DEPARTMENT OF THE NAVY
NAVAL SURFACE WARFARE CENTER
PANAMA CITY DIVISION
110 VERNON AVENUE
PANAMA CITY, FL 32407-7001

IN REPLY REFER TO:
5090
Ser B24/062
NOV 2 6 2012

Ms. Helen Golde
Acting Director, Office of Protected Resources
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1315 East-West Highway
SSMC3, Room 13821
Silver Spring, MD 20910-3282

Dear Ms. Golde:

The enclosed Incidental Harassment Authorization (IHA) application is provided pursuant to section 101(a)(5)(D) of the Marine Mammal Protection Act. This IHA application is for the incidental harassment of marine mammals from testing the AN/AQS-20A Mine Reconnaissance Sonar System in non-territorial waters of the Naval Surface Warfare Center Panama City Division (NSWC PCD) testing range from July 2013 through July 2014.

Enclosures (1),(2), and (3) focus on the specific information required by the National Marine Fisheries Service for consideration of the incidental harassment of marine mammals.

We appreciate your continued support in helping the Navy to meet its environmental responsibilities. The NSWC PCD point of contact is Ms. Carmen Ferrer at carmen.ferrer@navy.mil, or (850) 234-4146.

Sincerely,

E. S. PRATT
Captain, U.S. Navy
Commanding Officer

Enclosures:
1. IHA application
2. Testing the AN/AQS-20A Mine Reconnaissance Sonar System in the NSWC PCD Testing Range, 2012-2014 Overseas Environmental Assessment (OEA)
3. CD-ROM of IHA application and OEA

Copy to:
Ms. Jolie Harrison, NFMS Office of Protected Resources
Chief of Naval Operations (N45)
Commander, Naval Sea Systems Command (04RE)

INCIDENTAL HARRASSMENT AUTHORIZATION (IHA) APPLICATION FOR TESTING THE AN/AQS-20A MINE RECONNAISSANCE SONAR SYSTEM (Q-20)

IN THE

NAVAL SURFACE WARFARE CENTER PANAMA CITY DIVISION (NSWC PCD) STUDY AREA

Submitted To:

Office of Protected Resources
National Marine Fisheries Service
1315 East-West Highway
Silver Spring, MD 20910-3226

Prepared By:

Program Executive Office for Littoral Combat Ships (LCS)
Department of the Navy

November 2012

INCIDENTAL HARASSMENT AUTHORIZATION (IHA) APPLICATION FOR TESTING THE AN/AQS-20A MINE RECONNAISSANCE SONAR SYSTEM (Q-20) IN THE NAVAL SURFACE WARFARE CENTER PANAMA CITY DIVISION (NSWC PCD) STUDY AREA

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Program Executive Office for Littoral Combat Ships (LCS)
Department of the Navy (DON)

NOVEMBER 2012

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°	degree(s)
°C	degrees Celsius
°F	degrees Fahrenheit
°N	degrees North
°S	degrees South
3-D	three-dimensional
CASS-GRAB	Comprehensive Acoustic Simulation System/Gaussian Ray Bundle
dB	decibel(s)
dB re 1 μPa	decibel(s) referenced to 1 micropascal
dB re 1 μPa-m	decibel(s) referenced to 1 micropascal at 1 meter
dB re 1 μPa^2-s	decibel(s) referenced to 1 micropascal squared second
DOC	Department of Commerce
DON	Department of the Navy
EA	Environmental Assessment
EFD	energy flux density
EIS	Environmental Impact Statement
EL	energy flux density level
ESA	Endangered Species Act
ft	foot/feet
GOM	Gulf of Mexico
HFAS	High-Frequency Active Sonar
HFBL	High-Frequency Bottom Loss
hr	hour(s)
Hz	Hertz
IHA	Incidental Harassment Authorization
kHz	kilohertz
km	kilometer(s)
km^2	square kilometer(s)
LCS	Littoral Combat Ship
LFAS	Low-Frequency Active Sonar
LFBL	Low-Frequency Bottom Loss
m	meter(s)
m/sec	meter(s) per second
MCM	Mine Countermeasure
MFAS	Mid-Frequency Active Sonar
mi	mile(s)
min	minute(s)
MMPA	Marine Mammal Protection Act
MRA	Marine Resources Assessment

MSAT	Marine Species Awareness Training
nmi	nautical mile(s)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NODE	Navy OPAREA Density Estimate
NSWC PCD	Naval Surface Warfare Center Panama City Division
OEA	Overseas Environmental Assessment
OEIS	Overseas Environmental Impact Statement
OPAREA	operating area
PTS	permanent threshold shift
Q-20	AN/AQS-20A Mine Reconnaissance Sonar System
RDT&E	Research, Development, Test, and Evaluation
RL	received level
rms	root mean square
RMMV	Remote Multi-Mission Vehicle
SAR	Stock Assessment Report
sec	second(s)
SEL	sound exposure level
SL	source level
SOP	standard operating procedure
SPL	sound pressure level
SSC	Space and Naval Warfare Systems Center
SST	sea surface temperature
SURTASS	Surveillance Towed Array Sensor System
SVP	sound velocity profile
TACSIT	Tactical Situation
TL	transmission loss
TS	threshold shift
TTS	temporary threshold shift
U.S.	United States
USS	United States Ship
W-151	Military Warning Area 151

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1. DESCRIPTION OF ACTIVITIES

1.1 Introduction

Pursuant to the Marine Mammal Protection Act of 1972 (MMPA), this document is the annual application to the National Marine Fisheries Service (NMFS) for an Incidental Harassment Authorization (IHA) for incidental harassment of marine mammals from the United States (U.S.) Navy testing of the AN/AQS-20A Mine Reconnaissance Sonar System (hereafter referred to as the Q-20) in a portion of the Naval Surface Warfare Center Panama City Division (NSWC PCD) Study Area. The Proposed Action would be located within a portion of the NSWC PCD Testing Range, identified as the Tactical Situation (TACSIT) Channel in the non-territorial waters of the United States, and in adjacent waters that include Target and Operational Test Fields located in Military Warning Area 151 (W-151) (**Figure 1-1**). The northernmost portion of the TACSIT Channel is located approximately 59 kilometers (km) (32 nautical miles [nmi]) south of the city of Fort Walton Beach and continues for 69 km (37 nmi) in a generally southeastern direction. The test area is located in the northern Gulf of Mexico (GOM) between depths of 100 meters (m) and 250 m (330 feet [ft] to 820 ft) (DON 2012a). The U.S. Navy would temporarily deploy inert mine-like objects within this area to simulate a minefield. Mine shapes already in place for other test activities could also be used.

The MMPA as amended (16 United States Code Section (§) 101(a)(5)(D)), authorizes the issuance of IHAs for the incidental taking of marine mammals by a specified activity for a period not to exceed one year. The issuance occurs when the Secretary of Commerce finds, after notice has been published in the *Federal Register* and opportunity for comment has been provided, that such takes will have a negligible impact on the species and stocks of marine mammals and will not have an unmitigable adverse impact on their availability for subsistence uses. Furthermore, the issuance must identify the permissible methods of taking that would occur and mitigation, monitoring and reporting requirements. NMFS has promulgated implementing regulations under 50 Code of Federal Regulations § 216.101–106, which provide a mechanism for allowing the incidental harassment, but not serious injury or mortality, of marine mammals while engaged in a specified activity.

This document has been prepared in accordance with the applicable regulations and the MMPA, as amended by the National Defense Authorization Act for Fiscal Year 2004 (Public Law 108-136). Current year Q-20 test activities were authorized by an IHA. With this application, the U.S. Navy is requesting an IHA for a second year of Q-20 test activities that have the potential to affect marine mammals in non-territorial waters beginning 27 July 2013 and extending through 26 July 2014. The U.S. Navy respectfully requests that NMFS authorize this incidental taking of marine mammals pursuant to the MMPA, with the issuance of an IHA by 27 July 2013.

1.2 Purpose and Need

The purpose of the Proposed Action is to meet the developmental testing requirements of the Q-20 by verifying its performance in a realistic ocean and threat environment and supporting its integration with the Remote Multi-Mission Vehicle (RMMV), and ultimately with the Littoral

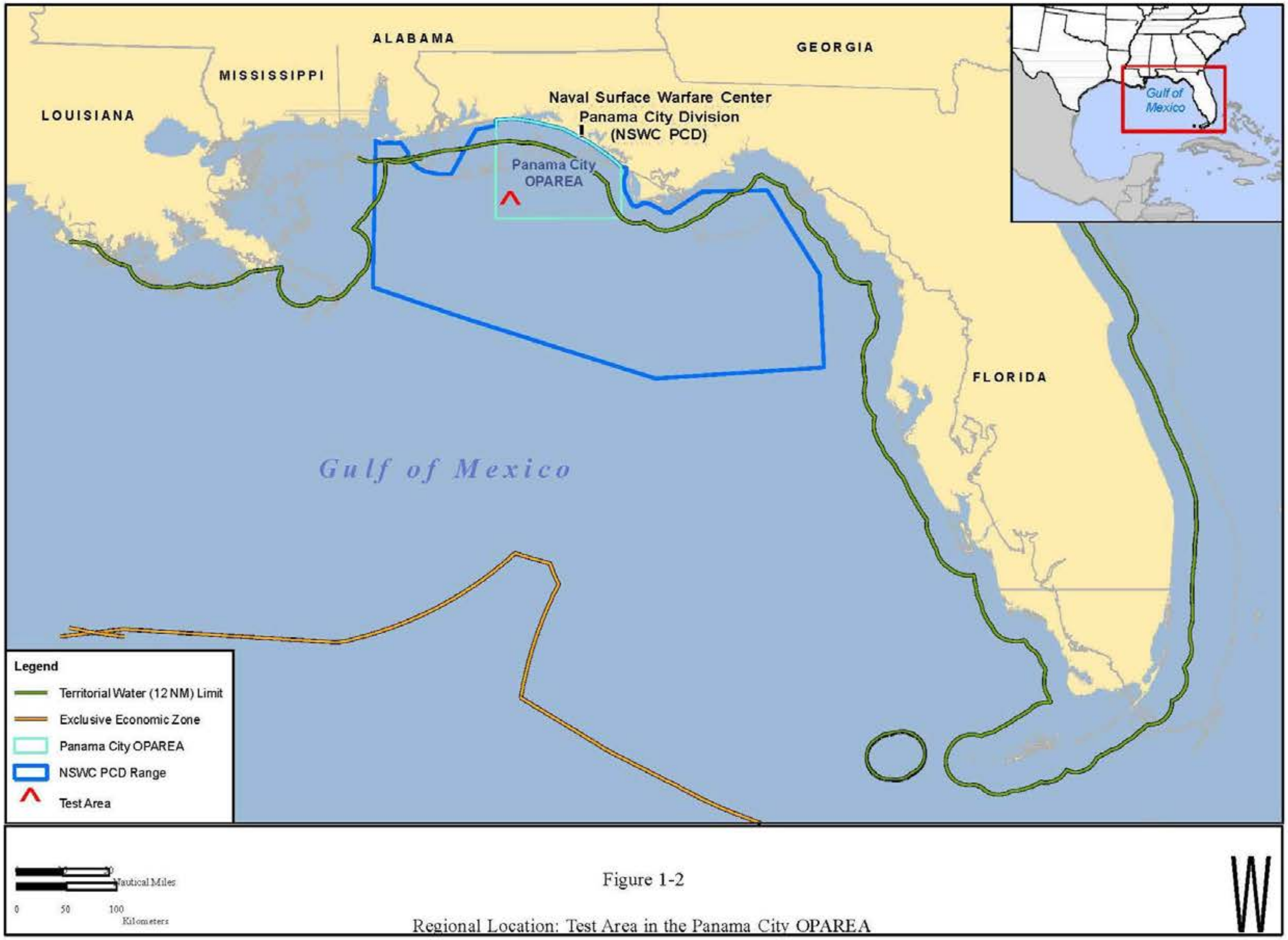

Figure 1-1. Regional Extent of the Q-20 Study Area.

Combat Ship (LCS). The need for the Proposed Action is to support the timely deployment of the Q-20 to the operational U.S. Navy for Mine Countermeasure (MCM) activities abroad, which would allow the U.S. Navy to meet its mission to deploy naval forces equipped and trained to meet existing and emergent threats worldwide and to enhance its ability to operate jointly with other components of the armed forces. Testing would include component, subsystem-level, and full-scale system testing in the operational environment.

1.3 Description of the Proposed Action

The Proposed Action is to test the Q-20 from the RMMV and from surrogate platforms (e.g., small surface vessel or helicopter). The RMMV and surrogate platforms will be deployed from the U.S. Navy‘s LCS or its surrogates. This IHA application is evaluating potential effects to marine mammals associated with the Q-20 test activities proposed for the Q-20 Study Area, which includes non-territorial waters of W-151 (which includes the Panama City Operating Area [OPAREA]). Q-20 test activities occur at sea in the waters present within the Q-20 Study Area and do not involve any land-based facilities. No hazardous waste is generated at sea during Q-20 test activities. This IHA request evaluates only the at-sea activities related to Q-20 test activities conducted within the Q-20 Study Area and does not address routine shore-side management functions performed by the supporting ashore U.S. Navy facility.

1.3.1 Basis for Operations Addressed in this IHA Application

This document addresses only mission components analyzed in the *Overseas Environmental Assessment for Testing the AN/AQS-20A in the NSWC PCD Testing Range, 2012-2014* (the Q-20 OEA) that may result in the incidental taking of marine mammal species. Test activities that have been identified with the potential to affect the underwater environment in regions inside and outside of the Q-20 Study Area include surface operations and sonar operations. Laser operations and mine field deployment and retrieval operations covered within the Proposed Action are eliminated from further discussion in this IHA application because these actions would not result in takes of marine mammal species as evaluated in the Q-20 OEA and concluded in the subsequent Finding of No Significant Harm (DON 2012a, DON 2012b).

1.3.2 Q-20 Test Activities

Surface Operations

A significant portion of Q-20 test activities rely on surface operations (i.e., naval and contracted vessels, towed bodies, etc.) to successfully complete missions. Q-20 test activities involving surface operations could result in incidental harassment of marine mammals by vessel collisions and behavioral disturbance. Three subcategories make up surface operations: support activities, tows, and vessel activity during deployment and recovery of equipment. Q-20 testing that requires surface operations may include a single test event (one day of activity) or a series of test events spread out over several days. The size of the surface vessels varies in accordance with the test requirements and vessel availability. Often, multiple surface craft are required to support a single test event. The following paragraphs provide details for each of these activities.

The first subcategory of surface operations is support activities that are required by nearly all of the Q-20 test missions within the Q-20 Study Area. These vessels serve as support platforms for testing and are used to carry test equipment and personnel to and from the test sites, and to secure and monitor the designated test area. Normally, these vessels remain on site and return to port following the completion of the test event; however, they occasionally remain on station throughout the duration of the test cycle (a maximum of 10 hr of sonar per day) to guard sensitive equipment in the water.

The remaining subcategories of surface operations include tows, and vessel activity during deployment and recovery of equipment. Tows involve either transporting the system to the designated test area where it is deployed and towed over a pre-positioned inert minefield or towing the system from shore-based facilities for operation in the designated test area. Surface vessels are also used to perform the deployment and recovery of the RMMV, mine-like objects, and other test systems. Surface vessels that are used in this manner normally return to port the same day. However, this is test-dependent, and under certain circumstance the surface vessel may be required to remain on site for an extended period of time.

Sonar Operations

Q-20 sonar operations involve the testing of various sonar systems at sea to demonstrate the system‘s software capability to detect, locate, and characterize mine-like objects under various environmental conditions. The data collected are used to validate the sonar systems‘ effectiveness and capability to meet their mission.

As sound travels through water, it creates a series of pressure disturbances (see **Appendix C**). *Frequency* is the number of complete cycles a sound or pressure wave occurs per unit of time (measured in cycles per second [sec], or Hertz [Hz]). The U.S. Navy has characterized low-, mid-, and high-frequency sonar as follows:

- **Low-frequency active sonar (LFAS) –** Below 1 kilohertz (kHz) (note: low-frequency will not be used during any Q-20 test activities).
- **Mid-frequency active sonar (MFAS) –** From 1 to 10 kHz (note: mid-frequency will not be used during any Q-20 test activities).
- **High-frequency active sonar (HFAS)** – Above 10 kHz (note: Q-20 test activities will use high-frequency sound sources).

The Q-20 proposed to be tested within the Q-20 Study Area ranges from 35 kHz to greater than 200 kHz. The sonar systems that operate at very high frequencies (i.e., greater than 200 kHz), well above the hearing sensitivities of any marine mammals, are not required to be quantitatively analyzed and are not included in this document. The source levels associated with the Q-20 that require analysis in this document range from 207 to 212 decibels referenced to 1 micropascal at 1 meter (dB re 1 µPa-m). Operating parameters of the Q-20 are found in **Appendix A**.

2. DURATION AND LOCATION OF THE ACTIVITIES

This IHA application addresses all of the Q-20 test activities involving sonar and surface operations that occur in the Q-20 Study Area. The Q-20 Study Area includes target and operational test fields located in W-151, an area within the GOM subject to military operations, which encompasses the Panama City OPAREA (**Figure 2-1**). The Q-20 test activities will be conducted in the non-territorial waters of the United States (waters beyond 22 km [12 nmi]). The locations and environments include:

- A wide coastal shelf with a bottom depth to 183 m (600 ft).
- Sea surface temperatures (SST) ranging from 27 degrees Celsius (°C; 80 degrees Fahrenheit [°F]) in summer to 10°C (50°F) in winter. Seasons are defined as 23 December through 2 April (winter) and 2 July through 24 September (summer) (DON 2007a).
- Mostly sandy bottom and good underwater visibility.
- Sea heights less than 0.91 m (3 ft) during 80 percent of the time in summer and 50 percent of the time in winter (DON 2009a).

This IHA application is for a time period of one year beginning 27 July 2013 and extending through 26 July 2014. Forty-two RDT&E test days would be conducted with a maximum sonar operation of 10 hours per test day.

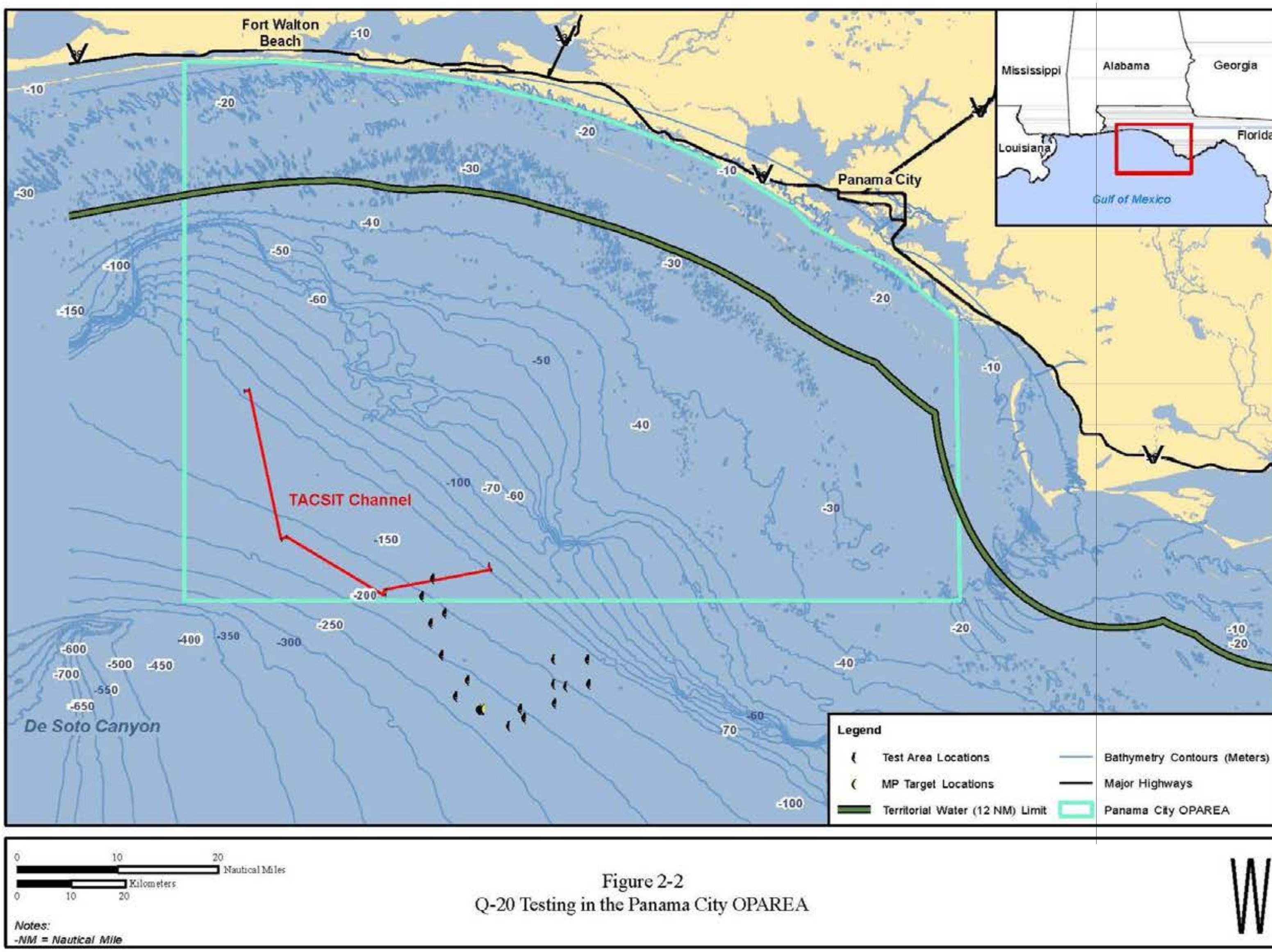

Figure 2-1. Q-20 Study Area.

3. MARINE MAMMAL SPECIES AND NUMBERS

Twenty-nine marine mammal species have documented occurrence in the GOM: 28 cetacean species (**Table 3-1**) and the West Indian manatee (*Trichechus manatus*) (Würsig et al. 2000). Because the manatee is under the jurisdiction of the U.S. Fish and Wildlife Service, this species will not be discussed further in this take permit request to NMFS. All marine mammal species are protected by the MMPA, and six cetacean species are additionally listed as endangered under the Endangered Species Act (ESA) (**Table 3-1**). No ESA-listed species are expected in the Q-20 Study Area as discussed in this section. The discussion below describes all of the species whose ranges include the GOM and identifies which are most likely to occur in the Q-20 Study Area (DON 2007a).

3.1 Marine Mammal Occurrence

Most of the cetacean species occurring in the GOM are toothed whales. The Bryde‘s whale (*Balaenoptera edeni*) is the only baleen whale species expected to occur regularly in the northeastern GOM where Q-20 sonar operations would be conducted. Since the Q-20 Study Area extends close to and in some cases over the continental shelf break, deepwater marine mammal species have a more likely occurrence.

Table 3-2 provides an overview of the abundance estimates for marine mammal stocks in the eastern GOM, which includes the Q-20 Study Area. The NMFS‘s 2012 Draft Stock Assessment Report (SAR) (NMFS 2012) provides the most recent abundance estimates. For a change in population estimate compared to previously published SARs, an increase or decrease was noted in the table. An increase constitutes any positive change, whereas a decrease constitutes any negative change, regardless of significance. If the population estimate did not change from previous SARs, then a no change was noted. **Table 3-2** addresses only those species that are carried forward for analysis of potential effects from Q-20 test activities in this IHA.

Table 3-3 identifies the species included in the analysis and provides a basis for the species that are eliminated from further discussion in this IHA application. Rarely sighted species include the North Atlantic right whale (*Eubalaena glacialis*), the humpback whale (*Megaptera novaeangliae*), the sei whale (*Balaenoptera borealis*), the fin whale (*Balaenoptera physalus*), and the blue whale (*Balaenoptera musculus*) (DON 2007a), which are all dismissed from further analysis.

Table 3-1. Cetacean Species with Occurrence Records in the GOM.

Common Name	Scientific Name	ESA Status	MMPA Status
Suborder Mysticeti (baleen whales)			
Family Balaenopteridae (rorquals)			
Blue whale	*Balaenoptera musculus*	Endangered	Depleted/Strategic
Bryde's whale	*Balaenoptera edeni*		Strategic
Fin whale	*Balaenoptera physalus*	Endangered	Depleted/Strategic
Humpback whale	*Megaptera novaeangliae*	Endangered	Depleted/Strategic
Minke whale	*Balaenoptera acutorostrata*		
Sei whale	*Balaenoptera borealis*	Endangered	Depleted/ Strategic
Family Balaenidae			
North Atlantic right whale	*Eubalaena glacialis*	Endangered	Depleted/Strategic
Suborder Odontoceti (toothed whales)			
Family Delphinidae (dolphins)			
Atlantic spotted dolphin	*Stenella frontalis*		
Bottlenose dolphin	*Tursiops truncatus*		Depleted/Strategic[1]
Clymene dolphin	*Stenella clymene*		
False killer whale	*Pseudorca crassidens*		
Fraser's dolphin	*Lagenodelphis hosei*		
Killer whale	*Orcinus orca*		
Melon-headed whale	*Peponocephala electra*		
Pantropical spotted dolphin	*Stenella attenuata*		
Pygmy killer whale	*Feresa attenuata*		
Risso's dolphin	*Grampus griseus*		
Rough-toothed dolphin	*Steno bredanensis*		
Short-finned pilot whale	*Globicephala macrorhynchus*		
Spinner dolphin	*Stenella longirostris*		
Striped dolphin	*Stenella coeruleoalba*		
Family Kogiidae			
Pygmy sperm whale	*Kogia breviceps*		
Dwarf sperm whale	*Kogia sima*		
Family Physeteridae (sperm whale)			
Sperm whale	*Physeter macrocephalus*	Endangered	Depleted/Strategic
Family Ziphiidae (beaked whales)			
Blainville's beaked whale	*Mesoplodon densirostris*		
Cuvier's beaked whale	*Ziphius cavirostris*		
Gervais' beaked whale	*Mesoplodon europaeus*		
Sowerby's beaked whale	*Mesopolodon bidens*		

[1]Nine bottlenose dolphin stocks currently have been identified in the GOM and its associated bay and estuaries. Six of these are currently considered depleted/strategic. The Northern GOM Coastal Stock, which occurs within the Q-20 Study Area is considered depleted/strategic.

Table 3-2. Abundance Estimates for Marine Mammal Stocks Occurring in the Q-20 Study Area as Provided by NMFS.

Species	Stock	Best Population Estimate	Minimum Population Estimate
Atlantic spotted dolphin[=]	Northern GOM	UNK	UNK
Bottlenose dolphin[=]	Northern GOM Continental Shelf	UNK	UNK
Bottlenose dolphin[+]	Northern GOM Oceanic	5,806	4,230
Bottlenose dolphin[=]	Northern GOM Coastal	2,473	2,004
Bryde‘s whale[+]	Northern GOM	33	16
Clymene dolphin[-]	Northern GOM	129	64
Cuvier‘s beaked whale[+]	Northern GOM	74	36
False killer whale[*]	Northern GOM	UNK	UNK
Fraser‘s dolphin	Northern GOM	NA	NA
Killer whale[-]	Northern GOM	28	14
Kogia sp. (Dwarf and pygmy sperm whales) [-]	Northern GOM	186	90
Melon-headed whale[-]	Northern GOM	2,235	1,274
Mesoplodon sp. (Blainville‘s and Gervais‘ beaked whales) [+]	Northern GOM	149	77
Pantropical spotted dolphin[+]	Northern GOM	50,880	40,699
Pygmy killer whale[-]	Northern GOM	152	75
Risso‘s dolphin[+]	Northern GOM	2,442	1,563
Rough-toothed dolphin[-]	Northern GOM	624	311
Short-finned pilot whale[+]	Northern GOM	2,415	1,456
Sperm whale[-]	Northern GOM	763	560
Spinner dolphin[+]	Northern GOM	11,441	6,221
Striped dolphin[-]	Northern GOM	1,849	1,041

Source: NMFS 2012

GOM = Gulf of Mexico; N/A = Not applicable, zero to one sighting available for estimate; SAR=Stock Assessment Report; UNK = Unknown, because data used to derive population estimates is at least 8 years old. Data older than at least 8 years are deemed unreliable by NMFS (Moore and Merrick 2011).

[+]Increase in size from previous SAR

[-]Decrease in size from previous SAR

[=]No change in size or estimation from previous SAR

[*] Numerical best and minimum population estimates previously provided for the false killer have been updated to unknown.

Table 3-3. Cetacean Species of the GOM Analyzed in this Q-20 IHA Application.

Species	Analyzed?	Reason for Dismissal
Atlantic spotted dolphin *Stenella frontalis*	Yes	
Blainville‘s beaked whale *Mesoplodon densirostris*	Yes	
Blue whale *Balaenoptera musculus*	No	Blue whales are considered extralimital[1] to the Q-20 Study Area; therefore, the species is dismissed from further discussion and analysis.
Bottlenose dolphin *Tursiops truncatus*	Yes	
Bryde‘s whale *Balaenoptera edeni*	Yes	
Clymene dolphin *Stenella clymene*	Yes	
Cuvier‘s beaked whale *Ziphius cavirostris*	Yes	
Dwarf sperm whale *Kogia simus*	Yes	
False killer whale *Pseudorca crassidens*	Yes	
Fin whale *Balaenoptera physalus*	No	Fin whales are considered extralimital[1] to the Q-20 Study Area; therefore, the species is dismissed from further discussion and analysis.
Fraser‘s dolphin *Lagenodelphis hosei*	Yes	
Gervais‘ beaked whale *Mesoplodon europaeus*	Yes	
Humpback whale *Megaptera novaeangliae*	No	Humpback whales are considered extralimital[1] to the Q-20 Study Area; therefore, the species is dismissed from further discussion and analysis.
Killer whale *Orcinus orca*	Yes	
Melon-headed whale *Peponocephala electra*	Yes	
Minke whale *Balaenoptera acutorostrata*	No	Minke whales have a low occurrence[1] in the GOM and no distribution is expected in the Q-20 Study Area. Therefore, the species is dismissed from further discussion and analysis.
North Atlantic right whale *Eubalaena glacialis*	No	Right whales are considered extralimital[1] to the Q-20 Study Area; therefore, the species is dismissed from further discussion and analysis.
Pantropical spotted dolphin *Stenella attenuata*	Yes	
Pygmy killer whale *Feresa attenuata*	Yes	
Pygmy sperm whale *Kogia breviceps*	Yes	

Species	Analyzed?	Reason for Dismissal
Risso‘s dolphin *Grampus griseus*	Yes	
Rough-toothed dolphin *Steno bredanensis*	Yes	
Sei whale *Balaenoptera borealis*	No	Sei whales are considered extralimital[1] to the Q-20 Study Area; therefore, the species is dismissed from further discussion and analysis.
Short-finned pilot whale *Globicephala macrorhynchus*	Yes	
Sowerby‘s beaked whale *Mesoplodon bidens*	No	Sowerby‘s beaked whales are considered extralimital[1] to the Q-20 Study Area; therefore, the species is dismissed from further discussion and analysis.
Sperm whale *Physeter macrocephalus*	Yes	
Spinner dolphin *Stenella longirostris*	Yes	
Striped dolphin *Stenella coeruleoalba*	Yes	

Source: DON 2007a

[1]Definitions:

Extralimital occurrence = area where species occasionally occur in very small numbers.

Low/unknown occurrence = area where the likelihood of encountering a species is rare or there is not sufficient data to support a more definitive conclusion.

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4. ASSESSMENT OF MARINE MAMMAL SPECIES OR STOCKS THAT COULD POTENTIALLY BE AFFECTED

This section provides detailed information on the marine mammal species in the Q-20 Study Area potentially affected by the proposed Q-20 testing. As defined in **Section 2**, Q-20 test activities take place in the non-territorial waters of W-151 (which includes Panama City OPAREA) in the GOM.

The U.S. Navy Marine Resources Assessment (MRA) program was implemented by the Commander, U.S. Fleet Forces Command, to collect data and information on the protected and commercial marine resources found in the U.S. Navy OPAREAs. Specifically, the goal of the MRA program is to describe and document the marine resources present in each of the U.S. Navy‘s OPAREAs. As such, an MRA was finalized in 2007 for the GOM, which comprises three adjacent OPAREAs, one of which is the Panama City OPAREA (DON 2007a). The MRA represents a compilation and synthesis of available scientific literature (e.g., journals, periodicals, theses, dissertations, project reports, and other technical reports published by government agencies, private businesses, or consulting firms) and NMFS reports, including stock assessment reports, recovery plans, and survey reports. The MRA summarizes the physical environment (e.g., marine geology, circulation and currents, hydrography, and plankton and primary productivity) for each test area and an in-depth discussion of the biological environment (e.g., marine mammals). **Appendix A** contains more information about each marine mammal species potentially found in the Q-20 Study Area. The GOM MRA also contains detailed information, with a species description, status, habitat preference, distribution, behavior and life history, as well as information on its acoustics and hearing ability (DON 2007a).

4.1 Mysticetes

The following mysticetes have probable or confirmed occurrence in the Q-20 Study Area in the GOM. The respective population estimates and statuses were taken from the most recent NMFS 2012 Draft SAR (NMFS 2012).

Bryde's Whale (Balaenoptera edeni)

Description **–** The Bryde‘s whale is a medium-sized baleen whale. Adults can be up to 15.5 m (51 ft) in length, but there is a smaller ―dwarf" species that rarely reaches over 10 m (33 ft) in length. Bryde‘s whales can be easily confused with sei whales; however, closer examination reveals them to have a number of distinctive characteristics. It is not clear how many species of Bryde‘s whales there are, but genetic analyses suggest the existence of at least two species. Bryde‘s whales are lunge-feeders, feeding primarily on fish, but they also take small crustaceans.

Status **–** Currently, the best estimate of abundance for Bryde‘s whales within the Northern GOM Stock is 33, with a minimum population size estimate of 16 whales (NMFS 2012). In 2011, the best estimate abundance recorded for Bryde‘s whales within the Northern GOM Stock was 15, with a minimum population estimate of 5 whales (Waring et al. 2012). It has been suggested that the Bryde‘s whales found in the GOM may represent a resident stock, but there is no information on stock differentiation (Waring et al. 2012). The NMFS SAR provisionally considers the GOM population a separate stock from the Atlantic Ocean stock(s).

Distribution **–** The Bryde‘s whale is found in tropical and subtropical waters, generally not moving poleward of 40 degrees (°) in either hemisphere. Long migrations are not typical of Bryde‘s whales although limited shifts in distribution toward and away from the equator in winter and summer, respectively, have been observed. Most sightings in the GOM have been made in the DeSoto Canyon region and off western Florida (DON 2007a). Additional information on reproductive areas and seasons for this species is not available.

Diving Behavior – Alves et al. (2010) reported a distribution of time spent shallow and deep diving for two whales tagged with a time-depth recorder near Madeira Island, Spain. Watwood and Buonantony (2012) report that the average percentage of time spent between the 0 and 40 m (0 and 131 ft) depth range is 84.5 percent, while 15.3 percent is spent in the 40 to 292 m (131-958 ft) range (Watwood and Buonantony 2012).

Acoustics and Hearing **–** Bryde‘s whales are classified in the low-frequency functional hearing group whose functional hearing range is 7 Hz to 22 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the low-frequency group ranges from 10 to 20 Hz and 137 to 192 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area – Bryde‘s whales found in the GOM may represent a resident stock. Bryde‘s whales are not frequently sighted in the GOM, although they are observed more frequently than any other species of baleen whale in this region. Nothing is known of their movement patterns in this area, and strandings are scattered throughout the coastline of the northern GOM. Therefore, there is a low or unknown occurrence of Bryde‘s whale from the shelf break to the 2,000-m (6,562-ft) isobath throughout most of the Q-20 Study Area (DON 2007a).

Bryde‘s whales are expected to occur year-round in an area encompassing the DeSoto Canyon and an area off western Florida, from the shelf break to the 2,000-m (6,562-ft) isobath, based on the fact that most sightings were made in this region during dedicated cetacean surveys (Davis et al. 2000, 2002). Also considered was the likelihood that Bryde‘s whale movements are taking place in oceanic waters in this area.

4.2 Odontocetes

The following odontocetes have probable or confirmed occurrence in the Q-20 Study Area in the GOM and are included in the analysis of potential effects to marine mammals from Q-20 sonar operations. Biographical information for each species with requested takes in this IHA application is presented here and was taken from the MRA for the GOM (DON 2007a). The respective population estimates and statuses were taken from the most recent NMFS 2012 Draft SAR (NMFS 2012).

Atlantic Spotted Dolphin (*Stenella frontalis)*

Status **–** The best estimate of abundance and minimum population estimate for Atlantic spotted dolphins in the northern GOM is currently unknown due to current data being at least 8 years old

(NMFS 2012). In 2008, the best estimate of abundance for Atlantic spotted dolphins in the northern GOM was 37,611, with a minimum population estimate of 29,844 individuals (Waring et al. 2009a).

Distribution **–** The Atlantic spotted dolphin, as its name suggests, is endemic to the tropical and warm-temperate Atlantic Ocean. In the western North Atlantic, this translates to waters from New England to the GOM and the Caribbean, and southward to the coast of Venezuela. Known densities of Atlantic spotted dolphins are highest in the eastern GOM, east of Mobile Bay. The large, heavily spotted coastal form of the Atlantic spotted dolphin typically occurs over the continental shelf inside or near the 185-m (607-ft) isobath, usually at least 8 to 20 km (4 to 11 nmi) offshore. Sightings of offshore spotted dolphins have been made along the north wall of the Gulf Stream and warm-core ring features. Additional information on reproductive areas and seasons is not available for this species (DON 2007a).

Diving Behavior – The only information on dive depth for Atlantic spotted dolphins is based on a satellite-tagged individual from the GOM. This individual made short, shallow dives (over 76 percent of the time to depths less than 10 m [33 ft]) over the continental shelf, although some dives were as deep as 40 to 60 m (131 to 197 ft) (DON 2007a). Watwood and Buonantony (2012) presented dive depth distribution for this species as: 87 percent at 0-20 m (0-66 ft), 8 percent at 20 to 30 m (66 to 98 ft), and 5 percent at 30 to 60 m (98 to 197 ft).

Acoustics and Hearing – Atlantic spotted dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 μPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** The Atlantic spotted dolphin is expected to occur in waters over the continental shelf in the GOM from the 10-m (33-ft) isobath to the shelf break. The majority of the past sightings support this determination. Taking into consideration sightings recorded seaward of the continental shelf break and over the continental slope near the Mississippi River Delta and in the southern GOM, there is a low or unknown occurrence of this species between the shelf break and the 2,000-m (6,562-ft) isobath. Occurrence is assumed to be similar during all seasons (DON 2007a).

Beaked Whales (Various Species)

Description **–** Worldwide, there are 20 recognized beaked whale species in five genera (Mead 2002). In the GOM, four have documented occurrence, including Cuvier‘s beaked whale (*Ziphius cavirostris*) and three members of the genus *Mesoplodon* (Gervais‘ [*Mesoplodon europaeus*], Blainville‘s [*Mesoplodon densirostris*], and Sowerby‘s beaked whales [*Mesoplodon bidens*]). Since Sowerby‘s beaked whale is considered extralimital, it is excluded from further analysis within this report.

Identification of *Mesoplodon* to species is very difficult, and in many cases, *Mesoplodon* and Cuvier‘s beaked whale (*Ziphius cavirostris*) cannot be distinguished; therefore, sightings of beaked whales (Family Ziphiidae) are identified as *Mesoplodon* sp., Cuvier‘s beaked whale, or unidentified Ziphiidae. Of the beaked whale species, the Cuvier's beaked whale is the easiest to identify. With the exception of the Cuvier's beaked whale, the aforementioned beaked whale species are nearly indistinguishable at sea. Little is known about the habitat preferences of beaked whales. All species of beaked whales probably feed at or close to the bottom in deep oceanic waters, taking whatever suitable prey they encounter or feeding on whatever species are locally abundant.

Mesoplodon species have maximum reported adult lengths of 6.2 m (20 ft); Blainville's beaked whales are documented to reach a maximum length of around 4.7 m (15 ft); and Gervais' beaked whale males reach lengths of at least 4.5 m (15 ft), while females reach at least 5.2 m (17 ft). Cuvier's beaked whales are relatively robust compared to other beaked whale species. Male and female Cuvier's beaked whales may reach 7.5 and 7.0 m (24.6 and 23.0 ft) in length, respectively.

Status – Currently, the best estimate of abundance for Cuvier's beaked whales in the northern GOM is 74 individuals, with a minimum population estimate of 36 Cuvier's beaked whales (NMFS 2012). In 2009, the best estimate of abundance for Cuvier's beaked whales in the northern GOM was 65, with a minimum population estimate of 39 (Waring et al. 2009a). Currently, the best estimate of abundance for *Mesoplodon* species (Blainville's and Gervais' beaked whales) in the northern GOM is 149 animals. The minimum population estimate for *Mesoplodon* species in the northern GOM is 77 (NMFS 2012). In 2009, the best estimate of abundance for *Mesoplodon* species in the northern GOM was 57, with a minimum population estimate of 24 (Waring et al. 2009a).

Distribution – Little is known about beaked whale habitat preferences. World-wide, beaked whales normally inhabit continental slope and deep oceanic waters, normally inhabiting deep ocean waters (below 2,000 m [6,562 ft]) or continental slopes (200 to 2,000 m [656 to 6,562 ft]), and rarely straying over the continental shelf. In the GOM, beaked whales are seen in waters with a bottom depth ranging from 420 to 3,487 m (1,378 to 11,440 ft). In many locales, occurrence patterns have been linked to physical features, in particular, the continental slope, canyons, escarpments, and oceanic islands.

Cuvier's beaked whales are the most widely distributed of the beaked whales and are present in most regions of all major oceans. This species occupies almost all temperate, subtropical, and tropical waters, as well as subpolar and even polar waters in some areas. Cuvier's and Blainville's beaked whales are generally sighted in waters with a bottom depth greater than 200 m (656 ft) and are frequently recorded at bottom depths greater than 1,000 m (3,281 ft). At oceanic islands, Cuvier's beaked whales may be found in deeper waters than Blainville's beaked whales. Information on reproductive areas and seasons is not available for these species.

The ranges of most mesoplodonts are poorly known. The distributions of these species in the GOM are known almost entirely from strandings, and may relate to water temperature (DON 2007a). Information on reproductive areas and seasons is not available for these species.

Blainville's and Gervais' beaked whales generally occur in warmer, southern waters. The Blainville's beaked whale is thought to have a continuous distribution throughout the tropical, subtropical, and warm-temperate waters of the world's oceans, occurring occasionally in cold temperate areas. There are occurrence records for the Blainville‘s beaked whale from Nova Scotia south to Florida, the Bahamas, and the GOM. The Gervais‘ beaked whale is restricted to warm-temperate and tropical Atlantic waters with records throughout the Caribbean Sea. The Gervais‘ beaked whale is the most frequently-stranded beaked whale in the GOM (DON 2007a). Information on reproductive areas and seasons is not available for these species.

Diving Behavior – Dives range from those near the surface where the animals are still visible to long, deep dives. Dive durations, as long as 87 minutes (min) and dives to depths of 1,990 m (6,529 ft), have been recorded for tagged Cuvier‘s beaked whales. Dive durations for *Mesoplodon* sp. are typically over 20 min. Tagged Blainville‘s beaked whale dives have been recorded to 1,408 m (4,619 ft) and lasting as long as 54 min. Several aspects of diving have been identified between Cuvier‘s and Blainville‘s beaked whales: (1) both may dive for 48 to 68 min to depths greater than 800 m (2,625 ft), with one long dive occurring on average every 2 hr; (2) ascent rates for long/deep dives are substantially slower than descent rates, while during shorter dives there is no consistent differences; and (3) both may spend prolonged periods of time (66 to 155 min) in the upper 50 m (164 ft) of the water column. Both species make a series of shallow dives after a deep foraging dive to recover from oxygen debt; average surface intervals between foraging dives have been recorded as 63 min for Cuvier‘s beaked whales and 92 min for Blainville‘s beaked whales (DON 2007a).

Watwood and Buonantony (2012) presented dive distribution for the Cuvier‘s beaked whale as: 56.14 percent at 0 to 100 m (0 to 328 ft), 24.4 percent at 100 to 500 m (328 to 1,640 ft), 13.1 percent at 500 to 1,000 m (1,640 to 3,281 ft), and 6.4 percent at 1,000 to 1,900 m (3,281 to 6,234 ft).

Watwood and Buonantony (2012) presented dive distribution for the Blainville‘s beaked whale as: 65.0 percent at 0 to 100 m (0 to 328 ft), 14.1 percent at 100 to 500 m (328 to 1,640 ft), 15.5 percent at 500 to 1,000 m (1,640 to 3,281 ft), and 1.29 percent at 1,000 to 1,360 m (3,281 to 4,462 ft).

There are no dive data for Gervais‘ beaked whale, so Watwood and Buonantony (2012) used Blainville‘s beaked whale as a surrogate species to model percentage of time at depth. Dive depth distribution is: 69.2 percent at 0 to 100 m (0 to 328 ft), 14.1 percent at 100 to 500 m (328 to 1,640 ft), 15.5 percent at 500 to 1,000 m (1,640 to 3,281 ft), and 1.3 at 1,000 to 1,360 m (3,281 to 4,462 ft).

Acoustics and Hearing – Beaked whales are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 μPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area – Based on the known preference of beaked whales for deep waters and the distribution of available sighting records for the GOM, beaked whales may be expected to occur throughout the GOM in waters off the continental shelf break in the eastern GOM. Occurrence is assumed to be the same year-round (DON 2007a).

Bottlenose Dolphin (*Tursiops truncatus*)

Status – The stock structure of bottlenose dolphins in the GOM is uncertain and appears to be complex. The multi-disciplinary research programs conducted over the last 37 years have begun to shed light on the structure of some of the stocks of bottlenose dolphins, though additional analyses are needed before stock structures can be elaborated on in the GOM. As research is completed, it may be necessary to revise stocks of bottlenose dolphins in the GOM (Waring et al. 2009a; NMFS 2012).

In the northern GOM, there are three types of coastal stocks; a continental shelf stock; an oceanic stock; and numerous bay, sound, and estuarine stocks. It is believed that many of these different stocks may overlap each other. Currently, the best estimate of abundance for the Northern GOM Coastal Stock is 2,473, with a minimum population estimate of 2,004. The current best estimate of abundance for the Eastern GOM Coastal Stock is 7,702, with a minimum population estimate of 6,551 (NMFS 2012). Currently, the best estimate of abundance and minimum population estimate along the GOM continental shelf and slope is unknown due to the fact that the data available are at least 8 years old. NMFS deems data at least 8 years old or older to be unreliable (Moore and Merrick 2011). However, in 2008, the best estimate of abundance for the GOM Continental Shelf and Slope Stock was 17,777, with a minimum population estimate of 13,667 (Waring et al. 2009a). The current best estimate of abundance for the GOM Oceanic Stock is 5,806, with a minimum population estimate of 4,230 (NMFS 2012). In 2011, the best estimate of abundance for GOM Oceanic Stock was 3,708, with a minimum population estimate of 2,641 (Waring et al. 2012).

Distribution – The overall range of the common bottlenose dolphin is worldwide in tropical and temperate waters. This species occurs in all three major oceans and many seas. Dolphins of the genus *Tursiops* generally do not range poleward of 45°, except around the United Kingdom and northern Europe. Climate changes can contribute to range extensions as witnessed in association with the 1982/83 El Niño event when the range of some bottlenose dolphins known to the San Diego, California area was extended northward by 600 km (324 nmi) to Monterey Bay (DON 2007a).

In the western North Atlantic, bottlenose dolphins occur as far north as Nova Scotia but are most common in coastal waters from New England to Florida, the GOM, the Caribbean, and southward to Venezuela and Brazil. Bottlenose dolphins may also be found in very deep waters. The range of the offshore bottlenose dolphin stock may include waters beyond the continental slope, and offshore bottlenose dolphins may move between the Atlantic and the GOM (DON 2007a).

The bottlenose dolphin is by far the most widespread and common cetacean in coastal waters of the GOM. Bottlenose dolphins are frequently sighted near the Mississippi River Delta and have even been known to travel several kilometers up the Mississippi River. Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – U.S. Navy bottlenose dolphins have been trained to reach maximum diving depths of about 300 m (984 ft). The presence of deep-sea fish in the stomachs of some individual offshore bottlenose dolphins suggests that they dive to depths of more than 500 m (1,640 ft). A tagged individual near Bermuda had maximum recorded dives of 600 to 700 m (1,969 to 2,297 ft) and durations of 11 to 12 minutes (min). Dive durations up to 15 min have been recorded for trained individuals. Typical dives, however, are more shallow and of a much shorter duration. Data from a tagged individual off Bermuda indicated a possible diel dive cycle (i.e., a regular daily dive cycle) in search of mesopelagic (living at depths between 180 and 900 m [591 and 2,953 ft] prey in the deep scattering layer (DON 2007a). Watwood and Buonantony (2012) presented dive depth distribution for this species as: 74 percent at 0 to 5 m (0 to 16 ft), 20 percent at 5 to 20 m (16 to 66 ft), and 6 percent at 20 to 45 m (66 to 148 ft).

