M., M. Solé, M. Lenoir, M. Durfort, C. Quero, A. Mas, A. Lombarte, M. van der Schaar, M. López-Bejar, M. Morell, S. Zaugg, and L. Houégnigan. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. Frontiers in Ecology and the Environment doi:10.1890/100124. Available at: http://www.seaturtle.org/PDF/AndreM_2011_FrontEcolEnviron.pdf. Accessed August 5, 2011.

Andriguetto-Filho, J.M., A. Ostrensky, M.R. Pie, U.A. Silva, and W.A. Boeger. 2005. Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. Continental Shelf Research 25:1720-1727.

Banner, A. and M. Hyatt. 1973. Effects of noise on eggs and larvae of two estuarine fishes. Transactions of the American Fisheries Society 102(1):134-136.

Bee, M.A. and E.N. Swanson. 2007. Auditory masking of anuran advertisement calls by road traffic noise. Animal Behaviour 74(6):1765-1776.

Booman, C., H. Dalen, H. Heivestad, A. Levsen, T. van der Meeren, and K. Toklum. 1996. Effekter av luftkanonskyting pa egg, larver og ynell. Havforskningsinstituttet, Issn 0071-5638.

Boudreau, M., S.C. Courtenay, and K. Lee, eds. 2009. Proceedings of a workshop held 23 January 2007 at the Gulf Fisheries Center. Potential impacts of seismic energy on snow crab: An update to the September 2004 review. Can. Tech. Rep. Fish. Aquat. Sci. 2836. 29 pp. Available at: http://www.dfo-mpo.gc.ca/Library/337176.pdf. Accessed August 5, 2011.

Brumm, H, and H. Slabbekoorn. 2005. Acoustic communication in noise. Advances in Behavior 35:151-209.

Budelmann, B.U. 1992. Hearing by crustacea. In: Webster, D.B., R.R. Fay, and A.N. Popper, eds. Evolutionary biology of hearing. New York: Springer-Verlag. Pp. 131-139.

California Department of Transportation (Caltrans). 2001. Pile installation demonstration project, fisheries impact assessment. PIDP EA 012081, Caltrans Contract 04A0148. San Francisco - Oakland Bay Bridge East Span Seismic Safety Project.

California Department of Transportation (Caltrans). 2010a. Effects of pile driving sound on juvenile steelhead. Prepared by ICF Jones & Stokes, Seattle, WA.

California Department of Transportation (Caltrans). 2010b. Necropsy and histopathology of steelhead trout exposed to steel pile driving at the Mad River Bridges, U.S. Highway 101, July 2009. Prepared by Gary D. Marty, DVM, Ph.D., Fish Pathology Services, Abbotsford, British Columbia, Canada.

Carlson, T.J., M.C. Hastings, and A.N. Popper. 2007. Update on recommendations for revised interim sound exposure criteria for fish during pile driving activities. Memorandum dated December 21, 2007, to Suzanne Theiss, California Department of Transportation and Paul Wagner, Washington Department of Transportation.

Casper, B.M. and D.A. Mann. 2006. Evoked potential audiograms of the nurse shark (*Ginglymostoma cirratum*) and the yellow stingray (*Urobatis jamaicensis*). Environmental Biology of Fishes 76:101-108.

Casper, B.M., P.S. Lobel, and H.Y. Yan. 2003. The hearing sensitivity of the little skate, *Raja erinacea*: A comparison of two methods. Environmental Biology of Fishes 68:371-379.

Casper, B.M., F.M. Matthews, M.B. Halvorsen, T.J. Carlson, and A.N. Popper. 2011a. Recovery from exposure to pile driving signals by Chinook salmon. J. Acoust. Soc. Am. 129(4):2436.

Casper, B.M., M.C. Halvorsen, and A.N. Popper. 2011b. Are sharks even bothered by a noisy environment? In: Popper, A.N. and A. Hawkins, eds. Effects of noise on aquatic life. New York: Springer Science and Business Media, LLC. (in press).

Chapman, C.J. and A.D. Hawkins. 1973. A field study of hearing in the cod, *Gadus morhua*. Journal of Comparative Physiology 85:147-167.

Corwin, J.T. 1981. Postembryonic production and aging in inner ear hair cells in sharks. J. Comp. Neurol. 201:541-553.

Culik, B.M., S. Koschinski, N. Tregenza, and G.M. Ellis. 2001. Reactions of harbour porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. Mar. Ecol. Prog. Ser. 211:255-260.

de Jong, C.A.F., P.J.G. van Beek, M.A. Ainslie, L.J. Bolle, O.A. van Keeken, C.J.G. van Damme, H.V. Winter, and D. de Haan. 2011. Testing mortality of fish larvae due to simulated offshore piling noise. J. Acoust. Soc. Am. 129(4):2437.

Deng, X., H.-J. Wagner, and A.N. Popper. 2011. The inner ear and its coupling to the swim bladder in the deep-sea fish *Antimora rostrata* (Teleostei: Moridae). Deep Sea Research, Part I 58:27-37.

Doksaeter, L, O.R. Godø, N.O. Handegard, P.H. Kvadsheim, F-P.A. Lam, C. Donovan, and P.J. Miller. 2009. Behavioral responses of herring (*Clupea harengus*) to 1–2 and 6–7 kHz sonar signals and killer whale feeding sounds. J. Acoust. Soc. Am. 125:554-564.

Dooling, R.J., E.W. West, and M.R. Leek. 2009. Conceptual and computation models of the effects of anthropogenic sound on birds. Proceedings of the Institute of Acoustics, 31(pt 1).

Dwyer, W.P., W. Fredenberg, and D.A. Erdahl. 1993. Influence of electroshock and mechanical shock on survival of trout eggs. North American Journal of Fisheries Management 13:839-843.

Engås, A., S. Løkkeborg, E. Ona, and A.V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Canadian Journal of Fisheries and Aquatic Sciences 53:2238-2249.

Enger, P.S. 1981. Frequency discrimination in teleosts-central or peripheral?. In: Tavolga, W.N., A.N. Popper, and R.R. Fay, eds. Hearing and sound communication in fishes. New York: Springer-Verlag. Pp. 243-255.

Fay, R.R. 1988. Hearing in vertebrates: A psychophysics fatabook. Winnetka, IL: Hill-Fay Associates.

Fay, R.R. 2005. Sound source localization by fishes. In: Popper, A.N. and R.R. Fay, eds. Sound source localization. New York: Springer Science + Business Media, LLC. Pp. 36-66.

Fay, R.R. and A. Megela-Simmons. 1999. The sense of hearing in fishes and amphibians. In: Fay, R.R. and A.N. Popper, eds. Comparative hearing: Fish and amphibians. New York: Springer-Verlag. Pp. 269-318.

Fay, R.R. and A.N. Popper. 2000. Evolution of hearing in vertebrates: The inner ears and processing. Hear. Res. 149:1-10.

Fish, J.F. and G.C. Offutt. 1972. Hearing thresholds from toadfish, *Opsanu tau*, measured in the laboratory and field. J. Acoust. Soc. Am. 51:1318-1321.

Guerra, A., A.F. Gonzalez, F. Rocha, and J. Gracia Ecobiomar. 2004. Calamares gigantes varados. Victimas de exploraciones acústicas. Investigación y Ciencia July:35-37.