Acoustics and Hearing – Bottlenose dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area – Based on the distribution of sighting records in the GOM, bottlenose dolphins are expected to occur from the shoreline to the 1,000-m (3,281-ft) isobath. There are concentrated occurrences of bottlenose dolphins from the shore to the 30-m (98-ft) isobath off west-central Florida and from the shore to just seaward of the continental shelf break from Cape San Blas, Florida to the east coast of Texas (DON 2007a).

Additionally, bottlenose dolphin occurrence is concentrated in a swath encompassing the shelf break east of Cape San Blas, as well as the Florida Keys. There is a low or unknown occurrence of bottlenose dolphins in waters with a bottom depth greater than 1,000 m (3,281 ft), which takes into consideration that comparatively little survey effort has taken place in deeper waters and also that there is a small possibility of encountering this species in that area. Bottlenose dolphin occurrence in the Q-20 Study Area is assumed to be similar throughout the year (DON 2007a).

Clymene Dolphin (*Stenella clymene*)

Status – Currently, the best estimate of abundance for Clymene dolphins in the GOM is considered to be 129 animals, with a suggested minimum population estimate of 64 (NMFS 2012). In 2009, the best estimate of abundance for Clymene dolphins in the northern GOM was 6,575 individuals, with a minimum population estimate of 4,901 (Waring et al. 2009b).

Distribution – The Clymene dolphin is found in tropical and subtropical waters in the Atlantic Ocean, occurring in both coastal and oceanic environments. Limits are near 40ºN and 30ºS. They are found off the United States Atlantic Coast, in the GOM, in the Caribbean, and southward to Brazil (Fertl et al. 2003). Sightings of these animals in the northern GOM occur primarily over the deeper waters off the continental shelf and primarily west of the Mississippi River (Waring et al. 2009b; 2012). In a study of habitat preferences in the GOM, Clymene dolphins were found more often on the lower slope and deep water areas in regions of cyclonic or confluence circulation. Clymene dolphins were found in waters with bottom depths ranging from 44 to 4,500 m (144 to 14,763 ft), with a mean depth of 1,870 m (6,135 ft) (Fertl et al. 2003). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – There is no diving information available for this species. Due to the paucity of diving data for the Clymene dolphin, Watwood and Buonantony (2012) used the pantropical spotted dolphin as a surrogate species to model dive depth distribution for the Clymene dolphin as: 20 percent at 0 to 5 m (0 to 16 ft), 38 percent at 5 to 10 m (16 to 33 ft), 21 percent at 10 to 20 m (33 to 66 ft), 20 percent at 20 to 100 m (66 to 328 ft), and 1 percent at 100-170 m (328 to 558 ft).

Acoustics and Hearing – Clymene dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** Based on the distribution of sighting records, the Clymene dolphin is expected to occur from the continental shelf break to the 3,000-m (9,843-ft) isobath. There has not been much survey effort in waters deeper than 3,000 m (9,843 ft), yet there are documented sightings seaward of the 3,000-m (9,843-ft) isobath. Therefore, there is a low or unknown occurrence of the Clymene dolphin seaward of the 3,000-m (9,843-ft) isobath. Occurrence is assumed to be the same during all seasons (DON 2007a).

False Killer Whale (*Pseudorca crassidens*)

Description **–** The false killer whale is a large, dark gray to black dolphin reaching lengths of 6.1 m (20.0 ft). The flippers have a characteristic hump on the leading edge; this is perhaps the best characteristic in distinguishing this species from the other “blackfish” (pygmy killer, melon-headed, and pilot whales).

Status **–** Currently, the best estimate of abundance and minimum population estimate for false killer whales in the northern GOM is unknown due to current data being at least 8 years old or older (Moore and Merrick 2011). However, in 2009, the best estimate of abundance for false killer whales in the northern GOM was 777, with a minimum population estimate of 501 (Waring et al. 2009b).

Distribution **–** False killer whales are found in tropical and temperate waters, generally between 50ºS and 50ºN with a few records north of 50ºN in the Pacific and the Atlantic. This species is found primarily in oceanic and offshore areas, though they do approach close to shore at oceanic islands. Inshore movements are occasionally associated with movements of prey and shoreward flooding of warm ocean currents. In the western North Atlantic, false killer whales have been reported off Maryland southward along the mainland coasts of North America, the GOM, and the southeastern Caribbean Sea. Although sample sizes are small, most false killer whale sightings in the GOM are east of the Mississippi River, and sightings of this species in the northern GOM occur in oceanic waters greater than 200 m (656 ft) deep (DON 2007a). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – There is no diving information available for this species. However, it is known that false killer whales primarily eat deep-sea cephalopods and fish, and have been known to attack other toothed whales, including sperm whales and baleen whales. False killer whales in many different regions are known to take tuna from long-lines worldwide. Dive depth distribution was based on the Risso's dolphin, as a surrogate species. Dive depth distribution would be in the 0 to 1 m (0 to 3 ft) depth range during 24.75 percent of the time, 13.5 percent in the 1 to 2 m range (3 to 7 ft), 16.5 percent in the 2 to 10 m (7 to 33 ft), 43.5 percent in the 10 to 50 m (33 to 164 ft), 1.1875 percent in the 50 to 100 m (164 to 328 ft), 0.1375 in 100 to 150 m (328 to 492 ft), and 0.425 percent in the 150 to 600 m (492 to 1,969 ft) (Watwood and Buonantony 2012).

Acoustics and Hearing – False killer whales are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 μPa-m, respectively (Southall et al. 2007).

Occurrence in the Q-20 Study Area – Most sightings of false killer whales in the GOM have been made in oceanic waters with a bottom depth greater than 200 m (656 ft); there also have been sightings from over the continental shelf. False killer whales are expected to occur between the continental shelf break and the 2,000-m (6,562-ft) isobath throughout the GOM. There is a low or unknown occurrence of this species seaward of the 2,000-m (6,562-ft) isobath, which is based on past sighting records. There is also a low or unknown occurrence of false killer whales between the 50-m (164-ft) isobath and the shelf break in the Q-20 Study Area. This was based on the fact that false killer whales sometimes make their way into shallower waters, such as off Hong Kong and in the GOM, as well as many sightings reported by sport fishermen in the mid-1960s of ―blackfish" (most likely false killer whales based on the descriptions) in waters offshore of Pensacola and Panama City, Florida. There have been occasional reports of fish stealing by these animals (the false killer whale frequently has been implicated in such fishery interactions). False killer whale occurrence patterns in the eastern GOM are expected to be the same throughout the year (DON 2007a).

Fraser's Dolphin (*Lagenodelphis hosei*)

Description – The Fraser's dolphin reaches a maximum length of 2.7 m (8.9 ft) and is generally more robust than other small delphinids. Fraser's dolphins feed on midwater fish, squid, and shrimp (DON 2007a).

Status – Currently, the best estimate of abundance and minimum population estimate for Fraser's dolphins in the northern GOM is not available. A survey was conducted in 2009, but Fraser's dolphins were not observed (NMFS 2012). In 2005, the best estimate of abundance for Fraser's dolphins in the northern GOM was 726, with a minimum population estimate of 427 (NMFS 2005).

Distribution – Fraser's dolphin is found in tropical and subtropical waters around the world, typically between 30ºN and 30ºS. Strandings in temperate areas are considered extralimital and usually are associated with anomalously warm water temperatures. This is an oceanic species except in places where deep water approaches the coast. In the GOM, this species occurs mostly in very deep waters well beyond the continental shelf break (DON 2007a). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – There is no information available on depths to which Fraser's dolphins may dive, but they are thought to be capable of deep diving. Despite their smaller size, dive depth distribution for the Fraser's dolphin was modeled by Watwood and Buonantony (2012) as a long-finned pilot whale, another species in the family Delphinidae which feeds on mesopelagic and bathypelagic prey at similar depths: 74.4 percent of the time at 0 to 17 m (0 to 56 ft), 5.2 percent at 17 to 35 m (56 to 115 ft), 2.2 percent at 35 to 53 m (115 to 174 ft), 3.8 percent at 53 to 101 m (174 to 331 ft), 2.8 percent at 101 to 149 m (331 to 489 ft), 1.8 percent at 149 to 197 m (331 to 646 ft), 3.4 percent at 197 to 299 m (646 to 981 ft), 2.6 percent at 299 to 401 m (981 to 1,316), 2.9 percent at 401 to 599 m (1,316 to 1,965 ft), and 0.9 percent at 599 to 797 m (1,965 to 2,615 ft).

Acoustics and Hearing – Fraser's dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** Fraser's dolphin occurrence is assumed to be the same for all four seasons in the eastern GOM, and is expected to occur from the continental shelf break to the 3,000-m (9,843-ft) isobath. This determination was based on the distribution of past sightings and the known habitat preferences of this species. Fraser's dolphins have been sighted in the past over the abyssal plain in the southern GOM. There is a low or unknown occurrence of the Fraser's dolphin seaward of the 3,000-m (9,843-ft) isobaths (DON 2007a).

Killer Whale (*Orcinus orca*)

Description **–** The killer whale is the largest member of the dolphin family; females may reach 7.7 m (25.3 ft) in length and males 9.0 m (29.5 ft). The black-and-white color pattern of this species is striking as is the tall, erect dorsal fin of the adult male (1.0 to 1.8 m [3.3 to 5.9 ft] in height). Killer whales feed on bony fish, elasmobranches, cephalopods, seabirds, sea turtles, and other marine mammals (DON 2007a).

Status **–** Currently, the best estimate of abundance for killer whales in the northern GOM is 28, with a minimum population estimate of 14 (NMFS 2012). In 2010, the best estimate of abundance for killer whales in the northern GOM was 49, with a minimum population estimate of 28 (Waring et al. 2010).

Distribution **–** This is a cosmopolitan species found throughout all oceans and contiguous seas, from equatorial regions to the polar pack ice zones. Although found in tropical waters and the open ocean, killer whales as a species are most numerous in coastal waters and at higher latitudes. Killer whales have the most ubiquitous distribution of any species of marine mammal, and they have been observed in virtually every marine habitat from the tropics to the poles and from shallow, inshore waters (and even rivers) to deep, oceanic regions. In coastal areas, killer whales often enter shallow bays, estuaries, and river mouths (DON 2007a).

Killer whales are sighted year-round in the northern GOM. It is not known whether killer whales in the GOM stay within the confines of the GOM or range more widely into the Caribbean and adjacent North Atlantic Ocean (DON 2007a). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – The maximum depth recorded for free-ranging killer whales diving off British Columbia is 264 m (866 ft). On average, however, for seven tagged individuals, less than 1 percent of all dives examined were to depths greater than 30 m (98 ft). A trained killer whale dove to a maximum of 260 m (853 ft). The longest duration of a recorded dive from a radio-tagged killer whale was 17 min. Watwood and Buonantony (2012) determined that for a fish-eating killer whale, 97.59 percent of the time is spent at depths of 0 to 30 m, while 2.41 percent is at 30 to 228 m. Mammal-eating killer whales spend 24 percent of their time at depths of 0 to 5 m (0 to 16 ft), 3.5 percent at 5 to 10 m (16 to 33), 2.5 percent at 10 to 15 m (33-49), 4.2 percent at 15 to 20 m (49 to 66 ft), 8 percent at 20 to 25 m (66 to 82 ft), 12 percent at 25 to 30 m (82-98 ft), 11 percent at 30 to 35 m (98 to 115 ft), 8.5 percent at 35 to 40 m (115 to 131 ft), 10.9 percent at 40 to 45 m (131 to 148 ft), 8.5 percent at 45 to 50 m (148 to 164 ft), 5 percent at 50 to 55 m (164 to 180 ft), 1.5 percent at 55 to 60 m (180 to 197 ft), and 0.4 percent at 60 to 65 m (197 to 213 ft) (Watwood and Buonantony 2012).

Acoustics and Hearing – Killer whales are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 μPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area – Killer whale sightings in the northern GOM are generally clustered in a broad region south of the Mississippi River Delta and in waters ranging in bottom depth from 256 to 2,652 m (840 to 8,701 ft). Based on this information, killer whales are expected to occur in an area south of the Mississippi River Delta from the shelf break into waters with an approximate bottom depth of 2,000 m (6,562 ft). Sightings have been made in waters over the continental shelf (including close to shore) as well as in waters past the 2,000-m (6,562-ft) isobath. There is a low or unknown possibility of encountering killer whales anywhere in the GOM (besides the before-mentioned area of expected occurrence) shoreward of the 10-m (33-ft) isobath (DON 2007a). Occurrence patterns are assumed to be similar for all seasons (DON 2007a).

Melon-Headed Whale (*Peponocephala electra*)

Description – Melon-headed whales at sea closely resemble pygmy killer whales. Melon-headed whales reach a maximum length of 2.75 m (9 ft). Melon-headed whales prey on squid, pelagic fish, and occasionally crustaceans. Most of the fish and squid families eaten by this species consist of mesopelagic species found in waters up to 1,500 m (4,921 ft) deep, suggesting that feeding takes place deep in the water column (DON 2007a).

Status – Currently, the best estimate of abundance for melon-headed whales in the northern GOM is 2,235, with a minimum population estimate of 1,274 (NMFS 2012). In 2009, the best estimate of abundance for melon-headed whales in the northern GOM was 2,283, with a minimum population estimate of 1,293 (Waring et al. 2009b).

Distribution **–** Melon-headed whales are found worldwide in deep tropical and subtropical waters. Little information is available on habitat preferences for this species. Most melon-headed whale sightings in the GOM have been in deep waters, well beyond the edge of the continental shelf and waters out over the abyssal plain (DON 2007a). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – There is no diving information available for this species. Melon-headed whales prey on squid, pelagic fish, and occasionally crustaceans. Most of the fish and squid families eaten by this species consist of mesopelagic species found in waters with bottom depths as deep as 1,500 m (4,921 ft), suggesting that feeding takes place deep in the water column. Watwood and Buonantony (2012) modeled the depth distribution of the melon-headed whale using the Risso‘s dolphin, another member of the same subfamily, Globicephalinae, which feeds on mesopelagic prey, as a surrogate. Melon-headed whales would be in the 0 to 1 m depth range during 24.75 percent of the time, 13.5 percent in the 1 to 2 m range (3 to 7 ft), 16.5 percent in the 2 to 10 m (7 to 33 ft), 43.5 percent in the 10 to 50 m (33 to 164 ft), 1.1875 percent in the 50 to 100 m (164 to 328 ft), 0.1375 percent in 100 to 150 m (328 to 492 ft), and 0.425 percent in the 150 to 600 m (492 to 1,969 ft) (DON 2007a).

Acoustics and Hearing – Melon-headed whales are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** Melon-headed whales and pygmy killer whales can be difficult to distinguish from one another, and on many occasions, only a determination of ―pygmy killer whale/melon-headed whale” can be made. The occurrence of both species is considered similar and therefore appears combined. Based on known preferences of the melon-headed whale for deep waters and the confirmed sightings of this species in the GOM, melon-headed whales are expected to occur between the continental shelf break and the 3,000-m (9,843-ft) isobaths (DoN 2007a). There is a low or unknown occurrence of melon-headed whales in waters with a bottom depth greater than 3,000 m (9,843 ft) based on the few available sighting records. Melon-headed whale occurrence patterns are expected to be the same year-round in the eastern GOM (DON 2007a).

Pantropical Spotted Dolphin (*Stenella attenuata*)

Status **–** The pantropical spotted dolphin is the most abundant and commonly-seen cetacean in deep waters of the northern GOM. Currently, the best estimate of abundance for pantropical spotted dolphins in the northern GOM is 50,880, with a minimum population of 40,699 animals (NMFS 2012). In 2011, the best estimate of abundance for pantropical spotted dolphins in the northern GOM was 34,067, with a minimum population estimate of 29,311 individuals (Waring et al. 2012).

Distribution **–** The pantropical spotted dolphin is distributed in tropical and subtropical waters worldwide, generally occurring in oceanic waters beyond the shelf break. Pantropical spotted dolphins in the GOM have been sighted in waters with bottom depths ranging from 435 to

2,121 m (1,427 to 6,959 ft). Pantropical spotted dolphins in the GOM do not appear to have a preference for any one specific habitat type (i.e., within the Loop Current, inside cold-core eddies, or along the continental slope) (DON 2007a).

Diving Behavior – Pantropical spotted dolphin dives during the day are generally shorter and shallower than dives at night; rates of descent and ascent are higher at night than during the day. Similar mean dive durations and depths have been obtained for tagged pantropical spotted dolphins in the Eastern Tropical Pacific and off Hawaii (DON 2007a). Watwood and Buonantony (2012) presented dive depth distribution for this species as: 20 percent at 0 to 5 m (0 to 16 ft), 38 percent at 5 to 10 m (16 to 33 ft), 21 percent at 10 to 20 m (33 to 66 ft), 20 percent at 20 to 100 m (66 to 328 ft), and 1 percent at 100 to 170 m (328 to 558 ft).

Acoustics and Hearing – Pantropical spotted dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 μPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** The pantropical spotted dolphin is an oceanic species found in the deeper waters off the continental shelf, and is the most common cetacean in the oceanic northern GOM. The pantropical spotted dolphin is expected to occur from the continental shelf break to the 3,000-m (9,843-ft) isobath. There is a low or unknown occurrence of the pantropical spotted dolphin seaward of the 3,000-m (9,843-ft) isobath based on the little survey effort in waters this deep compared to the waters off the shelf break and over the continental slope. Occurrence is assumed to be similar throughout the year (DON 2007a).

Pygmy and Dwarf Sperm Whales (*Kogia breviceps* and *Kogia sima*)

Description **–** There are two species of *Kogia*: the pygmy sperm whale and the dwarf sperm whale. They are difficult to distinguish from one another, and sightings of either species are often categorized as *Kogia* species (sp). The difficulty in identifying pygmy and dwarf sperm whales is exacerbated by their avoidance reaction toward ships and change in behavior toward approaching survey aircraft. Based on the cryptic behavior of these species and small group sizes (much like that of beaked whales), as well as similarity in appearance, it is difficult to identify these whales to species in sightings at sea. Pygmy and dwarf sperm whales reach body lengths of around 3 and 2.5 m (9.8 and 8.2 ft), respectively. *Kogia* feed on cephalopods and, less often, on deep-sea fish and shrimp. Zooplankton is likely part of the diet of one or more of the common prey species of *Kogia* (DON 2007a).

Status **–** *Kogia breviceps* and *Kogia sima* are difficult to differentiate therefore estimated abundances include both species of *Kogia*. The GOM population is provisionally being considered a separate stock for management purposes from the U.S. Atlantic stock, although there is currently no information to differentiate this stock from the Atlantic Ocean stock(s). Currently, the best estimate of abundance for pygmy and dwarf sperm whales in the northern GOM is 186, with a minimum population estimate of 90 (NMFS 2012). In 2009, the best estimate of abundance for pygmy and dwarf sperm whales in the northern GOM was 453, with a minimum population estimate of 340 (Waring et al. 2009b).

Distribution – Both *Kogia* species have a worldwide distribution in tropical and temperate waters. In the western Atlantic Ocean, *Kogia* sp. (specifically, the pygmy sperm whale) are documented as far north as the northern Gulf of St. Lawrence, as far south as Colombia (dwarf sperm whale), and as far west as Texas in the GOM. Worldwide, both species of *Kogia* generally occur in waters along the continental shelf break and over the continental slope. Data from the GOM suggest that *Kogia* may associate with frontal regions along the shelf break and upper continental slope, since these are areas with high epipelagic zooplankton biomass. A satellite-tagged, rehabilitated pygmy sperm whale released off the Atlantic coast of Florida remained along the continental slope and the western edge of the Gulf Stream during the time of the tag's operation. Dwarf sperm whales may have a more oceanic distribution than pygmy sperm whales and/or dive deeper during feeding bouts, based on hematological and stable-isotope data. Information on the reproductive areas and seasons for these species is not available (DON 2007a).

Diving Behavior – Whales of the genus *Kogia* make dives of up to 25 min. Median dive times of around 11 min are documented for *Kogia.* A satellite-tagged pygmy sperm whale released off Florida was found to make long nighttime dives, presumably indicating foraging on squid in the deep scattering layer. Watwood and Buonantony (2012) modeled *Kogia* dive depth distribution on data from the long-finned pilot whale: 74.4 percent of the time at 0 to 17 m (0 to 56 ft), 5.2 percent at 17 to 35 m (56 to 115 ft), 2.2 percent at 35 to 53 m (115 to 174 ft), 3.8 percent at 53 to 101 m (174 to 331 ft), 2.8 percent at 101 to 149 m (331 to 489 ft), 1.8 percent at 149 to 197 m (489 to 646 ft), 3.4 percent at 197 to 299 m (646 to 981 ft), 2.6 percent at 299 to 401 m (981 to 1,316 ft), 2.9 percent at 401 to 599 m (1,316 to 1,965 ft), and 0.9 percent at 599 to 797 m (1,965 to 2,615 ft).

Acoustics and Hearing – Pygmy and dwarf sperm whales are classified in the high-frequency functional hearing group whose functional hearing range is 200 Hz to 180 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the high-frequency group ranges from 100 Hz to 200 kHz and 120 to 205 dB re 1 μPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area – As noted earlier, identification to species for this genus is difficult, particularly at sea. Based on the distribution of the available sighting records and the known preference of both *Kogia* sp. for deep waters, pygmy and dwarf sperm whales are expected to occur between the continental shelf break and the 3,000-m (9,843-ft) isobath. There is a low or unknown occurrence of pygmy and dwarf sperm whales in the very deep waters seaward of the 3,000-m (9,843-ft) isobaths (DON 2007a).

There is no evidence that *Kogia* sp. regularly occur in continental shelf waters of the GOM. However, there are some sighting records for these species in waters over the continental shelf. Therefore, there is also a low or unknown occurrence of *Kogia* sp. between the 50-m (164-ft) isobath and the continental shelf break (DoN 2007a). Occurrence is assumed to be the same for all four seasons (DON 2007a).

Pygmy Killer Whale (*Feresa attenuata*)

Description **–** Pygmy killer whales and melon-headed whales can be difficult to distinguish from one another, and on many occasions, only a determination of "pygmy killer whale/melon-headed whale" can be made. The rounded flipper shape is the best distinguishing characteristic of a pygmy killer whale. Pygmy killer whales reach lengths of up to 2.6 m (8.5 ft). Pygmy killer whales eat mostly fish and squid, and sometimes attack other dolphins (DON 2007a).

Status **–** Currently, the best estimate of abundance for pygmy killer whales in the northern GOM is 152, with a minimum population estimate of 75 (NMFS 2012). In 2009, the best estimate of abundance for pygmy killer whales in the northern GOM was 323, with a minimum population estimate of 203 (Waring et al. 2009b).

Distribution **–** This species has a worldwide distribution in deep tropical, subtropical, and warm temperate oceans. Pygmy killer whales generally do not range north of 40ºN or south of 35ºS. The sparse number of pygmy killer whale sightings might be due to its somewhat cryptic behavior. The pygmy killer whale is a deepwater species, with a possible occurrence most likely in waters outside the continental shelf break. This species does not appear to be common in the GOM. In the northern GOM, the pygmy killer whale is found primarily in deeper waters beyond the continental shelf extending out to waters over the abyssal plain (DON 2007a).

Diving Behavior – There is no diving information available for this species. Since both pygmy killer whales and Risso‘s dolphins are found in deep water and feed on squid and other cephalopods, Watwood and Buonantony (2012) modeled the depth distribution of the pygmy killer as a Risso‘s dolphin. Pygmy killer whales would be in the 0 to 1 m (0 to 3 ft) depth range during 24.75 percent of the time, 13.5 percent in the 1 to 2 m (3 to 7 ft) range, 16.5 percent in the 2 to 10 m (7 to 33 ft), 43.5 percent in the 10 to 50 m (33 to 164 ft), 1.1875 percent in the 50 to 100 m (164 to 328 ft), 0.1375 in 100 to 150 m (328 to 492 ft), and 0.425 percent in the 150 to 600 m (492 to 1,969 ft).

Acoustics and Hearing – Pygmy killer whales are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** As stated previously, pygmy killer whales and melon-headed whales can be difficult to distinguish from one another, and on many occasions, only a determination of "pygmy killer whale/melon-headed whale" can be made. The occurrence of both species is considered similar and therefore appears combined. Based on confirmed sightings of the pygmy killer whale in the GOM and this species‘ propensity for deeper water, pygmy killer whales are expected to occur between the continental shelf break and the 3,000-m (9,843-ft) isobath. There is a low or unknown occurrence of pygmy killer whales in waters with a bottom depth greater than 3,000 m (9,843 ft) based on the few available sighting records. Pygmy killer whales are thought to occur year-round in the GOM in small numbers and occurrence patterns are expected to be the same year-round (DON 2007a). Additional information on reproductive areas and seasons is not available for this species.

Risso's Dolphin (*Grampus griseus*)

Description **–** The Risso's dolphin is a moderately large, robust animal reaching at least 3.8 m (12.5 ft) in length. Adults range from dark gray to nearly white and are heavily covered with white scratches and splotches. Cephalopods are the primary prey (DON 2007a).

Status **–** Currently, the best estimate of abundance for Risso's dolphins in the northern GOM is 2,442, with a minimum population estimate of 1,563 (NMFS 2012). In 2010, the best estimate of abundance for Risso's dolphins in the northern GOM was 1,589, with a minimum population estimate of 1,271 (Waring et al. 2010).

Distribution **–** The Risso's dolphin is distributed worldwide in tropical and warm-temperate waters, roughly between 60ºN and 60ºS, where surface water temperature is usually greater than 10ºC (50°F). In the western North Atlantic, this species is found from Newfoundland southward to the GOM, throughout the Caribbean, and around the equator. The strong correlation between the Risso's dolphin distribution and the steeper portions of the upper continental slope in the GOM is most likely the result of cephalopod distribution in the same area (DON 2007a). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – Individuals may remain submerged on dives for up to 30 min and dive as deep as 600 m. Watwood and Buonantony (2012) determined that Risso's dolphin would be in the 0 to 1 m (0 to 3 ft) depth range during 24.75 percent of the time, 13.5 percent in the 1 to 2 m (3 to 7 ft) range, 16.5 percent in the 2 to 10 m (7 to 33 ft), 43.5 percent in the 10 to 50 m (33 to 164 ft), 1.1875 percent in the 50 to 100 m (164 to 328 ft), 0.1375 in 100 to 150 m (328 to 492 ft), and 0.425 percent in the 150 to 600 m (492 to 1,969 ft).

Acoustics and Hearing – Risso's dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** The Risso's dolphin is most commonly found in areas with steep bottom topography. Based on this known habitat preference and the distribution of sighting records in the northern GOM, Risso's dolphins are expected to occur between the continental shelf break and the 2,000-m (6,562-ft) isobath throughout the year. There is a concentrated occurrence of the Risso's dolphin south of the Mississippi River Delta to approximately where the DeSoto Canyon begins, from the shelf break to the vicinity of the 1,000-m (3,281-ft) isobath. This is based on sighting concentrations, as well as the oceanography of the area being favorable to prey concentrations for this species. There is a low or unknown occurrence of this species in waters beyond the 2,000-m (6,562-ft) isobath.

Rough-Toothed Dolphin (*Steno bredanensis*)

Description **–** The rough-toothed dolphin is a relatively robust dolphin that reaches 2.8 m (9.2 ft) in length. Cephalopods and fish, including large fish such as dorado, are prey (DON 2007a).

Status **–** Currently, the best estimate of abundance for rough-toothed dolphins in the northern GOM is 624, with a minimum population estimate of 311 (NMFS 2012). In 2009, the best estimate of abundance for rough-toothed dolphins in the northern GOM was 2,653, with a minimum population estimate of 1,890 (Waring et al. 2009a).

Distribution **–** Rough-toothed dolphins are found in tropical to warm-temperate waters globally, rarely ranging north of 40°N or south of 35°S. Rough-toothed dolphins occur in low densities throughout the Eastern Tropical Pacific where surface water temperatures are generally above 25°C (77°F). This species is not a commonly-encountered species in the areas where it is known to occur. Not many records for this species exist from the western North Atlantic but they indicate that this species occurs from Virginia south to Florida, the GOM, the West Indies, and along the northeastern coast of South America (DON 2007a).

The rough-toothed dolphin is regarded as an offshore species that prefers deep waters; however, it can occur in waters with variable bottom depths. In the GOM, the rough-toothed dolphin occurs primarily in the deeper waters off the continental shelf. When stranded and rehabilitated individuals were released with tags off the Atlantic Coast of Florida in March 2005, they moved to waters as deep as 4,000 to 5,000 m (13,123 to 16,404 ft) in bottom depth. The rough-toothed dolphin may regularly frequent coastal waters and areas with shallow bottom depths. Sighting and tagging data indicate the use of continental shelf waters by this species in the northern GOM. Additionally, there are reports of rough-toothed dolphins over the continental shelf in shallow waters around La Gomera, Canary Islands, Puerto Rico and the Virgin Islands, the Bahamas, and in coastal waters off Brazil, including even in a lagoon system. All records for this species for Puerto Rico and the Virgin Islands are in waters on the continental shelf. Rough-toothed dolphins have been sighted on the continental shelf in Ilha Grande Bay (southeastern coast of Brazil), but there has not been much sighting effort in deep waters (DON 2007a). Information on reproductive areas and seasons is not available for this species.

Diving Behavior – Rough-toothed dolphins may stay submerged for up to 15 min and are known to dive as deep as 150 m (492 ft). Wells et al. (2008) reported time-at-depth data from four rehabilitated and released adult rough-toothed dolphins in the Atlantic. Only two of the animals made a total of three dives to the 200 to 300 m (656 to 984 ft) depth range, and dives were generally shallowest during the daytime. Watwood and Buonantony (2012) noted that although these data were collected from rehabilitated animals, the paucity of data on diving behavior of healthy animals necessitates that these data are used until better information becomes available. Dive depth distribution was determined to be: 77.99 percent at 0 to 10 m (0 to 33 ft), 16.24 percent at 10 to 25 m (33 to 82 ft), 3.81 percent at 25 to 30 m (82 to 98 ft), 0.29 percent at 75 to100 m (246 to 328 ft), 0.11 percent at 100 to 150 m (328 to 492 ft), 0.01 percent at 150 to 200 m (492 to 656 ft), 0.01 percent at 200 to 300 m (656 to 984 ft) (Watwood and Buonantony 2012).

Acoustics and Hearing **–** Rough-toothed dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** The rough-toothed dolphin is expected to occur seaward of the continental shelf break to the 3,000 m (9,843 ft) isobath based on the known preference of this species for deep waters and the distribution of available sighting records. There is a low or unknown occurrence of this species in waters with a bottom depth greater than 3,000 m (9,843 ft), based on a very small number of sightings in those waters. There is additionally an area of low or unknown occurrence between the 50-m (164-ft) isobath and the shelf break. Two separate mass strandings of rough-toothed dolphins occurred in the Florida Panhandle during December 1997 and 1998. Four of the stranded dolphins were rehabilitated and released, three with satellite-linked transmitters. Water depth at tracking locations of these individuals averaged 195 m (640 ft). Since the tagged individuals were observed again with wild rough-toothed dolphins off the Florida Panhandle, this suggests a previously undocumented regular occurrence of this species in the northeastern GOM and the possibility of encountering rough-toothed dolphins on the continental shelf (DON 2007a).

Short-Finned Pilot Whale (*Globicephala macrorhynchus*)

Description – Pilot whales are among the largest members of the dolphin family. The short-finned pilot whale may attain lengths of 5.5 m (18 ft) (females) and 6.1 m (20 ft) (males).

Status – Currently, the best estimate of abundance for short-finned pilot whales in the northern GOM is 2,415, with a minimum population estimate of 1,456 (NMFS 2012). In 2009, the best estimate of abundance for short-finned pilot whales in the GOM was 716, with a minimum population estimate of 542 (Waring et al. 2009b).

Distribution – The short-finned pilot whale usually does not range north of 50ºN or south of 40ºS. Pilot whales are found over the continental shelf break, in slope waters, and in areas of high topographic relief. Pilot whales are sometimes seen in waters over the continental shelf. A number of studies have found the distribution and movements of pilot whales to coincide closely with the abundance of squid. The occurrence of pilot whales in the Southern California Bight was found to be associated with high relief topography, which has been related to the squid-feeding habits of pilot whales. This is likely the case in other geographic locations (DON 2007a). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – Pilot whales are deep divers; foraging dives deeper than 600 m (1,969 ft) have been recorded. Pilot whales are able to stay submerged for up to 40 min. Watwood and Buonantony (2012) modeled short-finned pilot whale dive depth distribution on data from the long-finned pilot whale (*Globicephala melas*): 74.4 percent of the time at 0 to 17 m (0 to 56 ft), 5.2 percent at 17 to 35 m (56 to 115 ft), 2.2 percent at 35 to 53 m (115 to 174 ft), 3.8 percent at 53 to 101 m (174 to 331 ft), 2.8 percent at 101 to 149 m (331 to 489), 1.8 percent at 149 to 197 m (489 to 646 ft), 3.4 percent at 197 to 299 m (646 to 981 ft), 2.6 percent at 299 to 401 m (981 to 1,316 ft), 2.9 percent at 401 to 599 m (1,316 to 1,965 ft), and 0.9 percent at 599 to 797 m (1,965 to 2,615 ft).

Acoustics and Hearing – Pilot whales are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-freqeuency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area – Based on sightings and the apparent preference of pilot whales for steep bottom topography, this species is expected to occur from the continental shelf break to the 2,000-m (6,562-ft) isobath in the Q-20 Study Area. There is a low or unknown occurrence of pilot whales between the 10-m (33-ft) isobath and the shelf break, east of Cape San Blas, Florida, past the Florida Keys. There is a low or unknown occurrence of pilot whales between the 2,000- and 3,000-m (6,562- and 9,843-ft) isobaths. Pilot whales do have an oceanic distribution, and the few shipboard surveys that have occurred seaward of the 2,000-m (6,562-ft) isobath have occasionally recorded pilot whales (DON 2007a).

There is a preponderance of pilot whale sightings in the historical records for the northern GOM. Pilot whales, however, are less often reported during recent surveys, such as GulfCet (Davis et al. 2000, 2002). The reason for this apparent decline is not known, but it has been suggested that abundance or distribution patterns might have changed over the past few decades, perhaps due to changes in available prey species. Occurrence patterns are assumed to be the same throughout the year (DON 2007a).

Sperm Whale (Physeter macrocephalus)

Description – The sperm whale is the largest toothed whale species. Adult females can reach 12 m (39 ft) in length, while adult males measure as much as 18 m (59 ft) in length. Sperm whales prey on large mesopelagic squid and other cephalopods as well as demersal fish and occasionally benthic invertebrates (DON 2007a).

Status – Sperm whales are classified as endangered under the ESA, although they are not in any immediate danger of extinction globally. The species is considered a strategic stock. The sperm whale population in the northern GOM, as a stock, is considered to be distinct from the U.S. Atlantic Stock. Genetic analyses, coda vocalizations, and population structure support this. Currently, the best estimate of abundance for sperm whales in the GOM is 763, with a minimum population estimate of 560 (NMFS 2012). However, in 2010, the best estimate of abundance for sperm whales in the GOM was 1,665, with a minimum population estimate of 1,409 (Waring et al. 2010).

Distribution – Sperm whales are found from tropical to polar waters in all oceans of the world between approximately 70 degrees North (°N) and 70 degrees South (°S). Females use a subset of the waters where males are regularly found. Females are normally restricted to areas with SST greater than approximately 15°C (59°F), whereas males, and especially the largest males, can be found in waters as far poleward as the pack ice with temperatures close to 0°. The thermal limits on female distribution correspond approximately to the 40° parallels (50° in the North Pacific; Whitehead 2003). Photo-identification data analyzed by Jaquet et al. (2003) revealed that seven female sperm whales moved into the Gulf of California from the Galápagos Islands, traveling up to 3,803 km (2,052 nmi); these are among the longest documented movements for female sperm whales (DON 2007a).

Sperm whales show a strong preference for deep water (from the continental shelf break seaward). Sperm whale concentrations have been correlated with high productivity and steep bottom topography. In the GOM, the region of the Mississippi River Delta has been recognized for high densities of sperm whales and appears to represent an important calving and nursery area for these animals. Body sizes for most of the sperm whales seen off the mouth of the Mississippi River range from 7 to 10 m (23 to 33 ft), which is the typical size for females and younger animals. On the basis of photo-identification of sperm whale flukes and acoustic analyses, it is likely that some sperm whales are resident to the GOM. Tagging data demonstrated that some individuals spend several months at a time in the Mississippi River Delta and the Mississippi Canyon for several months, while other individuals move to other locations the rest of the year. Most tagged sperm whales in the GOM show a strong preference for the waters of the continental slope and canyon regions, while several individuals moved further offshore into waters with a bottom depth greater than 3,000 m (9,843 ft). Spatial segregation between the sexes was noted one year by Jochens et al. (2006); females and immatures showed high site fidelity to the region south of the Mississippi River Delta and Mississippi Canyon and in the western Gulf, while males were mainly found in the DeSoto Canyon and along the Florida Slope (DON 2007a).

Diving Behavior – Sperm whales forage during deep dives that routinely exceed a depth of 400 m (1,312 ft) and 30 min in duration. Sperm whales are capable of diving to depths of over 2,000 m (6,562 ft) with durations of over 60 min. Male sperm whales spend up to 83 percent of daylight hours underwater. In contrast, females spend prolonged periods of time at the surface (1 to 5 hr daily) without foraging. An average dive cycle consists of about a 45-min dive with a 9-min surface interval. The average swimming speed is estimated to be 0.7 m/sec (1.6 miles per hour [mi/hr]). Dive descents are about 9 to 11 min at a rate of 1.2 to 1.52 m/sec (2.7 to 3.40 mi/hr), and ascents average 11.8 min at a rate of 1.4 m/sec (3.1 mi/hr) (DON 2007a). Watwood and Buonantony (2012) presented percentage of time at depth for the sperm whale in the GOM as: 36.26 percent at 0 to 100 m (0 to 328 ft), 37.5 percent at 100 to 500 m (328 to 1,640 ft), 22.93 percent at 500-1,000 m (1,640 to 3,281 ft), and 3.31 percent at 1,000 to 2,000 m (3,281 to 6,562 ft).

Acoustics and Hearing – Sperm whales are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 μPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area – Sperm whales in the GOM aggregate along the continental slope in or near the perimeter of cyclonic (cold-core) eddies. The area of the Mississippi River Delta might represent an important calving and nursery area for sperm whales. On the basis of photo-identification of sperm whale flukes and acoustic analyses, it is likely that some sperm whales are resident to the GOM (DON 2007a).

The sperm whale is expected to occur from the continental shelf break to the 3,000 m (9,843 ft) isobath. There is a concentrated occurrence that encompasses the area off the Mississippi River Delta, and the influences of this river, between the continental shelf break and approximately the 1,000-m (3,281-ft) isobath. This is an area that has been recognized for high densities of sperm whales and represents a habitat where they can be predictably found. Sperm whales in this area appear to have affinity for cyclonic (cold-core) eddies. In fact, the largest numbers of encounters with sperm whales appeared to shift in response to shifts in distribution of eddies (DON 2007a).

There is a low or unknown occurrence of sperm whales in waters with a bottom depth greater than 3,000 m (9,843 ft), which reflects the fact that there has been comparatively little survey effort in waters this deep, yet there have been confirmed sightings of sperm whales. Occurrence is assumed to be the same throughout the year. Body sizes for most of the sperm whales seen off the mouth of the Mississippi River range from 7 to 10 m (23 to 32.8 ft), which is a typical size for females and younger animals. The area of the Mississippi River Delta might represent an important calving and nursery area for sperm whales. On the basis of photo-identification of sperm whale flukes and acoustic analyses, it is likely that some sperm whales are resident to the GOM (DON 2007a).

There has also been recent extensive work on the movements and habitat use of sperm whales in the northern GOM, such as the studies known as the Sperm Whale Acoustic Monitoring Program and the Sperm Whale Seismic Study. These studies include habitat cruises, physical oceanographic analyses, and long term satellite tag deployments. Several satellite tags operated for over 12 months and indicate movements generally along the shelf break (700 to 1,000 m [2,297 to 3,281 ft] bottom depth) throughout the Gulf, with some animals (more frequently males) using deeper, oceanic waters (Waring et al. 2012).

Spinner Dolphin (Stenella longirostris)

Status **–** Currently, the best estimate of abundance for spinner dolphins in the northern GOM is 11,441, with a minimum population estimate of 4,622 (NMFS 2012). In 2009, the best estimate of abundance for spinner dolphins in the northern GOM was 1,989, with a minimum population estimate of 1,356 individuals (Waring et al. 2009b).

Distribution **–** The spinner dolphin is found in tropical and subtropical waters worldwide, occurring in both coastal and oceanic environments. Limits are near 40ºN and 40ºS. In the western North Atlantic, they are known from South Carolina to Florida, the Caribbean, the GOM, and the West Indies southward to Venezuela. Sightings of this species off the United States Atlantic coast and GOM have occurred primarily in deeper waters (bottom depth greater than 2,000 m [6,562 ft]). Additional information on reproductive areas and seasons is not available for this species (DON 2007a).

Diving Behavior – Spinner dolphins feed primarily on small mesopelagic fish, squid, and sergestid shrimp, and they dive to at least 199 to 300 m (653 to 984 ft). Foraging takes place primarily at night when the mesopelagic prey migrates vertically towards the surface and also horizontally towards the shore. Spinner dolphins are well known for their propensity to leap high into the air and spin before landing in the water; the purpose of this behavior is unknown. Undoubtedly, spinner dolphins are one of the most aerially-active of all dolphin species (DON 2007a). No depth distribution data exist for the spinner dolphin. However, pantropical spotted dolphins also forage mostly at night on vertically migrating fish and cephalopod prey and their foraging dives are primarily limited to the upper 200 m (656 ft) of the water column (Baird et al. 2001). Therefore, the spinner dolphin was modeled with a surrogate species, the pantropical spotted dolphin (also in the genus *Stenella*), with 20 percent at 0 to 5 m (0 to 16 ft), 38 percent at 5 to 10 m (16 to 33 ft), 21 percent at 10 to 20 m (33-66 ft), 20 percent at 20 to 100 m (66 to 328 ft), and 1 percent at 100-170 m (328 to 558 ft).

Acoustics and Hearing – Spinner dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** As a species with a preference for deep waters, the spinner dolphin is expected to occur from the continental shelf break to the 2,000-m (6,562-ft) isobath. There is a low or unknown occurrence of the spinner dolphin seaward of the 2,000-m (6,562-ft) isobath (DoN 2007a). Occurrence is assumed to be similar throughout the year (DON 2007a).

Striped Dolphin (Stenella coeruleoalba)

Status **–** Currently, the best estimate of abundance for striped dolphins in the northern GOM is 1,849, with a minimum population estimate of 1,041 (NMFS 2012). In 2009, the best estimate of abundance for striped dolphins in the northern GOM was 3,325, with a minimum population estimate of 2,266 (Waring et al. 2009b).

Distribution **–** The striped dolphin has a worldwide distribution in cool-temperate to tropical waters. In the western North Atlantic, this species is known from Nova Scotia southward to the Caribbean, the GOM, and Brazil. Striped dolphins are usually found outside the continental shelf, typically over the continental slope out to oceanic waters, often associated with convergence zones and waters influenced by upwelling. This species appears to avoid waters with sea temperatures of less than 20°C (68°F). Additional information on reproductive areas and seasons is not available for this species (DON 2007a).

Diving Behavior – Striped dolphins often feed in pelagic or benthopelagic zones along the continental slope or just beyond it in oceanic waters. A majority of their prey possesses luminescent organs, suggesting that striped dolphins may be feeding at great depths, possibly diving to 200 to 700 m (656 to 2,297 ft) to reach potential prey. Striped dolphins may feed at night in order to take advantage of the deep scattering layer‘s diurnal vertical movements (DON 2007a). Little is known of the striped dolphin‘s diving behavior, so Watwood and Buonantony (2012) used the pantropical spotted dolphin (also in the genus *Stenella*) as a surrogate species to model dive depth distribution as: 20 percent at 0 to 5 m (0 to 16 ft), 38 percent at 5 to 10 m (16 to 33 ft), 21 percent at 10 to 20 m (33 to 66 ft), 20 percent at 20 to 100 m (66 to 328 ft), and 1 percent at 100 to 170 m (328 to 558 ft).

Acoustics and Hearing – Striped dolphins are classified in the mid-frequency functional hearing group whose functional hearing range is 150 Hz to 160 kHz (Southall et al. 2007). The frequency range and source level of sounds produced by species in the mid-frequency group ranges from 100 Hz to over 100 kHz and 137 to 236 dB re 1 µPa-m, respectively (Southall et al. 2007).

Occurrence in Q-20 Study Area **–** The striped dolphin is expected to occur from the continental shelf break to the 2,000-m (6,562-ft) isobath. There are a few confirmed sightings of striped dolphins seaward of the 2,000-m (6,562-ft) isobath; therefore, there is a low or unknown occurrence of striped dolphins in waters with a bottom depth greater than 2,000 m (6,562 ft). Occurrence is assumed to be the same throughout the year (DON 2007a).

5. HARASSMENT AUTHORIZATION REQUESTED

The U.S. Navy requests an IHA commencing 27 July 2013 for a 1-year period for the incidental harassment of marine mammals pursuant to Section 101(a)(5)(D) of the MMPA. The U.S. Navy‘s request includes authorization for:

- Level B harassment (i.e., behavioral disturbance) by sonar operations.

It is understood that an IHA is applicable for up to 1 year, is renewable, and is appropriate where authorization for harassment (but not serious injury or mortality of marine mammals) is requested. The effects will depend on the species as well as the distance and received level (RL) of the sound (see **Section 6**). Temporary disturbance or localized displacement reactions are the most likely to occur. **Section 6** provides details on the species and numbers of takes requested. No takes by serious injury or death are anticipated, given the planned mitigation and monitoring procedures (**Sections 11 and 12**). **Table 5-1** provides the requested takes for testing the Q-20 in the Q-20 Study Area.

Table 5-1. Requested Takes by Marine Mammal Species*.

Marine Mammal Species	Level A	Level B (TTS)	Level B (Behavioral)
Atlantic spotted dolphin	0	0	315
Bottlenose dolphin	0	0	399
Clymene dolphin	0	0	42
Pantropical spotted dolphin	0	0	126
Spinner dolphin	0	0	126
Striped dolphin	0	0	42

* **Section 6** and **Appendix A** provide the details and justification for requested takes.

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6. NUMBERS AND SPECIES EXPOSED

The MMPA requires applicants to determine the number of marine mammals that are expected to be incidentally harassed by an action and the nature of the harassment (Level A or Level B). The Proposed Action is a military readiness activity as defined in the MMPA, and the sections below define Level A and Level B harassment as applicable to military readiness activities. The following sections discuss the potential for ship strikes to occur from surface operations and the potential effects from noise related to sonar. **Section 6.2.1** presents how the Level A and Level B harassment definitions were applied to develop the quantitative acoustic analysis methodologies used to assess the potential for the Proposed Action to affect marine mammals. The information contained in this section is consistent with the *NSWC PCD Environmental Impact Statement/Overseas Environmental Impact Statement* (EIS/OEIS) and associated documents.

6.1 Surface Operations

6.1.1 Introduction

Typical operations occurring at the surface include the deployment or towing of MCM equipment, retrieval of equipment, and clearing and monitoring for non-participating vessels. As such, the potential exists for a ship to strike a marine mammal while conducting surface operations. Impacts to marine mammals will be minimized by implementation of protective measures discussed in **Section 11**.

6.1.2 Non-territorial Waters

Potential direct impacts to marine mammals from vessels include behavioral harassment of animals in the form of disturbance, and an increased potential for vessel collisions that could result in serious injuries or death. Marine mammal reactions to vessels depend on activities and experience, habitat, boat type, and boat behavior (Richardson et al. 1995; NRC 2003). Behavioral responses might include altered headings; fast swimming; changes in dive, surfacing, and respiration patterns; and changes in vocalizations (NRC 2003). Collisions with surface vessels can cause major wounds and may occasionally cause fatalities to marine mammals (Van Waerebeek et al. 2007). Dolphins are commonly attracted to moving vessels and spend periods of time following these vessels or swimming within the bow waves of moving ships and large boats. It is generally considered that because these species are agile, powerful swimmers that they should be capable of avoiding collisions with oncoming vessels; however, this is not always the case. As noted in a worldwide review by Van Waerebeek et al. (2007), small-boat propellers have long been recognized as a cause of traumas in small cetaceans, and it is possible that large ships could also strike these animals. Any vessel strike of a marine mammal would be considered a ―take," which might range from a short-term behavioral response to serious injury or death. Sublethal injuries would reduce fitness through a number of negative health consequences. These may include weakness from hemorrhage and opportunistic infections, stress-induced immunity impairment and hampered movements resulting in compromised foraging efficiency, predator avoidance, and reproductive fitness (Van Waerebeek et al. 2007).

Impacts on marine mammals will be minimized by the U.S. Navy following standard operating procedures (SOPs), ensuring that no ship strikes occur to marine mammals. The captain and other crew members keep watch during ship transits to avoid objects in the water. In addition, proposed U.S. Navy SOPs and protective measures are listed in **Section 11**. The U.S. Navy concludes that ship strikes will not affect annual rates of recruitment or survival and will not result in any –takes" of marine mammals in non-territorial waters.

6.2 Acoustic Effects: Sonar

6.2.1 Introduction and Approach to Analysis

Q-20 test activities include sonar operations transmitting in the high-frequency (>10 kHz) ranges. The following subsections present the background information for evaluation of potential exposures to marine mammals from HFAS at the Q-20 Study Area.

Conceptual Framework for Assessing Effects from Sound-Producing Activities

This conceptual framework describes the different types of effects that are possible and the potential relationships between sound stimuli and long-term consequences for the individual and population. The conceptual framework is central to the assessment of acoustic-related effects and is consulted multiple times throughout the process. It describes potential effects and the pathways by which an acoustic stimulus or sound-producing activity can potentially affect animals. The conceptual framework qualitatively describes costs to the animal (e.g., expended energy or missed feeding opportunity) that may be associated with specific reactions. Finally, the conceptual framework outlines the conditions that may lead to long-term consequences for the individual and population if the animal cannot fully recover from the short-term effects. Within each biological resource section (e.g., marine mammals, birds, and fish) the detailed methods to predict effects to specific taxa are derived from this conceptual framework.

An animal is considered –exposed" to a sound if the received sound level at the animal's location is above the background ambient noise level within a similar frequency band. A variety of effects may result from exposure to sound-producing activities. The severity of these effects can vary greatly between minor effects that have no real cost to the animal, to more severe effects that may have lasting consequences. Whether a marine animal is significantly affected must be determined from the best available scientific data regarding the potential physiological and behavioral responses to sound-producing activities and the possible costs and long-term consequences of those responses.

The major categories of potential effects are:

- Direct trauma.
- Auditory fatigue.
- Auditory masking.
- Behavioral reactions.
- Physiological stress.

Direct trauma refers to injury to organs or tissues of an animal as a direct result of an intense sound wave or shock wave impinging upon or passing through its body. Potential impacts on an animal‘s internal tissues and organs are assessed by considering the characteristics of the exposure and the response characteristics of the tissues. Trauma can be mild and fully recoverable, with no long-term repercussions to the individual or population, or more severe, with the potential for lasting effects or, in some cases, mortality.

Auditory fatigue may result from over-stimulation of the delicate hair cells and tissues within the auditory system. The most familiar effect of auditory fatigue is hearing loss, also called a noise-induced threshold shift (TS), meaning an increase in the hearing threshold.

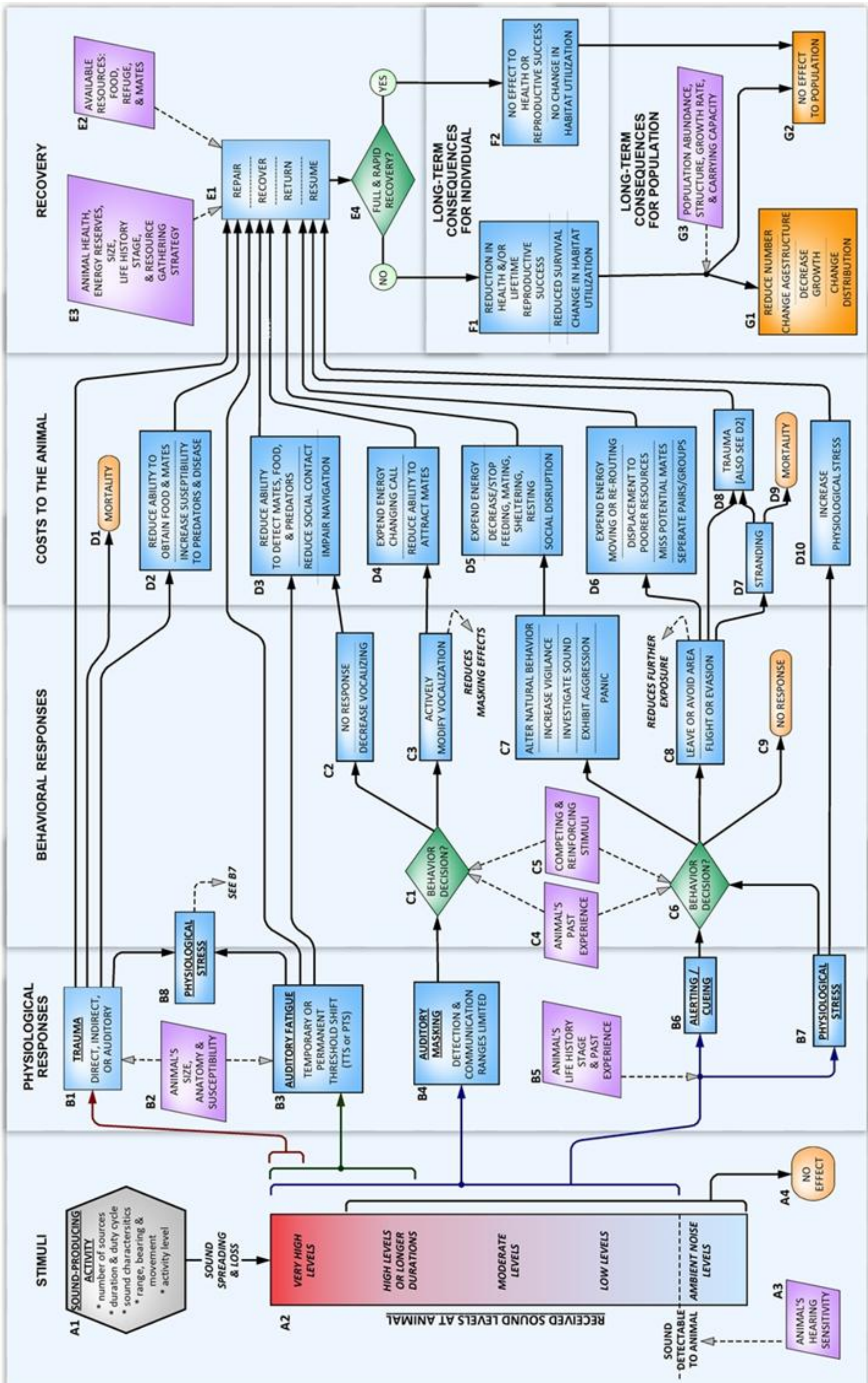
Audible natural and artificial sounds can potentially result in auditory masking, a condition that occurs when noise interferes with an animal‘s ability to hear other sounds. Masking occurs when the perception of a sound is interfered with by a second sound, and the probability of masking increases as the two sounds increase in similarity and the masking sound increases in level. It is important to distinguish auditory fatigue, which persists after the sound exposure, from masking, which only occurs during the sound exposure.

Marine animals naturally experience physiological stress as part of their normal life histories. Changing weather and ocean conditions, exposure to diseases and naturally occurring toxins, lack of prey availability, social interactions with conspecifics (members of the same species), and interactions with predators all contribute to the stress a marine animal naturally experiences. The physiological response to a stressor, often termed the stress response, is an adaptive process that helps an animal cope with changing external and internal environmental conditions. However, too much of a stress response can be harmful to an animal, resulting in physiological dysfunction. In some cases, naturally occurring stressors can have profound impacts on animals. Sound-producing activities have the potential to provide additional stress, which must be considered, not only for its direct impact on an animal‘s behavior but also for contributing to an animal‘s chronic stress level.

A sound-producing activity can cause a variety of behavioral reactions in animals ranging from very minor and brief, to more severe reactions such as aggression or prolonged flight. The acoustic stimuli can cause a stress reaction (i.e., startle or annoyance); they may act as a cue to an animal that has experienced a stress reaction in the past to similar sounds or activities, or that acquired a learned behavioral response to the sounds from conspecifics. An animal may choose to deal with these stimuli or ignore them based on the severity of the stress response, the animal‘s past experience with the sound, as well as other stimuli present in the environment. If an animal chooses to react to the acoustic stimuli, then the behavioral responses fall into two categories: alteration of natural behavior patterns or avoidance. The specific type and severity of these reactions helps determine the costs and ultimate consequences to the individual and population.

Flowchart

Figure 6-1 is a flowchart that diagrams the process used to evaluate the potential effects on marine animals from sound-producing activities. The shape and color of each box on the flowchart represent either a decision point in the analysis (green diamonds); specific processes



PTS: permanent threshold shift; TTS: temporary threshold shift

Figure 6-1. Flow Chart of the Evaluation Process of Sound-Producing Activities.

such as responses, costs, or recovery (blue rectangles); external factors to consider (purple parallelograms); and final outcomes for the individual or population (orange ovals and rectangles). Each box is labeled for reference throughout the following sections. For simplicity, sound is used here to include not only acoustic waves but also shock waves generated from explosive sources. The supporting text clarifies those instances where it is necessary to distinguish between the two phenomena.

Box A1, *the Sound-Producing Activity*, is the source of the sound stimuli and therefore the starting point in the analysis. Each of the five major categories of potential effects (i.e., direct trauma, auditory fatigue, masking, behavioral response, and stress) are presented as pathways that flow from left to right across the diagram. Pathways are not exclusive, and each must be followed until it can be concluded that an animal is not at risk for that specific effect. The vertical columns show the steps in the analysis used to examine each of the effect‘s pathways. These steps proceed from the *Stimuli,* to the *Physiological Responses*, to any potential *Behavioral Responses*, to the *Costs to the Animal*, to the *Recovery of the Animal*, and finally to the *Long-Term Consequences for the Individual and Population*.

<u>*Stimuli*</u>

The first step in predicting whether a sound-producing activity is capable of causing an effect on a marine animal is to define the stimuli experienced by the animal. The stimuli include the sound-producing activity, the surrounding acoustical environment, the characteristics of the sound when it reaches the animal, and whether the animal can detect the sound.

Sounds emitted from a *sound-producing activity* (**Box A1**) travel through the environment to create a spatially variable sound field. There can be any number of individual sound sources in a given activity, each with its own unique characteristics. For example, a U.S. Navy training exercise may involve several ships and aircraft, several types of sonar, and several types of ordnance. Each of the individual sound sources has unique characteristics: source level, frequency, duty cycle, duration, and rise-time (i.e., impulsive vs. non-impulsive). Each source also has a range, depth/altitude, bearing and directionality, and movement relative to the animal. Environmental factors such as temperature, salinity, bathymetry, bottom type, and sea state all impact how sound spreads through the environment and how sound decreases in amplitude between the source and the receiver (individual animal). Mathematical calculations and computer models are used to predict how the characteristics of the sound will change between the source and the animal under a range of realistic environmental conditions for the locations where sound-producing activities occur.

The details of the overall activity may also be important to place the potential effects into context and help predict the range of severity of the probable reactions. The overall activity level (e.g., number of ships and aircraft involved in exercise); the number of sound sources within the activity; the activity duration; and the range, bearing, and movement of the activity relative to the animal are all considered.

The *received sound at the animal* and the number of times the sound is experienced (i.e., repetitive exposures) (**Box A2**) determines the range of possible effects. Sounds that are higher than the ambient noise level and within an *animal's hearing sensitivity range* (**Box A3**) have the potential to cause effects. Very high exposure levels may have the potential to cause trauma; high-level exposures, long-duration exposures, or repetitive exposures may potentially cause auditory fatigue; lower-level exposures may potentially lead to masking; all perceived levels may lead to stress; and many sounds, including sounds that are not detectable by the animal, would have *no effect* (**Box A4**).

Physiological Responses

Physiological responses include direct trauma, hearing loss, auditory masking, and stress. The magnitude of the involuntary response is predicted based on the characteristics of the acoustic stimuli and the characteristics of the animal (species, susceptibility, life history stage, size, and past experiences).

Trauma

Physiological responses to sound stimulation may range from mechanical vibration (with no resulting adverse effects) to tissue trauma (injury). Direct *trauma* (**Box B1**) refers to the direct injury of tissues and organs by sound waves impinging upon or traveling through an animal's body. Marine animals‘ bodies, especially their auditory systems, are well adapted to large hydrostatic pressures and large, but relatively slow, pressure changes that occur with changing depth. However, mechanical trauma may result from exposure to very-high-amplitude sounds when the elastic limits of the auditory system are exceeded or when animals are exposed to intense sounds with very rapid rise times, such that the tissues cannot respond adequately to the rapid pressure changes. Trauma to marine animals from sound exposure requires high RLs. Trauma effects therefore normally only occur with very-high-amplitude, often impulsive, sources, and at relatively close range, which limits the number of animals likely exposed to trauma-inducing sound levels.

Direct trauma includes both auditory and non-auditory trauma. Auditory trauma is the direct mechanical injury to hearing-related structures, including tympanic membrane rupture, disarticulation of the middle ear ossicles, and trauma to the inner ear structures such as the organ of Corti and the associated hair cells. Auditory trauma differs from auditory fatigue in that the latter involves the overstimulation of the auditory system at levels below those capable of causing direct mechanical damage. Auditory trauma is always injurious but can be temporary. One of the most common consequences of auditory trauma is hearing loss (see below).

Non-auditory trauma can include hemorrhaging of small blood vessels and the rupture of gas-containing tissues such as the lung, swim bladder, or gastrointestinal tract. After the ear (or other sound-sensing organs), these are usually the most sensitive organs and tissues to acoustic trauma. An *animal's size and anatomy* are important in determining its *susceptibility to trauma* (**Box B2**), especially non-auditory trauma. Larger size indicates more tissue to protect vital organs that might be otherwise susceptible (i.e., there is more attenuation of the received sound before it impacts non-auditory structures). Therefore, larger animals should be less susceptible to trauma than smaller animals. In some cases, acoustic resonance of a structure may enhance the vibrations resulting from noise exposure and result in an increased susceptibility to trauma. Resonance is a phenomenon that exists when an object is vibrated at a frequency near its natural frequency of vibration, or the particular frequency at which the object vibrates most readily. The size, geometry, and material composition of a structure determine the frequency at which the object will resonate. The potential for resonance is determined by comparing the sound frequencies with the resonant frequency and damping of the tissues. Because most biological tissues are heavily damped, the increase in susceptibility from resonance is limited.

Vascular and tissue bubble formation resulting from sound exposure is a hypothesized mechanism of indirect trauma to marine animals. The risk of bubble formation from one of these processes, called rectified diffusion, is based on the amplitude, frequency, and duration of the sound (Crum and Mao 1996) and an animal‘s tissue nitrogen gas saturation at the time of the exposure. Rectified diffusion is the growth of a bubble that fluctuates in size because of the changing pressure field caused by the sound wave. An alternative, but related hypothesis has also been suggested: stable microbubbles could be destabilized by high-level sound exposures such that bubble growth then occurs through static diffusion of gas out of gas-supersaturated tissues. Bubbles have also been hypothesized to result from changes in the dive behavior of marine mammals as a result of sound exposure (Jepson et al. 2003). Vascular bubbles produced by this mechanism would not be a physiological response to the sound exposure, but a cost to the animal because of the change in behavior (**Costs to the Animal Subsection**). Under either of these hypotheses, several things could happen: (1) bubbles could grow to the extent that vascular blockage (emboli) and tissue hemorrhage occur; (2) bubbles could develop to the extent that a complement immune response is triggered or the nervous tissue is subjected to enough localized pressure that pain or dysfunction occurs; or (3) the bubbles could be cleared by the lung without negative consequence to the animal. Although rectified diffusion is a known phenomenon, its applicability to diving marine animals exposed to sound is questionable; animals would need to be highly supersaturated with gas and very close to a high-level sound source (Crum et al. 2005). The other two hypothesized phenomena are largely theoretical and have not been demonstrated under realistic exposure conditions.

<u>*Auditory Fatigue*</u>

Auditory fatigue is a reduction in hearing ability resulting from overstimulation to sounds. The mechanisms responsible for auditory fatigue differ from auditory trauma and may consist of a variety of mechanical and biochemical processes, including physical damage or distortion of the tympanic membrane and cochlear hair cell stereocilia, oxidative stress-related hair cell death, changes in cochlear blood flow, and swelling of cochlear nerve terminals resulting from glutamate excitotoxicity (Henderson et al. 2006; Kujawa and Liberman 2009). Although the outer hair cells are the most prominent target for fatigue effects, severe noise exposures may also result in inner hair cell death and loss of auditory nerve fibers (Henderson et al. 2006). Auditory fatigue is possibly the best studied type of effect from sound exposures in marine and terrestrial animals, including humans. The characteristics of the received sound stimuli are used and compared to the *animal's hearing sensitivity* and susceptibility to noise (**Box A3**) to determine the potential for auditory fatigue.

Auditory fatigue manifests itself as hearing loss, called a noise-induced TS. A threshold shift may be either permanent TS (PTS), or temporary shifts (TTS). Note that the term ―auditory fatigue” is often used to mean a TTS; however, in this analysis, a more general meaning to differentiate fatigue mechanisms (e.g., metabolic exhaustion and distortion of tissues) from auditory trauma mechanisms (e.g., physical destruction of cochlear tissues occurring at the time of exposure) is used.

The distinction between PTS and TTS is based on whether there is a complete recovery of hearing sensitivity following a sound exposure. If the TS eventually returns to zero (the animal‘s hearing returns to pre-exposure value), the TS is a TTS. If the TS does not return to zero but leaves some finite amount of TS, then that remaining TS is a PTS. **Figure 6-2** shows one hypothetical shifts that completely recovers, a TTS, and one that does not completely recover, leaving some PTS.

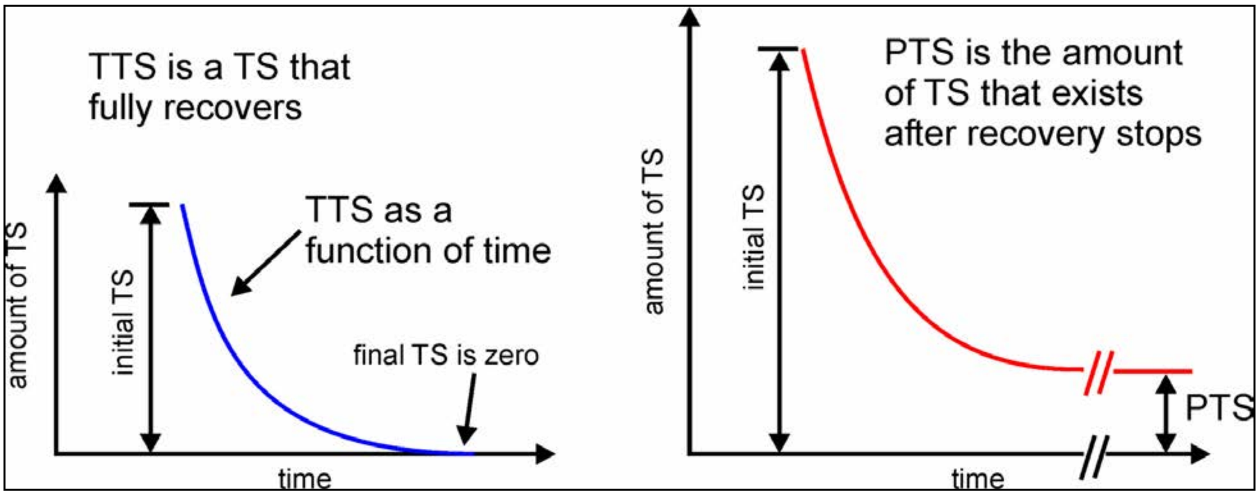


Figure 6-2. Hypothetical Temporary and Permanent Threshold Shifts.

The relationship between TTS and PTS is complicated and poorly understood, even in humans and terrestrial mammals, where numerous studies failed to delineate a clear relationship between the two. Relatively small amounts of TTS (e.g., less than 40 to 50 dB measured 2 min after exposure) will recover with no apparent long-term effects; however, terrestrial mammal studies revealed that large amounts of TTS (e.g., approximately 40 dB measured 24 hr after exposure) can result in permanent neural degeneration, despite the hearing thresholds returning to normal (Kujawa and Liberman 2009). The amounts of TTS induced by Kujawa and Liberman were described as being ―at the limits of reversibility." It is unknown whether smaller amounts of TTS can result in similar neural degeneration, or if effects would translate to other species such as marine animals.

The amplitude, frequency, duration, and temporal pattern of the sound exposure are important parameters for predicting the potential for auditory fatigue. Duration is particularly important because auditory fatigue is exacerbated with prolonged exposure time. The frequency of the sound also plays an important role in susceptibility to hearing loss. Experiments show that animals are most susceptible to *fatigue* (**Box B3**) within their most sensitive hearing range. Sounds outside of an animal‘s audible frequency range do not cause fatigue.

The greater the degree of TS, the smaller the ocean space within which an animal can detect biologically relevant sounds and communicate. This is referred to as reducing an animal‘s

―acoustic space." This reduction can be estimated given the amount of shifts incurred by an animal.

<u>*Auditory Masking*</u>

Auditory masking occurs if the noise from an activity interferes with an animal‘s ability to detect, understand, or recognize biologically relevant sounds of interest (**Box B4**). ―Noise" refers to unwanted or unimportant sounds that mask an animal‘s ability to hear ―sounds of interest." A sound of interest refers to a sound that is potentially being detected. Sounds of interest include those from conspecifics such as offspring, mates, and competitors; echolocation clicks; sounds from predators; natural, abiotic sounds that may aid in navigation; and reverberation, which can give an animal information about its location and orientation within the ocean.

The frequency, RL, and duty cycle of the sound determine the potential degree of auditory masking. Similar to hearing loss, the greater the degree of masking, the smaller the ocean space within which an animal can detect biologically relevant sounds.

<u>*Physiological Stress*</u>

If a sound is detected (i.e., heard or sensed) by an animal, a *stress* response can occur (**Box B7**); or the sound can *cue or alert* the animal (**Box B6**) without a direct, measurable stress response. If an animal suffers trauma or auditory fatigue, a *physiological stress* response will occur (**Box B8**). A stress response is a physiological change resulting from a stressor that is meant to help the animal deal with the stressor. The generalized stress response is characterized by a release of hormones (Reeder and Kramer 2005); however, it is now acknowledged that other chemicals produced in a stress response (e.g., stress markers) exist. For example, a release of reactive oxidative compounds, as occurs in noise-induced hearing loss (Henderson et al. 2006), occurs in response to some acoustic stressors. Stress hormones include those produced by the sympathetic nervous system, norepinephrine and epinephrine (i.e., the catecholamines), which produce elevations in the heart and respiration rate, increase awareness, and increase the availability of glucose and lipid for energy. Other stress hormones are the glucocorticoid steroid hormones cortisol and aldosterone, which are produced by the adrenal gland. These hormones are classically used as an indicator of a stress response and to characterize the magnitude of the stress response (Hennessy et al. 1979). Oxidative stress occurs when reactive molecules, called reactive oxygen species, are produced in excess of molecules that counteract their activity (i.e., antioxidants).

An acute stress response is traditionally considered part of the startle response and is hormonally characterized by the release of the catecholamines. Annoyance type reactions may be characterized by the release of either or both catecholamines and glucocorticoid hormones. Regardless of the physiological changes that make up the stress response, the stress response may contribute to an animal‘s decision to alter its behavior. Alternatively, a stimulus may not cause a measurable stress response but may act as an alert or cue to an animal to change its behavior. This response may occur because of learned associations; the animal may have experienced a stress reaction in the past to similar sounds or activities (**Box C4**), or it may have learned the response from conspecifics. The severity of the stress response depends on the *received sound level* at the animal (**Box A2**); the details of the *sound-producing activity*

(**Box A1**); the *animal's life history stage* (e.g., juvenile or adult; breeding or feeding season) (**Box B5**); and the *animal's past experience* with the stimuli (**Box B5**). These factors would be subject to individual variation, as well as variation within an individual over time.

An *animal's life history stage* is an important factor to consider when predicting whether a stress response is likely (**Box B5**). An animal‘s life history stage includes its level of physical maturity (i.e., larva, infant, juvenile, sexually mature adult) and the primary activity in which it is engaged such as mating, feeding, or rearing/caring for young. Animals engaged in a critical life activity such as mating or feeding may have a lesser stress response than an animal engaged in a more flexible activity such as resting or migrating (i.e., an activity that does not necessarily depend on the availability of resources). The animal‘s past experiences with the stimuli or similar stimuli are another important consideration. Prior experience with a stressor may be of particular importance because repeated experience with a stressor may dull the stress response via acclimation (St. Aubin and Dierauf 2001) or increase the response via sensitization.

Behavioral Responses

Any number of behavioral responses can result from a physiological response. An animal ―decides" how it will behave in response to the stimulus based on a number of factors in addition to the severity of the physiological response. An animal‘s experience with the sound (or similar sounds), the context of the acoustic exposure, and the presence of other stimuli contribute to determining its reaction from a suite of possible behaviors.

Behavioral responses fall into two major categories: alterations in natural behavior patterns and avoidance. These types of reactions are not mutually exclusive, and many overall reactions may be combinations of behaviors or a sequence of behaviors. Severity of behavioral reactions can vary drastically between minor and brief reorientations of the animal to investigate the sound, to severe reactions such as aggression or prolonged flight. The type and severity of the behavioral response will determine the cost to the animal.

Trauma and Auditory Fatigue

Direct trauma and auditory fatigue increases the animal‘s *physiological stress* (**Box B8**), which feeds into the *stress* response (**Box B7**). Direct trauma and auditory fatigue increase the likelihood or severity of a behavioral response and *increase* an animal's overall physiological stress level (**Box D10**).

Auditory Masking

A behavior decision is made by the animal when the animal detects increased background noise, or possibly when the animal recognizes that biologically relevant sounds are being masked (**Box C1**). An *animal's past experience* with the sound-producing activity or similar acoustic stimuli can affect its choice of behavior during auditory masking (**Box C4**). *Competing and reinforcing stimuli* may also affect its decision (**Box C5**).

An animal can choose a passive behavioral response when coping with auditory masking (**Box C2**). It may simply not respond and keep conducting its current natural behavior. An animal may also decide to stop calling until the background noise decreases. These passive responses do not present a direct energetic cost to the animal; however, auditory masking will continue, depending on the acoustic stimuli.

An animal can choose to actively compensate for auditory masking (**Box C3**). An animal can vocalize more loudly to make its signal heard over the masking noise. An animal may also shift the frequency of its vocalizations away from the frequency of the masking noise. This shift can actually reduce the masking effect for the animal and other animals that are ―listening” in the area. For example, in marine mammals, vocalization changes have been reported from exposure to anthropogenic noise sources such as sonar, vessel noise, and seismic surveying. Changes included mimicry of the sound, cessation of vocalization, increases and decreases in vocalization length, increases and decreases in vocalization rate, and increases in vocalization frequency and level, while other animals showed no significant changes in the presence of anthropogenic sound.

An animal's past experiences can be important in determining what behavior decision it may make when dealing with auditory masking (**Box C4**). Past experience can be with the sound-producing activity itself or with similar acoustic stimuli. For example, an animal may learn over time the best way to modify its vocalizations to reduce the effects of masking noise.

Other *stimuli* present in the environment can influence an animal‘s behavior decision (**Box C5**). These stimuli can be other acoustic stimuli not directly related to the sound-producing activity; they can be visual, olfactory, or tactile stimuli; the stimuli can be conspecifics or predators in the area; or the stimuli can be the strong drive to engage in a natural behavior. Competing stimuli tend to suppress any potential behavioral reaction. For example, an animal involved in mating or foraging may not react with the same degree of severity as it may have otherwise. Reinforcing stimuli reinforce the behavioral reaction caused by acoustic stimuli. For example, awareness of a predator in the area coupled with the acoustic stimuli may elicit a stronger reaction than the acoustic stimuli itself otherwise would have. The visual stimulus of seeing ships and aircraft, coupled with the acoustic stimuli, may also increase the likelihood or severity of a behavioral response.

Behavioral Reactions and Physiological Stress

A physiological stress response (**Box B7**) such as an annoyance or startle reaction, or a *cueing or alerting reaction* (**Box B6**) may cause an animal to make a *behavior decision* (**Box C6**). Any exposure that produces an injury or auditory fatigue is also assumed to produce a *stress* response (**Box B7**) and increase the severity or likelihood of a behavioral reaction. Both an *animal's past experience* (**Box C4**) and competing and reinforcing *stimuli* (**Box C5**) can affect an animal's behavior decision. The decision can result in three general types of behavioral reactions: *no response* (**Box C9**), *area avoidance* (**Box C8**), or *alteration of a natural behavior* (**Box C7**).

Little data exist that correlate specific behavioral reactions with specific stress responses. Therefore, in practice the likely range of behavioral reactions is estimated from the acoustic stimuli instead of the magnitude of the stress response. It is assumed that a stress response must exist to alter a natural behavior or cause an avoidance reaction. Estimates of the types of behavioral responses that could occur for a given sound exposure can be determined from the literature.

An animal's past experiences can be important in determining what behavior decision it may make when dealing with a stress response (**Box C4**). Past experience can be with the sound-producing activity itself or with similar sound stimuli. Habituation is the process by which an animal learns to ignore or tolerate stimuli over some period of time and return to a normal behavior pattern, perhaps after being exposed to the stimuli with no negative consequences. A habituated animal may have a lesser behavioral response than the first time it encountered the stimuli. Sensitization is when an animal becomes more sensitive to a set of stimuli over time, perhaps as a result of a past, negative experience with the stimuli or similar stimuli. A sensitized animal may have a stronger behavioral response than the first time it encountered the stimuli.

Other *stimuli* (**Box C5**) present in the environment can influence an animal's *behavior decision* (**Box C6**). These stimuli can be other acoustic stimuli not directly related to the sound-producing activity, such as visual stimuli; the stimuli can be conspecifics or predators in the area, or the stimuli can be the strong drive to engage or continue in a natural behavior. Competing stimuli tend to suppress any potential behavioral reaction. For example, an animal involved in mating or foraging may not react with the same degree of severity as an animal involved in less-critical behavior. Reinforcing stimuli reinforce the behavioral reaction caused by acoustic stimuli. For example, the awareness of a predator in the area coupled with the acoustic stimuli may elicit a stronger reaction than the acoustic stimuli themselves otherwise would have.

The visual stimulus of seeing human activities, such as ships and aircraft maneuvering, coupled with the acoustic stimuli, may also increase the likelihood or severity of a behavioral response. It is difficult to separate the stimulus of the sound from the stimulus of the ship or platform creating the sound. The sound may act as a cue, or as one stimulus of many that the animal is considering when deciding how to react. An activity with several platforms (e.g., ships and aircraft) may elicit a different reaction than an activity with a single platform, both with similar acoustic footprints. The total number of vehicles and platforms involved, the size of the activity area, and the distance between the animal and activity are important considerations when predicting behavioral responses.

An animal may reorient or become more *vigilant* if it detects a sound-producing activity (**Box C7**). Some animals may investigate the sound using other sensory systems (e.g., vision), and perhaps move closer to the sound source. Reorientation, vigilance, and investigation all require the animal to divert attention and resources and therefore slow or stop their presumably beneficial natural behavior. This can be a very brief diversion, after which the animal continues its natural behavior, or an animal may not resume its natural behaviors until after a longer period when the animal has habituated to the sound or the activity has concluded. An attentional change via an orienting response represents behaviors that would be considered mild disruption. More severe alterations of natural behavior would include aggression or panic.

An animal may choose to *leave or avoid an area* where a sound-producing activity is taking place (**Box C8**). Avoidance is the displacement of an individual from an area. A more severe form of this comes in the form of flight or evasion. A flight response is a dramatic change in normal movement to a directed and rapid movement away from the detected location of a sound source. Avoidance of an area can help the animal avoid further acoustic effects by avoiding or reducing further exposure.

An animal may choose *not to respond* to a sound-producing activity (**Box C9**). The physiological stress response may not rise to the level that would cause the animal to modify its behavior. The animal may have habituated to the sound or simply learned through past experience that the sound is not a threat. In this case a behavioral effect would not be predicted. An animal may choose not to respond to a sound-producing activity in spite of a physiological stress response. Some combination of competing stimuli may be present such as a robust food patch or a mating opportunity that overcomes the stress response and suppresses any potential behavioral responses. If the noise-producing activity persists over long periods or reoccurs frequently, the acute stress felt by animals could increase their overall chronic stress levels.

Costs to the Animal

The potential costs to a marine animal from an involuntary or behavioral response include no measurable cost, expended energy reserves, increased stress, reduced social contact, missed opportunities to secure resources or mates, displacement, and stranding or severe evasive behavior (which may potentially lead to secondary trauma or death). Animals suffer costs on a daily basis from a host of natural situations such as dealing with predators or competitor pressure. If the costs to the animal from an acoustic-related effect fall outside of its normal daily variations, then individuals must recover from significant costs to avoid long-term consequences.

Trauma

Trauma or injury to an animal may reduce its ability to secure food by reducing its mobility or the efficiency of its sensory systems, make the injured individual less attractive to potential mates, or increase *an individual's chances of contracting diseases or falling prey to a predator* (**Box D2**). A severe trauma can lead to the *death* of the individual (**Box D1**).

Auditory Fatigue and Auditory Masking

Auditory fatigue and masking can impair an animal's ability to hear biologically important sounds (**Box D3**), especially fainter and more distant sounds. Sounds could belong to conspecifics such as other individuals in a social group (i.e., pod, school, etc.), potential mates, potential competitors, or parents/offspring. Biologically-important sounds could also be an animal's own biosonar echoes used to detect prey, predators, and the physical environment. Therefore, auditory masking or a hearing loss could reduce an animal's ability to contact social groups, offspring, or parents; and reduce opportunities to detect or attract more distant mates. Animals may also use sounds to gain information about their physical environment by detecting the reverberation of sounds in the underwater space or sensing the sound of crashing waves on a nearby shoreline. These cues could be used by some animals to migrate long distances or navigate their immediate environment. Therefore, an animal's ability to navigate may be impaired if the animal uses acoustic cues from the physical environment to help identify its location. Auditory masking and fatigue both effectively reduce the animal's acoustic space and the ocean volume in which detection and communication are effective.

An animal that *modifies its vocalization* in response to auditory masking could incur a cost (**Box D4**). Modifying vocalizations may cost the animal energy from its finite energy budget. Additionally, shifting the frequency of a call can make an animal appear to be less fit to conspecifics. For example, songbirds that shift their calls up an octave to compensate for increased background noise attract fewer or less-desirable mates. Larger animals are typically capable of producing lower-frequency sounds than smaller conspecifics. Therefore, lower-frequency sounds are usually an indicator of a larger and presumably more fit and experienced potential mate.

Auditory masking or auditory fatigue may also lead to no measurable costs for an animal. Masking could be of short duration or intermittent such that biologically important sounds that are continuous or repeated are received by the animal between masking noise. Auditory fatigue could also be inconsequential for an animal if the frequency range affected is not critical for that animal to hear within, or the auditory fatigue is of such short duration (e.g., a few minutes) that there are no costs to the individual.

Behavioral Reactions and Physiological Stress

An animal that alters its natural behavior in response to stress or an auditory cue may slow or cease its presumably beneficial natural behavior and instead *expend energy* reacting to the sound-producing activity (**Box D5**). Beneficial natural behaviors include feeding, breeding, sheltering, and migrating. The cost of feeding disruptions depends on the energetic requirements of individuals and the potential amount of food missed during the disruption. Alteration in breeding behavior can result in delaying reproduction. The costs of a brief interruption to migrating or sheltering are less clear. Most behavior alterations also require the animal to expend energy for a nonbeneficial behavior. The amount of energy expended depends on the severity of the behavioral response.

An animal that avoids a sound-producing activity may expend additional energy moving around the area, be displaced to poorer resources, miss potential mates, or have social interactions affected (**Box D6**). Avoidance reactions can cause an animal to expend energy. The amount of energy expended depends on the severity of the behavioral response. Missing potential mates can result in delaying reproduction. Social groups or pairs of animals, such as mates or parent/offspring pairs, could be separated during a severe behavioral response such as flight. Offspring that depend on their parents may die if they are permanently separated. Splitting up an animal group can result in a reduced group size, which can have secondary effects on individual foraging success and susceptibility to predators.

Some severe behavioral reactions can lead to *stranding* (**Box D7**) or secondary *trauma* (**Box D8**). Animals that take prolonged flight, a severe avoidance reaction, may injure themselves or strand in an environment for which they are not adapted. Some trauma is likely to occur to an animal that strands (**Box D8**). Trauma can *reduce the animal's ability to secure food and mates*, and *increase the animal's susceptibility to predation and disease* (**Box D2**). An animal that strands and does not return to a hospitable environment quickly will likely *die* (**Box D9**).

Elevated stress levels may occur whether or not an animal exhibits a behavioral response (**Box D10**). Even while undergoing a stress response, competing stimuli (e.g., food or mating opportunities) may overcome an animal's initial stress response during the behavior decision. Regardless of whether the animal displays a behavioral reaction, this tolerated stress could incur a cost to the animal. Reactive oxygen species produced during normal physiological processes are generally counterbalanced by enzymes and antioxidants; however, excess stress can result in an excess production of reactive oxygen species, leading to damage of lipids, proteins, and nucleic acids at the cellular level (Berlett and Stadtman 1997; Sies 1997; Touyz 2004).

Recovery

The predicted recovery of the animal (**Box E1**) is based on the cost of any masking or behavioral response and the severity on any involuntary physiological reactions (e.g., direct trauma, hearing loss, or increased chronic stress). Many effects are fully recoverable upon cessation of the sound-producing activity, and the vast majority of effects are completely recoverable over time; whereas a few effects may not be fully recoverable. The availability of resources and the characteristics of the animal play a critical role in determining the speed and completeness of recovery.

Available resources fluctuate by season, location, and year and can play a major role in an animal's rate of recovery (**Box E2**). Plentiful food can aid in a quicker recovery, whereas recovery can take much longer if food resources are limited. If many potential mates are available, an animal may recover quickly from missing a single mating opportunity. Refuge or shelter is also an important resource that may give an animal an opportunity to recover or repair after an incurred cost or physiological response.

An *animal's health, energy reserves, size, life history stage, and resource gathering strategy* affect its speed and completeness of recovery (**Box E3**). Animals that are in good health and have abundant energy reserves before an effect, will likely recover more quickly. Adult animals with stored energy reserves (e.g., fat reserves) may have an easier time recovering than juveniles that expend their energy growing and developing and have less in reserve. Large individuals and large species may recover more quickly, also due to having more potential for energy reserves. Animals that gather and store resources, perhaps fasting for months during breeding or offspring rearing seasons, may have a more difficult time recovering from being temporarily displaced from a feeding area than an animal that feeds year round.

Damaged tissues from mild to moderate trauma may heal over time. The predicted recovery of direct trauma is based on the severity of the trauma, availability of resources, and characteristics of the animal. After a sustained injury an animal's body attempts to *repair* tissues. The animal may also need to *recover* from any potential costs due to a decrease in resource gathering efficiency and any secondary effects from predators or disease (**Box E1**). Moderate to severe trauma that does not cause mortality may never fully heal.

Small to moderate amounts of hearing loss may recover over a period of minutes to days, depending on the nature of the exposure and the amount of initial TS. Severe noise-induced hearing loss may not fully recover, resulting in some amount of permanent hearing loss.

Auditory masking only occurs when the sound source is operating; therefore, direct masking effects stop immediately upon cessation of the sound-producing activity (**Box E1**). Natural behaviors may *resume* shortly after or even during the acoustic stimulus after an initial assessment period by the animal. Any energetic expenditures and missed opportunities to find and secure resources incurred from masking or a behavior alteration may take some time to recover.

Animals displaced from their normal habitat due to an avoidance reaction may return over time and resume their natural behaviors, depending on the severity of the reaction and how often the activity is repeated in the area. In areas of repeated and frequent acoustic disturbance, some animals may habituate to the new baseline or fluctuations in noise level. More sensitive species, or animals that may have been sensitized to the stimulus over time due to past negative experiences, may not return to an area. Other animals may return but not resume use of the habitat in the same manner as before the acoustic-related effect. For example, an animal may return to an area to feed or navigate through it to get to another area, but that animal may no longer seek that area as refuge or shelter.

Frequent milder physiological responses to an individual may accumulate over time if the time between sound-producing activities is not adequate to give the animal an opportunity to fully recover. An increase in an animal's chronic stress level is also possible if stress caused by a sound-producing activity does not return to baseline between exposures. Each component of the stress response is variable in time, and stress hormones return to baseline levels at different rates. For example, adrenaline is released almost immediately and is used or cleared by the system quickly, whereas glucocorticoid and cortisol levels may take long periods (i.e., hours to days) to return to baseline.

Long-Term Consequences to the Individual and the Population

The magnitude and type of effect and the speed and *completeness of recovery* must be considered in predicting long-term consequences to the individual animal and its population (**Box E**). Animals that recover quickly and completely from explosive or acoustic-related effects will likely not *suffer reductions in their health or reproductive success, or experience changes in habitat utilization* (**Box F2**). *No population-level effects* would be expected if individual animals do not suffer reductions in their lifetime reproductive success or change their habitat utilization (**Box G2**).

Animals that do not recover quickly and fully could *suffer reductions in their health and lifetime reproductive success*, they could be permanently displaced or *change how they utilize the environment*, or they could *die* (**Box F1**).

Severe injuries can lead to reduced survivorship (longevity), elevated stress levels, and prolonged alterations in behavior that can reduce an animal‘s lifetime reproductive success. An animal with decreased energy stores or a lingering injury may be less successful at mating for one or more breeding seasons, thereby decreasing the number of offspring produced over its lifetime.

An animal whose hearing does not recover quickly and fully could suffer a reduction in lifetime reproductive success (**Box F1**). An animal with decreased energy stores or a PTS may be less successful at mating for one or more breeding seasons, thereby decreasing the number of offspring it can produce over its lifetime.

As mentioned above, the involuntary reaction of masking ends, when the acoustic stimuli conclude. The direct effects of auditory masking could have long-term consequences for individuals if the activity was continuous or occurred frequently enough; however, most of the proposed training and testing activities are normally spread over vast areas and occur infrequently in a specific area.

Missed mating opportunities can have a direct effect on reproductive success. Reducing an animal's energy reserves over longer periods can directly reduce its health and reproductive success. Some species may not enter a breeding cycle without adequate energy stores, and animals that do breed may have a decreased probability of offspring survival. Animals displaced from their preferred habitat, or those who utilize it differently, may no longer have access to the best resources. Some animals that leave or flee an area during a noise-producing activity, especially an activity that is persistent or frequent, may not return quickly or at all. This can further reduce an individual‘s health and lifetime reproductive success.

Frequent disruptions to natural behavior patterns may not allow an animal to fully recover between exposures, which increase the probability of causing long-term consequences to individuals. Elevated chronic stress levels are usually a result of a prolonged or repeated disturbance. Excess stress produces reactive molecules in an animal's body that can result in cellular damage (Berlett and Stadtman 1997; Sies 1997; Touyz 2004). Chronic elevations in the stress levels (e.g., cortisol levels) may produce long-term health consequences that can reduce lifetime reproductive success.

These long-term consequences to the individual can lead to consequences for the *population* (**Box G1**). Population *dynamics and abundance* play a role in determining how many individuals would need to suffer long-term consequences before there was an effect on the population (**Box G1**). Long-term abandonment or a change in the utilization of an area by enough individuals can *change the distribution of the population*. Death has an immediate effect in that no further contribution to the population is possible, which reduces the animal's lifetime reproductive success.

Carrying capacity describes the theoretical maximum number of animals of a particular species that the environment can support. When a population nears its carrying capacity, the lifetime reproductive success in individuals may decrease due to finite resources or predator-prey interactions. *Population growth* is naturally limited by available resources and predator pressure. If one, or a few animals, in a population are removed or gather fewer resources, then other animals in the population can take advantage of the freed resources and potentially increase their health and lifetime reproductive success. Abundant populations that are near their carrying capacity (theoretical maximum abundance) that suffer effects to a few individuals may not be affected overall.

Populations that are reduced well below their carrying capacity may suffer greater consequences from any lasting effects to even a few individuals. Population-level consequences can include a change in the population dynamics, a decrease in the growth rate, or a change in geographic distribution. Changing the dynamics of a population (the proportion of the population within each age group) or their geographic distribution can also have secondary effects on population growth rates.

Long-Term Consequences to the Individual and Population

Long-term consequences are considered in terms of a resource‘s existing population level, growth and mortality rates, other stressors on the resource from sonar operations, cumulative impacts on the resource, and the ability of the population to recover from or adapt to impacts. Impacts of multiple or repeated stressors on individuals are cumulative. When stressors are chronic, an organism may experience reduced growth, health, or survival, which could have population-level impacts (Billard et al. 1981), especially in the case of endangered species.

Acoustic Stressors

<u>Non-Impulsive Sound Sources</u>

Long recognized by the scientific community (Payne and Webb 1971) and summarized by the National Academies of Science, human-generated sound could possibly harm marine mammals or significantly interfere with their normal activities (NRC 2005). Assessing whether a sound may disturb or injure a marine mammal involves understanding the characteristics of the acoustic sources, the marine mammals that may be present in the vicinity of the sound, and the effects that sound may have on the physiology and behavior of those marine mammals. Although it is known that sound is important for marine mammal communication, navigation, and foraging (NRC 2003, 2005), there are many unknowns in assessing impacts such as the potential interaction of different effects and the significance of responses by marine mammals to sound exposures (Nowacek et al. 2007; Southall et al. 2007). Furthermore, many other factors besides just the received level of sound may affect an animal's reaction such as the animal's physical condition, prior experience with the sound, and proximity to the source of the sound.

Methods used to predict acoustic effects on marine mammals build on the Conceptual Framework for Assessing Effects from Sound Producing Activities. Additional research specific to marine mammals is presented where available.

Application of the MMPA to Potential Acoustic Effects

The MMPA prohibits the unauthorized harassment of marine mammals and provides the regulatory processes for authorization for any such incidental harassment that might occur during an otherwise lawful activity. Harassment that may result from Q-20 operations is unintentional and incidental to those activities.

For military readiness activities, MMPA Level A harassment includes any act that injures or has the significant potential to injure a marine mammal or marine mammal stock in the wild. Injury, as defined in this IHA application, is the destruction or loss of biological tissue from a species. The destruction or loss of biological tissue will result in an alteration of physiological function that exceeds the normal daily physiological variation of the intact tissue. For example, increased localized histamine production, edema, production of scar tissue, activation of clotting factors, white blood cell response, etc., may be expected following injury. Therefore, this IHA application assumes that all injury is qualified as a physiological effect and, to be consistent with prior actions and rulings, all injuries (slight to severe) are considered MMPA Level A harassment.

PTS is nonrecoverable and, by definition, results from the irreversible impacts on auditory sensory cells, supporting tissues, or neural structures within the auditory system. PTS, therefore, qualifies as an injury and is classified as Level A harassment under the wording of the MMPA. The smallest amount of PTS (onset-PTS) is taken to be the indicator for the smallest degree of injury that can be measured. The acoustic exposure associated with onset-PTS is used to define the outer limit of the Level A exposure zone.

Public Law 108-136 (2004) amended the MMPA definitions of Level B harassment for military readiness activities to be “any act that disturbs or is likely to disturb a marine mammal or marine mammal stock by causing disruption of natural behavioral patterns including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering to a point where such behaviors are abandoned or significantly altered.” Unlike MMPA Level A harassment, which is solely associated with physiological effects, both physiological and behavioral effects may cause MMPA Level B harassment.

TTS is recoverable and is considered to result from the temporary, non-injurious distortion of hearing-related tissues. In the Q-20 Study Area, the smallest measurable amount of TTS (onset-TTS) is taken as the best indicator for slight temporary sensory impairment. Because it is considered non-injurious, the acoustic exposure associated with onset-TTS is used to define the outer limit of the portion of the Level B exposure zone attributable to physiological effects. Short-term reduction in hearing acuity could be considered a temporary decrement similar in scope to a period of hearing masking or behavioral disturbance. As such, it is by the U.S. Navy and NMFS as a Level B effect overlapping the range of sounds producing behavioral effects.

The harassment status of slight behavior disruption has been addressed in workshops, previous actions, and rulings (NOAA 2008). The conclusion is that a momentary behavioral reaction of an animal to a brief, time-isolated acoustic event does not qualify as MMPA Level B harassment. This analysis uses behavioral criteria to predict the number of animals likely to experience a significant behavioral reaction, and therefore an MMPA Level B harassment.

NMFS also includes mortality as a possible outcome to consider in addition to MMPA Level A and Level B harassment. An individual animal predicted to experience simultaneous multiple injuries, multiple disruptions, or both, is counted as a single take (NOAA 2008). NMFS has generally identified a 24-hour period as the amount of time in which an individual can be harassed no more than once. Behavioral harassment, under the risk function presented in this analysis, uses the highest received sound pressure level (SPL) over a 24-hour period as the metric for determining the probability of a behavioral harassment.