Halvorsen, M.B., L.E. Wysocki, and A.N. Popper. 2006. Effects of high-intensity sonar on fish. J. Acoust. Soc. Am. 119:3283.

Halvorsen, M.B., C.M. Woodley, B.M. Casper, T.J. Carlson, and A.N. Popper. 2011a. Derivation of a response severity index model for physiological quantification of fish response to impulsive sound. J. Acoust. Soc. Am. 129(4):2435.

Halvorsen, M.B., B.M. Casper, C.M. Woodley, T.J. Carlson, and A.N. Popper. 2011b. Predicting and mitigating hydroacoustic impacts on fish from pile installations. National Cooperative Highway Research Program Transportation Research Board of The National Academies, (in press).

Hastings, M.C. 2008. Coming to terms with the effects of ocean noise on marine animals. Acoustics Today 4(2):22-34.

Hastings, M.C. 2009. A model for prediction of auditory tissue damage in fish. Final Report, Rev. 1. Submitted to the Joint Industry Program (JIP) on E&P Sound and Marine Life.

Hastings, M.C. and J. Miskis-Olds. 2011. Shipboard assessment of hearing sensitivity of tropical fishes immediately after exposure to seismic air gun emissions at Scott reef. In: Popper, A.N. and A. Hawkins, eds. Effects of noise on aquatic life. New York: Springer Science + Business Media, LLC (in press).

Hastings, M.C. and A.N. Popper. 2005. Effects of sound on fish. California Department of Transportation Contract 43A0139 Task Order, 1. Available at: http://www.dot.ca.gov/hq/env/bio/files/Effects_of_Sound_on_Fish23Aug05.pdf. Accessed August 5, 2011.

Hastings, M.C., A.N. Popper, J.J. Finneran, and P.J. Lanford. 1996. Effects of low-frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. J. Acoust. Soc. Am. 99(3):1759-1766.

Hastings, M.C., C.A. Reid, C.C. Grebe, R.L. Hearn, and J.G. Colman. 2008. The effects of seismic airgun noise on the hearing sensitivity of tropical reef fishes at Scott Reef, Western Australia. Underwater Noise Measurement, Impact and Mitigation, Proceedings.

Hildebrand, J.A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. Mar. Ecol. Prog. Ser. 395:5-20.

Iversen, R.T.B. 1967. Response of the yellowfin tuna (*Thunnus albacares*) to underwater sound. In: Tavolga, W.N., ed. Marine bio-acoustics II. New York: Pergamon Press. Pp. 105-121.

Iversen, R.T.B. 1969. Auditory thresholds of the scombrid fish *Euthynnus affinis*, with comments on the use of sound in tuna fishing. Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics, October 1967. FAO Fisheries Reports No. 62 Vol. 3. FRm/R62.3.

Jensen, J.O.T. and D.F. Alderdice. 1983. Changes in mechanical shock sensitivity of coho salmon (*Oncorhyncuus kisutch*) eggs during incubation. Aquaculture 32:303-312.

Jensen, J.O.T. and D.F. Alderdice. 1989. Comparison of mechanical shock sensitivity of eggs of five Pacific salmon (*Oncorhyncus*) species and steelhead trout (*Salmo gairdneri*). Aquaculture 78:163-181.

Jerkø, H., I. Turunen-Rise, P.S. Enger, and O. Sand. 1989. Hearing in the eel (*Anguilla anguilla*). Journal of Comparative Physiology 165:455-459.

Jorgenson, J.K. and E.C. Gyselman. 2009. Hydroacoustic measurements of the behavioral response of arctic riverine fishes to seismic airguns. J. Acoust. Soc. Am. 126:1598-1606.

Jørgensen, R., K.K. Olsen, I.B. Falk-Petersen, and P. Kanapthippilai. 2005. Investigations of potential effects of low frequency sonar signals on survival, development and behaviour of fish larvae and juveniles. The Norwegian College of Fishery Science, University of Tromsø, N-9037 Tromsø Norway.

Kane, A.S., J. Song, M.B. Halvorsen, D.L. Miller, J.D. Salierno, L.E. Wysocki, D. Zeddies, A.N. Popper. 2010. Exposure of fish to high intensity sonar does not induce acute pathology. J. Fish Biol. 76:1825-1840.

Karlsen, H.E. 1992. Infrasound sensitivity in the plaice (*Pleuronectes plattessa*). Journal of Experimental Biology 171:173-187.

Knudsen, F.R., P.S. Enger, and O. Sand. 1994. Avoidance responses to low frequency sound in downstream migrating Atlantic salmon smolt, *Salmo salar*. Journal of Fish Biology 45:227-233.

Kostyuchenko, L.P. 1972. Effects of elastic waves generated in marine seismic prospecting on fish eggs in the Black Sea. Hydrobiologia 9:45-46.

Kvadsheim, P.H. and E.M. Sevaldsen. 2005. The potential impact of 1-8 kHz active sonar on stocks of juvenile fish during sonar exercises. FFI/Report-2005/01027.

Ladich, F. and A.N. Popper. 2004. Parallel evolution in fish hearing organs. In: Manley, G.A., A.N. Popper, and R.R. Fay, eds. Evolution of the vertebrate auditory system, Springer handbook of auditory research. New York: Springer-Verlag. Pp. 95-127.

Lagardère, J.-P. 1982. Effects of noise on growth and reproduction of *Crangon crangon* in rearing tanks. Marine Biology 71:177-185.

Lagardère, J.-P. and M.R. Régnault. 1980. Influence du niveau sonore de bruit ambient sur la métabolisme de *Crangon crangon* (Decapoda: Natantia) en élevage. Marine Biology 57:157-164.

Laiolo, P. 2010. The emerging significance of bioacoustics in animal species conservation. Biological Conservation 143:1635-1645.

Leis, J.M., B.N. Carson-Ewart, A.C. Hay, and D.H. Cato. 2003. Coral-reef sounds enable nocturnal navigation by some reef-fish larvae in some places and at some times. Journal of Fish Biology 63724–737.

Le Prell, G., D. Henderson, R.R. Fay, and A.N. Popper, eds. 2011. Noise-induced hearing loss: Scientific advances. New York: Springer Science + Business Media, LLC (in press).

Løkkeborg, S., E. Ona, A. Vold, and A. Salthaug. 2011. Effects of sounds from seismic air guns on fish behavior and catch rates. In: Popper, A.N. and A. Hawkins, eds. Effects of noise on aquatic life. New York: Springer Science + Business Media, LLC (in press).

Lombarte, A. and A.N. Popper. 1994. Quantitative analyses of postembryonic hair cell addition in the otolithic endorgans of the inner ear of the European hake, *Merluccius merluccius* (Gadiformes, Teleostei). Journal of Comparative Neurology 345:419-428.

Lombarte, A. and A.N. Popper. 2004. Quantitative changes in the otolithic organs of the inner ear during the settlement period in European hake (*Merluccius merluccius*). Marine Ecol. Prog. Ser. 267:233-240.

Lombarte, A., H.Y. Yan, A.N. Popper, J.C. Chang, and C. Platt. 1993. Damage and regeneration of hair cell ciliary bundles in a fish ear following treatment with gentamicin. Hearing Research 66:166-174.

Lovell, J.M., M.M. Findlay, R.M. Moate, J.R. Nedwell, and M.A. Pegg. 2005. The inner ear morphology and hearing abilities of the Paddlefish (*Polyodon spathula*) and the lake sturgeon (*Acipenser fulvescens*). Comp Biochem Physiol A Mol Integr Physiol. 142:286-289.

Lu, Z. and Z. Xu. 2009. Effects of saccular otolith removal on hearing sensitivity of the sleeper goby (Dormitator latifrons). Journal of Comparative Physiology 188:595-602.

Mann, D.A., Z. Lu, and A.N. Popper. 1997. A clupeid fish can detect ultrasound. Nature 389:341.

Mann, D.A., D.M. Higgs, W.N. Tavolga, M.J. Souza, and A.N. Popper. 2001. Ultrasound detection by clupeiform fishes. J. Acoust. Soc. Am. 109:3048-3054.

Mann, D.A., A.N. Popper, and B. Wilson. 2005. Pacific herring hearing does not include ultrasound. Biology Letters 1:158-161.

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. J. Acoust. Soc. Am. 113(1):638-642.

Meyer, M., R.R. Fay, and A.N. Popper. 2010. Frequency tuning and intensity coding of sound in the auditory periphery of the lake sturgeon, *Acipenser fulvescens*. J. Exp. Biol. 213:1567-1578.

Mitson, R.B. and H.P. Knudsen. 2003. Causes and effects of underwater noise on fish abundance estimation. Aquatic Living Resources 16:255-263.

Mooney, T.A., R.T. Hanlon, J. Christensen-Dalsgaard, P.T. Madsen, D.R. Ketten, and P.E. Nachtigall. 2010. Sound detection by the longfin squid (*Loligo pealeii*) studied with auditory evoked potentials: sensitivity to low-frequency particle motion and not pressure. Journal of Experimental Biology 213:3748-3759.

Mueller-Blenkle, C., P.K. McGregor, A.B. Gill, M.H. Andersson, J. Metcalfe, V. Bendall, P. Sigray, D.T. Wood, and F. Thomsen. 2010. Effects of pile-driving noise on the behaviour of marine fish. COWRIE Ref: Fish 06-08, Technical Report 31st March 2010. Available at: http://www.offshorewind.co.uk/Assets/COWRIE%20FISH%2006-08_Technical%20report_Cefas_31-03-10.pdf. Accessed August 5, 2011.

Myrberg, A.A., Jr. 2001. The acoustical biology of elasmobranchs. Environmental Biology of Fishes 60:31-45.

Myrberg, A.A., Jr. and J.Y. Spires. 1980. Hearing in damselfishes: an analysis of signal detection among closely related species. Journal of Comparative Physiology 140:135-144.

Myrberg, A.A., Jr., C.R. Gordon, and A.P. Klimley. 1976. Attraction of free ranging sharks by low frequency sound, with comments on its biological significance. In: Schuijf, A. and A.D. Hawkins, eds. Sound reception in fish. Amsterdam: Elsevier. Pp. 205-228.

Nedwell, J.R., B. Edwards, A.W.H. Turnpenny, and J. Gordon. 2004. Fish and marine mammal audiograms: A summary of available information. Prepared by Subacoustech Ltd., Hamphire, UK. Report 534 R 0214.

Nelson, J.S. 2006. Fishes of the world. 4th Edition. Hoboken, NJ: John Wiley & Sons.

Ona, E., O.R. Godø, N.O. Handegard, V. Hjellvik, R. Patel, and G. Pedersen. 2007. Silent research vessels are not quiet. J. Acoust. Soc. Amer. 121(4):EL145-EL150. Available at: http://scitation.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=JASMAN0001210000040EL145000001&idtype=cvips&doi=10.1121/1.2710741&prog=normal&bypassSSO=1. Accessed August 5, 2011.

Parris, K.M., M. Velik-Lord, and J.M.A. North. 2009. Frogs call at a higher pitch in traffic noise. Ecology and Society 14(1):25.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1987. Effects of sounds from a geophysical survey device on fishing success. Report prepared by Battelle/Marine Research Laboratory for the Marine Minerals Service, United States Department of the Interior. Contract Number 14-12-0001-30273.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* ssp). Canadian Journal of Fisheries and Aquatic Sciences 49:1343-1356.

Pickering, A.D. 1981. Stress and fishes. New York: Academic Press.

Plachta, D.T.T. and A.N. Popper. 2003. Evasive responses of American shad *(Alosa sapidissima)* to ultrasonic stimuli. Acoust. Res. Lett. Online 4:25-30.

Popper, A.N. 1980 . Scanning electron microscopic studies of the sacculus and lagena in several deep-sea fishes. Am. J. Anat. 157:115-136.

Popper, A.N. 2003. Effects of anthropogenic sounds on fishes. Fisheries 28(10):24-31.

Popper, A.N. and R.R. Fay. 2010. Rethinking sound detection by fishes. Hear. Res. 273(1-2):25-36.

Popper, A.N. and M.C. Hastings. 2009a. The effects on fish of human-generated (anthropogenic) sound. Integrative Zool. 4:43-52.

Popper, A.N. and M.C. Hastings. 2009b. Effects of anthropogenic sources of sound on fishes. J. Fish Biol. 75:455-498.

Popper, A.N. and A. Hawkins, (eds.). 2011. Effects of noise on aquatic life. New York: Springer Science + Business Media, LLC (in press).

Popper, A.N. and B. Hoxter. 1984. Growth of a fish ear: 1. Quantitative analysis of sensory hair cell and ganglion cell proliferation. Hearing Research 15:133-142.

Popper, A.N. and S. Løkkeborg. 2008. Effects of anthropogenic sound on fish. Bioacoustics 17:214-217.

Popper, A.N., M. Salmon, and K.W. Horch. 2001. Acoustic detection and communication by decapod crustaceans. Journal of Comparative Physiology A 187:83-89.

Popper, A.N., R.R. Fay, C. Platt, and O. Sand. 2003. Sound detection mechanisms and capabilities of teleost fishes. In: Collin, S.P. and N.J. Marshall, eds. Sensory processing in aquatic environments. New York: Springer-Verlag. Pp. 3-38.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGillivray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. J. Acoust. Soc. Am. 117:3958-3971.

Popper, A.N., T.J. Carlson, A.D. Hawkins, B.L. Southall, and R.L. Gentry. 2006. Interim criteria for injury of fish exposed to pile driving operations: A white paper. Available at: http://www.wsdot.wa.gov/NR/rdonlyres/84A6313A-9297-42C9-BFA6-750A691E1DB3/0/BA_PileDrivingInterimCriteria.pdf. Accessed August 5, 2011.

Popper, A.N., M.B. Halvorsen, E. Kane, D.D. Miller, M.E. Smith, P. Stein, and L.E. Wysocki. 2007. The effects of high-intensity, low-frequency active sonar on rainbow trout. J. Acoust. Soc. Am., 122:623-635.

Popper, A.N. and C.R. Schilt. 2008. Hearing and acoustic behavior (basic and applied). In: Webb, J.F., R.R. Fay, and A.N. Popper, eds. Fish bioacoustics. New York: Springer Science + Business Media, LLC.

Ramcharitar, J.U., X. Deng, D. Ketten, and A.N. Popper. 2004. Form and function in the unique inner ear of a teleost fish: The silver perch (*Bairdiella chrysoura*). J. Comp. Neurol. 475:531-539. Available at: http://www.whoi.edu/csi/images/Ramcharitar_2004.pdf. Accessed August 5, 2011.