Criteria and Thresholds for Physiological Effects

This section presents the effect criteria and thresholds for physiological effects of sound leading to injury and behavioral disturbance as a result of sensory impairment. The tissues of the ear are the most susceptible to physiological effects of underwater sound. PTS and TTS were determined to be the most appropriate biological indicators of physiological effects that equate to the onset of injury (Level A harassment) and behavioral disturbance (Level B harassment), respectively. This section is, therefore, focused on criteria and thresholds to predict PTS and TTS in marine mammals.

The most appropriate information from which to develop PTS/TTS criteria for marine mammals are experimental measurements of PTS and TTS from marine mammal species of interest. TTS data exist for several marine mammal species and may be used to develop meaningful TTS criteria and thresholds. PTS data do not exist for marine mammals and are unlikely to be obtained. Therefore, PTS criteria must be developed from TTS criteria and estimates of the relationship between TTS and PTS.

This section begins with a review of the existing marine mammal TTS data. The review is followed by a discussion of the relationship between TTS and PTS. The specific criteria and thresholds for TTS and PTS used in this IHA application are then presented. This is followed by discussions of sound energy flux density level (EL), the relationship between EL and SPL, and the use of SPL and EL in previous U.S. Navy environmental compliance documents.

Energy Flux Density Level and Sound Pressure Level

EL is a measure of the sound energy flow per unit area expressed in decibels (dB). EL is stated in dB re 1 μPa^2-s for underwater sound.

SPL is a measure of the root mean square, or ―effective,” sound pressure in dB. SPL is expressed in decibels referenced at 1 micropascal (dB re 1 µPa) for underwater sound.

TTS for Sonar

A number of investigators have measured TTS in marine mammals. These studies measured hearing thresholds in trained marine mammals before and after exposure to intense sounds. Some of the more important data obtained from these studies are onset TTS levels, exposure levels sufficient to cause a just-measurable amount of TTS, often defined as 6 dB of TTS (e.g., Schlundt et al. 2000). The existing marine mammal TTS data are summarized in the following paragraphs.

Schlundt et al. (2000) reported the results of TTS experiments conducted with bottlenose dolphins and beluga whales (*Delphinapterus leucas*) exposed to 1-sec tones. This paper also included a re-analysis of preliminary TTS data released in a technical report by Ridgway et al. (1997). At frequencies of 3, 10, and 20 kHz, SPLs necessary to induce measurable amounts (6 dB or more) of TTS were between 192 and 201 dB re 1 µPa (EL = 192 to 201 dB re 1 μPa^2-s). The mean exposure SPL and EL for onset-TTS were 195 dB re 1 µPa and 195 dB re 1 μPa^2-s, respectively. The sound exposure stimuli (tones) and relatively large number of test subjects (five dolphins and two beluga whales) make the Schlundt et al. (2000) data the most directly relevant TTS information for the scenarios described in this IHA application.

Finneran et al. (2001, 2003, 2005) described TTS experiments conducted with bottlenose dolphins exposed to 3-kHz tones with durations of 1, 2, 4, and 8 sec. Small amounts of TTS (3 to 6 dB) were observed in one dolphin after exposure to ELs between 190 and 204 dB re 1 μPa^2-s. These results were consistent with the data of Schlundt et al. (2000) and showed that the

Schlundt et al. (2000) data were not significantly affected by the masking sound used. These results also confirmed that, for tones with different durations, the amount of TTS is best correlated with the exposure EL rather than the exposure SPL.

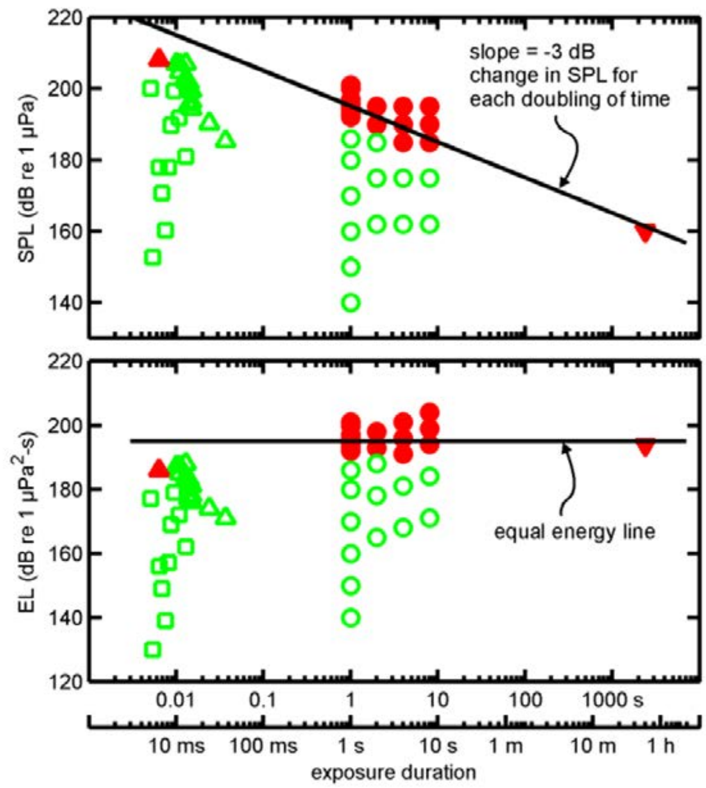
Nachtigall et al. (2003, 2004) measured TTS in a bottlenose dolphin exposed to octave-band sound centered at 7.5 kHz. Nachtigall et al. (2003) reported TTSs of about 11 dB measured 10 to 15 min after exposure to 30 to 50 min of sound with SPL 179 dB re 1 µPa (EL about 213 dB re μPa^2-s). No TTS was observed after exposure to the same sound at 165 and 171 dB re 1 µPa. Nachtigall et al. (2004) reported TTSs of around 4 to 8 dB 5 min after exposure to 30 to 50 min of sound with SPL 160 dB re 1 µPa (EL about 193 to 195 dB re 1 μPa^2-s). The difference in results was attributed to faster post-exposure threshold measurement; TTS may have recovered before being detected by Nachtigall et al. (2003). These studies showed that, for long-duration exposures, lower sound pressures are required to induce TTS than are required for short-duration tones. These data also confirmed that, for the cetaceans studied, EL is the most appropriate predictor for onset-TTS.

Finneran et al. (2000, 2002) conducted TTS experiments with bottlenose dolphins and beluga whales exposed to impulsive sounds similar to those produced by distant underwater explosions and seismic waterguns. These studies showed that, for very short-duration impulsive sounds, higher sound pressures were required to induce TTS than for longer-duration tones.

Kastak et al. (1999, 2005) conducted TTS experiments with three species of pinnipeds: California sea lion (*Zalophus californianus*), northern elephant seal (*Mirounga angustirostris*), and Pacific harbor seal (*Phoca vitulina*) exposed to continuous underwater sounds at levels of 80 and 95 dB sensation level (the level above the animal‘s threshold at that frequency) at 2.5 and 3.5 kHz for up to 50 min. Mean TTS shifts of up to 12.2 dB occurred with the harbor seals showing the largest shift of 28.1 dB. Increasing the sound duration had a greater effect on TTS than increasing the sound level from 80 to 95 dB.

Figure 6-3 shows the existing TTS data for cetaceans (dolphins and beluga whales). Individual exposures are shown in terms of SPL versus exposure duration (upper panel) and EL versus exposure duration (lower panel). **Figure 6-3** illustrates that the effects of the different sound exposures depend on the SPL and duration. As the duration decreases, higher SPLs are required to cause TTS. In contrast, the ELs required for TTS do not show the same type of variation with exposure duration.

The solid line in the upper panel of **Figure 6-3** has a slope of -3 dB per doubling of time. This line passes through the point where the SPL is 195 dB re 1 µPa and the exposure duration is 1 sec. Since EL = SPL + $10\log_{10}$ (duration), doubling the duration *increases* the EL by 3 dB. Subtracting 3 dB from the SPL *decreases* the EL by 3 dB. The line with a slope of -3 dB per doubling of time, therefore, represents an *equal energy line*, where all points on the line have the same EL, which is, in this case, 195 dB re 1 μPa^2-s. This line appears in the lower panel as a horizontal line at 195 dB re 1 μPa^2-s. The equal energy line at 195 dB re 1 μPa^2-s fits the tonal and sound data (the nonimpulsive data) very well, despite differences in exposure duration, SPL, experimental methods, and subjects.



Legend:	Filled symbol:	Exposure that produced TTS
	Open symbol:	Exposure that did not produce TTS
	Squares:	Impulsive test results from Finneran et al., 2000
	Triangles:	Impulsive test results from Finneran et al., 2002
	Circles:	3-, 10-, and 20-kHz data from Schlundt et al. (2000) and results of Finneran et al. (2003a)
	Inverted triangle:	Data from Nachtigall et al., 2003b

Figure 6-3. Existing TTS Data for Cetaceans.

In summary, the existing marine mammal TTS data show that, for the species studied and sounds (nonimpulsive) of interest, the following are true:

- The growth and recovery of TTS are comparable to those in land mammals. This means that, as in land mammals, cetacean TSs depend on the amplitude, duration, frequency content, and temporal pattern of the sound exposure. TSs will generally increase with the amplitude and duration of sound exposure. For continuous sounds, exposures of equal energy will lead to approximately equal effects (Ward 1997). For intermittent sounds, less TS will occur than from a continuous exposure with the same energy (some recovery will occur between exposures) (Ward 1997).
- SPL by itself is not a good predictor of onset-TTS, since the amount of TTS depends on both SPL and duration.
- Exposure EL is correlated with the amount of TTS and is a good predictor for onset-TTS for single, continuous exposures with different durations. This agrees with human TTS data presented by Ward et al. (1958, 1959).

- An EL of 195 dB re 1 μPa^2-s is the most appropriate predictor for onset-TTS from a single, continuous exposure.

Relationship Between TTS and PTS

Since no studies have been designed to intentionally induce PTS in marine mammals, onset-PTS levels for these animals must be estimated using empirical TTS data obtained in marine mammals and relationships between TTS and PTS established in terrestrial mammals.

TTS and PTS thresholds are based on TTS onset values for impulsive and non-impulsive sounds obtained from representative species of mid- and high-frequency cetaceans, and pinnipeds. These data are then extended to the other marine mammals for which data are not available.

Threshold Levels for Harassment from Physiological Effects

For this specified action, sound exposure thresholds for TTS and PTS are as presented in the following box:

195 dB re 1 μPa^2-s received EL for TTS
215 dB re 1 μPa^2-s received EL for PTS

Marine mammals predicted to receive an accumulated sound exposure with EL of 215 dB re 1 μPa^2-s or greater are assumed to experience PTS and are counted as Level A harassment exposures. Marine mammals predicted to receive a sound exposure with EL greater than or equal to 195 dB re 1 μPa^2-s but less than 215 dB re 1 μPa^2-s are assumed to experience TTS and are counted as Level B harassment exposures.

The TTS threshold is primarily based on the cetacean TTS data from Schlundt et al. (2000). Since these tests used short-duration tones similar to sonar pings, they are the most directly relevant data. The mean exposure EL required to produce onset-TTS in these tests was 195 dB re 1 μPa^2-s. This result is corroborated by the short-duration tone data of Finneran et al. (2000 and 2003) and the long-duration sound data from Nachtigall et al. (2003, 2004). Together, these data demonstrate that TTS in cetaceans is correlated with the received EL and that onset-TTS exposures are fit well by an equal-energy line passing through 195 dB re 1 μPa^2-s.

The PTS threshold is based on a 20 dB increase in exposure ELs over that required for onset-TTS. The 20 dB value is based on estimates from terrestrial mammal data of PTS occurring at 40 dB or more of TS, and on TS growth occurring at a rate of 1.6 dB/dB increase in exposure EL. This is conservative because: (1) 40 dB of TS is actually an upper limit for TTS used to approximate onset-PTS, and (2) the 1.6 dB/dB growth rate is the highest observed in the data from Ward et al. (1958, 1959).

Use of EL for Physiological Effect Thresholds

Effect thresholds are expressed in terms of total received EL. Energy flux density is a measure of the flow of sound energy through an area. Marine and terrestrial mammal data show that, for continuous-type sounds of interest, TTS and PTS are more closely related to the energy in the sound exposure than to the exposure SPL.

The EL for each individual ping is calculated from the following equation:

$$EL = SPL + 10\log_{10} (\text{duration})$$

The EL includes both the ping SPL and duration. Longer-duration pings and/or higher-SPL pings will have a higher EL.

If an animal is exposed to multiple pings, the energy flux density in each individual ping is summed to calculate the total EL. Since mammalian TS data show less effect from intermittent exposures compared to continuous exposures with the same energy (Ward 1997), basing the effect thresholds on the total received EL is a conservative approach for treating multiple pings; in reality, some recovery will occur between pings and lessen the effect of a particular exposure. Therefore, estimates are conservative because recovery is not taken into account; intermittent exposures are considered comparable to continuous exposures.

The total EL depends on the SPL, duration, and number of pings received. The TTS and PTS thresholds do not imply any specific SPL, duration, or number of pings. The SPL and duration of each received ping are used to calculate the total EL and determine whether the received EL meets or exceeds the effect thresholds. For example, the TTS threshold would be reached through any of the following exposures:

- A single ping with SPL = 195 dB re 1 μPa and duration = 1 sec.
- Two pings with SPL = 189 dB re 1 μPa and duration = 2 secs.

Summary of Criteria and Thresholds for Physiological Effects

PTS and TTS are used as the criteria for physiological effects resulting in injury (Level A harassment) and disturbance (Level B harassment), respectively. Sound exposure thresholds for TTS and PTS are 195 dB re 1 μPa^2-s received EL for TTS and 215 dB re 1 μPa^2-s received EL for PTS. The TTS threshold is primarily based on cetacean TTS data from Schlundt et al. (2000). Since these tests used short-duration tones similar to sonar pings, they are the most directly relevant data. The PTS threshold is based on a 20 dB increase in exposure EL over that required for onset-TTS. The 20-dB value is based on extrapolations from terrestrial mammal data indicating that PTS occurs at 40 dB or more of TS, and that TS growth occurring at a rate of approximately 1.6 dB/dB increase in exposure EL.

Analytical Methodology – MMPA Behavioral Harassment for MFAS/HFAS Sources

Behavioral Reactions

The response of a marine mammal to an anthropogenic sound will depend on the frequency, duration, temporal pattern and amplitude of the sound, as well as the animal‘s prior experience with the sound and the context in which the sound is encountered (i.e., what the animal is doing at the time of the exposure). The distance from the sound source and whether it is perceived as approaching or moving away can also affect the way an animal responds to a sound (Wartzok et al. 2003). For marine mammals, a review of responses to anthropogenic sound was first conducted by Richardson and others (Richardson et al. 1995). More recent reviews (Nowacek et al. 2007; Southall et al. 2007) address studies conducted since 1995 and focus on observations where the received sound level of the exposed marine mammal(s) was known or could be estimated.

Except for some vocalization changes in response to auditory masking, all behavioral reactions are assumed to occur due to a preceding stress or cueing response; however, stress responses cannot be predicted directly due to a lack of scientific data (**Physiological Stress Subsection**). Responses can overlap; for example, an increased respiration rate is likely to be coupled to a flight response. Differential responses between and within species are expected since hearing ranges vary across species and the behavioral ecologies of individual species are unlikely to completely overlap.

Southall et al. (2007) synthesized data from many past behavioral studies and observations to determine the likelihood of behavioral reactions at specific sound levels. While in general, the louder the sound source the more intense the behavioral response, it was clear that the proximity of a sound source and the animal‘s experience, motivation, and conditioning were also critical factors influencing the response (Southall et al. 2007). After examining all of the available data, the authors felt that the derivation of thresholds for behavioral response based solely on exposure level was not supported because context of the animal at the time of sound exposure was an important factor in estimating response. Nonetheless, in some conditions, consistent avoidance reactions were noted at higher sound levels, depending on the marine mammal species or group, allowing conclusions to be drawn. Most low-frequency cetaceans (mysticetes) observed in studies usually avoided sound sources at levels of less than or equal to 160 dB re 1 μPa. Published studies of mid-frequency cetaceans analyzed include sperm whales (*Physeter macrocephalus*), beluga whales, bottlenose dolphins, and river dolphins (Family Platinistidae). These groups showed no clear tendency, but for non-impulsive sounds, captive animals tolerated levels in excess of 170 dB re 1 μPa before showing behavioral reactions, such as avoidance, erratic swimming, and attacking the test apparatus. High-frequency cetaceans (observed from studies with harbor porpoises [*Phocoena phocoena*]) exhibited changes in respiration and avoidance behavior at levels between 90 and 140 dB re 1 μPa, with profound avoidance behavior noted for levels exceeding this. Recent studies with beaked whales (Family Ziphiidae) have shown them to be particularly sensitive to noise, with animals during three playbacks of sound breaking off foraging dives at levels below 142 dB SPL, although acoustic monitoring during actual sonar exercises revealed some beaked whales continuing to forage at levels as high as 157 dB SPL (Tyack et al. 2011).

<u>Behavioral Reactions to Sonar and other Active Acoustic Sources</u>

Mysticetes

Specific to U.S. Navy systems using low-frequency sound, studies were undertaken in 1997–1998 pursuant to the U.S. Navy‘s Low-Frequency Sound Scientific Research Program. These studies found only short-term responses to low frequency sound by mysticetes (fin, blue, and humpback whales), including changes in vocal activity and avoidance of the source vessel (Clark and Fristrup 2001; Croll et al. 2001; Fristrup et al. 2003; Miller et al. 2000; Nowacek et al. 2007). Baleen whales exposed to moderate low-frequency signals demonstrated no variation in foraging activity (Croll et al. 2001). However, five of six North Atlantic right whales exposed to an acoustic alarm interrupted their foraging dives, although the alarm signal was long in duration, lasting several minutes, and purposely designed to elicit a reaction from the animals as a prospective means to protect them from ship strikes (Nowacek et al. 2004). Although the animals' received SPL was similar in the latter two studies (133 to 150 dB SPL), the frequency, duration, and temporal pattern of signal presentation were different. Additionally, the right whales did not respond to playbacks of either right whale social sounds or vessel noise, highlighting the importance of the sound characteristics, species differences, and individual sensitivity in producing a behavioral reaction.

Low-frequency signals of the Acoustic Thermometry of Ocean Climate sound source were not found to affect dive times of humpback whales in Hawaiian waters (Frankel and Clark 2000) or to overtly affect elephant seal dives (Costa et al. 2003). However, they did produce subtle effects that varied in direction and degree among the individual seals, again illustrating the equivocal nature of behavioral effects and consequent difficulty in defining and predicting them.

Blue whales exposed to mid-frequency sonar in the Southern California Bight were less likely to produce low frequency calls usually associated with feeding behavior (Melcón et al. 2012). It is not known whether the lower rates of calling actually indicated a reduction in feeding behavior or social contact since the study used data from remotely deployed, passive acoustic monitoring buoys. In contrast, blue whales increased their likelihood of calling when ship noise was present, and decreased their likelihood of calling in the presence of explosive noise, although this result was not statistically significant (Melcón et al. 2012). Additionally, the likelihood of an animal calling decreased with the increased RL of mid-frequency sonar, beginning at a SPL of approximately 110 to 120 dB re 1 µPa (Melcón et al. 2012). Preliminary results from the 2010–2011 field season of the ongoing behavioral response study in southern California waters indicated that in some cases and at low RLs, tagged blue whales responded to mid-frequency sonar but that those responses were mild and there was a quick return to their baseline activity (Southall et al. 2011). These preliminary findings from Melcón et al. (2012) and Southall et al. (2011) are consistent with the U.S. Navy‘s criteria and thresholds for predicting behavioral effects to mysticetes (including blue whales) from sonar and other active acoustic sources used in the quantitative acoustic effects analysis. The behavioral risk function predicts a probability of a substantive behavioral reaction for individuals exposed to a received SPL of 120 dB re 1µPa or greater, with an increasing probability of reaction with increased RL as demonstrated in Melcón et al. (2012).

Odontocetes

From 2007 to 2012, behavioral response studies were conducted through the collaboration of various research organizations in the Bahamas, Southern California, Mediterranean, Cape Hatteras, and Norwegian waters. These studies attempted to define and measure responses of beaked whales and other cetaceans to controlled exposures of sonar and other sounds to better understand their potential impacts. Results from the 2007–2008 study conducted near the Bahamas showed a change in diving behavior of an adult Blainville's beaked whale to playback of mid-frequency source and predator sounds (Boyd et al. 2008; Tyack et al. 2011). Reaction to mid-frequency sounds included premature cessation of clicking and termination of a foraging dive, and a slower ascent rate to the surface. Preliminary results from similar behavioral response studies in southern California waters have been presented for the 2010 and 2011 field seasons (Southall et al. 2011, 2012). Cuvier's beaked whale (*Ziphius cavirostris*) responses suggested particular sensitivity to sound exposure as consistent with results for Blainville‘s beaked whale (*Mesoplodon densirostris*). Similarly, beaked whales exposed to sonar during British training exercises stopped foraging (DSTL 2007), and preliminary results of controlled playback of sonar may indicate feeding/foraging disruption of killer whales (*Orcinus orca*) and sperm whales (Miller et al. 2011).

In the 2007–2008 Bahamas study, playback sounds of a potential predator—a killer whale—resulted in a similar but more pronounced reaction, which included longer inter-dive intervals and a sustained straight-line departure of more than 20 km from the area. The authors noted, however, that the magnified reaction to the predator sounds could represent a cumulative effect of exposure to the two sound types since killer whale playback began approximately two hours after mid-frequency source playback. Long-finned pilot whales (*Globicephala melas*) and killer whales off Norway also exhibited horizontal avoidance of a transducer with outputs in the mid-frequency range (signals in the ranges of 1 to 2 kHz and 6 to 7 kHz) (Miller et al. 2011). Additionally, separation of a calf from its group during exposure to MFAS playback was observed (Miller et al. 2011). In contrast, preliminary analyses suggest that none of the pilot whales or false killer whales (*Pseudorca crassidens*) in the Bahamas showed an avoidance response to controlled exposure playbacks (Southall et al. 2009).

Through analysis of the behavioral response studies, a preliminary overarching effect of greater sensitivity to all anthropogenic exposures was seen in beaked whales compared to the other odontocetes studied (Southall et al. 2009). Therefore, recent studies have focused specifically on beaked whale responses to active sonar transmissions or controlled exposure playback of simulated sonar on various military ranges (DSTL 2007; Claridge and Durban 2009; McCarthy et al. 2011; Moretti et al. 2009; Tyack et al. 2011). In the Bahamas, Blainville‘s beaked whales located on the range will move off-range during sonar use and return only after the sonar transmissions have stopped, sometimes taking several days to do so (Claridge and Durban 2009; McCarthy et al. 2011; Moretti et al. 2009; Tyack et al. 2011).

In May 2003, killer whales in Haro Strait, Washington State, were observed exhibiting what were believed by some observers to be aberrant behaviors, which were observed while the USS Shoup was in the vicinity and engaged in mid-frequency active sonar operations. Sound fields modeled for the USS Shoup transmissions (NMFS 2005; Fromm 2009) estimated a mean received SPL of approximately 169.3 dB re 1μPa at the location of the killer whales at the closest point of approach between the animals and the vessel (estimated SPLs ranged from 150 to 180 dB re 1μPa).

Research on sperm whales near the Grenadines (Caribbean) in 1983 coincided with the United States intervention in Grenada, where animals were observed scattering and leaving the area in the presence of military sonar, presumably from nearby submarines (Watkins et al. 1985; Watkins and Schevill 1975). The authors did not report RLs from these exposures and reported similar reactions from noise generated by banging on their boat hull. It was unclear if the sperm whales were reacting to the sonar signal itself or to a potentially new unknown sound in general.

Additionally, sperm whales In the Caribbean stopped vocalizing when presented with sounds from nearby acoustic pingers (Watkins and Schevill 1975).

Researchers at the U.S. Navy's Marine Mammal Program facility in San Diego, California have conducted a series of controlled experiments on bottlenose dolphins and beluga whales to study TTS (Finneran et al. 2003; Finneran et al. 2001; Finneran et al. 2005; Finneran and Schlundt 2004; Schlundt et al. 2000). Ancillary to the TTS studies, scientists evaluated whether the marine mammals performed their trained tasks when prompted, during and after exposure to mid-frequency tones. Altered behavior during experimental trials usually involved refusal of animals to return to the site of the sound stimulus. This refusal included what appeared to be deliberate attempts to avoid a sound exposure or to avoid the location of the exposure site during subsequent tests (Finneran et al. 2002; Schlundt et al. 2000). Bottlenose dolphins exposed to 1-sec intense tones exhibited short-term changes in behavior above received sound levels of 178 to 193 dB re 1 μPa root mean square, and beluga whales did so at RLs of 180 to 196 dB re 1 μPa and above. In some instances, animals exhibited aggressive behavior toward the test apparatus (Ridgway et al. 1997; Schlundt et al. 2000). While these studies were generally not designed to test avoidance behavior and animals were commonly reinforced with food, the controlled environment and ability to measure RLs provide insight on received levels at which animals will behaviorally responds to noise sources.

Studies with captive harbor porpoises showed increased respiration rates upon introduction of acoustic alarms, such as those used on fishing nets to help deter marine mammals from becoming caught or entangled (Kastelein et al. 2006; Kastelein et al. 2001) and emissions for underwater data transmission (Kastelein et al. 2005). However, exposure of the same acoustic alarm to a striped dolphin under the same conditions did not elicit a response (Kastelein et al. 2006), again highlighting the importance in understanding species differences in the tolerance of underwater noise.

<u>*Repeated Exposures*</u>

Repeated exposures of an individual to multiple sound-producing activities over a season, year, or life stage could cause reactions with costs that can accumulate over time to cause long-term consequences for the individual. Conversely, some animals habituate to or become tolerant of repeated exposures over time, learning to ignore a stimulus that in the past has not accompanied any overt threat.

Repeated exposure to acoustic and other anthropogenic stimuli has been studied in several cases, especially as related to vessel traffic and whale watching. Common dolphins (*Delphinus* sp.) in New Zealand responded to dolphin-watching vessels by interrupting foraging and resting bouts, and took longer to resume behaviors in the presence of the vessel (Stockin et al. 2008). The authors speculated that repeated interruptions of the dolphins' foraging behaviors could lead to long-term implications for the population. Bejder et al. (2006) studied responses of bottlenose dolphins to vessel approaches and found stronger and longer lasting reactions in populations of animals that were exposed to lower levels of vessel traffic overall. The authors indicated that lesser reactions in populations of dolphins regularly subjected to high levels of vessel traffic could be a sign of habituation, or it could be that the more sensitive animals in this population previously abandoned the area of higher human activity.

Marine mammals exposed to high levels of human activities may leave the area, habituate to the activity, or simply tolerate the disturbance. Marine mammals that are more tolerant may stay in a disturbed area, whereas individuals that are more sensitive may leave for areas with less human disturbance. Terrestrial examples of this abound as human disturbance and development displace more sensitive species, and tolerant animals move in to exploit the freed resources and fringe habitat. Longer-term displacement can lead to changes in abundance or distribution patterns of the species in the affected region if they do not become acclimated to the presence of the sound (e.g., Richardson et al. 1995; Bejder et al. 2006). Gray whales *(Eschrichtius robustus*) in Baja California abandoned a historical breeding lagoon in the mid-1960s due to an increase in dredging and commercial shipping operations. Whales did repopulate the lagoon after shipping activities had ceased for several years (Bryant et al. 1984). Over a shorter time scale, studies on the Atlantic Undersea Test and Evaluation Center instrumented range in the Bahamas have shown that some Blainville's beaked whales may be resident during all or part of the year in the area, and that individuals may move off of the range for several days during and following a sonar event. However animals are thought to continue feeding at short distances (a few kilometers) from the range out of the louder sound fields (less than 157 dB re 1 μPa) (McCarthy et al. 2011; Tyack et al. 2011). Mysticetes off the northeastern United States tended to adjust to vessel traffic over a number of years, trending towards more neutral responses to passing vessels (Watkins 1986), indicating that some animals may habituate or otherwise learn to cope with high levels of human activity. Nevertheless, the long-term consequences of these habitat utilization changes are unknown, and likely vary depending on the species, geographic areas, and the degree of acoustic or other human disturbance.

Strandings

When a marine mammal (alive or dead) swims or floats onto shore and becomes beached or incapable of returning to sea, the event is termed a stranding (Geraci and Lounsbury 2005). Animals outside of their "normal" habitat are also sometimes considered "stranded" even though they may not have beached themselves. The legal definition for a stranding within the United States is that: "(A) a marine mammal is dead and is (i) on a beach or shore of the United States; or (ii) in waters under the jurisdiction of the U.S. (including any navigable waters); or (B) a marine mammal is alive and is (i) on a beach or shore of the United States and is unable to return to the water; (ii) on a beach or shore of the United States and, although able to return to the water, is apparently in need of medical attention; or (iii) in the waters under the jurisdiction of the United States (including any navigable waters), but is unable to return to its natural habitat under its own power or without assistance" (16 United States Code [U.S.C.] section 1421h).

Marine mammals are subjected to a variety of natural and anthropogenic factors, acting alone or in combination, which may cause a marine mammal to strand (Geraci and Lounsbury 2005). Even for the fractions of more thoroughly investigated strandings involving post-stranding data collection and necropsies, the cause (or causes) for the majority of strandings remain undetermined. Natural factors related to strandings include, for example, the availability of food, predation, disease, parasitism, climatic influences, and aging (e.g., Geraci and Lounsbury 2005). Anthropogenic factors include, for example, pollution, vessel strikes, fisheries interactions, entanglement, and noise. Several mass strandings (strandings that involve two or more individuals of the same species, excluding a single cow-calf pair) that have occurred over the past 2 decades have been associated with naval operations, seismic surveys, and other anthropogenic activities that introduced sound into the marine environment. An in-depth discussion of strandings is in the U.S. Navy‘s Cetacean Stranding Technical Report (DON 2012c).

It is possible that some marine mammal behavioral reactions to anthropogenic sound may result in strandings. Several “mass stranding” events—strandings that involve two or more individuals of the same species (excluding a single cow-calf pair)—that have occurred over the past 2 decades have been associated with naval operations, seismic surveys, and other anthropogenic activities that introduced sound into the marine environment. Sonar exposure has been identified as a contributing cause or factor in five specific mass stranding events: Greece in 1996; the Bahamas in March 2000; Madeira Island, Portugal in 2000; the Canary Islands in 2002; and Spain in 2006 (Advisory Committee on Acoustic Impacts on Marine Mammals 2006).

In these circumstances, exposure to acoustic energy has been considered an indirect cause of the death of marine mammals (Cox et al. 2006). Based on studies of lesions in beaked whales that have stranded in the Canary Islands and the Bahamas associated with exposure to naval exercises that involved sonar, several investigators have hypothesized that there are two potential physiological mechanisms that might explain why marine mammals stranded: tissue damage resulting from resonance effects (Ketten 2005) and tissue damage resulting from “gas and fat embolic syndrome” (Fernandez et al. 2005; Jepson et al. 2003, 2005). Models of nitrogen saturation in diving marine mammals have been used to suggest that altered dive behavior might result in the accumulation of nitrogen gas such that the potential for nitrogen bubble formation is increased (Houser et al. 2001; Zimmer and Tyack 2007). If so, this mechanism might explain the findings of gas and bubble emboli in stranded beaked whales. It is also possible that stranding is a behavioral response to a sound under certain conditions and that the subsequently observed physiological effects (e.g., overheating, decomposition, or internal hemorrhaging from being on shore) were the result of the stranding versus exposure to sonar (Cox et al. 2006).

Taken in context of marine mammal populations in general, sonar is not a major threat or a significant portion of the overall ocean noise budget (ICES 2005). This has also been demonstrated by monitoring in areas where the U.S. Navy operates (Bassett et al. 2010; Baumann-Pickering et al. 2010; McDonald et al. 2006; Tyack et al. 2011). Regardless of the direct cause, the U.S. Navy considers potential sonar-related strandings important and continues to fund research and work with scientists to better understand circumstances that may result in strandings.

Methodology for Applying Risk Function

Risk Function Adapted from Feller (1968)

To assess the potential effects on marine mammals associated with active sonar used during training activity, the U.S. Navy and NMFS applied a risk function that estimates the probability of behavioral responses that NMFS would classify as harassment for the purposes of the MMPA given exposure to specific RLs of MFAS. The mathematical function is derived from a solution in Feller (1968) as defined in the Surveillance Towed Array Sensor System (SURTASS) LFAS Final OEIS/EIS (DON 2001), and relied on in the Supplemental SURTASS LFAS EIS (DON 2007d) for the probability of MFAS risk for MMPA Level B behavioral harassment with input parameters modified by NMFS for MFAS for mysticetes and odontocetes (NMFS 2008). The same risk function and input parameters will be applied to HFAS (>10 kHz) sources until applicable data become available for high-frequency sources.

In order to represent a probability of risk, the function should have a value near zero at very low exposures, and a value near one for very high exposures. One class of functions that satisfies this criterion is cumulative probability distributions, a type of cumulative distribution function. In selecting a particular functional expression for risk, several criteria were identified:

- The function must use parameters to focus discussion on areas of uncertainty.
- The function should contain a limited number of parameters.
- The function should be capable of accurately fitting experimental data.
- The function should be reasonably convenient for algebraic manipulations.

As described in DON (2001), the mathematical function below is adapted from a solution in Feller (1968).

$$R = \frac{1 - \left(\frac{L-B}{K}\right)^{-A}}{1 - \left(\frac{L-B}{K}\right)^{-2A}}$$

Where: R = risk (0 – 1.0)
L = Received Level (RL) in dB
B = basement RL in dB; (120 dB)
K = the RL increment above basement in dB at which there is 50 percent risk
A = risk transition sharpness parameter (10).

In order to use this function, the values of the three parameters (B, K, and A) need to be established. As further explained in the section titled Input Parameters for the Risk Function, the values used in this analysis are based on three sources of data: TTS experiments conducted at the Space and Naval Warfare Systems Center (SSC) and documented in Finneran et al. (2001, 2003, and 2005) and Finneran and Schlundt (2004); reconstruction of sound fields produced by the United States Ship (USS) *Shoup* associated with the behavioral responses of killer whales observed in Haro Strait and documented in NMFS (2005), DON (2004), and Fromm (2004a, 2004b); and observations of the behavioral response of North Atlantic right whales exposed to alert stimuli containing mid-frequency components documented in Nowacek et al. (2004). The input parameters, as defined by NMFS, are based on very limited data that represent the best available science at this time.

Data Sources Used for Risk Function

There is widespread consensus that cetacean response to MFAS sound signals needs to be better defined using controlled experiments. The U.S. Navy is contributing to an ongoing behavioral response study in the Bahamas that is anticipated to provide some initial information on beaked whales, the species identified as the most sensitive to MFAS. NMFS is leading this international effort with scientists from various academic institutions and research organizations to conduct studies on how marine mammals respond to underwater sound exposures.

Until additional data are available, NMFS and the U.S. Navy have determined that the following three data sets are most applicable for the direct use in developing risk function parameters for MFAS/HFAS sonar. These data sets represent the only known data that specifically relate altered behavioral responses to exposure to MFAS sound sources.

Data from SSC's Controlled Experiments: Most of the observations of the behavioral responses of toothed whales resulted from a series of controlled experiments on bottlenose dolphins and beluga whales conducted by researchers at SSC's facility in San Diego, California (Finneran et al. 2001, 2003, 2005; Finneran and Schlundt 2004; Schlundt et al. 2000). In experimental trials with marine mammals trained to perform tasks when prompted, scientists evaluated whether the marine mammals performed these tasks when exposed to mid-frequency tones. Altered behavior during experimental trials usually involved refusal of animals to return to the site of the sound stimulus. This refusal included what appeared to be deliberate attempts to avoid a sound exposure or to avoid the location of the exposure site during subsequent tests (Schlundt et al. 2000; Finneran et al. 2002). Bottlenose dolphins exposed to 1-sec intense tones exhibited short-term changes in behavior above received sound levels of 178 to 193 dB re 1 µPa root mean square (rms), and beluga whales did so at RLs of 180 to 196 dB and above. Test animals sometimes vocalized after an exposure to impulsive sound from a seismic watergun (Finneran et al. 2002). In some instances, animals exhibited aggressive behavior toward the test apparatus (Ridgway et al. 1997; Schlundt et al. 2000).

1. Finneran and Schlundt (2004) examined behavioral observations recorded by the trainers or test coordinators during the Schlundt et al. (2000) and Finneran et al. (2001, 2003, and 2005) experiments featuring 1-sec tones. These included observations from 193 exposure sessions (fatiguing stimulus level > 141 dB re 1µPa) conducted by Schlundt et al. (2000) and 21 exposure sessions conducted by Finneran et al. (2001, 2003, 2005). The observations were made during exposures to sound sources at 0.4 kHz, 3 kHz, 10 kHz, 20 kHz, and 75 kHz. The TTS experiments that supported Finneran and Schlundt (2004) are further explained below:
    a. Schlundt et al. (2000) provided a detailed summary of the behavioral responses of trained marine mammals during TTS tests conducted at SSC San Diego with 1-sec tones. Schlundt et al. (2000) reported eight individual TTS experiments. Fatiguing stimuli durations were 1 sec; exposure frequencies were 0.4 kHz, 3 kHz, 10 kHz, 20 kHz and 75 kHz. The experiments were conducted in San Diego Bay. Because of the variable ambient noise in the bay, low-level broadband masking noise was used to keep hearing thresholds consistent despite fluctuations in the ambient noise. Schlundt et al. (2000) reported that ―behavioral alterations," or deviations from the behaviors the animals being tested had been trained to exhibit, occurred as the animals were exposed to increasing fatiguing stimulus levels.

b. Finneran et al. (2001, 2003, and 2005) conducted TTS experiments using tones at 3 kHz. The test method was similar to that of Schlundt et al. (2000) except the tests were conducted in a pool with very low ambient noise level (below 50 dB re 1 µPa/Hz), and no masking noise was used. Two separate experiments were conducted using 1-sec tones. In the first, fatiguing sound levels were increased from 160 to 201 dB SPL. In the second experiment, fatiguing sound levels between 180 and 200 dB re 1 µPa were randomly presented.

Data from Studies of Baleen (Mysticete) Whale Responses: The only mysticete data available resulted from a field experiment in which baleen whales (mysticetes) were exposed to sound sources from 120 Hz to 4500 Hz (Nowacek et al. 2004). An alert stimulus, with a mid-frequency component, was the only portion of the study used to support the risk function input parameters.

2. Nowacek et al. (2004) documented observations of the behavioral response of North Atlantic right whales exposed to alert stimuli containing mid-frequency components. To assess risk factors involved in ship strikes, a multi-sensor acoustic tag was used to measure the responses of whales to passing ships and experimentally tested their responses to controlled sound exposures, which included recordings of ship noise, the social sounds of conspecifics and a signal designed to alert the whales. The alert signal was 18-min of exposure consisting of three 2-min signals played sequentially three times over. The three signals had a 60 percent duty cycle and consisted of: (1) alternating 1-sec pure tones at 500 Hz and 850 Hz; (2) a 2-sec logarithmic down-sweep from 4,500 Hz to 500 Hz; and (3) a pair of low-to-high (1,500–2,000 Hz) sine wave tones amplitude modulated at 120 Hz and each 1-sec long. The purposes of the alert signal were (a) to provoke an action from the whales via the auditory system with disharmonic signals that cover the whales estimated hearing range; (b) to maximize the signal to noise ratio (obtain the largest difference from background noise) and c) to provide localization cues for the whale. Five out of six whales reacted to the signal designed to elicit such behavior. Maximum RLs ranged from 133 to 148 dB re 1µPa.

Observations of Killer Whales in Haro Strait in the Wild: In May 2003, killer whales were observed exhibiting behavioral responses while the USS Shoup was engaged in MFAS activities in the Haro Strait of Puget Sound, Washington. Although these observations were made in an uncontrolled environment, the sound field that may have been associated with the sonar operations had to be estimated, and the behavioral observations were reported for groups of whales, not individual whales, the observations associated with the USS Shoup provide the only data set available of the behavioral responses of wild, non-captive animal upon exposure to the AN/SQS-53 MFAS.

3. NMFS (2005), DON (2004), and Fromm (2004a, 2004b) documented reconstruction of sound fields produced by the USS Shoup associated with the behavioral response of killer whales observed in the Haro Strait. Observations from this reconstruction included an approximate closest approach time which was correlated to a reconstructed estimate of RL at an approximate whale location (which ranged from 150 to 180 dB), with a mean value of 169.3 dB.

<u>*Limitations of the Risk Function Data Sources*</u>

There are significant limitations and challenges to any risk function derived to estimate the probability of marine mammal behavioral responses; these are largely attributable to sparse data. Ultimately there should be multiple functions for different marine mammal taxonomic groups, but the current data are insufficient to support them. The goal is unquestionably that risk functions be based on empirical measurement.

The risk function presented here is based on three data sets that NMFS and the U.S. Navy have determined are the best available science at this time. The U.S. Navy and NMFS acknowledge each of these data sets has limitations. However, this risk function, if informed by the limited available data relevant to the MFAS application, has the advantages of simplicity and the fact that there is precedent for its application and foundation in marine mammal research.

While NMFS considers all data sets as being weighted equally in the development of the risk function, the U.S. Navy believes the SSC San Diego data are the most rigorous and applicable for the following reasons:

- The data represent the only source of information where the researchers had complete control over and ability to quantify the noise exposure conditions.
- The altered behaviors were identifiable due to long-term observations of the animals.
- The fatiguing noise consisted of tonal exposures with limited frequencies contained in the MFAS bandwidth.

However, the U.S. Navy and NMFS agree that the following are limitations associated with the three data sets used as the basis of the risk function:

- The three data sets represent the responses of only four species: captive bottlenose dolphins and beluga whales, North Atlantic right whales in the wild, and killer whales in the wild.
- None of the three data sets represent experiments designed for behavioral observations of animals exposed to MFAS.
- The behavioral responses of marine mammals that were observed in the wild are based solely on an estimated RL of sound exposure; they do not take into consideration (due to minimal or no supporting data):
    - Potential relationships between acoustic exposures and specific behavioral activities (e.g., feeding, reproduction, changes in diving behavior, etc.), variables such as bathymetry, or acoustic waveguides;
    - Differences in individuals, populations, or species, or the prior experiences, reproductive state, hearing sensitivity, or age of the marine mammal.

<u>*SSC San Diego Trained (Captive) Bottlenose Dolphins and Beluga Data Set:*</u>

- The animals were trained animals in captivity; therefore, they may be more or less sensitive than cetaceans found in the wild (Domjan 1998).

- The tests were designed to measure TTS, not behavior.
- Because the tests were designed to measure TTS, the animals were exposed to much higher levels of sound than the baseline risk function (only two of the total 193 observations were at levels below 160 dB re 1 μPa^2-s).
- The animals were not exposed in the open ocean but in a shallow bay or pool.

North Atlantic Right Whales in the Wild Data Set:

- The observations of behavioral response were from exposure to alert stimuli that contained mid-frequency components but were not similar to a MFAS ping. The alert signal was 18 min of exposure consisting of three 2-min signals played sequentially three times over. The three signals had a 60 percent duty cycle and consisted of: (1) alternating 1-sec pure tones at 500 Hz and 850 Hz; (2) a 2-sec logarithmic down-sweep from 4,500 Hz to 500 Hz; and (3) a pair of low (1,500 Hz)-high (2,000 Hz) sine wave tones amplitude modulated at 120 Hz and each 1 sec long. This 18-min alert stimulus is in contrast to the average 1-sec ping every 30 sec in a comparatively very narrow frequency band used by military sonar.
- The purpose of the alert signal was, in part, to provoke an action from the whales through an auditory stimulus.

Killer Whales in the Wild Data Set:

- The observations of behavioral harassment were complicated by the fact that there were other sources of harassment in the vicinity (other vessels and their interaction with the animals during the observation).
- The observations were anecdotal and inconsistent. There were no controls during the observation period, with no way to assess the relative magnitude of the any observed response as opposed to baseline conditions.

Input Parameters for the Risk Function

The values of B, K, and A need to be specified in order to utilize the risk function defined in the previous section titled *Methodology for Applying Risk Function*. The risk continuum function approximates the risk function in a manner analogous to pharmacological risk assessment. In this case, the risk function is combined with the distribution of sound exposure levels (SELs) to estimate aggregate impact on an exposed population.

Basement Value for Risk — The B Parameter

The B parameter defines the basement value for risk, below which the risk is so low that calculations are impractical. This 120 dB level is taken as the estimate RL below which the risk of significant change in a biologically important behavior approaches zero for the MFAS/HFAS sonar risk assessment. This level is based on a broad overview of the levels at which multiple species have been reported responding to a variety of sound sources, both mid-frequency and other, was recommended by the NMFS, and has been used in other publications. The U.S. Navy recognizes that for actual risk of changes in behavior to be zero, the signal-to-noise ratio of the animal must also be zero. However, the present convention of ending the risk calculation at 120 dB for MFAS/HFAS sonar has a negligible impact on the subsequent calculations, because the risk function does not attain appreciable values at RLs that low.

The K Parameter

NMFS and the U.S. Navy used the mean of the following values to define the midpoint of the function: (1) the mean of the lowest RLs (185.3 dB) at which individuals responded with altered behavior to 3-kHz tones in the SSC data set; (2) the estimated mean RL value of 169.3 dB produced by the reconstruction of the USS Shoup incident in which killer whales were exposed to MFAS (range of modeled possible RLs: 150 to 180 dB); and (3) the mean of the 5 maximum RLs at which Nowacek et al. (2004) observed significantly altered responses of right whales to the alert stimuli than to the control (no input signal) is 139.2 dB SPL. The arithmetic mean of these three mean values is 165 dB SPL. The value of K is the difference between the value of B (120 dB SPL) and the 50 percent value of 165 dB SPL; therefore, K=45.

Risk Transition – The A Parameter

The *A* parameter controls how rapidly risk transitions from low to high values with increasing RL. As *A* increases, the slope of the risk function increases. For very large values of A, the risk function can approximate a threshold response or step function. NMFS has recommended that the U.S. Navy use *A*=10 as the value for odontocetes (**Figure 6-4**) (NMFS 2008). This is the same value of *A* that was used for the SURTASS LFAS analysis. As stated in the SURTASS LFAS Final OEIS/EIS (DON 2001), the value of *A*=10 produces a curve that has a more gradual transition than the curves developed by the analyses of migratory gray whale studies (Malme et al. 1984). The choice of a more gradual slope than the empirical data was consistent with other decisions for the SURTASS LFAS Final OEIS/EIS to make conservative assumptions when extrapolating from other data sets (see Subchapter 1.4.3 and Appendix D of the SURTASS LFAS OEIS/EIS, DON 2001).

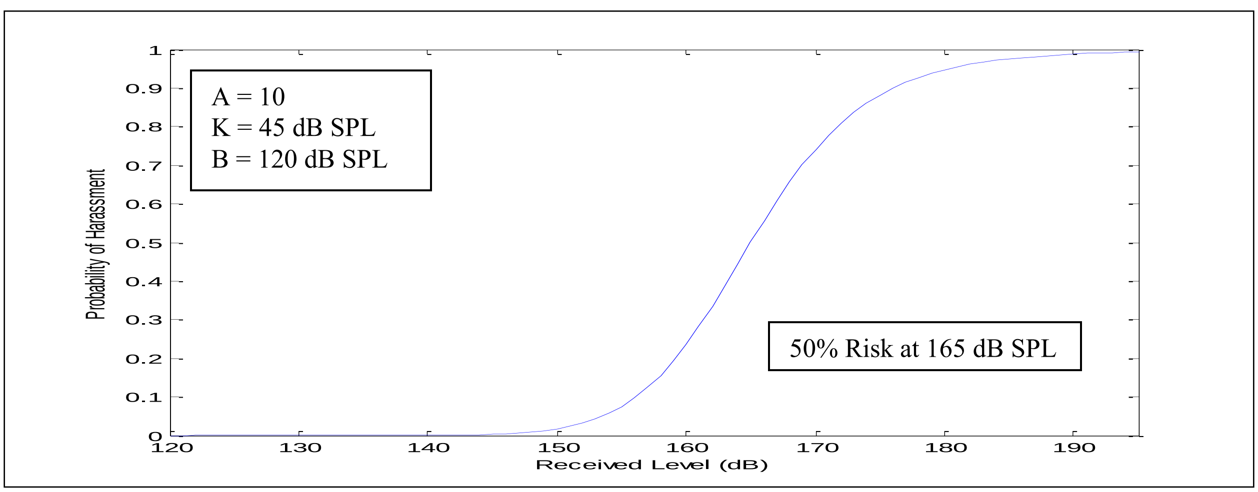


Figure 6-4. Risk Function Curve for Odontocetes (Toothed Whales).

Based on NMFS' direction, the U.S. Navy will use a value of *A*=8 for mysticetes to allow for greater consideration of potential harassment at the lower RLs based on Nowacek et al. (2004) (**Figure 6-5**) (NMFS 2008).