Ramcharitar, J., D. Gannon, and A. Popper. 2006. Bioacoustics of fishes of the family Sciaenidae (croakers and drums). Transactions of the American Fisheries Society 135:1409-1431.

Remage-Healey, L., D.P. Nowacek, and A.H. Bass. 2006. Dolphin foraging sounds suppress calling and elevate stress hormone levels in a prey species, the Gulf toadfish. Journal of Experimental Biology 209:4444-4451.

Richardson, W.J., C.R. Greene Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. New York: Academic Press.

Rogers, P.H. and M. Cox. 1988. Underwater sound as a biological stimulus. In: Atema, A., R.R. Fay, A.N. Popper, and W.N. Tavolga, eds. Sensory biology of aquatic animals. New York: Springer-Verlag. Pp. 131-149.

Sand, O. and H.E. Karlsen. 1986. Detection of infrasound by the Atlantic cod. J. Exp. Biol. 125:197-204.

Sand, O., H.E. Karlsen, and F.R. Knudsen. 2008. Comment on silent research vessels are not quiet. J. Acoust. Soc. Amer. 123:1831-1833.

Sarà, G., J.M. Dean, D. D'Amato, G. Buscaino, A. Oliveri1, S. Genovese, S. Ferro, G. Buffa, M. Lo Martire, and S. Mazzola. 2007. Effect of boat noise on the behaviour of bluefin tuna *Thunnus thynnus* in the Mediterranean Sea. Mar. Ecol. Prog. Ser. 331:243–253.

Scholik, A.R. and H.Y. Yan. 2001. Effects of underwater noise on auditory sensitivity of a cyprinid fish. Hearing Research 152:17-24.

Scholik. A.R. and H.Y. Yan. 2002. Effects of boat engine noise on the auditory sensitivity of the fathead minnow, *Pimephales promelas*. Environmental Biology of Fishes 63:203-209.

Skalski, J.R., W.H. Pearson, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Sciences 49:1357-1365.

Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate, and A.N. Popper. 2010. A noisy spring: the impact of globally rising underwater sound levels on fish. Trends in Ecology & Evolution 25:419-427.

Slotte, A., K. Kansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fisheries Research 67143-150.

Smith, M.E., A.S. Kane, and A.N. Popper. 2004a. Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*). Journal of Experimental Biology 207:427-435.

Smith, M.E., A.S. Kane, and A.N. Popper. 2004b. Acoustical stress and hearing sensitivity in fishes: does the linear threshold shift hypothesis hold water? Journal of Experimental Biology 207:3591-3602.

Smith, M.E., A.B. Coffin, D.L. Miller, and A.N. Popper. 2006. Anatomical and functional recovery of the goldfish (*Carassius auratus*) ear following noise exposure. Journal of Experimental Biology 209:4193-4202.

Song, J., A. Mathieu, R.F. Soper, and A.N. Popper. 2006. Structure of the inner ear of bluefin tuna *Thunnus thynnus*. Journal of Fish Biology 68:1767-1781.

Song, J., D.A., Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of northern Canadian freshwater fishes following exposure to seismic air gun sounds. J. Acoust. Soc. Am. 124:1360-1366.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33:411-521.

Stadler, J.H. and D.P. Woodbury. 2009. Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria. Inter-Noise 2009.

Stephenson, J.R., A.J. Gingerich, R.S. Brown, B.D. Pflugrath, Z. Deng, T.J. Carlson, M.J. Langeslay, M.L. Ahmann, R.L. Johnson, and A.G. Seaburg. 2010. Assessing barotrauma in neutrally and negatively buoyant juvenile salmonids exposed to simulated hydro-turbine passage using a mobile aquatic barotrauma laboratory. Fisheries Res. 106:271-278.

Sverdrup, A., E. Kjellsby, P.G. Krueger, R. Floys, F.R. Knudsen, P.S. Enger, G. Serck-Hanssen, and, K.B. Helle. 1994. Effects of experimental seismic shock on vasoactivity of arteries, integrity of the vascular endothelium and on primary stress hormones of the Atlantic salmon. Journal of Fish Biology 45:973-995.

Tavolga, W.N. and J. Wodinsky. 1963. Auditory capacities in fishes: Pure tone thresholds in nine species of marine teleosts. Bulletin of the American Museum of Natural History 126:177-240.

Urick, R.J. 1983. Principles of underwater sound. New York: McGraw-Hill.

Vasconcelos, R.O. and F. Ladich. 2008. Development of vocalization, auditory sensitivitiy and acoustic communication in the Lusitanian toadfish *Halobatrachus didactyllus*. Journal of Experimental Biology 211:502-509.

Vasconcelos, R.O., M.C.P. Amorim, and F. Ladich. 2007. Effects of ship noise on the detectability of communication signals in the Lusitanian toadfish. Journal of Experimental Biology 210:2104-2112.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic air guns on marine fish. Continental Shelf Research 21:1005-1027.

Webb, J.F., R.R. Fay, and A.N. Popper, eds. 2008. Fish bioacoustics. New York: Springer Science + Business Media, LLC.

Woodbury, D. and J. Stadler. 2008. A proposed method to assess physical injury to fishes from underwater sound produced during pile driving. Bioacoustics 17(1-3):289-291.

Wright, K.J., D.M. Higgs, J. Belanger, and J.M. Leis. 2005. Auditory and olfactory abilities of pre-settlement larvae and post-settlement juveniles of a coral reef damselfish (Pisces: Pomacentridae). Marine Biology 147:1425-1434. Available at: http://www.famer.unsw.edu.au/publications/Wright2005.pdf. Accessed August 5, 2011.

Wysocki L.E. and F. Ladich. 2005. Hearing in fishes under noise conditions. Journal of the Association for Research in Otolaryngology 6:28-36.

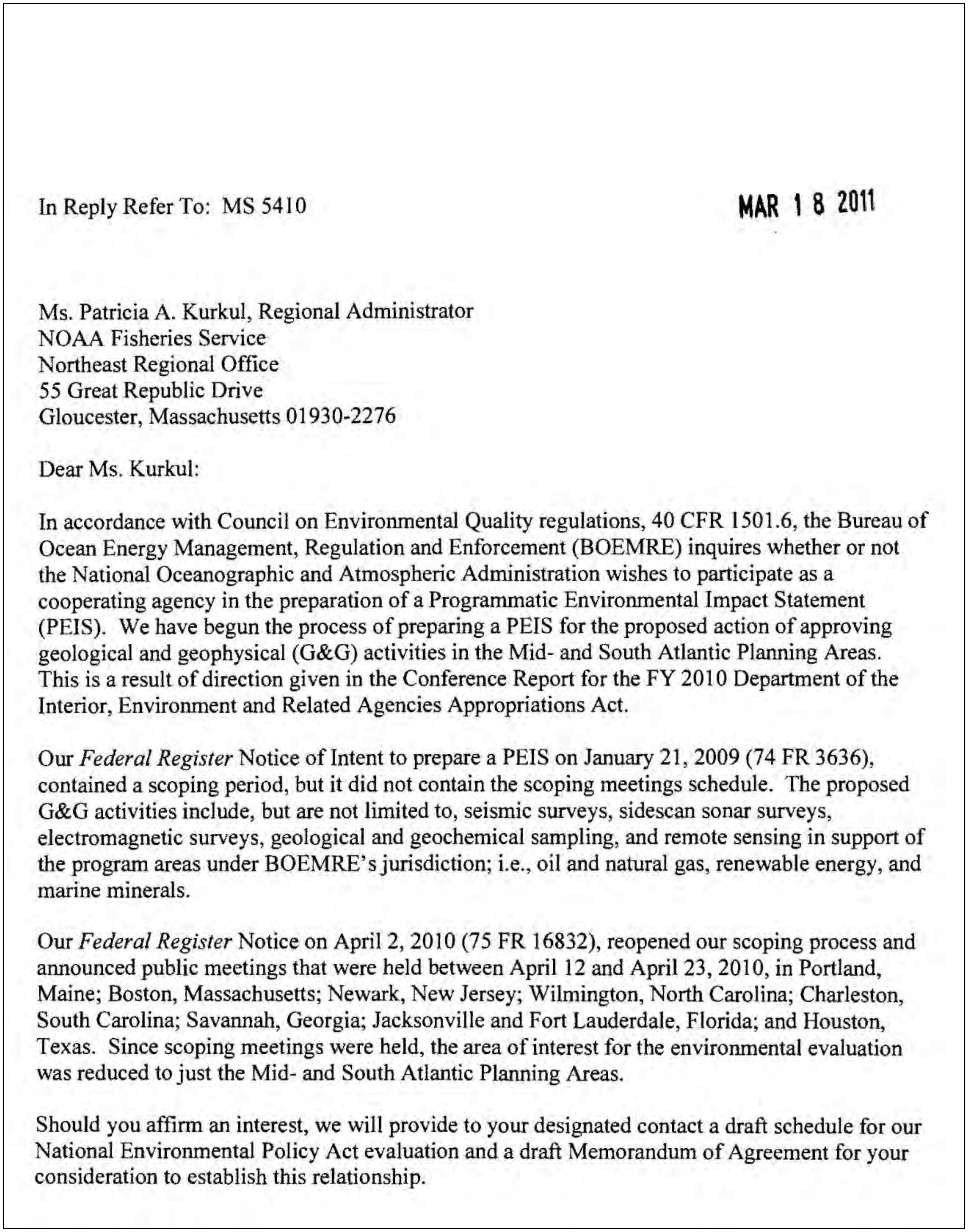
Wysocki, L.E., F. Ladich, and J. Dittami. 2006. Ship noise and cortisol secretion in European freshwater fishes. Biological Conservation 128:501-508.

Wysocki, L.E., J.W. Davidson, III, M.E. Smith, A.S. Frankel, W.T. Ellison, P.M. Mazik, A.N. Popper, and J. Bebak. 2007. Effects of aquaculture production noise on hearing, growth, and disease resistance of rainbow trout *Oncorhynchus mykiss*. Aquaculture 272:687-697.

Zelick, R., D. Mann, and A.N. Popper. 1999. Acoustic communication in fishes and frogs. In: Fay, R.R. and A.N. Popper, eds. Comparative hearing: Fish and amphibians. New York: Springer-Verlag. Pp. 363-411.

APPENDIX K

COOPERATING AGENCY



In Reply Refer To: MS 5410 MAR 18 2011

Ms. Patricia A. Kurkul, Regional Administrator
NOAA Fisheries Service
Northeast Regional Office
55 Great Republic Drive
Gloucester, Massachusetts 01930-2276

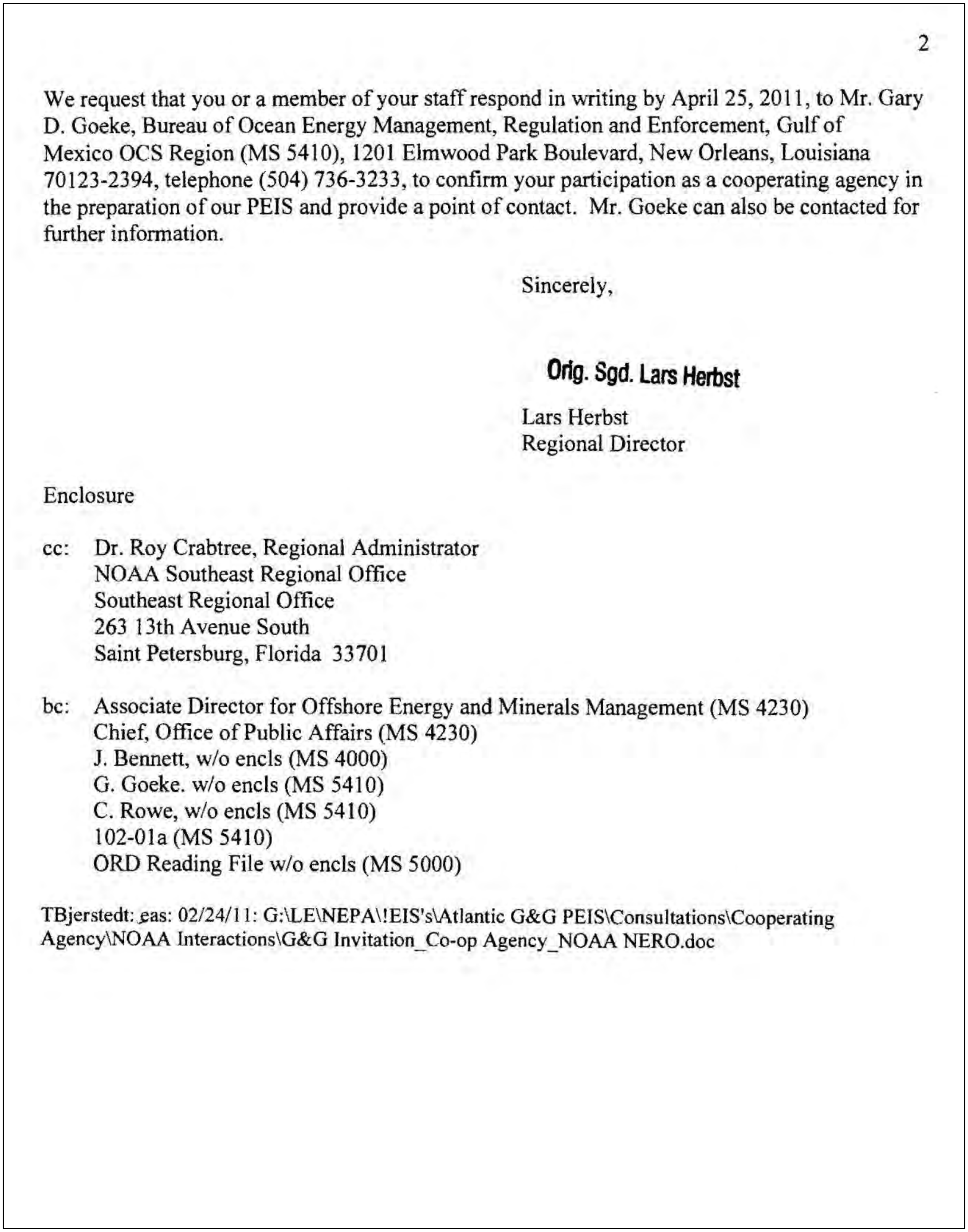
Dear Ms. Kurkul:

In accordance with Council on Environmental Quality regulations, 40 CFR 1501.6, the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) inquires whether or not the National Oceanographic and Atmospheric Administration wishes to participate as a cooperating agency in the preparation of a Programmatic Environmental Impact Statement (PEIS). We have begun the process of preparing a PEIS for the proposed action of approving geological and geophysical (G&G) activities in the Mid- and South Atlantic Planning Areas. This is a result of direction given in the Conference Report for the FY 2010 Department of the Interior, Environment and Related Agencies Appropriations Act.