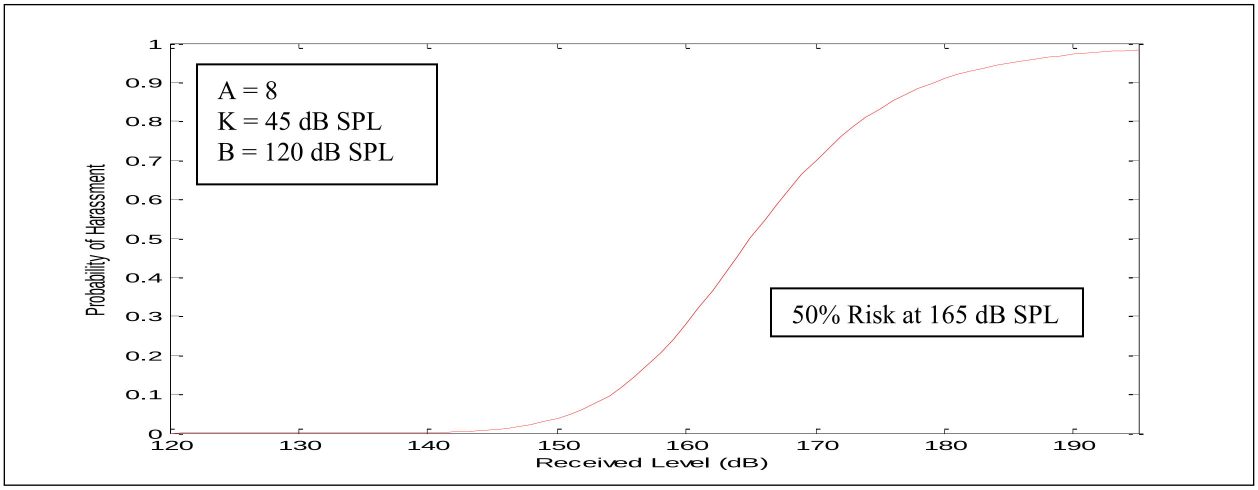


Figure 6-5. Risk Function Curve for Mysticetes (Baleen Whales).

Basic Application of the Risk Function

<u>*Relation of the Risk Function to the Current Regulatory Scheme*</u>

The risk function is used to estimate the percentage of an exposed population that is likely to exhibit behaviors that would qualify as harassment (as that term is defined by the MMPA applicable to military readiness activities, such as the U.S. Navy's testing and training with MFAS) at a given RL of sound. For example, at 165 dB SPL (dB re: 1μPa rms), the risk (or probability) of harassment is defined according to this function as 50 percent, and U.S. Navy/NMFS applies that by estimating that 50 percent of the individuals exposed at that RL are likely to respond by exhibiting behavior that NMFS would classify as behavioral harassment. The risk function is not applied to individual animals, only to exposed populations.

The data used to produce the risk function were compiled from four species that had been exposed to sound sources in a variety of different circumstances. As a result, the risk function represents a general relationship between acoustic exposures and behavioral responses that is then applied to specific circumstances. That is, the risk function represents a relationship that is deemed to be generally true, based on the limited, best-available science, but may not be true in specific circumstances. In particular, the risk function, as currently derived, treats the RL as the only variable that is relevant to a marine mammal's behavioral response. However, we know that many other variables—the marine mammal's gender, age, and prior experience; the activity it is engaged in during an exposure event, its distance from a sound source, the number of sound sources, and whether the sound sources are approaching or moving away from the animal—can be critically important in determining whether and how a marine mammal will respond to a sound source (Southall et al. 2007). The data that are currently available do not allow for incorporation of these other variables in the current risk functions; however, the risk function represents the best use of the data that are available.

As more specific and applicable data become available, NMFS can use these data to modify the outputs generated by the risk function to make them more realistic (and ultimately, data may exist to justify the use of additional, alternate, or multi-variate functions). As mentioned above, it is known that the distance from the sound source and whether it is perceived as approaching or moving away can affect the way an animal responds to a sound (Wartzok et al. 2003). Those distances would influence whether those animals might perceive the sound source as a potential threat, and their behavioral responses to that threat. Though there are data showing marine mammal responses to sound sources at that RL, NMFS does not currently have any data that describe the response of marine mammals to sounds at that distance (or to other contextual aspects of the exposure, such as the presence of higher frequency harmonics), much less data that compare responses to similar sound levels at varying distances. However, if data were to become available that suggested animals were less likely to respond (in a manner NMFS would classify as harassment) to certain levels beyond certain distances, or that they were more likely to respond at certain closer distances, the U.S. Navy will re-evaluate the risk function to try to incorporate any additional variables into the “take” estimates.

Last, pursuant to the MMPA, an applicant is required to estimate the number of animals that will be “taken” by their activities. This estimate informs the analysis that NMFS must perform to determine whether the activity will have a “negligible impact” on the species or stock. Level B (behavioral) harassment occurs at the level of the individual(s) and does not assume any resulting population-level consequences, though there are known avenues through which behavioral disturbance of individuals can result in population-level effects. Alternately, a negligible impact finding is based on the lack of likely adverse effects to annual rates of recruitment or survival (i.e., population-level effects). An estimate of the number of Level B harassment takes, alone, is not enough information on which to base an impact determination. In addition to considering estimates of the number of marine mammals that might be “taken” through harassment, NMFS must consider other factors, such as the nature of any responses (their intensity, duration, etc.), the context of any responses (critical reproductive time or location, migration, etc.), or any of the other variables mentioned in the first paragraph (if known), as well as the number and nature of estimated Level A takes, the number of estimated mortalities, and effects on habitat. For example, in the case of sonar usage in the Q-20 Study Area, due to the nature of sound propagation, a portion of the animals that are likely to be “taken” through behavioral harassment are expected to be exposed at relatively low RLs (120 to 135 dB) where the significance of those responses would be reduced because of the distance from a sound source. Alternatively, a portion of the animals that are expected to be “taken” through behavioral harassment are expected to occur when animals are exposed to higher RLs, such as those approaching the onset of TTS (180 to 195 dB). Generally speaking, the U.S. Navy and NMFS anticipate more severe effects from takes resulting from exposure to higher received levels (though this is in no way a strictly linear relationship throughout species, individuals, or circumstances) and less severe effects from takes resulting from exposure to lower RLs.

It is worth noting that the U.S. Navy and NMFS would expect a relatively large portion of the animals that are likely to be “taken” in the Q-20 Study Area (those that occur when an animal is exposed to the levels at the bottom of the risk function), to exhibit behavioral responses that are less likely to adversely affect the longevity, survival, or reproductive success of the animals that might be exposed, based on RL, and the fact that the exposures will occur in the absence of some of the other contextual variables that would likely be associated with increased severity of effects, such as the proximity of the sound source(s) or the proximity of other vessels, aircraft, submarines, etc. maneuvering in the vicinity of the exercise. NMFS will consider all available information (other variables, etc.), but all else being equal, takes that result from exposure to lower RLs and at greater distances from the exercises would be less likely to contribute to population level effects.

6.2.2 Calculation Methods

Detailed information and formulas to model the effects of sonar from RDT&E activities in the Q-20 Study Area is provided in **Appendix A**. The following section provides an overview of the methods used to conduct the analysis.

The quantitative analysis was based on conducting sonar operations in 14 different geographical regions, or provinces. Using combined marine mammal density and depth estimates, which are detailed later in this section, acoustical modeling was conducted to calculate the actual exposures. Refer to **Appendix B** for additional information on provinces. Refer to **Appendix C** for additional information regarding the acoustical analysis.

The approach for estimating potential acoustic effects from Q-20 test activities on cetacean species uses the methodology that the DON developed in cooperation with NMFS for the U.S. Navy‘s Undersea Warfare Training Range Final OEIS/EIS (DON 2009b), Undersea Warfare Exercise EA/OEA (DON 2007b), Rim of the Pacific EA/OEA (DON 2006b), Composite Training Unit Exercise/Joint Task Force Exercise EA/OEA (DON 2007c), and Hawaii Range Complex OEIS/EIS (DON 2008). The exposure analysis for behavioral response to sound in the water uses energy flux density for Level A harassment and the methods for risk function for Level B harassment (behavioral). The methodology is provided here to determine the number and species of marine mammals for which incidental take authorization is requested.

To estimate acoustic effects from the Q-20 test activities, acoustic sources to be used were examined with regard to their operational characteristics as described in the previous section. Systems with an operating frequency greater than 200 kHz were not analyzed in the detailed modeling as these signals attenuate rapidly resulting in very short propagation distances. Based on the information above, the U.S. Navy modeled the Q-20.

Sonar parameters including source levels, ping length, the interval between pings, output frequencies, directivity (or angle), and other characteristics were based on records from on previous test scenarios and projected future testing. Additional information on sonar systems and their associated parameters is in **Appendix A**.

Every active sonar operation includes the potential to expose marine animals in the neighboring waters. The number of animals exposed to the sonar in any such action is dictated by the propagation field and the manner in which the sonar is operated (i.e., source level, depth, frequency, pulse length, directivity, platform speed, repetition rate). The modeling for Q-20 test activities involving sonar occurred in five broad steps, listed below, and was conducted based on the typical RDT&E activities planned for the Q-20 Study Area.

- **Step 1. Environmental Provinces**. The Q-20 Study Area was divided into 14 environmental provinces, each having a unique combination of environmental conditions. These represent various combinations of six bathymetric provinces, one Sound Velocity Profile (SVP) province, and three Low-Frequency Bottom Loss (LFBL) geo-acoustic provinces and two High-Frequency Bottom Loss (HFBL) classes. These are addressed by defining eight fundamental environments in two seasons, which span the variety of depths, bottom types, sound speed profiles, and sediment thicknesses found in the Q-20 Study Area. The two seasons encompass winter and summer, which are the two extremes for the GOM, the acoustic propagation characteristics do not vary significantly between the two. Each marine modeling area can be quantitatively described as a unique combination of these environments.

- **Step 2. Transmission Loss**. Since sound propagates differently in these environments, separate transmission loss (TL) calculations must be made for each, in both seasons. The TL is predicted using Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS-GRAB) sound modeling software.
- **Step 3. Exposure Volumes.** The TL, combined with the source characteristics, gives the energy field of a single ping. The energy of over 10 hr of pinging is summed, carefully accounting for overlap of several pings, so an accurate average exposure of 1 hr of pinging is calculated for each depth increment. At more than 10 hr, the source is too far away and the energy is negligible. Repeating this calculation for each environment in each season gives the hourly ensonified volume, by depth, for each environment and season. This step begins the method for risk function modeling.
- **Step 4. Marine Mammal Densities.** The marine mammal densities were given in two dimensions, using reliable peer-reviewed literature sources (e.g., published literature and agency reports) described in the following subsection. The depth regimes of these marine mammals are used to project the two-dimensional densities (i.e., expressed as the number of animals per area where all individuals are assumed to be at the water‘s surface) into three dimensions (i.e., a volumetric approach whereby two-dimensional animal density incorporates depth into the calculation estimates).
- **Step 5. Exposure Calculations.** Each marine mammal‘s three-dimensional (3-D) density is multiplied by the calculated impact volume to that marine mammal depth regime. This value is the number of exposures per hr for that particular marine mammal. In this way, each marine mammal‘s exposure count per hr is based on its density, depth habitat, and the ensonified volume by depth.

The planned sonar hours were inserted and a cumulative number of exposures were determined for each alternative.

Marine Mammal Density

The density estimates presented in this IHA application are derived from the U.S. Navy OPAREA Density Estimates (NODE) for the GOM OPAREA report (DON 2007a). Density estimate calculations for cetaceans in U.S. Navy environmental documents can be modeled using available line-transect survey data or derived in order of preference: (1) through spatial models using line-transect survey data provided by NMFS (DON 2007e); (2) using abundance estimates from Mullin and Fulling (2003), Fulling et al. (2003), and/or Mullin and Fulling (2004); (3) or based on the cetacean abundance estimates found in the NMFS SAR (Waring et al. 2007) (see also **Appendix A** for more detail regarding NMFS SAR estimates). In the Q-20 Study Area which includes the GOM OPAREA, density estimates were derived via abundance estimates found in the NMFS SARs (Waring et al. 2007) based on Mullin and Fulling (2004). Since the most recent NMFS SAR is currently a draft (NMFS 2012), previous year data were used in calculation of density estimates.

For the model-based approach, density estimates were calculated for each species within areas containing survey effort. A relationship between these density estimates and the associated environmental parameters such as depth, slope, distance from the shelf break, SST, and chlorophyll a concentration was formulated using generalized additive models. This relationship was then used to generate a two-dimensional density surface for the region by predicting densities in areas where no survey data exist. For the GOM, all analyses for cetaceans were based on data collected through NMFS-Southeast Fisheries Science Center shipboard surveys conducted between 1996 and 2004. Species-specific density estimates derived through spatial modeling were compared with abundance estimates found in the most current NMFS SAR to ensure consistency. All spatial models and density estimates were reviewed by NMFS technical staff.

A list of all modeled species and how their densities were derived are shown in **Table 6-1**. It is important to note that various factors influence the detectability of marine mammals at sea, including animal behavior and appearance; group size; blow characteristics; dive characteristics and dive interval; viewing conditions (sea state, wind speed, wind direction, sea swell, and glare); observer experience, fatigue, and concentration; and vessel platform characteristics (pitch, roll, yaw, speed, and height above water). Because certain species can dive for long periods of time, their sightability/detectability during surface surveys can be diminished, which leads to underestimated density. The density estimates detailed in the NODE for the GOMEX OPAREA report (DON 2007e) are not corrected for dive times and may be underestimates for some species. For a more detailed description of the methodology involved in calculating the density estimates provided in this IHA application, please refer to the NODE for the GOMEX OPAREA (DON 2007e).

Abundance is the total number of individuals that make up a given stock as in the NMFS SARs, or the total number estimated within a particular study area, as in Mullin and Fulling (2003). NMFS stock abundances for most species represent the total estimate of individuals within the geographic area, if wholly known, which comprise that stock. For some species, this geographic area may extend beyond United States waters. Survey abundances are the total individuals estimated within the survey study area, which may or not align completely with a stock‘s geographic range as defined in the SAR. These surveys may also extend beyond United States waters. Both stock abundance and survey abundance are used in this IHA application to determine a density of marine mammal species within the Q-20 Study Area. That some portion of the animal‘s range may extend beyond the Q-20 Study Area or United States waters is irrelevant to the concentration of animals that could be present within the Q-20 Study Area at a given time. It is this concentration or density that is most important for conducting the analysis of the potential effects to marine mammals from Q-20 test activities. Only cetaceans for which densities are available are included in **Table 6-2**, which presents averaged densities for the eastern GOM region.

Table 6-1. Method of Density Estimation for Each Species/Species Group in the Q-20 Study Area.

Model-Derived Density Estimates
Atlantic spotted dolphin (*Stenella frontalis*)
Beaked Whales (Family Ziphiidae)
Bottlenose dolphin (*Tursiops truncatus*)
Dwarf/pygmy sperm whale (Family Kogiidae)
Pantropical spotted dolphin (*Stenella attenuata*)
Risso's dolphin (*Grampus griseus*)
Rough-toothed dolphin (*Steno bredanensis*)
Sperm whale (*Physeter macrocephalus*)
Spinner dolphin (*Stenella longirostris*)
Striped dolphin (*Stenella coeruleoalba*)
SAR or Literature-Derived Density Estimates
Bryde‘s whale (*Balaenoptera brydei*)
Clymene dolphin (*Stenella clymene*)
False killer whale (*Pseudorca crassidens*)
Fraser‘s dolphin (*Lagenodelphis hosei*)
Killer whale (*Orcinus orca*)
Melon-headed whale (*Peponocephala electra*)
Pygmy killer whale (*Feresa attenuata*)
Short-finned pilot whale (*Globicephala macrorhynchus*)

Source: DON 2007e; SAR = NMFS Stock Assessment Report

Dive Depth Distribution

There are limited dive-depth-distribution data for most marine mammals. Due to the difficulty of adhering a tag to the skin of a cetacean using glue, most tags must be implanted into the skin/blubber. There are a few different methodologies/techniques that can be used to determine depth distribution percentages, but by far the most widely used technique currently is the time-depth recorder. Depth information can be collected via satellite tags, sonic tags, digital acoustic tags, and, for sperm and beaked whales, via acoustic tracking of sounds produced by the animal itself. Additional information on depth distribution for marine mammals in the Q-20 Study Area is included in **Appendix A**, specifically in **Table A-8**.

There are suitable depth-distribution data for some marine mammal species. Sample sizes are usually extremely small, almost always encompassing fewer than 10 animals total and usually including only one or two animals. Depth-distribution information can also be interpreted from other dive and/or preferred prey characteristics, and from methods including behavioral observations, stomach content analysis, and habitat preference analysis. Depth distributions for species for which no data are available are extrapolated from similar species.

Table 6-2. Marine Mammal Densities for the Q-20 Study Area.

Common Name	Winter (number of animals per square kilometer)	Summer (number of animals per square kilometer)
Baleen Whales		
Bryde's whale	0.00003495	0.00003495
Toothed Whales		
Atlantic spotted dolphin	0.1057	0.1057
Beaked whales	0.000001294	0.000001291
Bottlenose dolphin	0.1223	0.1223
Clymene dolphin	0.01516	0.01516
Dwarf and pygmy sperm whales	0.0003810	0.0003810
False killer whale	0.0009070	0.0009070
Fraser's dolphin	0.0006344	0.0006344
Killer whale	0.0001162	0.0001162
Melon-headed whale	0.003015	0.003015
Pantropical spotted dolphin	0.03989	0.04287
Pygmy killer whale	0.0003566	0.0003566
Risso's dolphin	0.003632	0.003632
Rough-toothed dolphin	0.0003885	0.0003885
Short-finned pilot whale	0.002087	0.002087
Sperm whale	0.0003024	0.0003345
Spinner dolphin	0.03810	0.03810
Striped dolphin	0.009272	0.009272

Density and Depth Distribution Combined

Density is nearly always reported per unit area (e.g., animals per square kilometer [km^2]). Analyses of survey results using distance sampling techniques may include correction factors for animals at the surface but not seen and for animals below the surface but not observed. Therefore, although the area (e.g., km^2) appears to represent only the surface of the water (two-dimensional), density actually implicitly includes animals anywhere within the water column under that surface area. Density assumes that animals are uniformly distributed within the prescribed area, although this assumption is likely rare. Marine mammals are usually clumped in areas of greater importance, for example, in areas of high productivity, lower predation, and safe calving. Density can be calculated occasionally for smaller areas that are used regularly by marine mammals; however, oftentimes there are insufficient data to calculate density for small areas. Therefore, assuming an even distribution within the prescribed area remains the standard method.

Assuming that marine mammals are distributed evenly within the water column does not accurately reflect marine mammal behavior. The ever-expanding database of marine mammal behavioral and physiological parameters obtained through tagging and other technologies has demonstrated that marine mammals use the water column in various ways. Some species are capable of regular deep dives greater than 800 m (2,625 ft) and others dive to less than 200 m (656 ft), regardless of the bottom depth. Assuming that all species are evenly distributed from the surface to the bottom is almost never appropriate and can present a distorted view of marine mammal distribution in any region.

By combining marine mammal density with depth distribution information, a 3-D density estimate is possible. These 3-D estimates allow more accurate modeling of potential marine mammal exposures from specific sonar systems.

Other Potential Acoustic Effects to Marine Mammals

Auditory Trauma

Relatively little is known about auditory system trauma in marine mammals resulting from a known sound exposure. There are no known occurrences of direct auditory trauma in marine mammals exposed to sonar or other non-impulsive sound sources; therefore, no further discussion is warranted.

Bubble Formation

One suggested indirect cause of injury to marine mammals is rectified diffusion (Crum and Mao 1996), which is the process of increasing the size of a bubble by exposing it to a sound field. This process depends on many factors, including the SPL and duration. Under this hypothesis, microscopic bubbles assumed to exist in the tissues of marine mammals may experience one of three things: (1) bubbles grow to the extent that tissue hemorrhage (injury) occurs, (2) bubbles develop to the extent that an immune response is triggered or nervous system tissue is subjected to enough localized pressure that pain or dysfunction occurs (a stress response without injury), or (3) the bubbles are cleared by the lung without negative consequence to the animal. The probability of rectified diffusion, or any other indirect tissue effect, will necessarily be based on what is known about the specific process involved. Rectified diffusion is facilitated if the environment in which the ensonified bubbles exist is supersaturated with a gas, such as nitrogen, which makes up approximately 78 percent of air. Repetitive diving by marine mammals can cause the blood and some tissues to accumulate gas to a greater degree than is supported by the surrounding environmental pressure (Ridgway and Howard 1979). Deeper and longer dives of some marine mammals (e.g., beaked whales) are theoretically predicted to induce greater supersaturation (Houser et al. 2001). If rectified diffusion were possible in marine mammals exposed to high-level sound, conditions of tissue supersaturation could theoretically speed the rate and increase the size of bubble growth. Subsequent effects due to tissue trauma and emboli would presumably mirror those observed in humans suffering from decompression sickness (e.g., nausea, disorientation, localized pain, breathing problems, etc.).

It is unlikely that the short duration of sonar pings would be long enough to drive bubble growth to any substantial size, if such a phenomenon occurs. However, an alternative but related hypothesis has also been suggested: stable microbubbles could be destabilized by high-level sound exposures so that bubble growth would occur through static diffusion of gas out of the tissues. In such a scenario, the marine mammal would need to be in a gas-supersaturated state for a long enough period of time for bubbles to become of a problematic size. Recent research with *ex vivo* supersaturated bovine tissues suggests that for a 37-kHz signal, a sound exposure of approximately 215 dB re 1 µPa would be required before microbubbles became destabilized and grew (Crum et al. 2005). Assuming spherical spreading loss and a nominal sonar source level of 235 dB re 1 µPa, a whale would need to be within 33 ft. (10 m) of the sonar dome to be exposed to such sound levels. Furthermore, tissues in the study were supersaturated by exposing them to pressures of 400 to 700 kilopascals for periods of hours and then releasing them to ambient pressures. Assuming the equilibration of gases with the tissues occurred when the tissues were exposed to the high pressures, levels of supersaturation in the tissues could have been as high as 400 to 700 percent. These levels of tissue supersaturation are substantially higher than model predictions for marine mammals (Houser et al. 2001). It is improbable that this mechanism would be responsible for stranding events or traumas associated with beaked whale strandings. Both the degree of supersaturation and exposure levels observed to cause microbubble destabilization are unlikely to occur, either alone or in concert.

There is considerable disagreement among scientists as to the likelihood of bubble formation in diving marine mammals (Evans and Miller 2003; Piantadosi and Thalmann 2004). Although it has been argued that traumas from recent beaked whale strandings are consistent with gas emboli and bubble-induced tissue separations (Fernández et al. 2005; Jepson et al. 2003), nitrogen bubble formation as the cause of the traumas has not been verified. The presence of bubbles postmortem, particularly after decompression, is not necessarily indicative of bubble pathology. Prior experimental work demonstrates that the postmortem presence of bubbles following decompression in laboratory animals can occur as a result of invasive investigative procedures (Stock et al. 1980). Also, variations in diving behavior or avoidance responses can possibly result in nitrogen tissue supersaturation and nitrogen off-gassing, possibly to the point of deleterious vascular bubble formation (Jepson et al. 2003). The mechanism for bubble formation would be different from rectified diffusion, but the effects would be similar. Although hypothetical, the potential process is under debate in the scientific community. The hypothesis speculates that if exposure to a startling sound elicits a rapid ascent to the surface, tissue gas saturation sufficient for the evolution of nitrogen bubbles might result (Fernández et al. 2005; Jepson et al. 2003). In this scenario, the rate of ascent would need to be sufficiently rapid to compromise behavioral or physiological protections against nitrogen bubble formation.

Recent modeling suggests that even unrealistically rapid rates of ascent from normal dive behaviors are unlikely to result in supersaturation to the extent that bubble formation would be expected in beaked whales (Zimmer and Tyack 2007). Tyack et al. (2006) suggested that emboli observed in animals exposed to mid-frequency active sonar (Fernández et al. 2005; Jepson et al. 2003) could stem instead from a behavioral response that involves repeated dives, shallower than the depth of lung collapse. A bottlenose dolphin was trained to repetitively dive to specific depths to elevate nitrogen saturation to the point that asymptomatic nitrogen bubble formation was predicted to occur. However, inspection of the vascular system of the dolphin via ultrasound did not demonstrate the formation of any nitrogen gas bubbles (Houser et al. 2009).

More recently, modeling has suggested that the long, deep dives performed regularly by beaked whales over a lifetime could result in the saturation of long-halftime tissues (e.g. fat, bone lipid) to the point that they are supersaturated when the animals are at the surface (Hooker et al. 2009). Proposed adaptations for prevention of bubble formation under conditions of persistent tissue saturation have been suggested (Fahlman et al. 2006; Hooker et al. 2009), while the condition of supersaturation required for bubble formation has been demonstrated in bycatch animals drowned at depth and brought to the surface (Moore et al. 2009). Since bubble formation is facilitated by compromised blood flow, it has been suggested that rapid stranding may lead to bubble formation in animals with supersaturated, long-halftime tissues because of the stress of stranding and the cardiovascular collapse that can accompany it (Houser et al. 2009).

A fat embolic syndrome was identified by Fernández et al. (2005) coincident with the identification of bubble emboli in stranded beaked whales. The fat embolic syndrome was the first pathology of this type identified in marine mammals, and was thought to possibly arise from the formation of bubbles in fat bodies, which subsequently resulted in the release of fat emboli into the blood stream. The pathogenesis of fat emboli formation is yet undetermined and remains largely unstudied, and it would therefore be inappropriate to prematurely causally link it to nitrogen bubble formation. Because evidence of nitrogen bubble formation following a rapid ascent by beaked whales is arguable and requires further investigation (Evans and Miller 2003; Piantadosi and Thalmann 2004), this analysis makes no assumptions about it being the causative mechanism in beaked whale strandings associated with sonar operations. No similar findings to those found in beaked whales stranding coincident with sonar activity have been reported in other stranded animals following known exposure to sonar operations. By extension, no marine mammals addressed in this analysis are given differential treatment due to the possibility for acoustically mediated bubble growth.

Acoustic Resonance

In 2002, NMFS convened a panel of government and private scientists to address the issue of MFAS-induced resonance of gas-containing structures (Evans 2002). It modeled and evaluated the likelihood that U.S. Navy MFAS caused resonance effects in beaked whales that eventually led to their stranding (DOC and DON 2001). The conclusions of that group were that resonance in air-filled structures was not likely to have caused a mass stranding event in the Bahamas in 2000 (Evans 2002). The frequencies at which resonance was predicted to occur were below the frequencies used by the mid-frequency sonar systems associated with the Bahamas event. Furthermore, air cavity vibrations were not considered to be of sufficient magnitude to cause tissue damage, even at the worst-case resonant frequencies that would lead to the greatest vibratory response. These same conclusions would apply to other U.S. Navy training and testing activities involving acoustic sources. Therefore, this IHA application request concludes that acoustic resonance leading to tissue damage is not likely under realistic conditions during Q-20 testing, and this type of impact is not considered further in this analysis.

Prolonged Exposure

Q-20 test activities will not result in prolonged exposure because of the intermittent nature of sonar transmissions and the generally short duration of tests. The implementation of the protective measures discussed in **Section 11** will further reduce the likelihood of any prolonged exposure.

Auditory Masking

Natural and artificial sounds can disrupt behavior by masking, or interfering with an animal‘s ability to hear other sounds. Masking occurs when the receipt of a sound is interfered with by a second sound at similar frequencies and at similar or higher levels. If the second sound were artificial, it could be potentially harassing if it disrupted hearing-related behavior such as communications or echolocation. It is important to distinguish TTS and PTS, which persist after the sound exposure, from masking, which occurs during the sound exposure.

Historically, principal masking concerns have been with prevailing background sound levels from natural and man-made sources (e.g., Richardson et al. 1995). Dominant examples of the latter are the accumulated sound from merchant ships and sound of seismic surveys. Both cover wide frequency bands and are long in duration.

The majority of proposed Q-20 test activities is located away from harbors or heavily traveled shipping lanes. The sonar signals are likely within the audible range of most cetaceans, but are very limited in the temporal and frequency domains. In particular, the pulse lengths are short and the duty cycle is low, and these HFASs transmit within a narrow band of frequencies (typically less than one-third octave). For the reasons outlined above, the chance of sonar operations causing masking effects is considered negligible.

6.2.3 Marine Mammal Exposures

Sonar operations in non-territorial waters may expose up to six species to sound likely to result in Level B (behavioral) harassment (**Table 6-3**). They include the bottlenose dolphin, Atlantic spotted dolphin, pantropical spotted dolphin, striped dolphin, spinner dolphin, and Clymene dolphin. No marine mammals would be exposed to levels of sound likely to result in TTS. Marine mammal exposures listed in **Table 6-3** are equivalent to the requested takes listed in **Table 5-1**.

Potential for Long-Term Effects

Q-20 test activities will be conducted in the same general areas, so marine mammal populations could be exposed to repeated activities over time. However, as described earlier, this IHA application assumes that short-term noninjurious SELs predicted to cause temporary behavioral disruptions qualify as Level B harassment. It is highly unlikely that all behavioral disruptions will result in long-term significant effects.

Potential for Effects on ESA-Listed Species

To further examine the possibility of sperm whale exposures from the proposed testing, CASS-GRAB sound modeling software was used to estimate TL and received SPLs from the Q-20 system when operating in the test area. Specifically, four radials out towards De Soto Canyon were calculated. The results, as shown in **Figure 6-6**, indicate the relatively rapid attenuation of SPLs with distance from the source, which is not surprising given the high frequency of the source. **Figure 6-7** shows the ―zone of influence" for Q-20 testing along the TACSIT Channel, using the 120 dB ―basement value" of the risk function to define the zone of

Table 6-3. Estimates of Marine Mammal Exposures from Sonar in Non-territorial Waters Per Year.

Marine Mammal Species	Level A	Level B (TTS)	Level B (Behavioral)
All beaked whales	0	0	0
Atlantic spotted dolphin	0	0	315
Bryde's whale	0	0	0
Bottlenose dolphin	0	0	399
Clymene dolphin	0	0	42
False killer whale	0	0	0
Fraser's dolphin	0	0	0
Melon-headed whale	0	0	0
Pantropical spotted dolphin	0	0	126
Pygmy killer whale	0	0	0
Pygmy/sperm whale	0	0	0
Risso's dolphin	0	0	0
Rough-toothed dolphin	0	0	0
Short-finned pilot whale	0	0	0
Sperm whale	0	0	0
Spinner dolphin	0	0	126
Striped dolphin	0	0	42

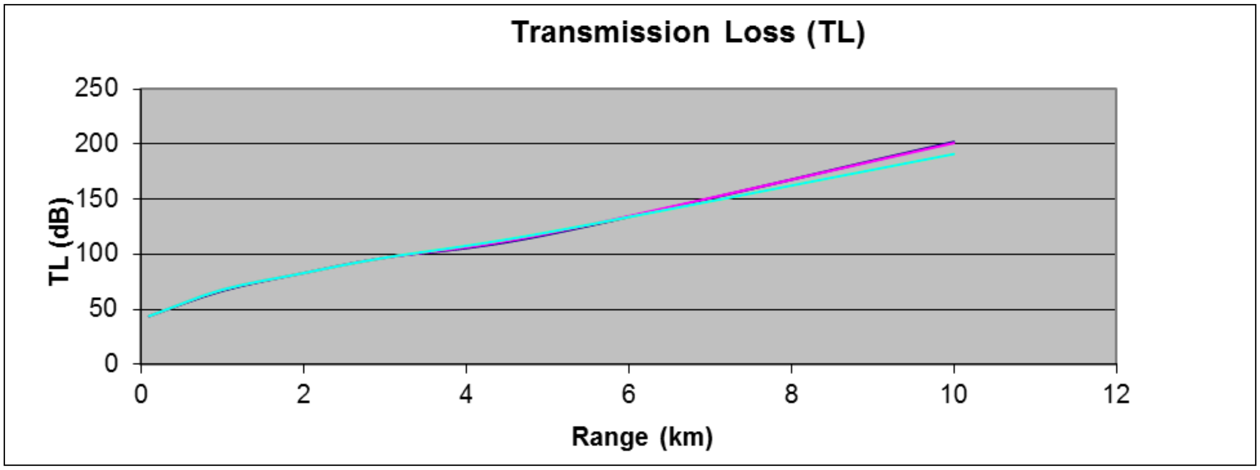
influence for potential effects on marine mammals. Below 120 dB, the risk of significant change in a biologically important behavior approaches zero. This threshold is reached at a distance of only 2.8 km (1.5 nmi) from the source. With the density of sperm whales being near zero in this potential zone of influence, this calculation reinforces the conclusion of no effect on sperm whales. It should also be noted that, by reference to **Figures 6-6 and 6-7**, DeSoto Canyon is well beyond the distance at which SPLs from the Q-20 attenuate to zero.

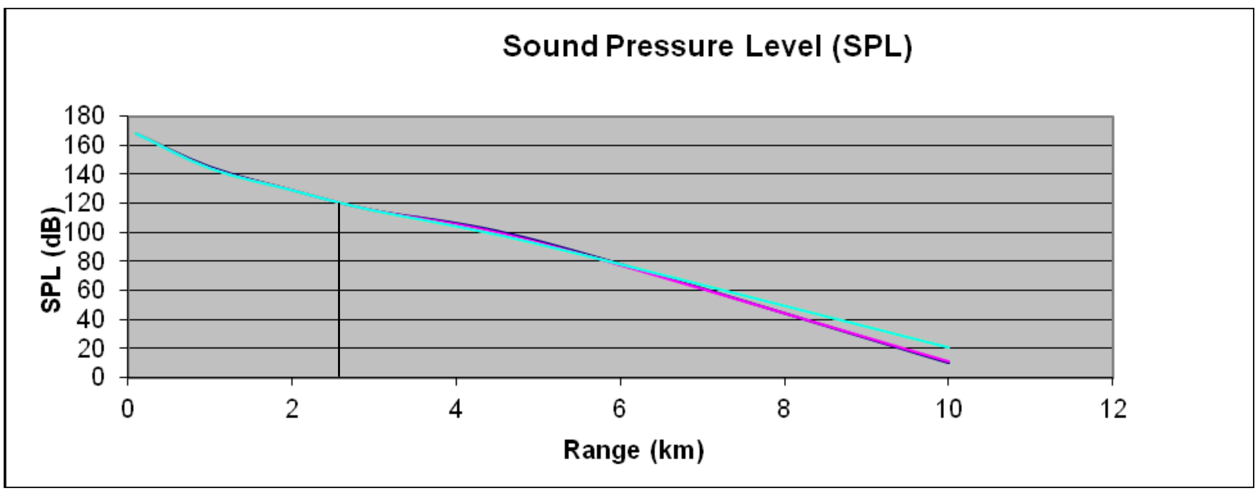
6.2.4 Summary of Potential Acoustic Effects from Sonar by Marine Mammal Species

Acoustical modeling provides an estimate of the predicted exposures. As previously mentioned, Q-20 test activities involve HFAS activities.

Non-Territorial Waters

The following subsections present the summary for species with potential to be exposed to sound based on the previous sonar analysis. The results of this analysis indicate that no marine mammal species will be exposed to levels of sound likely to result in Level A harassment or Level B (TTS) harassment. The following subsections will present information for the marine mammal species with the potential to be exposed to sound levels resulting in Level B (behavioral) harassment. **Table 6-4** summarizes the requested takes for each marine mammal species discussed in the subsections below.





Note: Vertical line inserted to show distance at which SPL falls to 120 dB.

Figure 6-6. Attenuation of SPLs with Distance from the Q-20 Source.

Bottlenose Dolphin

The best estimate of abundance for bottlenose dolphins along the GOM continental shelf and slope is currently unknown (NMFS 2012). Based upon 2002–2003 survey data, the best estimate of abundance for bottlenose dolphins along the GOM continental shelf and slope is 17,777 (Waring et al. 2009a). The risk function and U.S. Navy post-modeling analysis estimates that 399 bottlenose dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on the exposure data, 2.24 percent of the Northern GOM Stock of bottlenose dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA.

Based on the best available science, the U.S. Navy concludes that exposures to bottlenose dolphins due to Q-20 test activities would result in short-term effects to most individuals exposed and would likely not affect annual rates of recruitment or survival. The protective measures presented in **Section 11** will further reduce the potential for exposures to occur to bottlenose dolphins.

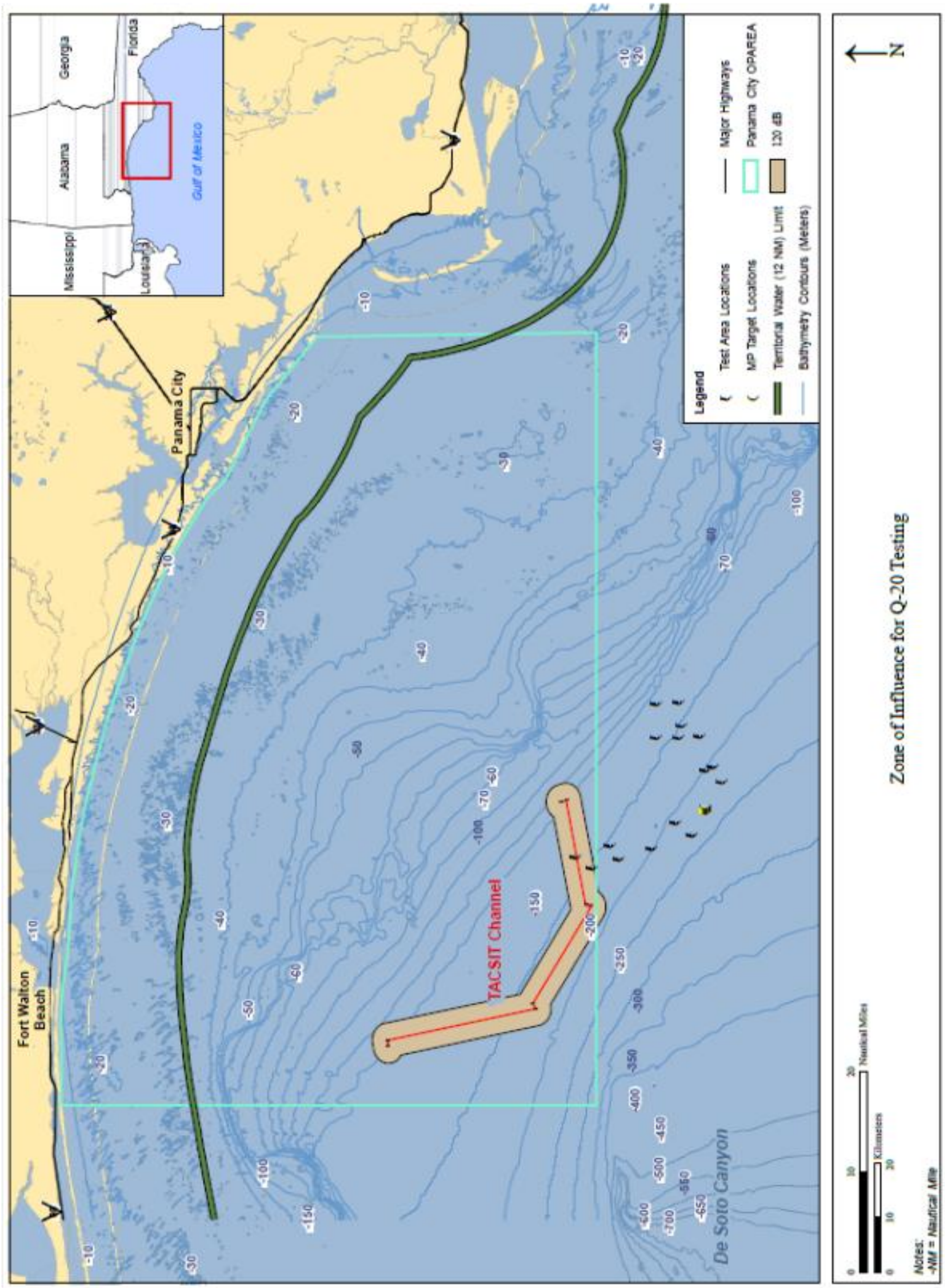


Figure 6-7. Zone of Influence (120 dB SPL) for Q-20 Testing.

Table 6-4. Requested Takes of Marine Mammal Species.

Marine Mammal Species	Level A	Level B (TTS)	Level B (Behavioral)
Atlantic spotted dolphin	0	0	315
Bottlenose dolphin	0	0	399
Clymene dolphin	0	0	42
Pantropical spotted dolphin	0	0	126
Spinner dolphin	0	0	126
Striped dolphin	0	0	42

Atlantic Spotted Dolphin

The best estimate of abundance for Atlantic spotted dolphins in the northern GOM is currently unknown (NMFS 2012). Based upon 2002–2003 survey data, the best estimate of abundance for Atlantic spotted dolphins in the northern GOM is 37,611 (Waring et al. 2009a). The risk function and U.S. Navy post-modeling analysis estimates that 315 Atlantic spotted dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on the exposure data, 0.84 percent of the Northern GOM Stock of Atlantic spotted dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA.

Based on the best available science, the U.S. Navy concludes that exposures to Atlantic spotted dolphins due to Q-20 test activities would result in short-term effects to most individuals exposed and would likely not affect annual rates of recruitment or survival. The protective measures presented in **Section 11** will further reduce the potential for exposures to occur to Atlantic spotted dolphins.

Pantropical Spotted Dolphin

Currently, the best estimate of abundance for pantropical spotted dolphins in the northern GOM is 50,880 (NMFS 2012). In 2009, NMFS reported a best estimate of abundance of 34,067 for pantropical spotted dolphins in the northern GOM (Waring et al. 2009b). The risk function and U.S. Navy post-modeling analysis estimates that 126 pantropical spotted dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on the exposure data, 0.037 percent of the Northern GOM Stock of pantropical spotted dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA.

Based on the best available science, the U.S. Navy concludes that exposures to pantropical spotted dolphins due to Q-20 test activities would result in short-term effects to most individuals exposed and would likely not affect annual rates of recruitment or survival. The protective measures presented in **Section 11** will further reduce the potential for exposures to occur to pantropical spotted dolphins.

Striped Dolphin

The best abundance estimate for striped dolphins in the northern GOM is 1,849 individuals (NMFS 2012). In 2009, the best estimate of abundance for striped dolphins in the northern GOM was 3,325 animals (Waring et al. 2009b). The risk function and U.S. Navy post-modeling analysis estimates that 42 striped dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on these exposure data, 1.26 percent of the Northern GOM Stock of striped dolphin will exhibit behavioral responses that NMFS will classify as harassment under the MMPA.

Based on the best available science, the U.S. Navy concludes that exposures to striped dolphins due to Q-20 test activities would result in short-term effects to most individuals exposed and would likely not affect annual rates of recruitment or survival. The protective measures presented in **Section 11** will further reduce the potential for exposures to occur to striped dolphins.

Spinner Dolphin

The best estimate of abundance for spinner dolphins in the northern GOM is 11,441 animals (NMFS 2012). In 2009, the best estimate of abundance for spinner dolphins in the northern GOM was 1,989 individuals (Waring et al. 2009b). The risk function and U.S. Navy post-modeling analysis estimates that 126 spinner dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on these exposure data and the best estimate of abundance, 6.33 percent of the Northern GOM Stock of spinner dolphin will exhibit behavioral responses that NMFS will classify as harassment under the MMPA.

Based on the best available science, the U.S. Navy concludes that exposures to spinner dolphins due to Q-20 test activities would result in short-term effects to most individuals exposed and would likely not affect annual rates of recruitment or survival. The protective measures presented in **Section 11** will further reduce the potential for exposures to occur to spinner dolphins.

Clymene dolphin

The best estimate of abundance for Clymene dolphins in the northern GOM is 129 animals (NMFS 2012). In 2009, the best estimate of abundance for Clymene dolphins in the northern GOM was 6,575 individuals (Waring et al. 2009b). The risk function and U.S. Navy post-modeling analysis estimates that 42 Clymene dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on these exposure data and the best estimate of abundance, 0.64 percent of the Northern GOM Stock of Clymene dolphin will exhibit behavioral responses that NMFS will classify as harassment under the MMPA.

Based on the best available science, the U.S. Navy concludes that exposures to Clymene dolphins due to Q-20 test activities would result in short-term effects to most individuals exposed and would likely not affect annual rates of recruitment or survival. The protective measures presented in **Section 11** will further reduce the potential for exposures to occur to Clymene dolphins.

7. IMPACTS ON MARINE MAMMAL SPECIES OR STOCKS

Overall, the conclusions in this analysis find effects to marine mammal species and stocks would be negligible for the following reasons:

- All acoustic exposures are within the behavioral effects zones (Level B harassment).
- Although the estimated exposure numbers represent estimated harassment under the MMPA, as described above, they are conservative estimates of harassment by behavioral disturbance as discussed in the analysis approach presented in **Section 6**. In addition, the model estimates exposures without taking into consideration the implementation of standard protective measures, and model results are not indicative of a likelihood of either injury or harm.
- Additionally, the protective measures described in **Section 11** are designed to reduce sound exposure of marine mammals to levels below those that may cause ―behavioral disruptions” and to achieve the least practicable adverse effect on marine mammal species or stocks.

Consideration of negligible impact is required for NMFS to authorize incidental take of marine mammals. By definition, an activity has a ―negligible impact” on a species or stock when it is determined that the total taking is not likely to reduce annual rates of adult survival or recruitment (i.e., offspring survival, birth rates). An analysis of the potential impacts of the Proposed Action on species recruitment or survival is presented in **Section 6** for each species based on each species‘ life history information, the characteristics of the Q-20 test activity locations, and an analysis of the behavioral disturbance levels in comparison to the overall population. These species-specific analyses support the conclusion that Q-20 test activities would have a negligible impact on marine mammals.

7.1 Surface Operations

The use of vessels during Q-20 test activities will not result in take of any marine mammals in the non-territorial waters of the GOM, due to adherence to mitigation and monitoring measures presented in **Sections 11 and 13**. Furthermore, since no critical habitat has been designated for the ESA-listed sperm whale here, there will be no impacts on critical habitat by surface operations.

7.2 Sonar

No Level A takes are anticipated from Q-20 test activities involving sonar in non-territorial waters of the GOM due to adherence to mitigation and monitoring measures presented in **Sections 11 and 13**. Takes by incidental harassment (Level B behavioral disturbance) are requested for six marine mammal species: bottlenose dolphin, Atlantic spotted dolphin, pantropical spotted dolphin, striped dolphin, spinner dolphin, and Clymene dolphin. Because sonar testing in the Q-20 Study Area results in temporary and intermittent takings by Level B harassment (i.e., behavioral disturbance), there will be a negligible effect on to affected species or stocks. In addition, since no critical habitat has been designated for the ESA-listed sperm whale here, no critical habitat will be affected by sonar operations.

8. IMPACT ON SUBSISTENCE USE

There are no traditional subsistence hunting areas in the vicinity of the Proposed Action, and there are no activities related to the Proposed Action that may affect the availability of a species or stock of marine mammals for subsistence uses. Therefore, no impacts would occur to the targeted species or stocks available for Native American subsistence use.

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9. IMPACTS ON THE MARINE MAMMAL HABITAT AND THE LIKELIHOOD OF RESTORATION

The Q-20 OEA considered the components of the Q-20 test activities that could affect marine mammal habitat, including changes in the amount and distribution of prey (DON 2012a). Q-20 test activities that may affect marine mammal habitat include the introduction of sound into the water column, and transiting vessels. Each of these components was considered in the Q-20 OEA and determined to have no effect on marine mammal habitat (DON 2012a, DON 2012b). A summary of the conclusions is included in subsequent sections.

9.1 Sound in the Environment

Potential cumulative impacts associated with active sonar operations include the addition of underwater sound to oceanic ambient noise levels, which in turn could potentially affect marine animals. Two principal sources of underwater ambient noise include noise from wind and commercial shipping. In deep water, shipping traffic generally dominates in the 10- to 300-Hz frequency band while weather noise (as measured by wave height or wind speed) generally dominates above 300 Hz (Snyder and Orlin 2007). Other anthropogenic sources of ambient noise that are most likely to contribute to increases in ambient noise levels include offshore oil and gas exploration and drilling, as well as naval and other use of sonar (DON 2007b). The potential impact that HFAS may have on the overall oceanic ambient noise level are reviewed in the following contexts:

- Recent changes to ambient sound levels in the GOM.
- Operational parameters of sonar operating during Q-20 test activities, including proposed mitigation.
- Contributions of active sonar operations to oceanic noise levels relative to other human generated sources of oceanic noise.
- Cumulative impacts and synergistic effects.