Our *Federal Register* Notice of Intent to prepare a PEIS on January 21, 2009 (74 FR 3636), contained a scoping period, but it did not contain the scoping meetings schedule. The proposed G&G activities include, but are not limited to, seismic surveys, sidescan sonar surveys, electromagnetic surveys, geological and geochemical sampling, and remote sensing in support of the program areas under BOEMRE's jurisdiction; i.e., oil and natural gas, renewable energy, and marine minerals.

Our *Federal Register* Notice on April 2, 2010 (75 FR 16832), reopened our scoping process and announced public meetings that were held between April 12 and April 23, 2010, in Portland, Maine; Boston, Massachusetts; Newark, New Jersey; Wilmington, North Carolina; Charleston, South Carolina; Savannah, Georgia; Jacksonville and Fort Lauderdale, Florida; and Houston, Texas. Since scoping meetings were held, the area of interest for the environmental evaluation was reduced to just the Mid- and South Atlantic Planning Areas.

Should you affirm an interest, we will provide to your designated contact a draft schedule for our National Environmental Policy Act evaluation and a draft Memorandum of Agreement for your consideration to establish this relationship.



We request that you or a member of your staff respond in writing by April 25, 2011, to Mr. Gary D. Goeke, Bureau of Ocean Energy Management, Regulation and Enforcement, Gulf of Mexico OCS Region (MS 5410), 1201 Elmwood Park Boulevard, New Orleans, Louisiana 70123-2394, telephone (504) 736-3233, to confirm your participation as a cooperating agency in the preparation of our PEIS and provide a point of contact. Mr. Goeke can also be contacted for further information.

Sincerely,

Orig. Sgd. Lars Herbst

Lars Herbst
Regional Director

Enclosure

cc: Dr. Roy Crabtree, Regional Administrator
NOAA Southeast Regional Office
Southeast Regional Office
263 13th Avenue South
Saint Petersburg, Florida 33701

bc: Associate Director for Offshore Energy and Minerals Management (MS 4230)
Chief, Office of Public Affairs (MS 4230)
J. Bennett, w/o encls (MS 4000)
G. Goeke. w/o encls (MS 5410)
C. Rowe, w/o encls (MS 5410)
102-01a (MS 5410)
ORD Reading File w/o encls (MS 5000)

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In Reply Refer To: MS 5410

MAR 1 8 2011

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NOAA Fisheries Service
Southeast Regional Office
263 13th Avenue South
Saint Petersburg, Florida 33701

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Orig. Sgd. Lars Herbst

Lars Herbst
Regional Director

Enclosure

cc: Ms. Patricia A. Kurkul, Regional Administrator
NOAA Northeast Regional Office
Northeast Regional Office
55 Great Republic Drive
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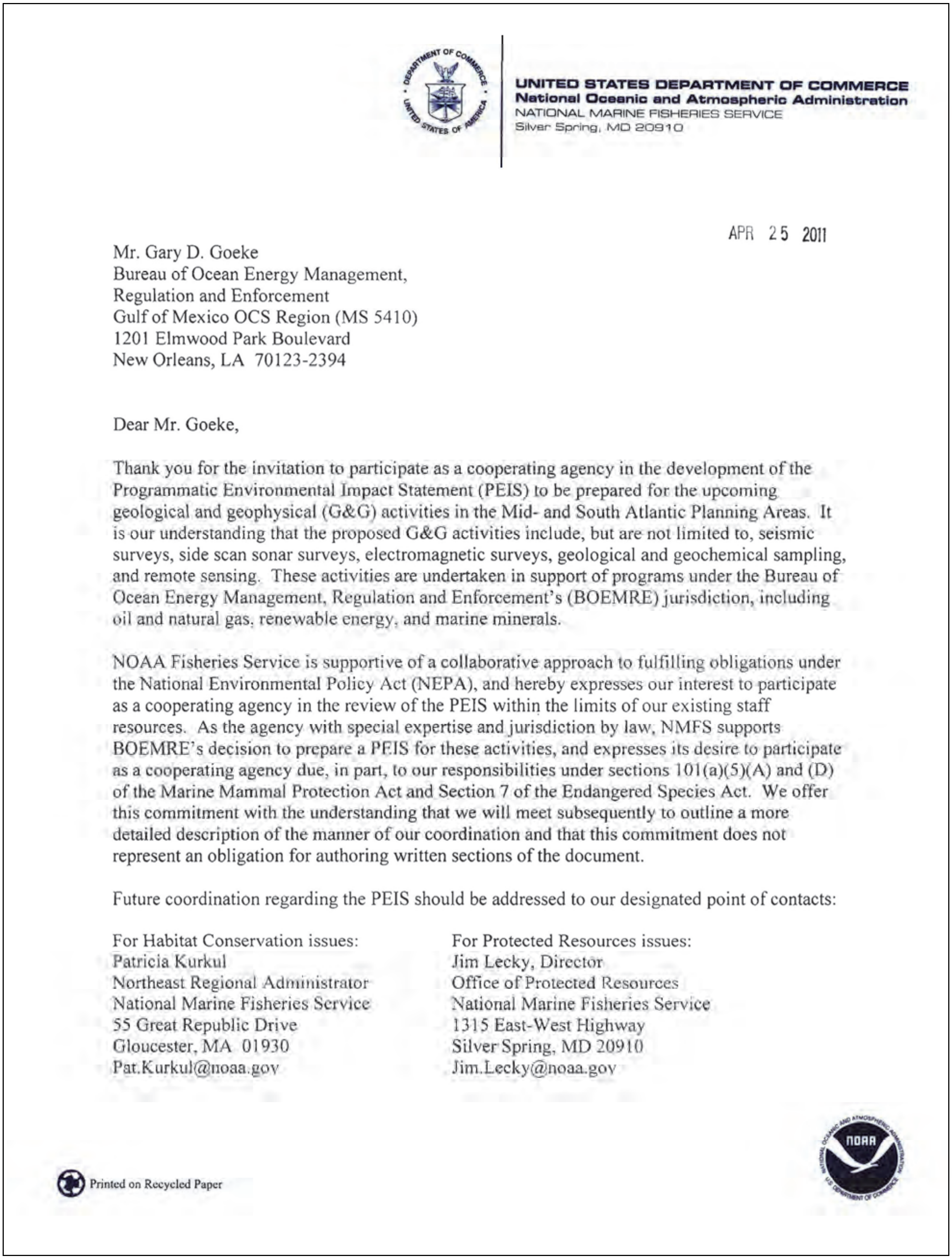


UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Silver Spring, MD 20910

APR 25 2011

Mr. Gary D. Goeke
Bureau of Ocean Energy Management,
Regulation and Enforcement
Gulf of Mexico OCS Region (MS 5410)
1201 Elmwood Park Boulevard
New Orleans, LA 70123-2394

Dear Mr. Goeke,

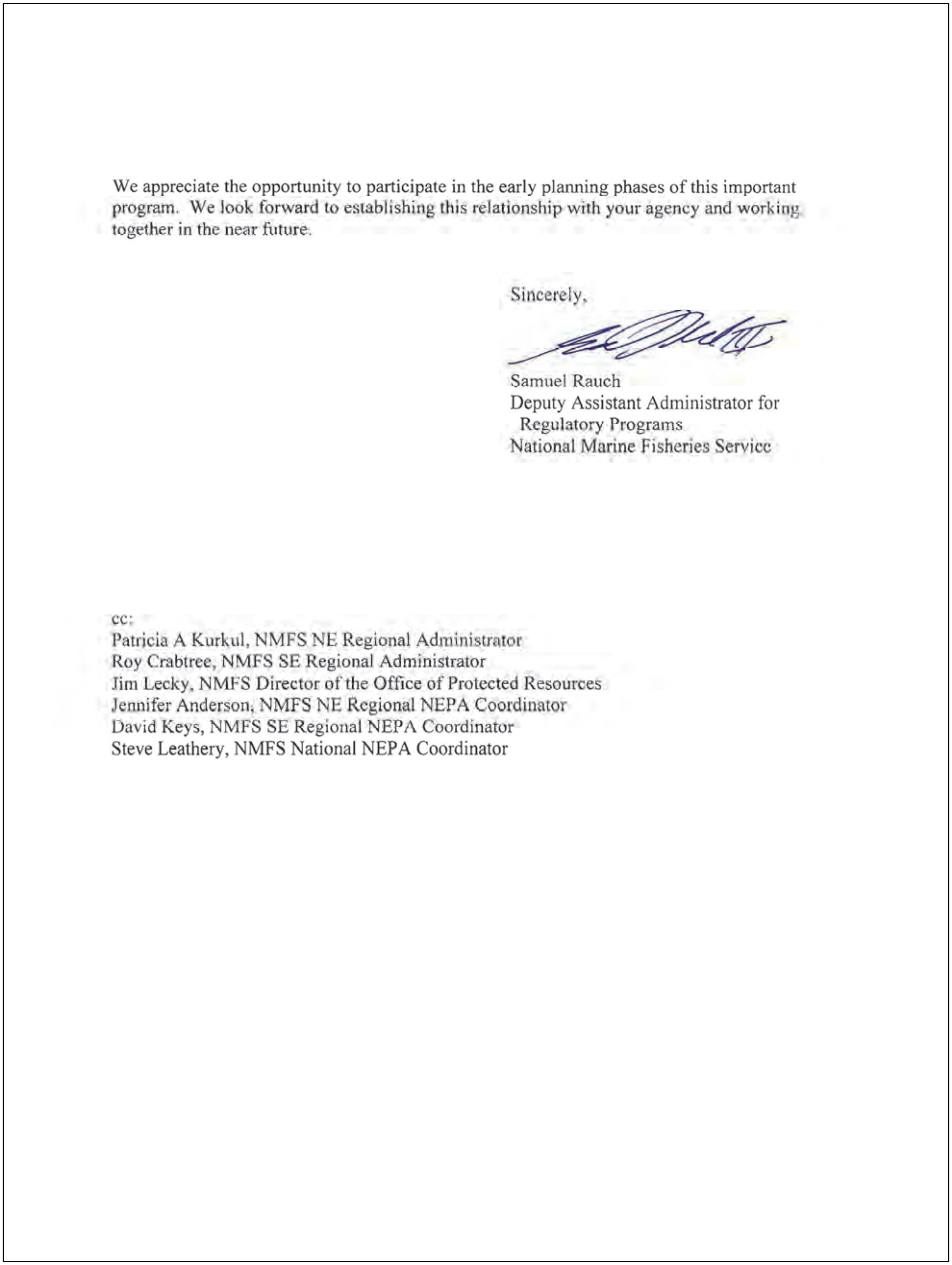
Thank you for the invitation to participate as a cooperating agency in the development of the Programmatic Environmental Impact Statement (PEIS) to be prepared for the upcoming geological and geophysical (G&G) activities in the Mid- and South Atlantic Planning Areas. It is our understanding that the proposed G&G activities include, but are not limited to, seismic surveys, side scan sonar surveys, electromagnetic surveys, geological and geochemical sampling, and remote sensing. These activities are undertaken in support of programs under the Bureau of Ocean Energy Management, Regulation and Enforcement's (BOEMRE) jurisdiction, including oil and natural gas, renewable energy, and marine minerals.

NOAA Fisheries Service is supportive of a collaborative approach to fulfilling obligations under the National Environmental Policy Act (NEPA), and hereby expresses our interest to participate as a cooperating agency in the review of the PEIS within the limits of our existing staff resources. As the agency with special expertise and jurisdiction by law, NMFS supports BOEMRE's decision to prepare a PEIS for these activities, and expresses its desire to participate as a cooperating agency due, in part, to our responsibilities under sections 101(a)(5)(A) and (D) of the Marine Mammal Protection Act and Section 7 of the Endangered Species Act. We offer this commitment with the understanding that we will meet subsequently to outline a more detailed description of the manner of our coordination and that this commitment does not represent an obligation for authoring written sections of the document.

Future coordination regarding the PEIS should be addressed to our designated point of contacts:

For Habitat Conservation issues:
Patricia Kurkul
Northeast Regional Administrator
National Marine Fisheries Service
55 Great Republic Drive
Gloucester, MA 01930
Pat.Kurkul@noaa.gov

For Protected Resources issues:
Jim Lecky, Director
Office of Protected Resources
National Marine Fisheries Service
1315 East-West Highway
Silver Spring, MD 20910
Jim.Lecky@noaa.gov