Very few studies have been conducted to determine ambient noise levels in the GOM directly off the Florida panhandle. However, ambient sound levels for the Eglin Gulf Test and Training Range, which is located in the northeastern GOM, generally range from approximately 40 to about 110 dB re 1 μPa (U.S. Air Force 2002). Few studies have been conducted on historical changes in ambient sound levels. Frisk (2012) noted that a growing body of literature suggests that low-frequency, ambient noise levels in the open ocean increased approximately 3.3 dB per decade from 1950 to 2007. Frisk (2012) also showed that this increase can be attributed primarily to commercial shipping activity, which in turn, can be linked to global economic growth. Furthermore, Frisk (2012) concluded that ambient noise levels can be directly related to global economic conditions.

Anthropogenic sound can be introduced into the ocean by a number of sources, including vessel traffic, industrial operations onshore, seismic profiling for oil exploration, oil drilling, and sonar operation. In open oceans, the primary persistent anthropogenic sound source tends to be commercial shipping, since over 90 percent of global trade depends on transport across the seas (Scowcroft et al. 2006). Moreover, approximately 20,000 large commercial vessels are at sea worldwide at any given time. Large commercial vessels produce relatively loud and predominately low-frequency sounds. Most of these sounds are produced as a result of propeller cavitation (when air spaces created by the motion of propellers collapse) (Southall 2005). In 2004, NOAA hosted a symposium entitled ―Shipping Noise and Marine Mammals.” During the Session I presentation ―Trends in the Shipping Industry and Shipping Noise,” statistics were presented that indicated foreign waterborne trade into the United States had increased 2.45 percent each year over a 20-year period (1981 to 2001) (Southall 2005). International shipping volumes and densities are expected to continually increase in the foreseeable future (Southall 2005). The increase in shipping volumes and densities will most likely increase overall ambient sound levels in the ocean. However, it is not known whether these increases would have an effect on marine mammals (Southall 2005).

According to the NRC (2003), the oil and gas industry has five categories of activities which create sound: seismic surveys, drilling, offshore structure emplacement, offshore structure removal, and production and related activities. Seismic surveys are conducted using air guns, sparker sources, sleeve guns, innovative new impulsive sources, and sometimes explosives, and are routinely conducted in offshore exploration and production operations to define subsurface geological structure. The resultant seismic data are necessary to determine drilling location. Currently, seismic survey is the only method to accurately find hydrocarbon reserves. Since the reserves are deep in the earth, the low-frequency band (5 to 20 Hz) is of greatest value for seismic surveys because lower frequency signals are able to travel farther into the seafloor with less attenuation (DON 2007d).

Air-gun firing rate is dependent on the distance from the array to the substrate. The typical intershot time is 9 to 14 sec, but for surveys in very deep waters, inter-shot times are as high as 42 sec. Air-gun acoustic signals are broadband and typically measured in peak-to-peak pressures. Peak levels from the air guns are generally higher than continuous sound levels from any other ship or industrial noise. Broadband SLs of 248 to 255 dB re 1 µPa-m from peak-to-peak are typical for a full-scale array. The most powerful arrays have source levels as high as 260 dB re 1 µPa-m, peak-to-peak with air gun volumes of 130 liters (7,900 cubic inches). Smaller arrays have SLs of 235 to 246 dB re 1 µPa-m, peak-to-peak (DON 2007d).

For deeper-water surveys, most emitted energy is around 10 to 120 Hz. However, some pulses contain energy up to 1,000 Hz (Richardson et al. 1995) and higher. Drill-ship activities are one of the noisiest at-sea operations, because the hull of the ship is a good transmitter of all the ship‘s internal noises and the ships use thrusters to stay in the same location rather than anchoring. Auxiliary noise, such as noise associated with helicopters and supply boats, is also produced during drilling activities. Offshore drilling-structure emplacement creates some localized noise for brief periods of time, and emplacement activities can last for a few weeks. Additional noise is created during other oil production activities, such as borehole logging, cementing, pumping, and pile driving. Although SPLs for some of these activities have not yet been calculated, others have (e.g., pile-driving). More activities are occurring in deep water in the GOM. These oil and gas industry activities collectively occur year-round and are usually operational 24 hr per day and 7 days a week (U.S. Air Force 2002).

There are both military and commercial sonars: military sonars are used for target detection, localization, and classification; and commercial sonars are used for depth sounding, bottom profiling, fish finding, and detecting obstacles in the water. Commercial sonars are typically higher in frequency and lower in power. Commercial sonar use is expected to continue to increase, although it is not believed that the acoustic characteristics will change (DON 2007d). Even though an animal‘s exposure to active sonar may occur more than one time, the intermittent nature of the sonar signal, its low duty-cycle, and movement by both the vessel and animal provide only a small chance that exposure to active sonar for individual animals and stocks would be repeated over extended periods of time, such as those caused by shipping noise. Moreover, it was determined in the Q-20 OEA that active sonar transmissions will not significantly increase anthropogenically-created ocean noise (DON 2012a). Protective measures will be employed during Q-20 test activities to minimize potential effects to marine mammals to the greatest extent practicable. As such, there would be no significant impact to marine mammals from the introduction of sound into the marine environment.

9.2 Transiting Vessels

Collisions with commercial and U.S. Navy ships can cause major wounds and may occasionally cause mortality and stranding. The most vulnerable marine mammals are those that spend extended periods of time at the surface in order to restore oxygen levels within their tissues after deep dives (e.g., the sperm whale). In addition, some baleen whales, such as the North Atlantic right whale, seem generally unresponsive to ship sound, making them more susceptible to ship strikes (Nowacek et al. 2004). Laist et al. (2001) identified 11 species known to be hit by ships worldwide. Of these species, fin whales are struck most frequently; right whales, humpback whales, sperm whales, and gray whales are hit commonly. These species are primarily large, slow-moving whales and only the sperm whale could be expected to occur within the Q-20 Study Area. Smaller marine mammals, for example bottlenose and Atlantic spotted dolphins, move quickly throughout the water column and are often seen riding the bow waves of large ships. Marine mammal responses may include avoidance and changes in dive pattern (NRC 2003; Dolman et al. 2006; DON 2012c).

Accordingly, the U.S. Navy has adopted SOPs and protective measures to reduce the potential for collisions to occur with surfaced marine mammals (for more details refer to **Section 11**). These include:

- Using Lookouts trained to detect all objects on the surface of the water, including marine mammals.
- Implementing reasonable and prudent actions to avoid the close interaction of U.S. Navy assets with marine mammals.
- Maneuvering to keep away from any observed marine mammal.

Q-20 test activities incorporate a variety of marine craft including the *Athena 1*, *Athena 2*, and a large research vessel; several 4.0- to 7.6-m (13- to 25-ft) outboard motor boats; a 9.1-m (30-ft) rigid-hulled inflatable boat; and 9.8-m (32-ft), 20-m (65-ft), and 21-m (68-ft) inboard diesel vessels. Large surface vessels associated with the RDT&E activities are present; however, typically they transit to and from a test location once per test and are stationary for a large proportion of operations. Thus, effects to marine mammal habitat from these vessels would be negligible.

10. IMPACTS ON MARINE MAMMALS FROM LOSS OR MODIFICATION OF HABITAT

Based on the previous discussion in this IHA application, there will be no impacts on marine mammals resulting from loss or modification of marine mammal habitat.

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11. MEANS OF EFFECTING THE LEAST PRACTICABLE ADVERSE IMPACTS – PROTECTIVE MEASURES

The U.S. Navy identified protective measures to reduce any potential risks to marine mammals. The actions described in this request present a potential risk to marine mammals. Protective measures and monitoring will limit the number of exposures.

11.1 Protective Measures Related to Surface Operations

Visual surveys will be conducted for all test operations to reduce the potential for vessel collisions to occur with a protected species. If necessary, the ship‘s course and speed will be adjusted.

11.2 Protective Measures Related to Effects from Sonar

To meet current and future national and global defense challenges, the U.S. Navy must develop a robust capability using realistic conditions to research, develop, test, and evaluate systems within the Q-20 Study Area. The U.S. Navy recognizes that such developments have the potential to cause behavioral disruption of some marine mammal species in the vicinity of RDT&E activities. This section presents the U.S. Navy‘s mitigation measures that will be implemented to protect marine mammals, federally listed species, and other aspects of the marine environment during RDT&E activities. Several of these mitigation measures align with protective measures in the training arena for the U.S. Navy, which have been in place since 2004.

11.2.1 Personnel Training

Marine mammal mitigation training for those who participate in Q-20 test activities involving active sonar is a key element of the protective measures. The goal of this training is for key personnel onboard U.S. Navy platforms in the Q-20 Study Area to understand the protective measures and be competent to execute them. The Marine Species Awareness Training (MSAT) is provided to all applicable participants, where appropriate. The program addresses environmental protection, laws governing the protection of marine species, U.S. Navy stewardship, and general observation information including more detailed information for spotting marine mammals. MMO training will be provided before active sonar testing begins. MSAT has been reviewed by NMFS and acknowledged as suitable training. MMOs will be aware of the specific actions to be taken based on the RDT&E platform if a marine mammal or sea turtle is observed.

11.2.2 Range Operating Procedures

The following procedures will be implemented to maximize the ability of U.S. Navy personnel to recognize instances when marine mammals are in the vicinity.

General Maritime Protective Measures: Personnel Training

Marine observers will be trained to quickly and effectively communicate within the command structure to facilitate implementation of protective measures if marine mammals are spotted.

General Maritime Protective Measures: Observer Responsibilities

- Marine observers will have at least one set of binoculars available for each person to aid in the detection of marine mammals.
- Marine observers will scan the water from the ship to the horizon and be responsible for all observations in their sectors. In searching the assigned sector, the lookout will always start at the forward part of the sector and search aft (toward the back). To search and scan, the lookout will hold the binoculars steady such that the horizon is in the top third of the field of vision and will direct the eyes just below the horizon. The lookout will scan for approximately 5 sec in as many small steps as possible across the field seen through the binoculars. The lookout will search the entire sector in approximately 5° steps, pausing between steps for approximately 5 sec to scan the field of view. At the end of the sector search, the binoculars will be lowered to allow the eyes to rest for a few sec, and then the lookout will search back across the sector with the naked eye.
- Observers will be responsible for informing the Test Director of any marine mammal or sea turtle that may need to be avoided, as warranted.
- These procedures would apply as much as possible during RMMV operations. When an RMMV is operating over the horizon, it is impossible to follow and observe it during the entire path. An observer will be located on the support vessel or platform to observe the area when the system is undergoing a small track close to the support platform.

Operating Procedures

Section 11.3 presents detailed information on clearance procedures. The following gives a general overview of the requirements of monitoring during RDT&E activities that involve sonar.

- Test Directors will, as appropriate to the event, make use of marine species detection cues and information to limit interaction with marine species to the maximum extent possible, consistent with the safety of the ship.
- U.S. Navy aircraft participating, will conduct and maintain, when operationally feasible, required, and safe, surveillance for marine species of concern as long as it does not violate safety constraints or interfere with the accomplishment of primary operational duties.
- Marine mammal detections by aircraft will be immediately reported to the Test Director. This action will occur when it is reasonable to conclude that the course of the ship will likely close the distance between the ship and the detected marine mammal.

Special Conditions Applicable for Bow-Riding Dolphins

If, after conducting an initial maneuver to avoid close quarters with dolphins, the ship concludes that dolphins are deliberately closing in on the ship to ride the vessel‘s bow wave, no further mitigation actions will be necessary because dolphins are out of the main transmission axis of the active sonar while in the shallow-wave area of the vessel bow.

11.3 Clearance Procedures

When the test platform (surface vessel or aircraft) arrives at the test site, an initial evaluation of environmental suitability will be made. This evaluation will include an assessment of sea state and verification that the area is clear of visually detectable marine mammals, sea turtles, and indicators of their presence. The cleared area will encompass a radius size of 914 m (1,000 yards) from the vessel. Large *Sargassum* rafts and large concentrations of jellyfish are considered indicators of potential sea turtle presence. Large flocks of birds and large schools of fish are considered indicators of potential marine mammal presence.

If the initial evaluation indicates that the area is clear, visual surveying will begin. The area will be visually surveyed for about 15 min for the presence of protected species and protected species indicators. Visual surveys will be conducted from the test platform before test activities begin. If the platform is a surface vessel, no additional aerial surveys will be required except for events involving large detonations. For surveys requiring only surface vessels, aerial surveys may be opportunistically conducted by aircraft participating in the test.

Shipboard monitoring will be staged from the highest point possible on the vessel. The observer(s) will be experienced in shipboard surveys, familiar with the marine life of the area, and equipped with binoculars of sufficient magnification. Each observer will be provided with a two-way radio that will be dedicated to the survey, and will have direct radio contact with the Test Director. Observers will report to the Test Director any sightings of marine mammals, sea turtles, or indicators of these species, as described previously. Distance and bearing will be provided when available. A test would be delayed if a marine mammal is observed within 183 m (200 yards) of the source. Observers may recommend a ―Go”/―No Go” decision, but the final decision will be the responsibility of the Test Director.

Post-mission surveys will be conducted from the surface vessel(s) and aircraft used for pre-test surveys. Any affected marine species will be documented and reported to NMFS. Post-mission surveys will last for approximately 15 min. The report will include the date, time, location, test activities, species (to the lowest taxonomic level possible), behavior, and number of animals.

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12. MONITORING AND REPORTING MEASURES

12.1 Proposed Monitoring for this IHA

The RDT&E Monitoring Program, proposed by the U.S. Navy as part of this IHA application, is focused on mitigation-based monitoring. Main monitoring techniques include use of civilian personnel as marine mammal observers during pre-, during-, and post-test events.

Systematic monitoring of the affected area for marine mammals will be conducted prior to, during, and after test events using aerial and/or ship-based visual surveys. Marine mammal observers will record information during the test activity. Data recorded will include exercise information (time, date, and location) and marine mammal and/or indicator presence. Personnel will immediately report observed stranded or injured marine mammals to the NMFS stranding response network and NMFS Southeast Regional Office. Reporting requirements from the issued IHA will be included in the NSWC PCD Mission Activities Annual Mission Activity Report and the NSWC PCD Mission Activities Annual Monitoring Report as required by its Final Rule (DON 2009a; NMFS 2010).

12.2 Ongoing Monitoring

The NSWC PCD Monitoring Plan (DON 2011) was initially developed in support of the NSWC PCD Mission Activities Final EIS/OEIS and subsequent Final Rule by the NMFS (DON 2009a; NMFS 2010). The Monitoring Plan, adjusted annually in consultation under an adaptive management review process with NMFS, includes aerial- and ship-based visual observations, acoustic monitoring, and other efforts such as oceanographic observations. The U.S. Navy is not currently committing to increased visual surveys at this time, but will research opportunities for leveraged work that could be added under an Adaptive Management provision of this IHA application for future Q-20 Study Area monitoring.

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13. RESEARCH

The U.S. Navy sponsors a significant portion of research concerning the effects of human-generated sound on marine mammals. World-wide, the U.S. Navy funded over $16 million in marine mammal research in 2012. Major topics of U.S. Navy-supported research include:

- Gaining a better understanding of marine species distribution and important habitat areas.
- Developing methods to detect and monitor marine species before and during training.
- Understanding the effects of sound on marine mammals.
- Developing tools to model and estimate potential effects of sound.

This research is directly applicable to the Q-20 Study Area, particularly with respect to the investigations of the potential effects of underwater noise sources on marine mammals and other protected species.

Furthermore, various research cruises by NMFS and academic institutions have been augmented with additional funding from the U.S. Navy. The U.S. Navy has also sponsored several workshops to evaluate the current state of knowledge and potential for future acoustic monitoring of marine mammals. The workshops brought together acoustic experts and marine biologists from the U.S. Navy and other research organizations to present data and information on current acoustic monitoring research efforts and to evaluate the potential for incorporating similar technology and methods on instrumented ranges.

The U.S. Navy will continue to fund ongoing marine mammal research, and includes projected funding at levels greater than $14 million per year in subsequent years. The U.S. Navy also has plans to continue in the coordination of long-term monitoring and studies of marine mammals on various established ranges and within its OPAREAs. The U.S. Navy will continue to research and contribute to university/external research to improve the state of the knowledge of the science regarding the biology and ecology of marine species, and potential acoustic effects on species from naval activities. These efforts include mitigation and monitoring programs, data sharing with NMFS and via the literature for research and development efforts, and future research, as described previously.

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This IHA application was prepared for the U.S. Navy by NSWC PCD and HDR. A list of key preparation and review personnel is included.

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Appendix A – Supplemental Information for Underwater Noise Analysis

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

CASS-GRAB	Comprehensive Acoustic Simulation System/Gaussian Ray Bundle
CPA	Closest Points of Approach
dB	decibel(s)
DON	Department of the Navy
ft	foot/feet
GOM	Gulf of Mexico
H	number of animals harassed with 100% unharassed population
HFBL	High-Frequency Bottom Loss
hr	hours
kHz	kilohertz
km	kilometer(s)
LFBL	Low-Frequency Bottom Loss
m	meter(s)
m/sec	meter(s) per second(s)
nmi	nautical mile(s)
NMFS	National Marine Fisheries Service
NODE	Navy OPAREA Density Estimate
NSWC PCD	Naval Surface Warfare Center Panama City Division
OPAREA	operating area
$\mathbf{P_n}$	unharassed population after ping n
$\mathbf{P_o}$	local population
PTS	permanent threshold shift
Q-20	AN/AQS-20A Mine Reconnaissance Sonar System
$\mathbf{R_{max}}$	maximum range
sec	second(s)
SOA	sonar operating area
SPL	sound pressure level
SVP	Sound Velocity Profile
TL	transmission loss
TTS	temporary threshold shift
U.S.	United States
VSS	Volume Search Sonar

SUPPLEMENTAL INFORMATION FOR UNDERWATER NOISE ANALYSIS

A.1 Acoustic Sources

The AN/AQS-20A Mine Reconnaissance Sonar System (Q-20) acoustic sources are active sonars categorized as narrowband (producing sound over a frequency band that is small in comparison to the center frequency). The transmission loss (TL) used to determine the impact ranges of narrowband active sonars can be adequately characterized by model estimates at a single frequency. Detailed description of the sonar source is provided in the following subsections.

A.1.1 Sonars

Activities in the Q-20 Study Area involve high-frequency sources. The permanent threshold shift (PTS) and temporary threshold shift (TTS) impact ranges for virtually all of these sources is less than the size of the source itself; the implication of the limited impact ranges is that the source is more likely to collide with a protected marine animal than harass it acoustically. Exposure estimates are calculated on a 24-hour (hr) basis. **Table A-1** presents the frequency class of the source. **Table A-2** gives an overview of the number of operating hours for the systems in non-territorial waters (waters beyond 22 kilometers [km; 12 nautical miles [nmi]]).

Table A-1. Representative Active Sonars Employed for Q-20 Test Activities

Sonar	Description	Frequency Class	Exposures Reported
AN/AQS-20	Helicopter-towed deep-water mine detection sonar	High-frequency	Per year

Table A-2. Hours of Sonar operations by Representative System for Non-Territorial Waters

System	Preferred Alternative
AN/AQS-20	10 hr per test day

The acoustic modeling that is necessary to support the exposure estimates for this sonar relies upon a generalized description of the manner of the sonar‘s operating modes. This description includes the following:

- ―Effective” energy source level – The total energy across the band of the source, scaled by the pulse length (10 log10 [pulse length]), and corrected for source beam width so that it reflects the energy in the direction of the main lobe. The beam pattern correction consists of two terms:
  - Horizontal directivity correction: $10 \log_{10}$ (360 / horizontal beam width).

    - Vertical directivity correction: $10 \log_{10} (2 / [\sin(\theta_1) - \sin(\theta_2)])$, where θ_1 and θ_2 are the 3-decibels (dB) down points on the main lobe.
- Source depth – Depth of the source in meters (m).
- Nominal frequency – Typically the center band of the source emission. These are frequencies that have been reported on in open literature and are used to avoid classification issues. Differences between these nominal values and actual source frequencies are small enough to be of little consequence to the output impact volumes.
- Source directivity – The source beam is modeled as the product of a horizontal beam pattern and a vertical beam pattern. Two parameters define the horizontal beam pattern:
    - Horizontal beam width – Width of the source beam (degrees) in the horizontal plane (assumed constant for all horizontal steer directions).
    - Horizontal steer direction – Direction in the horizontal in which the beam is steered relative to the direction in which the platform is heading.

The horizontal beam is rectangular with constant response across the width of the beam and with flat, 20-dB down sidelobes. (Note that steer directions ϕ, $-\phi$, $180^o - \phi$, and $180^o + \phi$ all produce equal impact volumes.)

- Similarly, two parameters define the vertical beam pattern:
    - Vertical beam width (D/E) – Width of the source beam (degrees) in the vertical plane measured at the 3-dB down point. (The width is that of the beam steered towards broadside and not the width of the beam at the specified vertical steer direction.)
    - Vertical steer direction – Direction in the vertical plane that the beam is steered relative to the horizontal (upward looking angles are positive).

To avoid sharp transitions that a rectangular beam might introduce, the power response at vertical angle θ is

$$\max \{ \sin^2 [n\square(\theta_s - \theta)] / [n \sin (\theta_s - \theta)]^2, 0.01 \}$$

where $n = 180^o / \theta_w$ is the number of half-wavelength-spaced elements in a line array that produces a main lobe with a beam width of θ_w. θ_s is the vertical beam steer direction.

- Ping spacing – Distance between pings. For most sources this is generally just the product of the speed of advance of the platform and the repetition rate of the sonar. Animal motion is generally of no consequence as long as the source motion is greater than the speed of the animal (nominally, three knots). For stationary (or nearly stationary) sources, the –average” speed of the animal is used in place of the platform speed. The attendant assumption is that the animals are all moving in the same constant direction.

These parameters are defined in **Table A-3**:

Table A-3. AN/AQS-20 Source Description of Q-20 Active Sonars

System	Center Frequency (kHz)	Sound Pressure Level (dB)	Pulse Length (sec)	Emission Spacing (m)	D/E Angle (°)	D/E Width (°)	Azimuth Angle (°)	Azimuth Width (°)
Volume Search Sonar	35	212	0.00432	6.0	45	90	90	30
Forward Looking Sonar	85	207			60		60	

kHz = kilohertz; dB = decibel(s); sec = second(s); m = meter(s); ° = degree(s)

A.2 Impact Volumes and Impact Ranges

United States (U.S.) Navy actions include the potential to injure or harass marine animals in the neighboring waters through noise emissions. The number of animals exposed to potential harassment in any such action is dictated by the propagation field and the characteristics of the noise source.

The impact volume associated with a particular activity is defined as the volume of water in which some acoustic metric exceeds a specified threshold. The product of this impact volume with a volumetric animal density yields the expected value of the number of animals exposed to that acoustic metric at a level that exceeds the threshold. The acoustic metric can either be an energy term (energy flux density, either in a limited frequency band or across the full band) or a pressure term (such as peak pressure or positive impulse). The thresholds associated with each of these metrics define the levels at which half of the animals exposed will experience some degree of harassment (ranging from behavioral change to mortality).

Impact volume is particularly relevant when trying to estimate the effect of repeated source emissions separated in either time or space. Impact range, which is defined as the maximum range at which a particular threshold is exceeded for a single source emission, is used to define the range to which marine mammal activity is monitored in order to meet mitigation requirements.

The sole relevant measure of potential harm to the marine wildlife due to sonar operations is the accumulated (summed over all source emissions) energy flux density received by the animal over the duration of the activity.

Estimating the number of animals that may be exposed to the potential risk of harassment in a particular environment entails the following steps.

- Each source emission is modeled according to the particular operating mode of the sonar. The ―effective” energy source level is computed by integrating over the bandwidth of the source, scaling by the pulse length, and adjusting for gains due to source directivity. The location of the source at the time of each emission must also be specified.
- For the relevant environmental acoustic parameters, TL estimates are computed, sampling the water column over the appropriate depth and range intervals. TL data are

sampled at the typical depth(s) of the source and at the nominal center frequency of the source. If the source is relatively broadband, an average over several frequency samples is required.

- The accumulated energy within the waters that the source is “operating” is sampled over a volumetric grid. At each grid point, the received energy from each source emission is modeled as the effective energy source level reduced by the appropriate propagation loss from the location of the source at the time of the emission to that grid point and summed. For the peak pressure or positive impulse, the appropriate metric is similarly modeled for each emission. The maximum value of that metric (over all emissions) is stored at each grid point.
- The impact volume for a given threshold is estimated by summing the incremental volumes represented by each grid point for which the appropriate metric exceeds that threshold.
- Finally, the number of exposures is estimated as the “product” (scalar or vector, depending upon whether an animal density depth profile is available) of the impact volume and the animal densities.

This section describes in detail the process of computing impact volumes (that is, the first four steps described above). The relevant assumptions associated with this approach and the limitations that are implied are also presented. The final step, computing the number of exposures is discussed in **Subsection A.5**.

A.2.1 Computing Impact Volumes for Active Sonars

This section provides a detailed description of the approach taken to compute impact volumes for active sonars. Included in this discussion are:

- Identification of the underwater propagation model used to compute TL data, a listing of the source-related inputs to that model, and a description of the output parameters that are passed to the energy accumulation algorithm.
- Definitions of the parameters describing each sonar type.
- Description of the algorithms and sampling rates associated with the energy accumulation algorithm.

The following bullets provide an overview of the steps in simplistic terms followed by detailed information for the calculations.

- **Step 1. Environmental Provinces**. The Q-20 Study Area is divided into 14 environmental provinces, and each has a unique combination of environmental conditions. These represent various combinations of eight bathymetry provinces, one sound velocity profile (SVP) province, and three (Low-Freqeuncy Bottom Loss [LFBL]) geo-acoustic provinces and two High-Frequency Bottom Loss (HFBL) classes. These are addressed by defining environments in two seasons that span the variety of depths, bottom types, sound speed profiles, and sediment thicknesses found in the Q-20 Study

Area. The two seasons encompass winter and summer, which are the two extremes and for the Gulf of Mexico (GOM) the acoustic propagation characteristics do not vary significantly between the two. Each marine modeling area can be quantitatively described as a unique combination of these environments.

- **Step 2. Transmission Loss**. Since sound propagates differently in these environments, separate TL calculations must be made for each, in both seasons. The TL is predicted using Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS-GRAB) sound modeling software.
- **Step 3. Exposure Volumes**. The TL, combined with the source characteristics, gives the energy field of a single ping. The energy of over 10 hr of pinging is summed, carefully accounting for overlap of several pings, so an accurate average exposure of an hour of pinging is calculated for each depth increment. At more than 10 hr, the source is too far away and the energy is negligible.

  Repeating this calculation for each environment in each season gives the hourly ensonified volume, by depth, for each environment and season. This step begins the method for risk function modeling.
- **Step 4. Marine Mammal Densities**. The marine mammal densities were given in two dimensions, but using peer-reviewed literature sources (published literature and agency reports) described in the following subsection, the depth regimes of these marine mammals are used to project the two dimensional densities (expressed as the number of animals per area where all individuals are assumed to be at the water‘s surface) into three dimensions (a volumetric approach whereby two-dimensional animal density incorporates depth into the estimates).
- **Step 5. Exposure Calculations**. Each marine mammal‘s 3-D density is multiplied by the calculated impact volume—to that marine mammal depth regime. This value is the number of exposures per hour for that particular marine mammal. In this way, each marine mammal‘s exposure count per hour is based on its density, depth habitat, and the ensonified volume by depth.

A.2.2 Transmission Loss Calculations

TL data are pre-computed for each of two seasons in the 14 environmental provinces described in the previous subsection using the GRAB propagation loss model (Keenan et al. 2000). The use of GRAB is predicated on the following factors:

- GRAB is certified as a U.S. Navy-standard TL model over the frequency regime of interest.
- GRAB describes the propagation field parametrically by a set of eigenrays (propagation paths connecting source to receiver), which affords the following modeling efficiencies:
  - The source vertical directivity does not need to be included at the time of the TL calculation, allowing alternative source directivities to be modeled without additional TL calculations.

- ○ TL estimates at a given frequency can be extrapolated to other ―nearby" frequencies by simply correcting for differences in absorption loss thus potentially reducing the number of TL calculations.
- ○ The coherent effects of surface-image interference that persist over range can be accounted for with a simple model that does not require an unwieldy number of TL model runs across frequency.

The TL output consists of data describing each significant eigenray (or propagation path) including the departure angle from the source (used to model the source vertical directivity later in this process), the propagation time from the source to the animal (used to make corrections to absorption loss for minor differences in frequency and to incorporate a surface-image interference correction at low frequencies), and the TL suffered along the eigenray path.

The frequency TL inputs are specified in **Table A-4** for the Volume Search Sonar (VSS). It has been used as a worst-case scenario to model potential effects of the Q-20 sonar, since it operates at a lower frequency and higher source level and presents the greatest potential for exposures that would constitute takes under the MMPA; all sonar operations are assumed to involve the VSS.

Table A-4. TL Frequency and Source Depth by Sonar Type

Sonar	TL Input Frequency
Volume Search Sonar	35 kHz

TL = transmission loss; kHz = kilohertz

In most cases, the actual frequency of the source is somewhat different from the input frequency of the TL calculation. To account for this difference, the TL for each eigenray is adjusted for the difference in absorption loss between the two frequencies. The path length of the eigenray is estimated as the product of the eigenray's travel time and a nominal sound speed of 1,500 meters per second (m/sec). Generally, this correction is relatively small at the ranges of interest and only becomes significantly large at ranges that are well beyond the impact range.

The eigenray data for a single GRAB model run are sampled at uniform increments in range out to a maximum range for a specific ―animal" (or ―target" in GRAB terminology) depth. Multiple GRAB runs are made to sample the animal depth dependence. The depth and range sampling parameters are summarized in **Table A-5**. Note that these parameters are a function of the TL input frequency; **Table A-5** can be used to map them to a particular sonar source.

Table A-5. TL Depth and Range Sampling Parameters by Sonar Type

Frequency	Range Step	Maximum Range	Animal Depth Step
35 kHz	10 m (32.8 ft)	20 km (10.8 nmi)	5 m (16.4 ft)

kHz = kilohertz; ft = feet; km = kilometer(s); nmi = nautical mile(s); m = meter(s)

Although GRAB provides the option of including the effect of source directivity in its eigenray output, this capability is not exercised. By preserving data at the eigenray level, this allows source directivity to be applied later in the process and results in fewer TL calculations.

A.2.3 Energy Summation

The summation of energy flux density over multiple pings in a range-independent environment is a straight forward exercise for the most part. A volumetric grid that covers the waters in and around the area of sonar operation is initialized. The source then begins its set of pings. For the first ping, the TL from the source to each grid point is determined (summing the appropriate eigenrays after they have been modified by the vertical beam pattern), the ―effective” energy source level is reduced by that TL, and the result is added to the accumulated energy flux density at that grid point. After each grid point has been updated, the accumulated energy at grid points in each depth layer is compared to the specified threshold. If the accumulated energy exceeds that threshold, then the incremental volume represented by that grid point is added to the impact volume for that depth layer. Once all grid points have been processed, the resulting sum of the incremental volumes represents the impact volume for one ping.

The source is then moved along one of the axes in the horizontal plane by the specified ping separation range and the second ping is processed in a similar fashion. Again, once all grid points have been processed, the resulting sum of the incremental volumes represents the impact volume for two pings. This procedure continues until the maximum number of pings specified has been reached.

Defining the volumetric grid over which energy is accumulated is the trickiest aspect of this procedure. The volume must be large enough to contain all volumetric cells for which the accumulated energy is likely to exceed the threshold but not so large as to make the energy accumulation computationally unmanageable.

Determining the size of the volumetric grid begins with an iterative process to determine the lateral extent to be considered. Unless otherwise noted, throughout this process the source is treated as directional and the only animal depth that is considered is the TL target depth that is closest to the source depth (placing source and receiver at the same depth is generally an optimal TL geometry).

The first step is to determine the impact range for a single ping. The impact range in this case is the maximum range (R_{max}) at which the effective energy source level reduced by the TL is greater than the threshold. Next the source is moved along a straight-line track and energy flux density is accumulated at a point that has a Closest Points of Approach (CPA) range of R_{max} at the mid-point of the source track. That total energy flux density summed over all pings is then compared to the prescribed threshold. If it is greater than the threshold (which, for the first R_{max}, it must be) then R_{max} is increased by 10 percent, the accumulation process is repeated, and the total energy is again compared to the threshold. This continues until R_{max} grows large enough to ensure that the accumulated energy flux density at that lateral range is less than the threshold. The lateral range dimension of the volumetric grid is then set at twice R_{max}, with the grid centered along the source track. In the direction of advance for the source, the volumetric grid extends of the interval from [–R_{max}, 3 R_{max}] with the first source position located at zero in this dimension. Note that the source motion in this direction is limited to the interval [0, 2 R_{max}]. Once the source reaches 2 R_{max} in this direction, the incremental volume contributions have approximately reached their asymptotic limit and further pings add essentially the same amount. This geometry is demonstrated in **Figure A-1**.

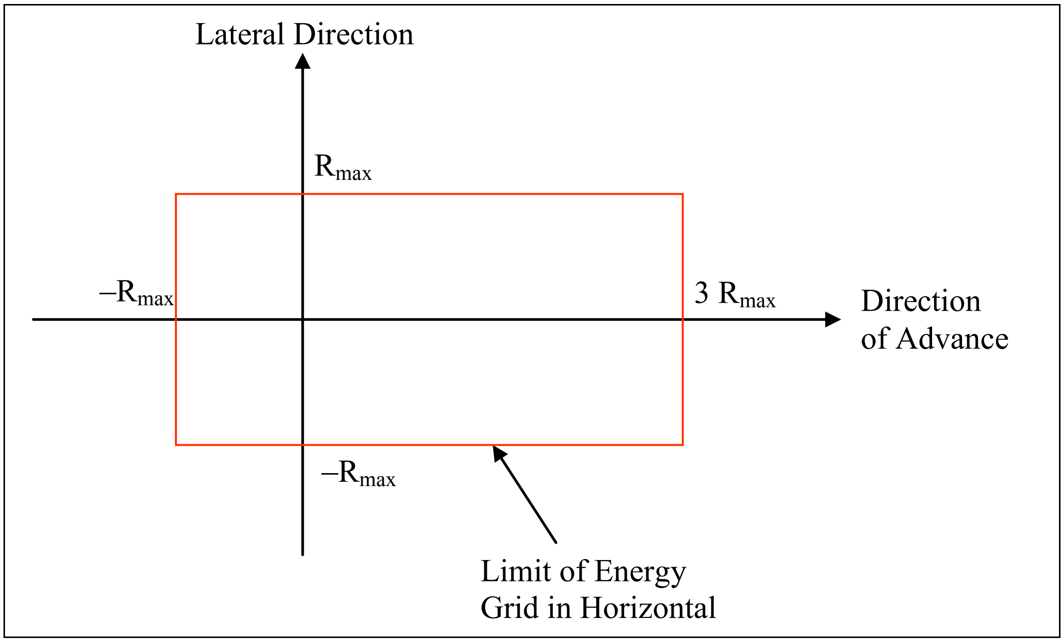

Figure A-1. Horizontal Plane of Volumetric Grid for Omni-Directional Source

If the source is directive in the horizontal plane, then the lateral dimension of the grid may be reduced and the position of the source track adjusted accordingly. For example, if the main lobe of the horizontal source beam is limited to the starboard side of the source platform, then the port side of the track is reduced substantially as demonstrated in **Figure A-2**.

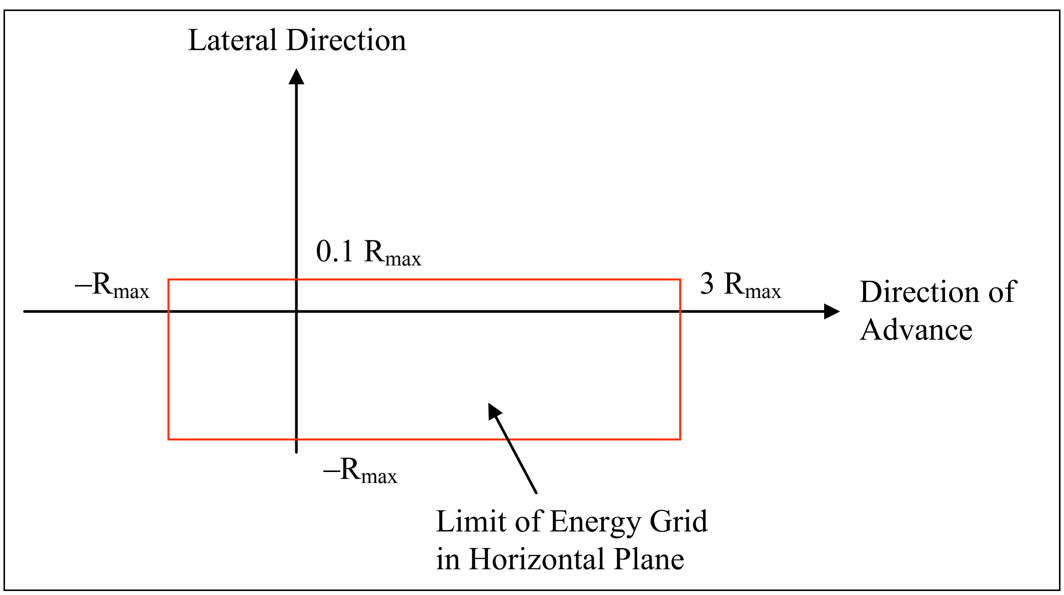

Figure A-2. Horizontal Plane of Volumetric Grid for Starboard Beam Source

Once the extent of the grid is established, the grid sampling can be defined. In both dimensions of the horizontal plane the sampling rate is approximately $R_{max}/100$. The round-off error associated with this sampling rate is roughly equivalent to the error in a numerical integration to determine the area of a circle with a radius of R_{max} with a partitioning rate of $R_{max}/100$

(approximately one percent). The depth-sampling rate of the grid is comparable to the sampling rates in the horizontal plane but discretized to match an actual TL sampling depth. The depth-sampling rate is also limited to no more that 33 ft (10 m) to ensure that significant TL variability over depth is captured.

A.2.4 Impact Volume per Hour of Sonar Operation

The impact volume for a sonar moving relative to the animal population increases with each additional ping. The rate at which the impact volume increases varies with a number of parameters but eventually approaches some asymptotic limit. Beyond that point the increase in impact volume becomes essentially linear.

The slope of the asymptotic limit of the impact volume at a given depth is the impact volume added per ping. This number multiplied by the number of pings in an hour gives the hourly impact volume for the given depth increment. Completing this calculation for all depths in a province, for a given source, gives the hourly impact volume vector, v_n, which contains the hourly impact volumes by depth for province n. **Figure A-3** provides an example of an hourly impact volume vector for a particular environment.

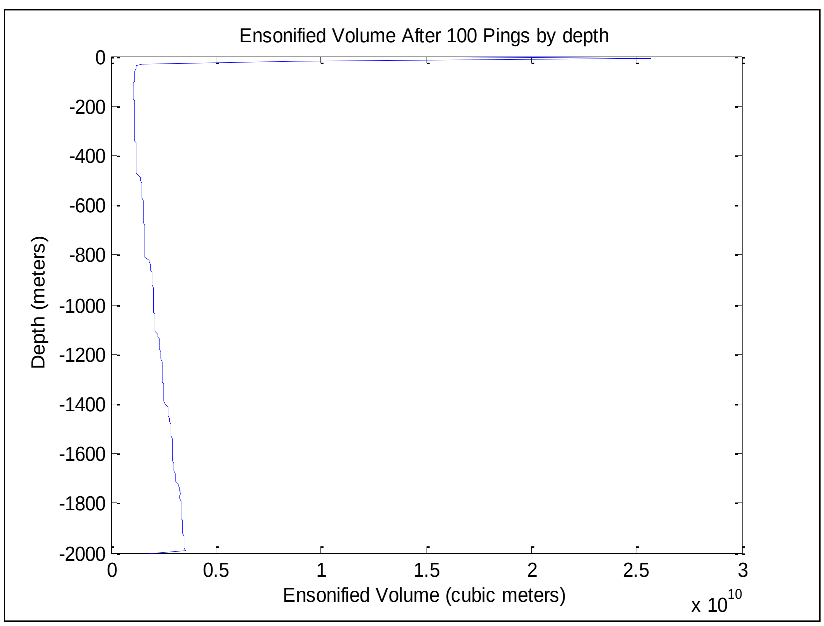

Figure A-3. Example of an Impact Volume Vector

A.3 Risk Function: Theoretical and Practical Implementation

This section discusses the recent addition of a risk response –threshold” for the acoustic effects analysis procedure. This approach includes two parts: a new metric and a function to map exposure level under the new metric to probability of harassment. The following subsections discuss what these two parts mean, how they affect exposure calculations, and how they are implemented.

A.3.1 Calculation of Expected Exposures

Determining the number of expected exposures for disturbance is the object of this analysis.

$$\text{Expected exposures in volume } V = \int_V \rho(V) D(m_a(V)) dV$$

Where ρ is the animal density at a given point, or set of points.

For this analysis, $m_a = m_{\max SPL}$, so

$$\int_V \rho(V) D(m_a(V) dV = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \rho(x,y,z) D(m_{\max SPL}(x,y,z)) dxdydz$$

In this analysis, the densities are constant over the *x-y* plane, and the *z* dimension is always negative, so this reduces to

$$\int_{-\infty}^{0} \rho(z) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z)) dxdydz$$

A.3.2 Numeric Integration

Numeric integration of $\int_{-\infty}^{\infty} \rho(z) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z)) dxdydz$ can be involved because, although the bounds are infinite, *D* is nonnegative out to 141 dB, which, depending on the environmental specifics, can drive propagation loss calculations and their numerical integration out to more than 100 km.

The first step in the solution is to separate out the *x-y* plane portion of the integral:

$$\text{Define f(z)=} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z)) dxdy .$$

Calculation of this integral is the most involved and time-consuming part of the calculation. Once it is complete,

$$\int_{-\infty}^{0} \rho(z) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z)) dxdydz = \int_{-\infty}^{0} \rho(z) f(z) dz ,$$

which, when numerically integrated, is a simple dot product of two vectors.

Thus, the calculation of *f(z)* requires the majority of the computation resources for the numerical integration. The rest of this subsection outlines the steps to calculate *f(z)* and preserve the results efficiently.

The concept of numerical integration is, instead of integrating over continuous functions, to sample the functions at small intervals and sum the samples to approximate the integral. The smaller the size of the intervals, the closer the approximation but the longer the calculation; thus, a balance between accuracy and time is determined in the decision of step size. For this analysis, *z* is sampled in 5 m (16.4 ft) steps to 1,000 m (3,281 ft) deep and 10 m (33 ft) steps to 2,000 m (6,562 ft), which is the limit of animal depth in this analysis. The step size for *x* is 5 m (16.4 ft), and *y* is sampled with an interval that increases as the distance from the source increases. Mathematically,

$$\begin{aligned} z &\in Z = \{0,5,...1000,1010,...,2000\} \\ x &\in X = \{0,\pm 5,...,\pm 5k\} \\ y &\in Y = \{0,\pm 5(1.005)^0, 5 \pm (1.005)^1, \pm 5(1.005)^2,...,5(1.005)^j\} \end{aligned}$$

for integers *k, j*, which depend on the propagation distance for the source. For this analysis, $k = 20{,}000$ and $j = 600$.

Following these steps, $f(z_0) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z_0))dxdy$ is approximated as

$$\sum_{z \in Y}\sum_{x \in X} D(m_{\max SPL}(x,y,z_0))\Delta x \Delta y$$

where *X, Y* are defined as above.

This calculation must be repeated for each $z_0 \in Z$, to build the discrete function *f(z)*.

With the calculation of *f(z)* complete, the integral of its product with $\rho(z)$ must be calculated to complete evaluation of

$$\int_{-\infty}^{\infty} \rho(z) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z))dxdydz = \int_{-\infty}^{0} \rho(z) f(z) dz$$

Since *f(z)* is discrete, and $\rho(z)$ can be readily made discrete, This is approximated numerically as $\sum_{z \in Z} \rho(z) f(z)$, a dot product.

Preserving Calculations for Future Use

Calculating *f(z)* is the most time-consuming part of the numerical integration, but the most time-consuming portion of the entire process is calculating $m_{\max SPL}(x,y,z)$ over the area range required for the minimum cutoff value (141 dB). The calculations usually require propagation estimates out to over 100 km, and those estimates, with the beam pattern, are used to construct a sound field that extends 200 km × 200 km (108 nmi x 108 nmi), or 40,000 km^2 (11,662 nmi^2), with a calculation at the steps for every value of *X* and *Y*, defined above. This is repeated for each depth, to a maximum of 2,000 m (6,562 ft).

Saving the entire $m_{\max SPL}$ for each *z* is unrealistic, requiring great amounts of time and disk space. Instead, the different levels in the range of $m_{\max SPL}$ are sorted into bins of 0.5 dB; the volume of water at each bin level is taken from $m_{\max SPL}$ and associated with its bin. Saving this, the amount of water ensonified at each level, at 0.5 dB resolution, preserves the ensonification information without using the space and time required to save $m_{\max SPL}$ itself. Practically, this is a histogram of occurrence of level at each depth, with 0.5 dB bins. Mathematically, this is simply defining the discrete functions $V_z(L)$, where $L = \{.5a\}$ for every positive integer a, for all $z \in Z$. These functions, or histograms, are saved for future work. The information lost by saving only the histograms is *where* in space the different levels occur, although *how often* they occur is saved. But the thresholds (risk function curves) are purely a function of level, not location, so this information is sufficient to calculate *f(z).*

Applying the risk function to the histograms is a dot product:

$$\sum_{\ell \in L_1} D(\ell) V_{z_0}(\ell) \approx \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z_0))\,dxdy$$

Once the histograms are saved, neither $m_{\max SPL}(x,y,z)$ nor *f(z)* must be recalculated to generate

$$\int_{-\infty}^{0} \rho(z) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x,y,z))\,dxdydz$$

for a new threshold function.

The following subsection includes an in-depth discussion of the method, software, and other details of the *f(z)* calculation.

Software Details

The risk function metric uses the cumulative normal probability distribution to determine the probability that an animal is affected by a given sound pressure level (SPL). The probability distribution is defined by a mean, standard deviation, and low-level cutoff, below which it is assumed that animals are not affected. The acoustic quantity of interest is the maximum SPL experienced over multiple pings in a range-independent environment. The procedure for calculating the impact volume at a given depth is relatively simple. In brief, given the SPL of the source and the TL curve, the SPL is calculated on a volumetric grid. For a given depth, volume associated with a SPL interval is calculated. Then this volume is multiplied by the probability that an animal will be affected by that SPL. This gives the impact volume for that depth, which can be multiplied by the animal densities at that depth to obtain the number of animals affected at that depth. The process repeats for each depth to construct the impact volume as a function of depth.

The case of a single emission of sonar energy, one ping, illustrates the computational process in more detail. First, the SPLs are segregated into a sequence of bins that cover the range encountered in the area. The SPLs are used to define a volumetric grid of the local sound field. The impact volume for each depth is calculated as follows: for each depth in the volumetric grid, the SPL at each *x-y* plane grid point is calculated using the SPL of the source, the TL curve, the horizontal beam pattern of the source, and the vertical beam patterns of the source. The SPLs in this grid become the bins in the volume histogram. **Figure A-4** shows a volume histogram for a low-power sonar. Level bins are 0.5 dB in width and the depth is 50 m (164 ft) in an environment with water depth of 100 m (328 ft). The oscillatory structure at very low levels is due the flattening of the TL curve at long distances from the source, which magnifies the fluctuations of the TL as a function of range. The –expected” impact volume for a given level at a given depth is calculated by multiplying the volume in each level bin by the risk probability function at that level. Total expected impact volume for a given depth is the sum of these –expected” volumes. **Figure A-5** is an example of the impact volume as a function of depth at a water depth of 100 m (328 ft).

The volumetric grid covers the waters in and around the area of sonar operation. The grid for this analysis has a uniform spacing of 5 m (16.4 ft) in the *x* coordinate and a slowly expanding spacing in the *y* coordinate that starts with 5 m (16.4 ft) spacing at the origin. The growth of the grid size along the *y* axis is a geometric series. Each successive grid size is obtained from the previous by multiplying it by 1 + *Ry*, where *Ry* is the *y* axis growth factor. This forms a geometric series. The n^{th} grid size is related to the first grid size by multiplying by $(1+Ry)^{(n-1)}$. For an initial grid size of 5 m (16.4 ft) and a growth factor of 0.005, the 100^{th} grid increment is 8.19 m (26.9 ft). The constant spacing in the *x* coordinate allows greater accuracy as the source moves along the *x* axis. The slowly increasing spacing in *y* reduces computation time, while maintaining accuracy, by taking advantage of the fact that TL changes more slowly at longer distances from the source. The *x* and *y* coordinates extend from $-R_{max}$ to $+R_{max}$, where R_{max} is the maximum range used in the TL calculations. The *z* direction uses a uniform spacing of 5 m (16.4 ft) down to 1,000 m (3,281 ft) and 10 m (33 ft) from 1,000 to 2,000 m (3,281 to 6,562 ft). This is the same depth mesh used for the effective energy metric as described above. The depth mesh does not extend below 2,000 m (6,562 ft), on the assumption that animals of interest are not found below this depth.

Figures A-6, A-7, and A-8 indicate how the accuracy of the calculation of impact volume depends on the parameters used to generate the mesh in the horizontal plane. **Figure A-6** shows the relative change of impact volume for one ping as a function of the grid size used for the *x* axis. The *y* axis grid size is fixed at 5 m (16.4 ft), and the *y* axis growth factor is 0, i.e., uniform spacing. The impact volume for a 5 m (16.4 ft) grid size is the reference. For grid sizes between 2.5 and 7.5 m (8.3 and 24.6 ft), the change is less than 0.1 percent. A grid size of 5 m (16.4 ft) for the *x* axis is used in the calculations. **Figure A-7** shows the relative change of impact volume for one ping as a function of the grid size used for the *y* axis. The *x* axis grid size is fixed at 5 m (16.4 ft), and the *y* axis growth factor is 0. The impact volume for a 5 m (16.4 ft) grid size is the reference. This figure is very similar to that for the *x* axis grid size. For grid sizes between 2.5 and 7.5 m (8.2 and 24.6 ft), the change is less than 0.1 percent. A grid size of 5 m (16.4 ft) is used for the *y* axis in our calculations. **Figure A-8** shows the relative change of impact volume for one ping as a function of the *y* axis growth factor. The *x* axis grid size is fixed at 5 m and the initial *y* axis grid size is 5 m (16.4 ft). The impact volume for a growth factor of 0 is the reference. For growth factors from 0 to 0.01, the change is less than 0.1 percent. A growth factor of 0.005 is used in the calculations.

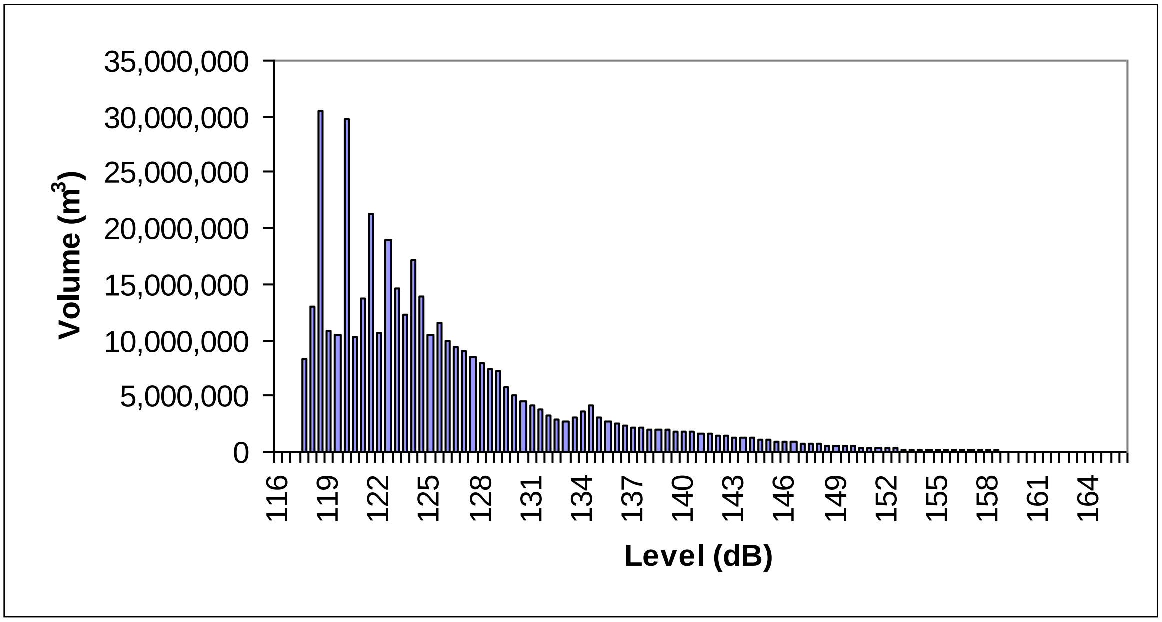

Figure A-4. Example of a Volume Histogram

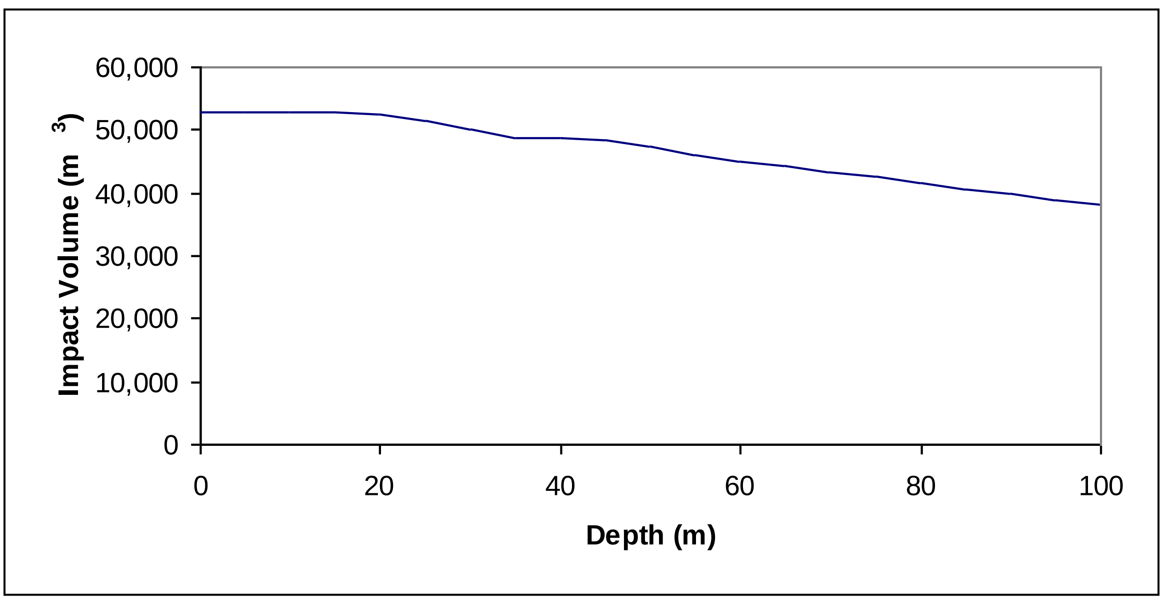

Figure A-5. Example of the Dependence of Impact Volume

Another factor influencing the accuracy of the calculation of impact volumes is the size of the bins used for SPL. The SPL bins extend from 100 dB (far lower than required) up to 300 dB (much higher than that expected for any sonar system). **Figure A-9** shows the relative change of impact volume for one ping as a function of the bin width. The *x* axis grid size is fixed at 5 m (16.4 ft), the initial *y* axis grid size is 5 m (16.4 ft), and the *y* axis growth factor is 0.005. The impact volume for a bin size of 0.5 dB is the reference. For bin widths from 0.25 dB to 1.00 dB, the change is about 0.1 percent. A bin width of 0.5 is used in our calculations.

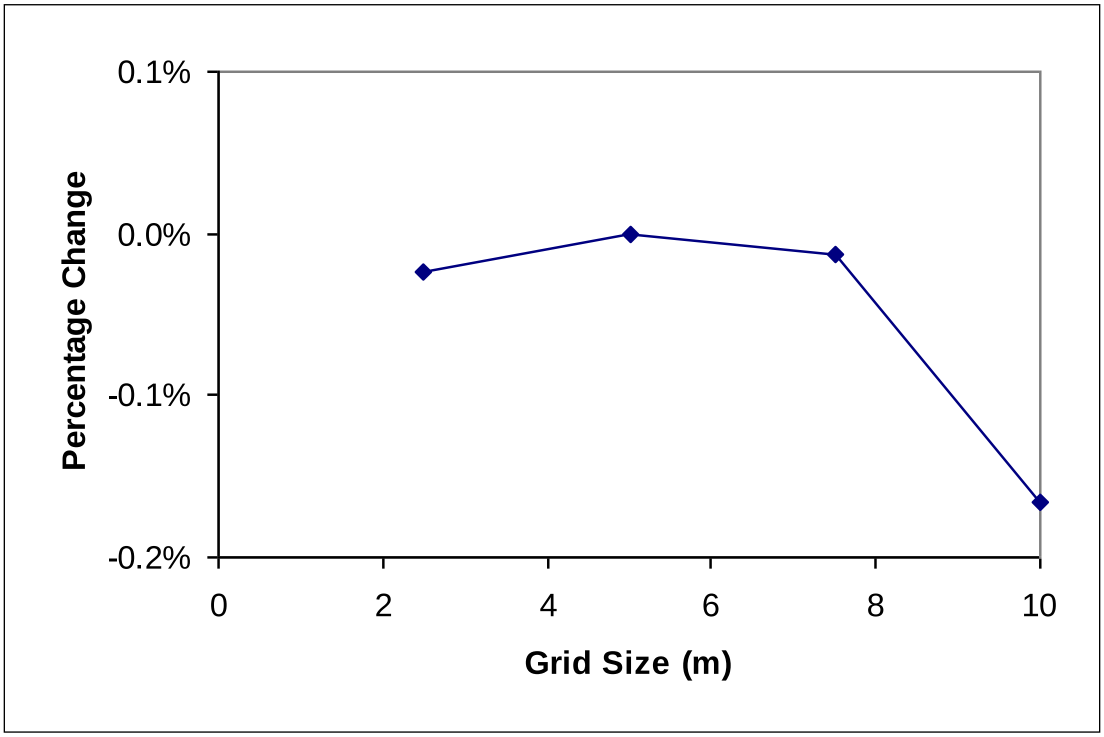

Figure A-6. Change of Impact Volume as a Function of *X* Axis Grid Size

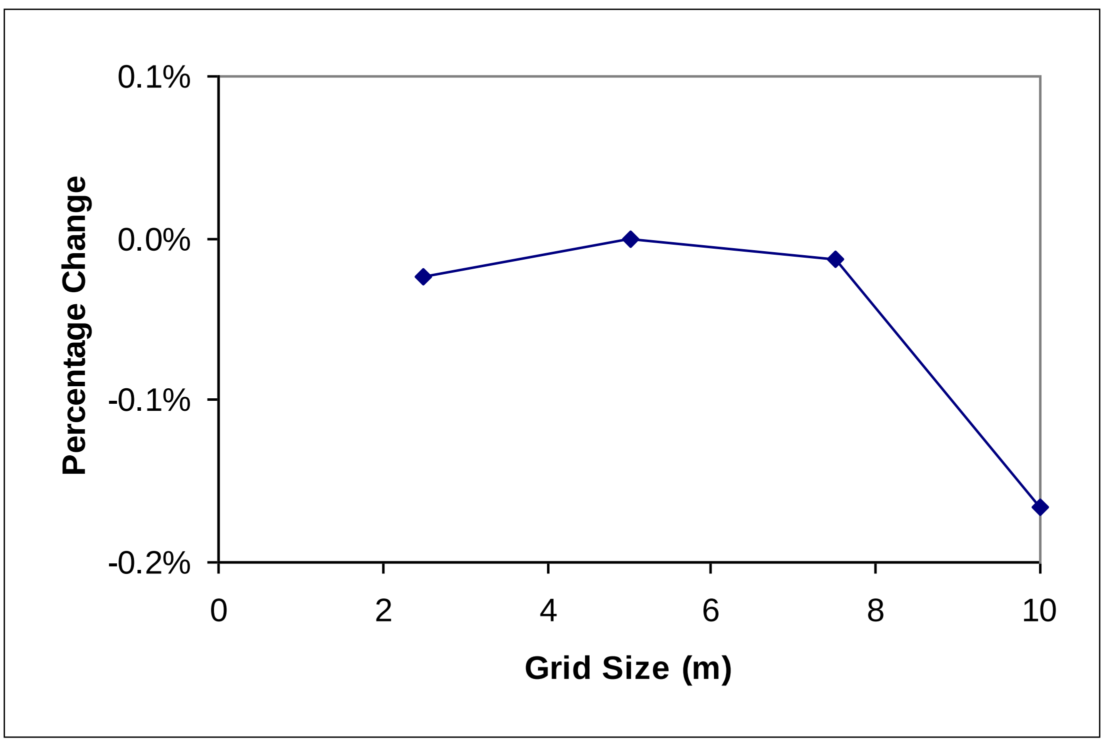

Figure A-7. Change of Impact Volume as a Function of *Y* Axis Grid Size

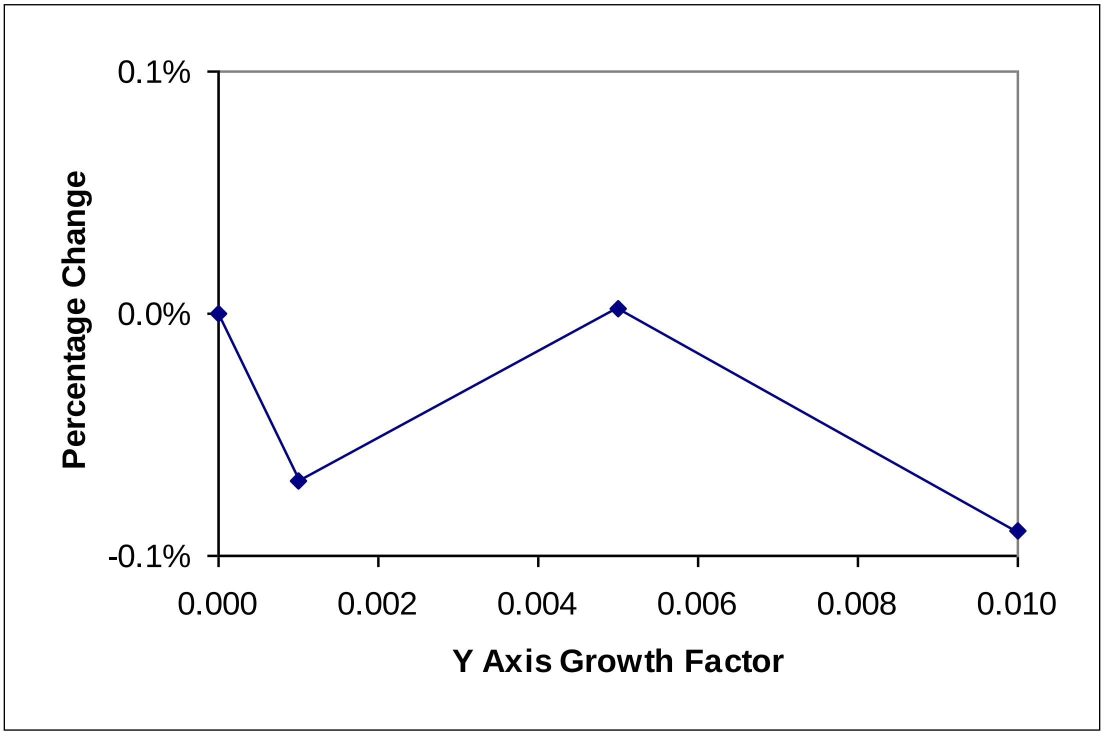

Figure A-8. Change of Impact Volume as a Function of *Y* Axis Growth Factor

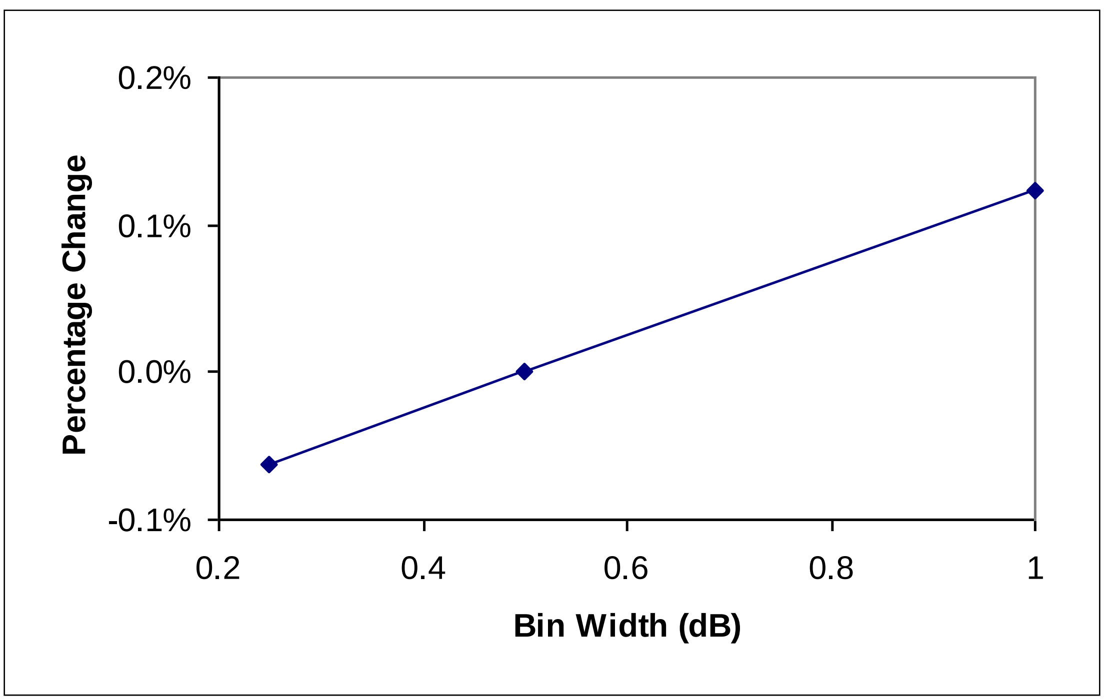

Figure A-9. Change of Impact Volume as a Function of Bin Width

Two other issues for discussion are the R_{max} and the spacing in range and depth used for calculating TL. The TL generated for the energy accumulation metric is used for risk function analysis. The same sampling in range and depth is adequate for this metric because it requires a less-demanding computation (i.e., maximum value instead of accumulated energy). Using the same value of R_{max} needs some discussion since it is not clear that the same value can be used for both metrics. R_{max} was set so that the TL at R_{max} is more than needed to reach the energy accumulation threshold of 173 dB for 1,000 pings. Since energy is accumulated, the same TL can be used for one ping with the source level increased by 30 dB (10 $\log_{10}$(1,000)). Two other issues for discussion are the maximum range (Rmax) and the spacing in range and depth used for calculating TL. The TL generated for the energy accumulation metric is used for risk function analysis. The same sampling in range and depth is adequate for this metric because it requires a less-demanding computation (i.e., maximum value instead of accumulated energy).

The process of obtaining the maximum SPL at each grid point in the volumetric grid is straightforward. The active sonar starts at the origin and moves at constant speed along the positive *x* axis, emitting a burst of energy, a ping, at regularly spaced intervals. For each ping, the distance and horizontal angle connecting the sonar to each grid point is computed. Calculating the TL from the source to a grid point involves several steps. The TL is made up of the sum of many eigenrays connecting the source to the grid point. The beam pattern of the source is applied to the eigenrays based on the angle at which they leave the source. After summing the vertically beam-formed eigenrays on the range mesh used for the TL calculation, the vertically beam-formed TL for the distance from the sonar to the grid point is derived by interpolation. Next, the horizontal beam pattern of the source is applied using the horizontal angle connecting the sonar to the grid point. To avoid problems in extrapolating TL, only use grid points with distances less than R_{max} are used. To obtain the SPL at a grid point, the SPL of the source is reduced by that TL. For the first ping, the volumetric grid is populated by the calculated SPL at each grid point. For the second ping and subsequent pings, the source location increments along the *x* axis by the spacing between pings and the SPL for each grid point are again calculated for the new source location. Since the risk function metric uses the maximum of the SPLs at each grid point, the newly calculated SPL at each grid point is compared to the SPL stored in the grid. If the new level is larger than the stored level, the value at that grid point is replaced by the new SPL.

For each bin, a volume is determined by summing the ensonified volumes with a maximum SPL in the bin‘s interval. This forms the volume histogram shown in **Figure A-4**. Multiplying by the risk probability function for the level at the center of a bin gives the impact volume for that bin. The result can be seen in **Figure A-5**, which is an example of the impact volume as a function of depth.

The impact volume for a sonar moving relative to the animal population increases with each additional ping. The rate at which the impact volume increases for the risk function metric is essentially linear with the number of pings. **Figure A-10** shows the dependence of impact volume on the number of pings. The function is linear; the slope of the line at a given depth is the impact volume added per ping. This number multiplied by the number of pings in an hour gives the hourly impact volume for the given depth increment. Completing this calculation for all depths in a province, for a given source, gives the hourly impact volume vector, which contains the hourly impact volumes by depth for a province. **Figure A-11** provides an example of an hourly impact volume vector for a particular environment. Given the speed of the sonar, the hourly impact volume vector could be displayed as the impact volume vector per km of track.

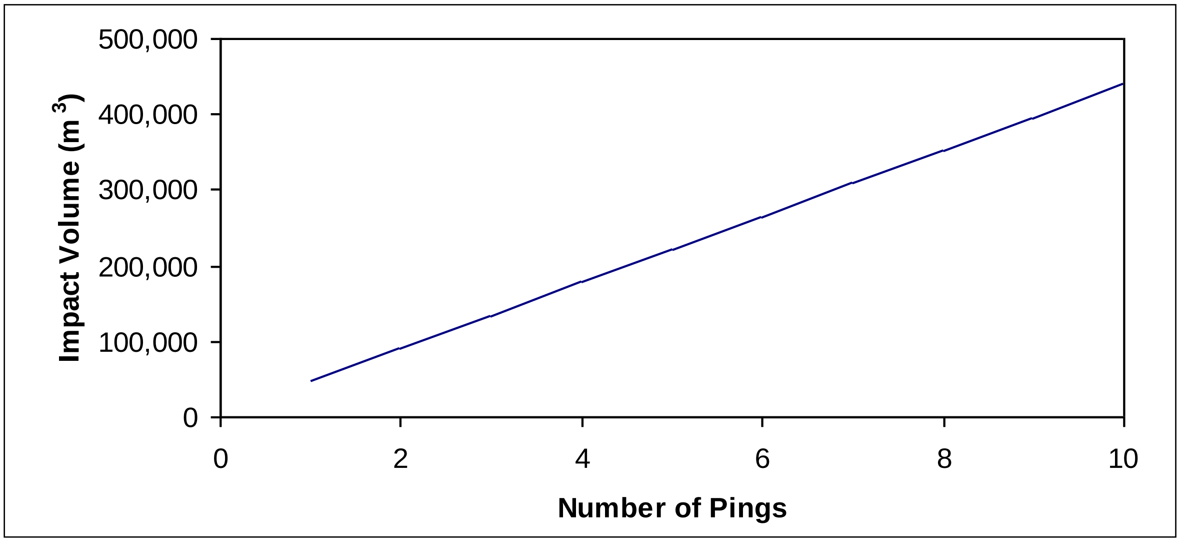

Figure A-10. Dependence of Impact Volume on the Number of Pings

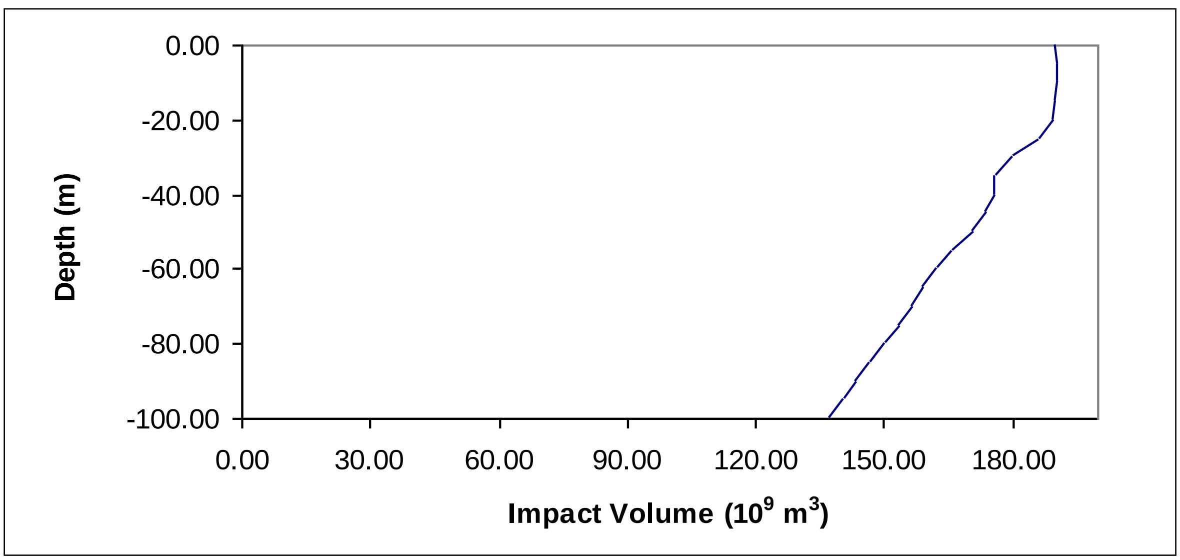

Figure A-11. Example of an Hourly Impact Volume Vector

A.4 Additional Modeling Considerations in a General Modeling Scenario

When modeling the effect of sound projectors in the water, the ideal task presents modelers with complete *a priori* knowledge of the location of the source(s) and transmission patterns during the times of interest. In these cases, calculation inputs include the details of source path, proximity of shoreline, high-resolution density estimates, and other details of the scenario. However, in the Q-20 Study Area, there are sound-producing events for which the source locations and transmission patterns are unknown, but still require analysis to predict effects. For these cases, a more general modeling approach is required: ―We will be operating somewhere in this large area for X hr. What are the potential effects on average? ”

Modeling these general scenarios requires a statistical approach to incorporate the scenario nuances into harassment calculations. For example, one may ask: ―If an animal receives 130 dB SPL when the source passes at CPA on Tuesday morning, how do we know it doesn‘t receive a higher level on Tuesday afternoon?” This question cannot be answered without knowing the path of the source (and several other facts). Because the path of the source is unknown, the number of an individual‘s re-exposures cannot be calculated directly. But it can, on average, be accounted for by making appropriate assumptions.

Table A-6 lists unknowns created by uncertainty about the specifics of a future proposed action, the portion of the calculation to which they are relevant, and the assumption that allows the effect to be computed without the detailed information.

Table A-6. Unknowns and Assumptions

Unknowns	Relevance	Assumption
Path of source(esp. with respect to animals)	Ambiguity of multiple exposures, Local population: upper bound of harassments	Most conservative case: sources can be anywhere within area
Source locations	Ambiguity of multiple exposures, land shadow	Equal distribution of action in each modeling area
Direction of sonar transmission	Land shadow	Equal probability of pointing any direction

The following sections discuss two topics that require action details, and describe how the modeling calculations used the general knowledge and assumptions to overcome the future-action uncertainty with respect to re-exposure of animals, and land shadow.

A.4.1 Multiple Exposures in General Modeling Scenario

Consider the following hypothetical scenario. A box is painted on the surface of a well-studied ocean environment with well-known propagation. A sonar-source and 1,000 whales are inserted into that box and a curtain is drawn. What will happen? This is the general scenario. The details of what will happen behind the curtain are unknown, but the existing knowledge, and general assumptions, can allow for a general calculation of average affects.

For the first period of time, the source is traveling in a straight line and pinging at a given rate. In this time, it is known how many animals, on average, receive their max SPLs from each ping. As long as the source travels in a straight line, this calculation is valid. However, after an undetermined amount of time, the source will change course to a new and unknown heading.

If the source changes direction 180 degrees and travels back through the same swath of ocean, all the animals the source passes at CPA before the next course change have already been exposed to what will be their maximum SPL, so the population is not ―fresh.” If the direction does not change, only new animals will receive what will be their maximum SPL from that source (though most have received sound from it), so the population is completely ―fresh.” Most source headings lead to a population of a mixed ―freshness,” varying by course direction. Since the route and position of the source over time are unknown, the freshness of the population at CPA with the source is unknown. This ambiguity continues through the remainder of the exercise.

What is known? The source and, in general, the animals remain in the Q-20 Study Area. Thus, if the farthest range to a possible effect from the source is X km, no animals farther than X km outside of the operating area (OPAREA) can be harassed. The intersection of this area with a given animal‘s habitat multiplied by the density of that animal in its habitat represents the maximum number of animals that can be harassed by activity in that sonar operating area (SOA), which shall be defined as ―the local population.” Two details: first, this maximum should be adjusted down if a risk function is being used, because not 100 percent of animals within X km of the OPAREA border will be harassed. Second, it should be adjusted up to account for animal motion in and out of the area.

The ambiguity of population freshness throughout the exercise means that multiple exposures cannot be calculated for any individual animal. It must be dealt with generally at the population level.

Solution to the Ambiguity of Multiple Exposures in the General Modeling Scenario

At any given time, each member of the population has received a maximum SPL (possibly zero) that indicates the probability of harassment in the exercise. This probability indicates the contribution of that individual to the expected value of the number of harassments. For example, if an animal receives a level that indicates 50 percent probability of harassment, it contributes 0.5 to the sum of the expected number of harassments. If it is passed later with a higher level that indicates a 70 percent chance of harassment, its contribution increases to 0.7. If two animals receive a level that indicates 50 percent probability of harassment, they together contribute 1 to the sum of the expected number of harassments. That is, we statistically expect exactly one of them to be harassed. Let the expected value of harassments at a given time be defined as ―the harassed population” and the difference between the local population (as defined above) and the harassed population be defined as ―the unharassed population.” As the exercise progresses, the harassed population will never decrease and the unharassed population will never increase.

The unharassed population represents the number of animals statistically ―available” for harassment. Since we do not know where the source is, or where these animals are, we assume an average (uniform) distribution of the unharassed population over the area of interest. The densities of unharassed animals are lower than the total population density because some animals in the local population are in the harassed population.

Density relates linearly to expected harassments. If action A in an area with a density of two animals per square kilometer produces 100 expected harassments, then action A in an area with one animal per square kilometer produces 50 expected harassments. The modeling produces the number of expected harassments per ping starting with 100 percent of the population unharassed. The next ping will produce slightly fewer harassments because the pool of unharassed animals is slightly less.

For example, consider the case where 1 animal is harassed per ping when the local population is 100, 100 percent of which are initially unharassed. After the first ping, 99 animals are unharassed, so the number of animals harassed during the second ping are,

$10\left(\frac{99}{100}\right) = 1(.99) = 0.99$ animals and so on for the subsequent pings.

Mathematics

A closed form function for this process can be derived as follows.

Define $P_n =$ unharassed population after ping n

Define $H =$ number of animals harassed in a ping with 100 percent unharassed population

$P_0 =$ local population

$$P_1 = P_0 - H$$
$$P_2 = P_1 - H\left(\frac{P_1}{P_0}\right)$$
$$\ldots$$
$$P_n = P_{n-1} - H\left(\frac{P_{n-1}}{P_0}\right)$$

Therefore,

$$P_n = P_{n-1}\left(1-\left(\frac{H}{P_0}\right)\right) = P_{n-2}\left(1-\left(\frac{H}{P_0}\right)\right)^2 = \ldots = P_0\left(1-\left(\frac{H}{P_0}\right)\right)^n$$

Thus, the total number of harassments depends on the per-ping harassment rate in an unharassed population, the local population size, and the number of operation hours.

Local Population: Upper Bound on Harassments

As discussed above, U.S. Navy planners have confined period of sonar use to operation areas. The size of the harassed population of animals for an action depends on animal re-exposure, so uncertainty about the precise source path creates variability in the ―harassable” population. Confinement of sonar use to an SOA allows modelers to compute an upper bound, or worst case, for the number of harassments with respect to location uncertainty. This is done by assuming that there is a sonar transmitting from each point in the confined area throughout the action length.

National Marine Fisheries Service (NMFS) has defined a 24-hr ―refresh rate,” or amount of time in which an individual can be harassed no more than once. The U.S. Navy has determined that, in a 24-hr period, all sonar operations in the Q-20 Study Area transmit for a subset of that time (**Table A-7**).

Table A-7. Duration of Sonar Use During 24-hr Period

System	Longest continuous interval (in hr)
AN/AQS-20	10

Creating the most conservative source position by assuming that a sonar transmits from each point in the SOA simultaneously can produce an upper bound on harassments for a single ping, but animal motion over the period in the above table can bring animals into range that otherwise would be out of the harassable population.

Animal Motion Expansion

Though animals often change course to swim in different directions, straight-line animal motion would bring the more animals into the harassment area than a ―random walk” motion model. Since precise and accurate animal motion models exist more as speculation than documented fact and because the modeling requires an undisputable upper bound, calculation of the upper bound for Q-20 modeling areas uses a straight-line animal motion assumption. This is a conservative assumption.

For a circular area, the straight-line motion with initial random direction assumption produces an identical result to the initial fixed direction. Since the Q-20 Study Area are non-circular polygons, choosing the initial fixed direction as perpendicular to the longest diagonal produces greater results than the initial random direction. Thus, the product of the longest diagonal and the distance the animals move in the period of interest gives an overestimate of the expansion in Q-20 modeling areas due to animal motion. The Q-20 expansions use this overestimate for the animal-motion expansion.

Figure A-12 illustrates an example that illustrates the overestimation, which occurs during the second arrow.

Risk Function Expansion

The expanded area contains the number of animals that will enter the SOA over the period of interest. However, an upper bound on harassments must also include animals outside the area that would be affected by a source transmitting from the area‘s edge. A gross overestimation could simply include all area with levels greater than the risk function cutoff. In the case of the Q-20 Study Area, this would include all areas within approximately 65 km from the edge of the adjusted box. This basic method would give a crude and inaccurately high upper bound, since only a fraction of the population is affected in much of that area. A more refined upper bound on harassments can be found by maintaining the assumption that a sonar is transmitting from each point in the adjusted box and calculating the expected ensonified area.

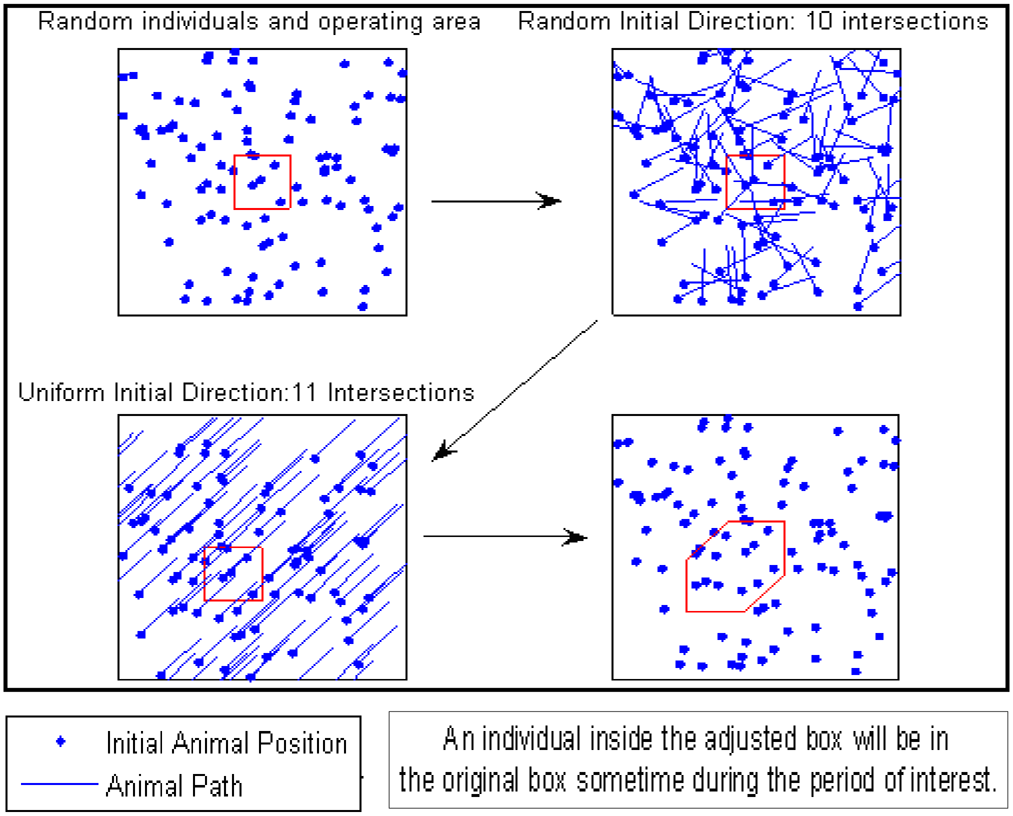

Figure A-12. Process of Overestimating Individuals Present in Area at Any Time

The expected lateral range from the edge of a polygon to the cutoff range can be expressed as,

$$\int_{0}^{L^{-1}(120dB)} D(L(r))dr \quad ,$$

where D is the risk function with domain in level and range in probability, L is the SPL function with domain in range and range in level, and r is the range from the SOA.

At the corners of the polygon, additional area can be expressed as

$$\frac{[\pi - \theta] \int_{0}^{L^{-1}(120dB)} D(L(r))rdr}{2\pi}$$

with D, L, and r as above, and θ the inner angle of the polygon corner, in radians.

For the risk function and TL of the Q-20 Study Area, this method adds an area equivalent to expanding the boundaries of the adjusted box by four kilometers. The resulting shape, the adjusted box with a boundary expansion of 4 km, does not possess special meaning for the problem. But the number of individuals contained by that shape, as demonstrated above, is an overestimate of the number of harassments that would occur if sonars transmitted continuously from each point in the SOA over the exercise length, an upper bound on harassments for that operation.

Plots shown in **Figure A-13** illustrate the growth of area for the sample case above. The shapes of the boxes are unimportant. The area after the final expansion, though, gives an upper bound on the “harassable,” or unharassed population.

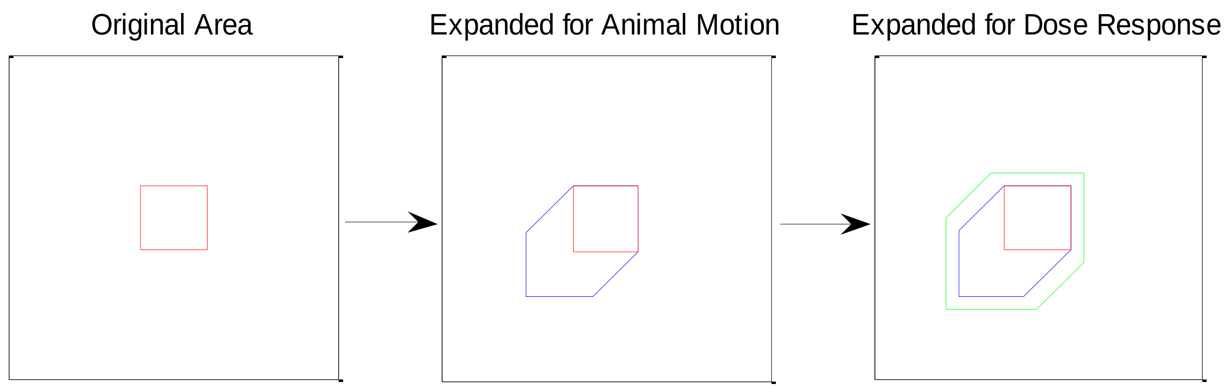

Figure A-13. Process of Expanding Area to Create Upper Bound of Harassments

Example Case

Consider a sample case for the Q-20 sonar, the expected summer rate of harassment for pantropical spotted dolphins (*Stenella attenuata*) is 0.000038 harassments per ping, with 7,462 pings per hour of operation.

Area 2 has an area of approximately 9,033 km^2 (2,634 nmi^2) and a largest side of 300 km (162 nmi). Adjusting this with straight-line (upper bound) animal motion brings the total upper-bound of the affected area to 12,333 km^2 (3,596 nmi^2).

For this analysis, pantropical spotted dolphins have an average density of approximately 0.0399 animals per square kilometer, so the upper bound number of pantropical spotted dolphins that can be affected by Q-20 activity in Area 2 during a 24-hr period is 12,333*0.0399 = 480.1167 dolphins.

In the first ping, 0.000038 pantropical spotted dolphins will be harassed. Using the formula derive above, after one hr of continuous operation, the remaining unharassed population is

$$P_{7462} = P_0\left(1-\left(\frac{h}{P_0}\right)\right)^{7462} = 480.1167\left(1-\left(\frac{0.000038}{480.1167}\right)\right)^{7462} \approx 479.8334$$

So the harassed population will be 480.1167-479.8334 = 0.2833 animals.

The results are not dramatically different compared to linear accumulation for this case, but the calculation still ensures that animals are not double-counted. In other cases where the ratio of per-ping harassment to harassable population is larger, then the dilution‘s effect is more pronounced.

A.4.2 Land Shadow

The risk function considers harassment possible if an animal receives 120 dB SPL, or above. In the Q-20 Study Area, this occurs as far away as 65 km (35 nmi), so over a large ―effect" area, sonar sound could, but does not necessarily, harass an animal. The harassment calculations for a general modeling case must assume that this effect area covers only water fully populated with animals, but in some portions of the Q-20 Study Area, land partially encroaches on the area, obstructing sound propagation.

As discussed in the introduction of ―Additional Modeling Considerations…," U.S. Navy planners do not know the exact location and transmission direction of the sonars at future times. These factors however, completely determine the interference of the land with the sound, or ―land shadow," so a general modeling approach does not have enough information to compute the land shadow effects directly. However, modelers can predict the reduction in harassments at any point due to land shadow for different pointing directions and use expected probability distribution of activity to calculate the average land shadow for operations in each SOA.

For the Naval Surface Warfare Center Panama City Division (NSWC PCD) Study Area, a much larger area than the Q-20 Study Area, the land shadow was calculated in Department of the Navy (DON 2009a). On average, across the NSWC PCD Study Area, the reduction in effect due to land shadow was zero, consequently for the Q-20 land shadow effect will be zero.

A.5 Harassments

This section defines the animal densities and their depth distributions for the Q-20 Study Area. A short discussion is presented on how harassments are calculated from the ensonification volumes, two dimensional animal densities, and animal depth distributions.

A.5.1 Marine Mammal Density and Depth Distribution for Q-20 Study Area, Eastern Gulf of Mexico

Marine mammal species occurring in the eastern GOM include baleen whales (mysticetes) and toothed whales (odontocetes). This section first addresses the densities used from the U.S. Navy OPAREA Density Estimates (NODE) reports and then details the depth distribution data incorporated to provide 3-D aspect to the modeling of exposure estimates. All density information is taken directly from the Gulf of Mexico Operating Area (GOM OPAREA) NODE report (DON 2007a).

There are limited depth distribution data for most marine mammals. This is especially true for cetaceans, as they must be tagged at-sea with a tag that either must be implanted in the skin/blubber in some manner or adhere to the skin. There is slightly more data for some pinnipeds, as they can be tagged while on shore during breeding or molting seasons and the tags can be glued to the pelage rather than implanted. There are a few different methodologies and techniques that can be used to determine depth distribution percentages, but by far the most widely used technique currently is the time-depth recorder. These instruments are attached to the animal for a fairly short period of time (several hours to a few days) via a suction cup or glue, and then retrieved immediately after detachment or (for pinnipeds) when the animal returns to the beach. Depth information is also collected via satellite tags, sonic tags, digital tags.

There are somewhat suitable depth distribution data for some marine mammal species. Sample sizes are usually extremely small, nearly always fewer than ten animals total and often only one or two animals. Depth distribution information can also be interpreted from other dive and/or preferred prey characteristics, and from methods including behavioral observations, stomach content analysis and habitat preference analysis. Depth distributions for species for which no data are available are extrapolated from similar species.

Table A-8 provides depth information for each of the species in the Q-20 Study Area. Dive profiles and foraging characteristics do not significantly differ among different geographic regions. Furthermore, information for some species is limited and therefore, the best available information was used.

A.5.1.1 Densities

Density estimates were derived from the GOM NODE Report, as well as from “best” abundance estimates for each species from the NMFS stock assessment report (SAR) (Waring et al. 2007) based on analyses by Mullin and Fulling (2003). For the purpose of this document, this estimate was applied to the entire Q-20 Study Area and across all seasons.

MYSTICETES

Bryde’s whale distribution and habitat preferences:

- In the GOM, all Bryde‘s whale sightings have been predominantly near the shelf break in and near DeSoto Canyon and off western Florida.
- The Bryde‘s whale may occur throughout the year in the GOM.

Bryde’s whale density and abundance estimates:

- The “best” estimate of abundance for this species came from the NMFS stock assessment report (SAR) (Waring et al. 2007) based on analyses by Mullin and Fulling (2003). For the purpose of this document, this estimate was applied to the entire Q-20 Study Area and across all seasons.

Minke whale, *Balaenoptera acutorostrata* - Extralimital

There is no abundance or density estimate.

Table A-8. Summary of Depth Information for Marine Mammal Species with Densities in the Q-20 Study Area

Common Name	Scientific Name	Depth Distribution	Reference
MYSTICETES - Baleen whales			
Bryde's whale	*Balaenoptera edeni*	53% at <20 m (66 ft); 47% at 21 – 65 m (69 – 213 ft)	Extrapolated from minke whale
Fin whale	*Balaenoptera physalus*	44% in <50m (164 ft); 23% in 50 – 225 m (164 – 738 ft); 33% at >225 m (738 ft)	Goldbogen et al. (2006)
Humpback whale	*Megaptera novaeangliae*	37% of time in <4 m (13 ft), 25% of time in 4 – 20 m (13 – 66 ft), 7% of time in 21 – 35 m (69 – 115 ft), 4% of time in 36 – 50 m (118 – 164 ft), 6% of time in 51 – 100 m (167 – 328 ft), 7% of time in 101 – 150 m (331 – 492 ft), 8% of time in 151 – 200 m (495 – 656 ft), 6% of time in 201 – 300 m (659 – 984 ft), and <1% in >300 m (984 ft)	Dietz et al. (2002)
Minke whale	*Balaenoptera acutorostrata*	53% at <20 m (66 ft); 47% at 21 – 65 m (69 – 213 ft)	Blix and Folkow (1995)
North Atlantic right whale	*Eubalaena glacialis*	32% at <5 m (16 ft); 15% at 5 – 79 m (16 – 259 ft); and 53% at >79 m (259 ft)	Baumgartner and Mate (2003)
Sei whale	*Balaenoptera borealis*	53% at <20 m (66 ft); 47% at 21 – 65 m (69 – 213 ft)	Extrapolated from minke whale
ODONTOCETES – Toothed whales			
Atlantic spotted dolphin	*Stenella frontalis*	76% in <10 m (33 ft); 20% in 10 – 20 m (33 – 66 ft); 4% in 21 – 60 m (69 – 197 ft)	Davis et al. (1996); Santos and Haimovici (2001)
Beaked whales	Family Ziphiidae	27% in <2 m (7 ft) (surface); 29% in 2 – 220 m (7 – 722 ft); 4% in 221 – 400 m (725 – 1,312 ft); 4% in 401 – 600 m (1,316 – 1,969 ft); 4% in 601 – 800 m (1,972 – 2,625 ft); 5% in 801 – 1,070m (2,628 – 3,510 ft); 27% in >1,070 m (3,510 ft)	Extrapolated from Cuvier's beaked whale
Bottlenose dolphin	*Tursiops truncatus*	Daytime: 96% at <0 – 50 m (0 – 164 ft), 4% at >50 m (164 ft); Nighttime: 51% at <50 m (164 ft), 8% at 50 – 100 m (164 – 328 ft), 19% at 101 – 250 m (331 – 820 ft), 13% at 251 – 450 m (823 – 1,476 ft) and 9% at >450 m (1,476 ft)	Klatsky et al. (2007)
Clymene dolphin	*Stenella clymene*	Daytime: 100% at 0 – 50 m (0 – 164 ft); nighttime: 100% at 0 – 400 m (0 – 1,312 ft)	extrapolated from spinner dolphin
False killer whale	*Pseudorca crassidens*	96% at 0 – 30 m (0 – 98 ft); 4% at >30 m (98 ft)	Extrapolated from killer whale
Fraser's dolphin	*Lagenodelphis hosei*	Daytime, 100% at 0 – 50 m (0 – 164 ft); Nighttime, 100% at 0 – 700 m (0 – 2,297 ft)	Dolar et al. (2003)

Common Name	Scientific Name	Depth Distribution	Reference
ODONTOCETES – Toothed whales (continued)			
Killer whale	*Orcinus orca*	96% at 0 – 30 m (0 – 98 ft); 4% at >30 m (98 ft)	Baird et al. (2003a)
Melon-headed whale	*Peponocephala electra*	Daytime, 100% at 0 – 50 m (0 – 164 ft); Nighttime, 100% at 0 – 700 m (0 – 2,297 ft)	Extrapolated from Fraser's dolphin
Pantropical spotted dolphin	*Stenella attenuata*	Daytime, 89% at 0 – 10 m (0 – 33 ft), 10% at 11 – 50 m (36 – 164 ft), 1% at 51 – 122 m (167 – 400 ft); Nighttime, 80% at 0 – 10 m (0 – 33 ft), 8% at 11 – 20 m (36 – 66 ft), 2% at 21 – 30 m (69 – 98 ft), 2% at 31 – 40 m (102 – 131 ft), 2% at 41 – 50 m (135 – 164 ft), and 6% at 51 – 213 m (167 – 699 ft)	Baird et al. (2001)
Pilot whales	*Globicephala* sp.	60% at <7 m (23 ft); 36% at 7 – 17 m (23 – 56 ft); 4% at 18 – 828 m (59 – 2,717 ft)	Heide-Jørgensen et al. (2002)
Pygmy and dwarf sperm whales	*Kogia breviceps* and *Kogia sima*, respectively	26% in <2 m (7 ft) (surface); 41% in 2 – 71 m (7 – 233 ft); 2% in 72 – 200 m (236 – 656 ft); 4% in 201 – 400 m (659 – 1,312 ft); 4% in 401 – 600 m (1,316 – 1,969 ft); 4% in 601 – 835 m (1,972 – 2,740 ft); 19% in >835 m (2,740 ft)	Extrapolated from Blainville's beaked whale
Pygmy killer whale	*Feresa attenuata*	96% at 0 – 30 m (0 – 98 ft); 4% at >30 m (98 ft)	Extrapolated from killer whale
Risso's dolphin	*Grampus griseus*	50% at <50 m (164 ft); 15% at 51 – 200 m (167 – 656 ft); 15% at 201 – 400 m (659 – 1,312 ft); 10% at 401 – 600 m (1,316 – 1,969 ft) and 10% at >600 m (1,969 ft)	Öztürk et al. (2007)
Rough-toothed dolphin	*Steno bredanensis*	100% at 0 – 70 m (0 – 230 ft)	Jefferson (2002)
Sperm whale	*Physeter macrocephalus*	31% in <10 m (33 ft), 8% in 10 – 200 m (33 – 656 ft), 9% in 201 – 400 m (659 – 1,312 ft), 9% in 401 – 600 m (1,316 – 1,969 ft), 9% in 601 – 800 m (1,972 – 2,625 ft) and 34% in >800 m (2,625 ft)	Amano and Yoshioka (2003)
Spinner dolphin	*Stenella longirostris*	Daytime: 100% at 0 – 50 m (0 – 164 ft); nighttime: 100% at 0 – 400 m (0 - 1,312 ft)	Benoit-Bird and Au (2003)
Striped dolphin	*Stenella coeruleoalba*	Daytime, 89% at 0 – 10 m (0 – 33 ft), 10% at 11 – 50 m (36 – 164 ft), 1% at 51 – 122 m (167 – 400 ft); Nighttime, 80% at 0 – 10 m (0 – 33 ft), 8% at 11 – 20 m (36 – 66 ft), 2% at 21 – 30 m (69 – 98 ft), 2% at 31 – 40 m (102 – 131 ft), 2% at 41 – 50 m (135 – 164 ft), and 6% at 51 – 213 m (167 – 699 ft)	Extrapolated from pantropical spotted dolphin

Humpback whale, *Megaptera novaeangliae* - Extralimital

There is no abundance or density estimate.