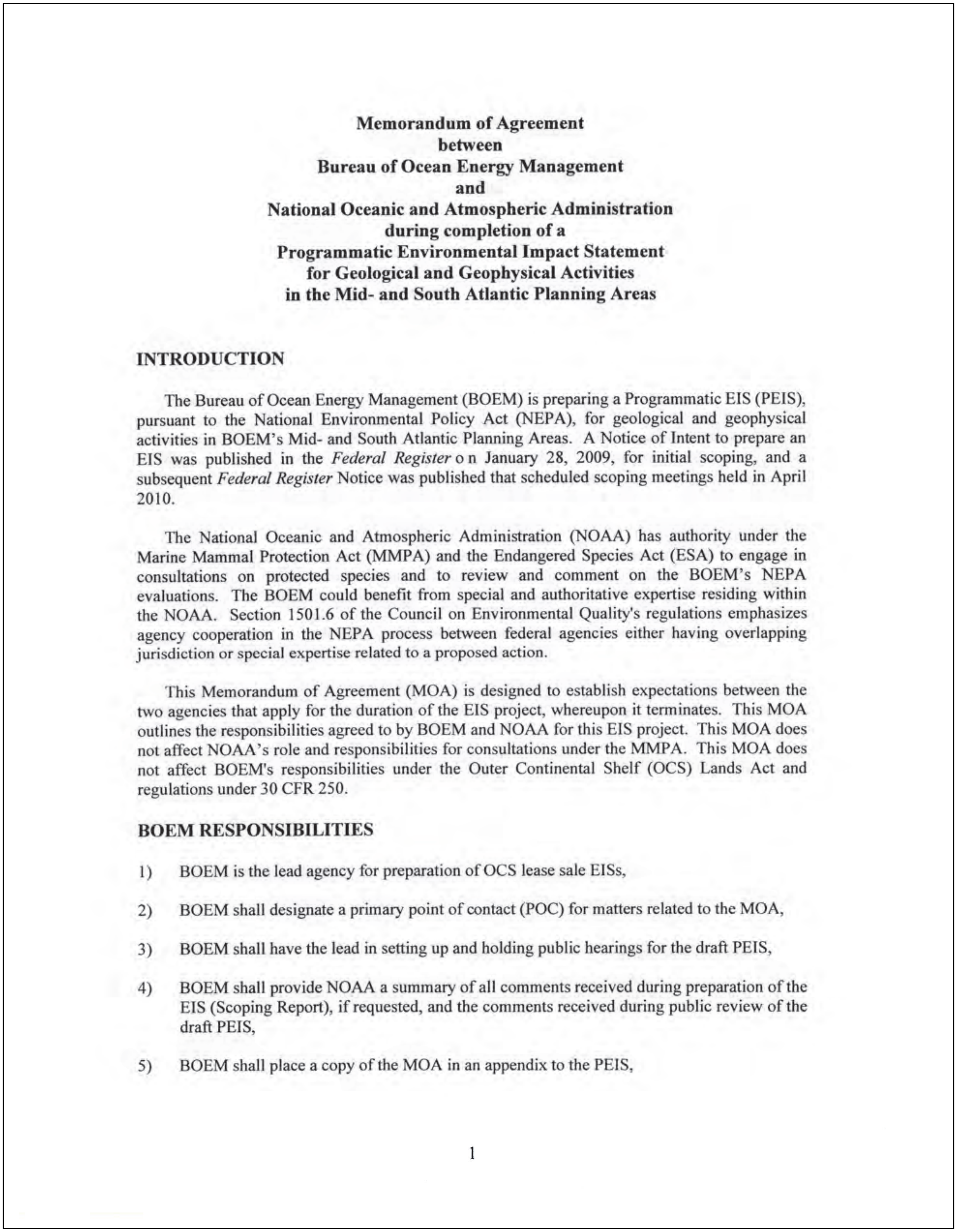


We appreciate the opportunity to participate in the early planning phases of this important program. We look forward to establishing this relationship with your agency and working together in the near future.

Sincerely,

Samuel Rauch
Deputy Assistant Administrator for
Regulatory Programs
National Marine Fisheries Service

cc:
Patricia A Kurkul, NMFS NE Regional Administrator
Roy Crabtree, NMFS SE Regional Administrator
Jim Lecky, NMFS Director of the Office of Protected Resources
Jennifer Anderson, NMFS NE Regional NEPA Coordinator
David Keys, NMFS SE Regional NEPA Coordinator
Steve Leathery, NMFS National NEPA Coordinator



Memorandum of Agreement
between
Bureau of Ocean Energy Management
and
National Oceanic and Atmospheric Administration
during completion of a
Programmatic Environmental Impact Statement
for Geological and Geophysical Activities
in the Mid- and South Atlantic Planning Areas

INTRODUCTION

The Bureau of Ocean Energy Management (BOEM) is preparing a Programmatic EIS (PEIS), pursuant to the National Environmental Policy Act (NEPA), for geological and geophysical activities in BOEM's Mid- and South Atlantic Planning Areas. A Notice of Intent to prepare an EIS was published in the *Federal Register* on January 28, 2009, for initial scoping, and a subsequent *Federal Register* Notice was published that scheduled scoping meetings held in April 2010.

The National Oceanic and Atmospheric Administration (NOAA) has authority under the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) to engage in consultations on protected species and to review and comment on the BOEM's NEPA evaluations. The BOEM could benefit from special and authoritative expertise residing within the NOAA. Section 1501.6 of the Council on Environmental Quality's regulations emphasizes agency cooperation in the NEPA process between federal agencies either having overlapping jurisdiction or special expertise related to a proposed action.

This Memorandum of Agreement (MOA) is designed to establish expectations between the two agencies that apply for the duration of the EIS project, whereupon it terminates. This MOA outlines the responsibilities agreed to by BOEM and NOAA for this EIS project. This MOA does not affect NOAA's role and responsibilities for consultations under the MMPA. This MOA does not affect BOEM's responsibilities under the Outer Continental Shelf (OCS) Lands Act and regulations under 30 CFR 250.

BOEM RESPONSIBILITIES

1) BOEM is the lead agency for preparation of OCS lease sale EISs,
2) BOEM shall designate a primary point of contact (POC) for matters related to the MOA,
3) BOEM shall have the lead in setting up and holding public hearings for the draft PEIS,
4) BOEM shall provide NOAA a summary of all comments received during preparation of the EIS (Scoping Report), if requested, and the comments received during public review of the draft PEIS,
5) BOEM shall place a copy of the MOA in an appendix to the PEIS,

6) BOEM shall provide NOAA with early versions of the PEIS sections as arranged between the BOEM and NOAA POCs,

7) BOEM shall provide NOAA with a preliminary copy of the draft PEIS for review prior to final lead agency approval and distribution of the document, and

8) BOEM shall respond to all comments received from NOAA.

NOAA RESPONSIBILITIES

1) NOAA is a cooperating agency for preparation of the PEIS,

2) NOAA's responsibilities for any environmental consultations required by law are not affected by this MOA,

3) NOAA shall designate a primary POC to represent NOAA in matters related to this MOA,

4) NOAA shall participate, as they deem appropriate, in the public hearing process,

5) NOAA shall provide BOEM a brief description of NOAA's reason(s) for participating as a cooperating agency for the PEIS,

6) NOAA comments on the draft PEIS submitted outside of the formal agency comment submission shall receive full and due consideration, but may not be made a part of the record,

7) NOAA shall comply with the schedule agreed upon between NOAA and BOEM for PEIS preparation and for all solicited inputs and review periods , and

8) NOAA shall be responsible for any expenses incurred by NOAA related to this MOA.

TERMINATION

The MOA may be terminated by written notice by either of the below signatories at any time. This MOA terminates at the conclusion of the PEIS project.

LIMITATIONS

All commitments made in the MOA are subject to the availability of appropriated funds and each agency's budget priorities. Nothing in the MOA obligates BOEM or NOAA to expend appropriations or to enter into any contract, assistance agreement, interagency agreement, or incur other financial obligations. This MOA is neither a fiscal nor a funds obligation document. Any endeavor involving reimbursement or contribution of funds between the parties to this MOA will be handled in accordance with applicable laws, regulations, and procedures, and will be subject to separate subsidiary agreements that will be effected in writing by representatives of both parties. This MOA does not create any right or benefit enforceable against the BOEM or NOAA, their officers or employees, or any other person. This MOA does not apply to any person outside BOEM and NOAA.

PREDECISIONAL MATERIALS

The undersigned hereby agrees to maintain confidentiality of information and documents shared between NOAA and the BOEM during completion of this PEIS. These confidentiality provisions apply to all communications, including: e-mail messages; notes to the file; agendas, pre-meeting materials, presentations, and meeting notes or summaries; letters, reviews, evaluations, and all documents created and shared as part of the collaboration established in this MOA.

Documents generated or shared in furtherance of this MOA shall be maintained as confidential by the parties. The parties have the right to expressly waive any privilege with regard to such documents and may do so by advising the other party in writing of its decision to waive the privilege.

Alan Thornhill, Ph.D.
Chief Environmental Officer
Bureau of Ocean Energy Management

1/3/12
Date

Samuel Rauch
Deputy Assistant Administrator
for Regulatory Programs
National Marine Fisheries Service
National Oceanic and Atmospheric Administration

12/12/11
Date

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

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.