North Atlantic right whale, *Eubalaena glacialis* - Extralimital

There is no abundance or density estimate.

ODONTOCETES

Atlantic spotted dolphin distribution and habitat preferences:

- This species primarily occurs on the continental shelf in the GOM.
- Griffin and Griffin (2003) specifically noted a mid-shelf (20 to 180 m [66 to 591 ft]) habitat preference in the eastern GOM.
- In their less common habitat of oceanic waters of the GOM, Atlantic spotted dolphins (*Stenella frontalis*) usually occur near the shelf break in waters less than 500 m (1,640 ft) in bottom depth.

Beaked whales

Three species of beaked whales may occur in the GOM, including the Cuvier‘s, Gervais‘, and Blainville‘s beaked whales. Only one stranding record exists for the Sowerby‘s beaked whale (*Mesoplodon bidens*); this species is considered to be more northerly distributed and, therefore, extralimital to the GOM (Jefferson and Schiro 1997; MacLeod et al. 2006).

Beaked whales distribution and habitat preferences:

- The Cuvier‘s beaked whale is the most widely distributed beaked whale species. It is probably the most common beaked whale species occurring in the GOM. The Blainville‘s beaked whale is the most widely distributed of the *Mesoplodon* sp.; it is considered to inhabit all tropical, sub-tropical and warm-temperate waters, with occasional occurrences in cold-temperate areas. The Gervais‘ beaked whale is endemic to the warm-temperate to tropical Atlantic.
- World-wide, beaked whales normally inhabit continental slope and deep oceanic waters (>200 m [656 ft]). Areas of steep bathymetry, such as submarine canyons have also been described as important habitat. Beaked whales in the eastern tropical Pacific are found in waters over the continental slope to the abyssal plain, ranging from well-mixed to highly stratified.
- Beaked whales are expected to occur year-round throughout the GOM in waters off the continental shelf break. The northern GOM continental shelf margins recently were identified as known key areas for beaked whales. Habitat characterization modeling for the GOM predicted areas greater than 1,000 m (3,280 ft) in bottom depth as potential beaked whale habitat. The probability of beaked whale presence reaches a maximum along the slope, decreasing towards the continental shelf and deep abyssal region.

- World-wide, beaked whales only rarely stray over the continental shelf. In the GOM, a few beaked whale sightings on the continental shelf are reported.

Bottlenose dolphin

The category for bottlenose dolphins (*Tursiops truncatus*) includes both the coastal (near shore) and the offshore forms. As noted by Mullin and Fulling (2004), if genetic structure for this species in the GOM is similar to that for the species in the western North Atlantic (offshore from ≥34 km [18 nmi] from shore and bottom depth greater than 34 m [112 ft]), then all bottlenose dolphins in oceanic waters are the offshore ecotype.

Bottlenose dolphin distribution and habitat preferences:

- The bottlenose dolphin is regularly found in shallow waters of the continental shelf. The bottlenose dolphin is the most widespread and most common cetacean in coastal waters of the GOM.
- Mullin et al. (2004) reported sighting bottlenose dolphins in waters with bottom depths averaging less than 300 m (984 ft). Bottlenose dolphins appear to have an almost bimodal distribution in the GOM: the shallow continental shelf (0 to 150 m [0 to 492 ft]) and just seaward of the shelf break (200 to 750 m [656 to 2,461 ft]). These regions may represent the individual depth preferences for the near shore and offshore forms. Baumgartner et al. (2001) hypothesized a potential association of bottlenose dolphins with oceanographic fronts at the shelf break.
- Mullin and Fulling (2004) reported encountering bottlenose dolphins primarily in upper continental slope waters less than 1,000 m (3,280 ft) in bottom depth, with highest densities in the northeastern GOM.
- Mullin and Fulling (2004) reported that groups of bottlenose dolphins were generally confined to the shelf break except in the northeastern GOM, where their distribution extended well seaward of the shelf break.

Clymene dolphin distribution and habitat preferences:

- There are more Clymene dolphin (*Stenella clymene*) records from the GOM than from the rest of this species‘ range combined.
- Clymene dolphins are typically sighted in offshore waters offshore of the shelf break; Fertl et al. (2003) reported that Clymene dolphins were sighted in waters with a mean bottom depth of 1,870 m (6,135 ft), throughout their range. There has not been much survey effort in waters with a bottom depth greater than 3,000 m (9,843 ft) in the GOM, yet there are documented sightings.
- In a study of habitat preferences in the GOM, oceanic stenellids were found more often on the lower continental slope and in deepwater areas in regions of cyclonic or confluence circulation.
- Mullin and Fulling (2004) noted that Clymene dolphins were sighted primarily west of Mobile Bay.

False killer whale distribution and habitat preferences:

- This species is found primarily in oceanic and offshore areas world-wide.
- Most sightings of false killer whales (*Pseudorca crassidens*) in the GOM are on the upper continental slope.
- False killer whales sometimes make their way into shallower waters. There have been sightings from over the continental shelf. Many sightings were reported by sport fishermen in the mid-1960s of ―blackfish” (most likely false killer whales based on the descriptions) in waters offshore of Pensacola and Panama City, Florida.
- Most false killer whale sightings in the GOM are east of Mobile Bay.

Fraser's dolphin density and abundance estimates:

- The ―best” estimate of abundance for the Fraser‘s dolphin *(Lagenodelphis hosei*) came from the NMFS SAR (Waring et al. 2007) based on analyses by Mullin and Fulling (2003). For the purpose of this document, this estimate was applied to the entire Q-20 Study Area and across all seasons.

Killer whale distribution and habitat preferences:

- Globally, killer whales (*Orcinus orca*) are found in the open sea, as well as in coastal areas.
- Killer whales are sighted year-round in the northern GOM. Sightings are generally clumped in a broad region south of the Mississippi River Delta, in waters ranging in bottom depth from 42 to 2,571 m (138 to 8,435 ft). Mullin and Fulling (2004) reported that killer whales were sighted primarily west of Mobile Bay.
- Sightings also have been made in waters over the continental shelf (including close to shore).

Killer whale density and abundance estimates:

- The ―best” estimate of abundance for this species came from the NMFS SAR (Waring et al. 2007) based on analyses by Mullin and Fulling (2003). For the purpose of this document, this estimate was applied to the entire Q-20 Study Area and across all seasons.

Melon-headed whale distribution and habitat preferences:

- Little information is available on the general habitat preferences of the melon-headed whale (*Peponocephala electra*). Most melon-headed whale sightings in the GOM are in deep waters, well beyond the continental shelf break and out over the abyssal region.
- Mullin and Fulling (2004) reported that melon-headed whales were sighted primarily west of Mobile Bay.

Melon-headed whale density and abundance estimates:

- The ―best” estimate of abundance for this species came from the SAR (Waring et al. 2007) based on analyses by Mullin and Fulling (2003). For the purpose of this document, this estimate was applied to the entire Q-20 Study Area and across all seasons.

Pantropical spotted dolphin distribution and habitat preferences:

- Most sightings of this pantropical spotted dolphin in the GOM extend from the upper continental slope out over the abyssal region. Mullin et al. (2004) reported that sightings for this species were made in waters with a mean bottom depth of greater than 1,000 m (3,280 ft).
- The pantropical spotted dolphin is rarely found on the continental shelf in the GOM.
- Baumgartner et al. (2001) reported that pantropical spotted dolphins in the GOM do not appear to have a preference for any one habitat (within the Loop Current, inside a cold-core eddy, or along the continental slope), while Davis et al. (2000; 2002) reported finding oceanic stenellids more often over the lower continental slope and abyssal regions in areas of cyclonic or confluence circulation. Baumgartner et al. (2001) noted that while no such relationship was detected in their study, other factors including temporal variability in habitat associations could easily account for this difference in the study results.

Pygmy and dwarf sperm whales (*Kogia* sp.) distribution and habitat preferences:

- There are two species that make up this category: the pygmy sperm whale (*Kogia breviceps*) and the dwarf sperm whale (*Kogia sima*). Globally, both species of *Kogia* generally occur in waters along the continental shelf break and over the continental slope.
- In the GOM, *Kogia* is distributed mostly over the upper continental slope.
- Fulling and Fertl (2003) reported that 67 percent of *Kogia* sp. sightings in the GOM were between the shelf break and the 2,000 m (6,562 ft) isobath; 46 percent of these were on the upper continental slope between the 500 and 1,000 m (1,640 and 3,280 ft) isobaths. Although there has been little survey effort seaward of the 3,000 m (9,843 ft) isobath, there were some sightings of individuals in those very deep waters.
- There is no evidence that *Kogia* regularly occurs in continental shelf waters of the GOM, however, there were some sighting records in waters over the continental shelf (Fulling and Fertl 2003).
- Fulling and Fertl (2003) remarked on the noticeable concentration of sightings in continental slope waters near the Mississippi River Delta.

Pygmy killer whale distribution and habitat preferences:

- The pygmy killer whale (*Feresa attenuata*) does not appear to be common in the GOM.
- In the northern GOM, this species is found primarily in deeper waters off the continental shelf and over the abyssal region. Sightings are typically over the upper continental slope.

Pygmy killer whale density and abundance estimates:

- The ―best” estimate of abundance for this species came from the SAR (Waring et al. 2007) based on analyses by Mullin and Fulling (2003). For the purpose of this document, this estimate was applied to the entire Q-20 Study Area and across all seasons.

Risso’s dolphin distribution and habitat preferences:

- A number of studies world-wide have noted that Risso‘s dolphins (*Grampus griseus*) are found along the continental slope.
- There is a strong correlation between Risso‘s dolphin distribution and the steeper portions (200 to 1,000 m [656 to 3,280 ft]) of the upper continental slope in the GOM. This correlation is most likely the result of cephalopod distribution in the same area.

Rough-toothed dolphin

- In the GOM, the rough-toothed dolphin occurs primarily over the deeper waters (bottom depths of 950 to 1,100 m [3,117 to 3,609 ft]) off the continental shelf.
- Occurrences over the continental shelf, off the Florida Panhandle and central Texas in northeastern GOM, are known from tagging and survey data. Two separate mass strandings of rough-toothed dolphins occurred in the Florida Panhandle during December 1997 and 1998. Four stranded rough-toothed dolphins (three with satellite-linked transmitters) were rehabilitated and released in 1998 off the Gulf Coast of Florida. Water depth at tracking locations of these individuals averaged 195 m (640 ft) off the Florida Panhandle.
- During May 2005, seven more rough-toothed dolphins (stranded in the Florida Keys in March 2005 and rehabilitated) were tagged (two with satellite, the others with very high frequency) and released by the Marine Mammal Conservancy in the Florida Keys. During an initial period of apparent disorientation in the shallow waters west of Andros Island, they continued to the east, then moved north through Crooked Island Passage, and paralleled the West Indies. The last signal placed them northeast of the Lesser Antilles. During September 2005, two more individuals (stranded with the previous group in the Florida Keys in March 2005 and rehabilitated) were satellite-tagged and released east of the Florida Keys by the Marine Mammal Conservancy. The tagging data demonstrated that these individuals proceeded south to a deep trench close to the north coast of Cuba.

Short-finned pilot whale

Based on known distribution and habitat preferences of pilot whales, it is assumed that all of the pilot whale records in the northern GOM are of the short-finned pilot whale (*Globicephala macrorynchus*).

Short-finned pilot whale distribution and habitat preferences:

- Pilot whales are typically found over the continental shelf break, in slope waters, and in areas with steep bottom topography. A number of studies have suggested that the distribution and movements of pilot whales coincide closely with the abundance of squid.
- Sightings in the GOM are primarily on the upper continental slope.
- While pilot whales are typically distributed along the continental shelf break, movements over the continental shelf are commonly observed in the northeastern United States. In the GOM, pilot whales are sometimes seen in waters over the continental shelf.
- Mullin and Fulling (2004) reported that short-finned pilot whales were sighted primarily west of Mobile Bay.
- There is a preponderance of pilot whales in the historical records for the northern GOM. Pilot whales, however, are less often reported during recent surveys, such as GulfCet. The reason for this apparent decline is not known, but Jefferson and Schiro (1997) suggested that abundance or distribution patterns might have changed over the past few decades, perhaps due to changes in available prey species.

Short-finned pilot whale density and abundance estimates:

- The ―best” estimate of abundance for this species came from the NMFS SAR (Waring et al. 2007) based on analyses by Mullin and Fulling (2003). For the purpose of this document, this estimate was applied to the entire Q-20 Study Area and across all seasons.

Sperm whale distribution and habitat preferences:

- Sperm whales occur year-round in the GOM, aggregating along the continental slope and in canyon regions. During GulfCet surveys, sperm whales were concentrated around the 1,000-m (3,280 ft) isobath, south of the Mississippi River Delta. This area has been recognized for high densities of sperm whales and represents a habitat where they can be predictably found.
- Tagging data demonstrated that some individuals spend several months at a time in the Mississippi River Delta and the Mississippi Canyon for several months, while other individuals move to other locations the rest of the year. There is high site fidelity by females and immatures to the region south of the Mississippi River Delta and Mississippi Canyon on the upper continental slope and in the western GOM. Males were found on the upper continental slope, but also move more often into the central GOM and into areas of the lower continental slope and abyssal (depths greater than 3,000 m [9,843 ft]) region. Males were mainly found in the DeSoto Canyon and along the Florida Slope.
- In the GOM, higher numbers of sperm whales are found in areas of cyclonic circulation and cyclone-anticylone confluence. Data suggest that sperm whales appear to adjust their movements to stay in or near cold-core rings. This trend would demonstrate that sperm whales shift their movements in relation to prey concentrations.

Spinner dolphin distribution and habitat preferences:

- Spinner dolphins (*Stenella longirostris*) occur year-round in the deep waters of the GOM. Mullin and Fulling (2004) noted that the vast majority of spinner dolphin sightings made were over the continental slope in the northeastern GOM.
- Davis et al. (1998) characterized the physical habitat of cetaceans found along the continental slope in the north-central and western GOM. Spinner dolphins are usually found over intermediate bottom depths, with its distribution overlapping with that of purely pelagic and purely coastal species.

Striped dolphin distribution and habitat preferences:

- Striped dolphins (*Stenella coeruleoalba*) are usually found outside the continental shelf, typically over the continental slope out to oceanic waters, often associated with convergence zones and waters influenced by upwelling.
- Davis et al. (2000; 2002) reported finding oceanic stenellids more often over the lower continental slope and abyssal regions in areas of cyclonic or confluence circulation.

A.5.1.2 Depth Distribution

MYSTICETES

Bryde's whale

Bryde‘s whales feed on pelagic schooling fish, small crustaceans including euphausiids and copepods, and cephalopods (Kato 2002). Feeding appears to be regionally different. Off South Africa, the inshore form feeds on epipelagic fish while the offshore form feeds on mesopelagic fish and euphausiids (Best 1977; Bannister 2002). Stomach content analysis from whales in the southern Pacific and Indian Oceans indicated that most feeding apparently occurred at dawn and dusk, and primarily consisted of euphausiids (Kawamura 1980). There have been no depth distribution data collected on Bryde‘s whales. In lieu of depth data, minke whale depth distribution percentages will be extrapolated to Bryde‘s whales. Minke whales feed on small schooling fish and krill. The only depth distribution data for this species are reported from a study on daily energy expenditure conducted off northern Norway and Svalbard (Blix and Folkow 1995). The limited depth information available (from Figure 2 in Blix and Folkow 1995) is representative of a 75-min diving sequence where the whale was apparently searching for capelin, then foraging, then searching for another school of capelin. Search dives were mostly to approximately 20 m (66 ft), while foraging dives were to 65 m (213 ft). Based on this very limited depth information, rough estimates for percentage of time at depth are as follows: 53 percent at <20 m (66 ft) and 47 percent at 20 to 65 m (66 to 213 ft).

ODONTOCETES

Atlantic spotted dolphin

Atlantic spotted dolphins feed on epipelagic and meso-pelagic fish, squid and benthic invertebrates, and there is some evidence for nocturnal feeding (Perrin 2009a; Richard and

Barbeau 1994). Stomach contents from animals collected off Brazil yielded small and medium-sized cephalopods (Santos and Haimovici 2001). Davis et al. (1996) attached a satellite-linked time-depth recorder to a single animal in the GOM. Most dives were shallow regardless of the time of day, with the deepest dives to 40 to 60 m (131 to 197 ft). Based on this limited information, the depth distribution for Atlantic spotted dolphins is 76 percent at <10 m (33 ft), 20 percent at 10 to 20 m (33 to 66 ft) and four percent at 21 to 60 m (69 to 197 ft).

Beaked whales

Ziphiids feed primarily on mesopelagic squid and some fish, with most prey likely caught at >200 m (656 ft) (Pitman 2002). Most are believed to be suction feeders. There are no depth distribution data for the entire family, however good dive information has been collected for a few species (e.g., Cuvier‘s beaked whale *Ziphius cavirostris*). Cuvier‘s beaked whales feed on meso-pelagic or deep water benthic organisms, particularly squid (Heyning 2002). Stomach content analysis indicates that they take advantage of a larger range of prey species than other deep divers do (e.g., Santos et al. 2001; Blanco and Raga 2000). Cuvier‘s, like other beaked whales, are likely suction feeders based on the relative lack of teeth and enlarged hyoid bone and tongue muscles. Foraging dive patterns appear to be U-shaped, although inter-ventilation dives are shallower and have a parabolic shape (Baird et al. 2006). Depth distribution studies in Hawaii (Baird et al. 2005a; Baird et al. 2006) found that Cuvier‘s beaked whales undertook three or four different types of dives, including intermediate (to depths of 292-568 m [958-1,864 ft]), deep (>1,000 m [3,280 ft]) and short-inter-ventilation (within 2-3 m [7-10 ft] of surface); this study was of a single animal. Studies in the Ligurian Sea indicated that Cuvier‘s beaked whales dived to >1,000 m (3,280 ft) and usually started ―clicking” (actively searching for prey) around 475 m (1,558 ft) (Johnson et al. 2004; Soto et al. 2006). Clicking continued at depths and ceased once ascent to the surface began, indicating active foraging at depth. In both locations, Cuvier‘s spent more time in deeper water than did Blainville‘s beaked whale, although maximum dive depths were similar. There was no significant difference between day and night diving indicating that preferred prey likely does not undergo vertical migrations.

Dive information for Cuvier‘s beaked whales was collected in the Ligurian Sea (Mediterranean) via digital acoustic recording tags on a total of seven animals (Tyack et al. 2006). Despite the geographic difference and the author‘s cautions about the limits of the data set, the Ligurian Sea dataset represents a more complete snapshot than that from Hawaii (Baird et al. 2006). Cuvier‘s conducted two types of dives – U-shaped deep foraging dives (DFD) and shallow duration dives. Dive cycle commenced at the start of a DFD and ended at the start of the next DFD, and included shallow duration dives made in between DFD.

Mean length of dive cycle = 121.4 min (mean DFD plus mean Inter-deep dive interval)
Number of DFD recorded = 28
Mean DFD depth = 1,070 m (3,510 ft) (range 689 to 1,888 m [2,260 to 6,194 ft])
Mean length DFD = 58.0 min
Mean Vocal phase duration = 32.8 min
Mean inter-deep dive interval = 63.4 min
Mean shallow duration dive = 221 m (725 ft) (range 22 to 425 m [72 to 1,394 ft])
Mean number of shallow duration dives per cycle = 2 (range 0 to 7)
Mean length of shallow duration dives = 15.2 min

Total time at surface (0-2 m [0-7 ft]) was calculated by subtracting the mean length of DFD and two shallow duration dives from the total dive cycle (121.4 - 58.0 - 30.4 = 33 min). Total time at deepest depth was taken from the vocal phase duration time, as echolocation clicks generally commenced when animals were deepest, and was 32.8 min. The amount of time spent descending and ascending on DFDs was calculated by subtracting the mean vocal phase duration time from the mean total DFD (58.0 - 32.8 = 25.2 min) and then dividing by five (number of 200 m [656 ft] depth categories between surface and 1,070 m [3,510 ft]) which equals about five min per 200 m (656 ft). The five-min value was applied to each 200 m (656 ft) depth category from 400 to 1,070 m (1,312 to 3,510 ft); for the 2 to 220 m (7 to 722 ft) category, the mean length of shallow duration dives was added to the time for descent/ascent (30.4 + 5 = 35.4 min). Therefore, the depth distribution for Cuvier‘s beaked whales based on best available information from Tyack et al. (2006) is: 27 percent at <2 m (7 ft), 29 percent at 2 to 220 m (7 to 722 ft), four percent at 221 to 400 m (725 to 1,312 ft), four percent at 401 to 600 m (1,316 to 1,969 ft), four percent at 601 to 800 m (1,972 to 2,625 ft), five percent at 801 to 1,070 m (2,628 to 3,510 ft) and 27 percent in >1,070 m (3,510 ft).

Bottlenose dolphin

Bottlenose dolphins feed on a large variety of fish and squid (Wells and Scott 2009). Several studies on bottlenose dolphin feeding preferences illustrate variation at different geographic locations. Rossbach and Herzing (1997) observed bottlenose dolphins in the Bahamas feeding on the bottom (7 to 13 m [23 to 43 ft]) by orienting their heads down and moving from side to side, and several species regularly fed on prey along the sea floor (Wells and Scott 2009). Corkeron and Martin (2004) reported on two dolphins that spent 66 percent of time in the top 5 m (16 ft) of the water column; maximum dive depth was greater than 150 m (492 ft) and there was no apparent diurnal pattern. Stomach content analysis from Brazil indicated that small and medium-sized cephalopods were primary prey of animals found in shelf regions (Santos and Haimovici 2001), while off Tasmania, bottlenose dolphin prey consisted of oceanic species that were known to commonly occur on the shelf as well (Gales et al. 1992). Klatsky et al. (2007) reported on dive data of dolphins tagged at the Bermuda Pedestal in the north Atlantic. Dolphins dove to at least 492 m (1,614 ft) depth, with deep dives (>100 m [328 ft]) occurring exclusively at night. Dives during the day were to shallower depths than at night, with 90 percent of all dives to within 50 m (164 ft) of the surface. Based on data presented in Klatsky et al. (2007; Figure 3), the following depth distribution has been estimated for bottlenose dolphins: daytime: 96 percent at <0 to 50 m (0 to 164 ft), four percent at >50 m (164 ft); nighttime: 51 percent at <50 m (164 ft), eight percent at 50 to 100 m (164 to 328 ft), 19 percent at 101 to 250 m (331 to 820 ft), 13 percent at 251 to 450 m (823 to 1,476 ft) and nine percent at >450 m (1,476 ft). Data on time spent at the surface were not published; therefore surface time was included in the least shallow depth category published.

Clymene dolphin

There is little information on the feeding habits of Clymene dolphins, and no diving studies have been carried out. Individuals normally feed on mesopelagic fish and squids, which are vertical migrators, during the night. However, Fertl et al. (1997) reported Clymene dolphins feeding during the daytime in a coordinated manner on schooling fish in the GOM in water 1,243 m deep. In lieu of the lack of information specific to this species, the depth distributions for spinner dolphins will be adopted for the Clymene dolphin: daytime: 100 percent at 0 to 50 m (0 – 164 ft); nighttime: 100 percent at 0 to 400 m (0 to 1,312 ft) (Benoit-Bird and Au 2003).

False killer whale

False killer whales feed on oceanic fish and squid, and have been known to prey on smaller marine mammals (Baird 2002a; Koen Alonso et al. 1999; Santos and Haimovici 2001). The only study conducted on diving of false killer whales in Hawaii has not been published in any detail (Ligon and Baird 2001), but an abstract provide limited information. False killer whales did not dive deep and instead recorded maximum dives of 22, 52 and 53 m (72, 171, and 174 ft) in near-shore Hawaiian waters. In lieu of other information, the depth distribution for killer whales will be extrapolated to this species: four percent of time at depths >30 m (98 ft) and 96 percent of time at depths 0-30 m (0-98 ft).

Fraser's dolphin

Fraser‘s dolphins prey on mesopelagic fish, crustaceans and cephalopods, and take advantage of vertically migrating prey at night (Dolar 2002). Stomach contents from dolphins in the Sulu Sea, Philippines, contained crustaceans, cephalopods and myctophid fish (Dolar et al. 2003). Fraser‘s dolphins took larger prey than spinner dolphins feeding in the same area, and likely foraged to depths of at least 600 m (1,969 ft), based on prey composition and behavior. This species has also been observed herding fish and feeding at the surface, taking short dives and surfacing in the middle of the herded fish school (Watkins et al. 1994). Based on this very limited information, the following are very rough order estimates of time at depth: daytime, 100 percent at 0 to 50 m (0 to 164 ft); Nighttime, 100 percent at 0 to 700 m (0 to 2,297 ft).

Killer whale

Killer whales feed on a variety of prey, including salmon, herring, cod, tuna and cephalopods (Ford 2002). ―Transient" stocks of killer whales feed on other marine mammals, including other whales, pinnipeds (e.g., London 2006) and sea otters (e.g., Estes et al. 1998). Diving studies on killer whales have been undertaken mainly on ―resident" (fish-eating) killer whales in Puget Sound and may not be applicable across all populations of killer whales. Diving is usually related to foraging, and mammal-eating killer whales may display different dive patterns. Killer whales in one study (Baird et al. 2005b) dove as deep as 264 m (866 ft), and males dove more frequently and more often to depths >100 m (328 ft) than females, with fewer deep dives at night. Dives to deeper depths were often characterized by velocity bursts which may be associated with foraging or social activities. Using best available data from Baird et al. (2003a), it would appear that killer whales spend about four percent of time at depths >30 m (98 ft) and 96 percent of time at depths 0 to 30 m (0 to 98 ft).

Melon-headed whale

Melon-headed whales feed on squid, fish and occasionally crustaceans in the water column (Jefferson and Barros 1997). Their prey is known to occur at depths to 1,500 m (4,921 ft), although there is no direct evidence that the whales feed to that depth. Stomach content analysis suggests that they feed on prey similar to Fraser‘s dolphins (Jefferson and Barros 1997). Diet composition analyzed by Pauly et al. (1998) indicated that most of the diet (70 percent) was small and large squids with the remaining composition including small pelagics, mesopelagics and miscellaneous fish. There are no depth distribution data for this species; the depth distribution for Fraser‘s dolphins will be extrapolated to melon-headed whales: daytime, 100 percent at 0 to 50 m (0 to 164 ft); nighttime, 100 percent at 0 to 700 m (0 to 2,297 ft).

Pantropical spotted dolphin

Pantropical spotted dolphins feed on small epipelagic fish, squids and crustaceans, and may vary their preferred prey seasonally (Perrin 2009b; Wang et al. 2003). Stomach contents of dolphins collected near Taiwan indicated that the distribution of primary prey was 0 to 200 m (0 to 656 ft) at night and >300 m (984 ft) during the day, indicating that these animals feed at night (Wang et al. 2003). One study on this species, conducted in Hawaii, contains dive information (Baird et al. 2001). The biggest differences recorded were in the increase in dive activity at night. During the day, 89 percent of time was spent within 0 to 10 m (0 to 33 ft), most of the rest of the time was 10 to 50 m (33 to 164 ft), and the deepest dive was to 122 m (400 ft). At night, only 59 percent of time was spent from 0 to 10 m (0 to 33 ft) and the deepest dive was to 213 m (699 ft); dives were especially pronounced at dusk. The following depth distributions are applicable: Daytime, 89 percent at 0 to 10 m (0 to 33 ft), 10 percent at 11 to 50 m (36 to 164 ft) and one percent at 51 to 122 m (167 to 400 ft); nighttime, 80 percent at 0 to 10 m (0 to 33 ft), eight percent at 11 to 20 m (36 to 66 ft), two percent at 21 to 30 m (69 to 98 ft), two percent at 31 to 40 m (102 to 131 ft), two percent at 41 to 50 m (135 to 164 ft), and six percent at 51 to 213 m (167 to 699 ft).

Pilot whales including short-finned pilot whale

Short-finned pilot whales feed on squid and fish. Stomach content analysis of pilot whales in the southern California Bight consisted entirely of cephalopod remains (Sinclair 1992). The most common prey item identified by Sinclair (1992) was *Loligo opalescens*, which has been documented in spawning concentrations at depths of 20 to 55 m (66 to 180 ft). Stomach content analysis from the closely related long-finned pilot whale (*Globicephala melas*) from the U.S mid-Atlantic coast demonstrated preference for cephalopods as well as a relatively high diversity of prey species taken (Gannon et al. 1997). Stomach content analysis from long-finned pilot whales off New Zealand did not show the same diversity of prey (Beatson et al. 2007) which indicates that pilot whales may differ significantly in prey selection based on geographic location. The only study conducted on short-finned pilot whales in Hawaii has not been published in any detail (Baird et al. 2003b), but an abstract indicated that there were significant differences between day and night diving; dives of >100 m (328 ft) were far more frequent at night, likely to take advantage of vertically-migrating prey; night dives regularly were to 300 to 500 m (98 to 1,640 ft). Deepest dives were during the day, however, perhaps because prey was deeper. A diving study on long-finned pilots also showed marked differences in daytime and nighttime diving in studies in the Ligurian Sea (Baird et al. 2002b), but there was no information on percentage of time at various depth categories. A study following two rehabilitated and released long-finned pilot whales provides a breakdown of percentage of time at depth distribution for two whales (Nawojchik et al. 2003), although this data may be skewed due to the unique situation. Heide-Jørgensen et al. (2002) studied diving behavior of long-finned pilot whales near the Faroe Islands in the north Atlantic. Most diving activity occurred at depth of less than 36 m (118 ft) and >90 percent of dives were within 12 to 17 m (39 to 56 ft). Based on this information, the following are estimates of time at depth for both species of pilot whale:

60 percent at <7 m (23 ft), 36 percent at 7 to 17 m (23 to 56 ft) and four percent at 18 to 828 m (59 to 2,717 ft).

Pygmy and dwarf sperm whales

There are no depth distribution data for this species. An attempt to record dive information on a rehabilitated pygmy sperm whale failed when the time-depth-recorder package was never recovered (Scott et al. 2001). Prey preference, based on stomach content analysis from Atlantic Canada (McAlpine et al. 1997) and New Zealand (Beatson 2007), appears to be mid- and deep-water cephalopods, crustaceans and fish. There is some evidence that *Kogia* may use suction-feeding and feed at or near the bottom. They may also take advantage of prey undergoing vertical migrations to shallower waters at night (Beatson 2007). In lieu of any other information, Blainville‘s beaked whale depth distribution data will be extrapolated to pygmy sperm whales as the two species appear to have similar prey preferences and are closer in size than either is to the sperm whale or the Cuvier‘s beaked whale. Blainville‘s beaked whales undertake shallower non-foraging dives in between deep, foraging dives. Blainville‘s beaked whale depth distribution data, taken from Tyack et al. (2006) and summarized in greater depth later in this document is: 26 percent at <2 m (7 ft), 41 percent at 2 to 71 m (7 to 233 ft), two percent at 72 to 200 m (236 to 656 ft), four percent at 201 to 400 m (659 to 1,312 ft), four percent at 401 to 600 m (1,316 to 1,969 ft), four percent at 601 to 835 m (1,972 to 2,740 ft) and 19 percent at >835 m (2,740 ft).

Pygmy killer whale

Pygmy killer whales feed on cephalopods, small fish and small delphinids (Donahue and Perryman 2002; Santos and Haimovici 2001). There have not been any studies of diving patterns specific to this species. In lieu of other information, the depth distribution for killer whales will be extrapolated to this species: four percent of time at depths >30 m (98 ft) and 96 percent of time at depths 0 to 30 m (0 to 98 ft).

Risso's dolphin

There are no depth distribution data for this species. They are primarily squid eaters and feeding is presumed to take place at night. A study undertaken in the GOM demonstrated that Risso‘s dolphins are distributed non-uniformly with respect to depth and depth gradient (Baumgartner 1997), utilizing mainly the steep sections of upper continental slope bounded by the 350-m (1,148-ft) and 975-m (3,199-ft) isobaths. Those data agree closely with Blanco et al. (2006), who collected stomach samples from stranded Risso‘s dolphins in the western Mediterranean. Their results indicated that, based on prey items, Risso‘s dolphins fed on the middle slope at depths ranging from 600 to 800 m (1,969 to 2.625 ft). Stomach content analysis from three animals elsewhere in the Mediterranean indicated that Risso‘s dolphins fed on species that showed greater vertical migrations than those ingested by striped dolphins (Öztürk et al. 2007). In lieu of depth distribution information or information on shape of dives, the following are rough estimates of time at depth based on habitat and prey distribution: 50 percent at <50 m (164 ft), 15 percent at 51 to 200 m (167-656 ft), 15 percent at 201 to 400 m (659 to 1,312 ft), 10 percent at 401 to 600 m (1,317 to 1,969 ft) and 10 percent at >600 m (1,969 ft).

Rough-toothed dolphin

Rough-toothed dolphins feed on fish and cephalopods, both oceanic and coastal species (Jefferson 2002). Based on anatomy, they appear to be adapted to deep diving (Miyazaki and Perrin 1994), although the maximum recorded dive is to only 70 m (230 ft) (Jefferson 2002). There have been no depth distribution studies done on this species. In lieu of other information, the following is a rough estimation of time at depth: 100 percent at 0 to 70 m (0 to 230 ft).

Sperm whale

Unlike other cetaceans, there is a preponderance of dive information for this species, most likely because it is the deepest diver of all cetacean species, which generates a lot of interest. Sperm whales feed on large and medium-sized squid, octopus, rays and sharks, on or near the ocean floor. Some evidence suggests that they do not always dive to the bottom of the sea floor (likely if food is elsewhere in the water column), but that they do generally feed at the bottom of the dive. Davis et al. (2007) report that dive-depths (100 to 500 m [328 to 1,640 ft]) of sperm whales in the Gulf of California overlapped with depth distributions (200 to 400 m [656 to 1,312 ft]) of jumbo squid, based on data from satellite-linked dive recorders placed on both species, particularly during daytime hours. Their research also showed that sperm whales foraged throughout a 24-hr period, and that they rarely dove to the sea floor bottom (>1,000 m [3,280 ft]). The most consistent sperm whale dive type is U-shaped, whereby the whale makes a rapid descent to the bottom of the dive, forages at various velocities while at depth (likely while chasing prey) and then ascends rapidly to the surface. Amano and Yoshioka (2003) attached a tag to a female sperm whale near Japan in an area where water depth was 1,000 to 1,500 m (3,280 to 4,921 ft). Based on values derived by Amano and Yoskioka (2003 [Table 1]) for dives with active bottom periods, the total mean dive sequence was 45.9 min (mean surface time plus dive duration). Mean post dive surface time divided by total time (8.5 min/45.9 min), plus time at surface between deep dive sequences yields a percentage of time at the surface (<10 m [33 ft]) of 31 percent. Mean bottom time divided by total time (17.5 min/45.9 min) and adjusted to include the percentage of time at the surface between dives, yields a percentage of time at the bottom of the dive (in this case >800 m [2,625 ft] as the mean maximum depth was 840 m [2,756 ft]) of 34percent. Total time spent in the water column, descending or ascending, equals duration of dive minus bottom time (37.4 min - 17.5 min) or about 20 min. Assuming a fairly equal descent and ascent rate (as shown in the table) and a fairly consistent descent/ascent rate over depth, the DON assumes 10 min each for descent and ascent and equal amounts of time in each depth gradient in either direction. Therefore, 0 to 200 m (0 to 656 ft) = 2.5 min one direction (which correlates well with the descent/ascent rates provided) and, therefore, 5 min for both directions. This derivation is the same for 201 to 400 m (659 to 1,312 ft), 401 to 600 m (1,316 to 1,969 ft) and 601 to 800 m (1,972 to 2,625 ft). Therefore, the depth distribution for sperm whales based on information in the Amano and Yoskioka (2003) is: 31 percent in <10 m (33 ft), eight percent in 10 to 200 m (33 to 656 ft), nine percent in 201 to 400 m (659 to 1,312 ft), nine percent in 401 to 600 m (1,316 to 1,969 ft), nine percent in 601-800 m (1,972 to 2,625 ft) and 34 percent in >800 m (2,625 ft). The percentages derived above from data in Amano and Yoshioka (2003) are fairly close in agreement with those derived from Watwood et al. (2006, Table 1) for sperm whales in the Ligurian Sea, Atlantic Ocean, and GOM.

Spinner dolphin

Spinner dolphins feed on small mesopelagic fish, and likely feed at night (Perrin 2009c; Benoit-Bird and Au 2003). Stomach content analysis of spinner dolphins collected in the Sulu Sea, Philippines, indicated that they fed on mesopelagic crustaceans, cephalopods and fish that undertake vertical migrations to approximately 250 m (820 ft) (Dolar et al., 2003). There was also evidence that they preyed on non-vertical migrating species found at approximately 400 m (1,312 ft), and that they likely did not have the same foraging range as Fraser‘s dolphins in the same area (to 600 m [1,969 ft]). Studies on spinner dolphins in Hawaii have been carried out using active acoustics (fish-finders) (Benoit-Bird and Au 2003). These studies show an extremely close association between spinner dolphins and their prey (small, mesopelagic fish). Mean depth of spinner dolphins was always within 10 m (33 ft) of the depth of the highest prey density. These studies have been carried out exclusively at night, as stomach content analysis indicates that spinners feed almost exclusively at night when the deep scattering layer moves toward the surface bringing potential prey into relatively shallower (0 to 400 m [0 to 1,312 ft]) waters. Prey distribution during the day is estimated at 400 to 700 m (1,312 to 2,297 ft). Based on these data, the following are very rough order estimates of time at depth: daytime: 100 percent at 0 to 50 m (0 to 164 ft); Nighttime: 100 percent at 0 to 400 m (0 to 1,312 ft).

Striped dolphin

Striped dolphins feed on pelagic fish and squid and may dive during feeding to depths exceeding 200 m (656 ft) (Archer 2009). However, studies are rare on this species. Stomach content remains from three dolphins in the Mediterranean near Turkey included several species of cephalopod as well as some fish, and suggested that striped dolphins may not feed quite as deep as Risso‘s dolphins in the same area (Ozturk et al. 2007). Blanco et al. (1995) analyzed stomach content remains from the western Mediterranean, and identified a mixed diet of muscular and gelatinous body squids of pelagic and bathypelagic origin. There is some evidence that striped dolphins feed at night to take advantage of vertical migrations of the deep scattering layer. In lieu of other information, pantropical spotted dolphin depth distribution data will be extrapolated to striped dolphins: Daytime, 89 percent at 0 – 10 m (0 – 33 ft), ten percent at 11 – 50 m (36 – 164 ft), and one percent at 51 – 122 m (167 – 400 ft); Nighttime, 80 percent at 0 – 10 m (0 – 33 ft), eight percent at 11 – 20 m (36 – 66 ft), two percent at 21 – 30 m (69 – 98 ft), two percent at 31 – 40 m (102 – 131 ft), two percent at 41 – 50 m (135 – 164 ft), and six percent at 51 – 213 m (167 – 699 ft) (Baird et al. 2001).

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Appendix B – Geographic Description of Environmental Provinces

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ft	foot/feet
GOM	Gulf of Mexico
HFBL	High-Frequency Bottom Loss
km	kilometer(s)
kn	knot(s)
LCS	Littoral Combat Ship
LFBL	Low-Frequency Bottom Loss
m	meter(s)
m/sec	meter(s) per second(s)
mi	mile(s)
mi/hr	mile(s)/hour
nmi	nautical mile(s)
OPAREA	Operating Area
Q-20	AN/AQS-20A Mine Reconnaissance Sonar System
RDT&E	Research, Development, Testing, and Evaluation
sec	second(s)
SVP	sound velocity profile
U.S.	United States
ZOE	Zone of Effect

GEOGRAPHIC DESCRIPTION OF ENVIRONMENTAL PROVINCES

Propagation loss ultimately determines the extent of the zone of effect (ZOE) for a particular source activity. In turn, propagation loss as a function of range responds to a number of environmental parameters:

- Water depth,
- Sound speed variability throughout the water column,
- Bottom geo-acoustic properties, and
- Wind speed.

Due to the importance that propagation loss plays in Anti-Submarine Warfare, the United States (U.S.) Navy has over the last four to five decades invested heavily in measuring and modeling these environmental parameters. The result of this effort is the following collection of global databases of these environmental parameters, most of which are accepted as standards for all U.S. Navy modeling efforts:

- **Water depth** – Digital Bathymetry Data Base Variable Resolution,
- **Sound speed** – Generalized Digital Environmental Model,
- **Bottom loss** – Low-Frequency Bottom Loss (LFBL), Sediment Thickness Database, and High-Frequency Bottom Loss (HFBL), and
- **Wind speed** – U.S. Navy Marine Climatic Atlas of the World.

This section provides a discussion of the relative impact of these various environmental parameters. These examples then are used as guidance for determining environmental provinces (that is, regions in which the environmental parameters are relatively homogenous and can be represented by a single set of environmental parameters) within the AN/AQS-20A Reconaissance Sonar System (Q-20) Study Area.

B.1 Impact of Environmental Parameters

Within a typical Operating Area (OPAREA), bathymetry is the environmental parameter that tends to vary the most. It is not unusual for water depths to vary by an order of magnitude or more, resulting in a significant impact upon the ZOE calculations. Bottom loss can also vary considerably over typical OPAREAs, but its impact upon ZOE calculations tends to be limited to waters on the continental shelf and the upper portion of the slope. Generally, the primary propagation paths in deep water from the source to most of the ZOE volume do not involve any interaction with bottom. In shallow water, particularly if the sound velocity profile directs all propagation paths to interact with the bottom, bottom loss variability can play a large role.

The spatial variability of the sound speed field is generally small over OPAREAs of typical size. The presence of a strong oceanographic front is a noteworthy exception to this rule. To a lesser extent, variability in the depth and strength of a surface duct can be of some importance. In the mid-latitudes, seasonal variation often provides the most significant variation in the sound speed field. For this reason, both summer and winter profiles are modeled for each selected environment.

B.2 Environmental Provincing Methodology

The underwater acoustic environment can be quite variable over ranges in excess of 10 kilometers (km) (6.2 miles [mi]). For the Littoral Combat Ship (LCS) research, development, test, and evaluation (RDT&E) applications, ranges of interest are often sufficiently large as to warrant the modeling of the spatial variability of the environment. In the propagation loss calculations, each of the environmental parameters is allowed to vary (either continuously or discretely) along the path from acoustic source to receiver. In such applications, each propagation loss calculation is conditioned upon the particular locations of the source and receiver.

On the other hand, the range of interest for marine animal harassment by most U.S. Navy activities is more limited. This reduces the importance of the exact location of source and marine animal, and makes the modeling required more manageable in scope.

In lieu of trying to model every environmental profile that can be encountered in an OPAREA, this effort utilizes a limited set of representative environments. Each environment is characterized by a fixed water depth, sound velocity profile, and bottom loss type. The OPAREA is then partitioned into homogeneous regions (or provinces) and the most appropriately representative environment is assigned to each. This process is aided by some initial provincing of the individual environmental parameters. The U.S. Navy-standard HFBL database in its native form is globally partitioned into nine classes. (LFBL is likewise provinced in its native form, although it is not considered in this selection of environmental provinces. The sources for which LFBL loss would be of interest have limited impact ranges thus rendering bottom loss of little consequence in this analysis.) The U.S. Navy-standard sound velocity profiles database is also available as a provinced subset. Only the U.S. Navy-standard bathymetry database varies continuously over the world‘s oceans. However, even this environmental parameter is easily provinced by selecting a finite set of water depth intervals. ―Octave-spaced” intervals (20, 50, 100, 200, 500, 1,000, 2,000, and 5,000 meters (m) (66, 164, 328, 656, 1,640, 3,281, 6,562, and 16,404 feet [ft]) provide an adequate sampling of water depth dependence.

ZOE volumes are then computed using propagation loss estimates derived for the representative environments. Finally, a weighted average of the ZOE volumes is taken over all representative environments; the weighting factor is proportional to the geographic area spanned by the environmental province.

The selection of representative environments is subjective. However, the uncertainty introduced by this subjectivity can be mitigated by selecting more environments and by selecting the environments that occur most frequently over the OPAREA of interest.

As discussed in the previous subsection, ZOE estimates are most sensitive to water depth. Unless otherwise warranted, at least one representative environment is selected in each bathymetry province. Within a bathymetry province, additional representative environments are selected as needed to meet the following requirements:

- In shallow water (less than 1,000 m [3,281 ft]), bottom interactions occur at shorter ranges and more frequently, thus significant variations in bottom loss need to be represented.
- Surface ducts provide an efficient propagation channel that can greatly influence ZOE estimates. Variations in the mixed layer depth need to be accounted for if the water is deep enough to support the full extent of the surface duct.

Depending upon the size and complexity of the OPAREA, the number of environmental provinces tends to range from 5 to 20.

B.2.1 Description of Environmental Provinces Used in Acoustic Modeling

This section describes the representative environmental provinces selected for the entire Q-20 Study Area. The narrowband sources described in **Appendix A** are, for the most part, deployed throughout the Q-20 Study Area. The broadband sources are primarily limited to portions of the continental shelf. For all of these provinces, the average winter wind speed is 14 knots (kn) (16 miles per hour [mi/hr]) and the average summer wind speed is 9 kn (10 mi/hr).

The Q-20 Study Area contains a total of 14 distinct environmental provinces. These represent the various combinations of eight bathymetry provinces, one sound velocity profile (SVP) provinces, three LFBL geoacoustic provinces, and two HFBL classes. The bathymetry provinces represent depths ranging from 20 m (66 ft) to more than 1 km (0.5 nautical miles [nmi]). Nearly 75 percent of the Q-20 Study Area is located on the continental shelf in waters less than 200 m (656 ft) in bottom depth. The distribution of the bathymetry provinces over the entire Q-20 Study Area is provided in **Table B-1.**

A single SVP province includes the entire Q-20 Study Area. The seasonal variation is somewhat limited in its dynamic range, as might be expect given that the range is located in temperate waters. The winter profile‘s surface sound speed profile is approximately 25 meters per second (m/sec) (56 knots [kn]) slower than the summer profile, as depicted in **Figure B-1**, and features a 50 m (164 ft) surface duct.

Table B-1. Distribution of Bathymetry Provinces in the Q-20 Study Area

Province Depth (m) (ft)	Frequency of Occurrence (%)
20 (66)	12.48
40 (131)	16.88
80 (262)	14.21
160 (525)	23.63
320 (1,050)	22.39
640 (2,100)	4.38

m = meters; ft - feet

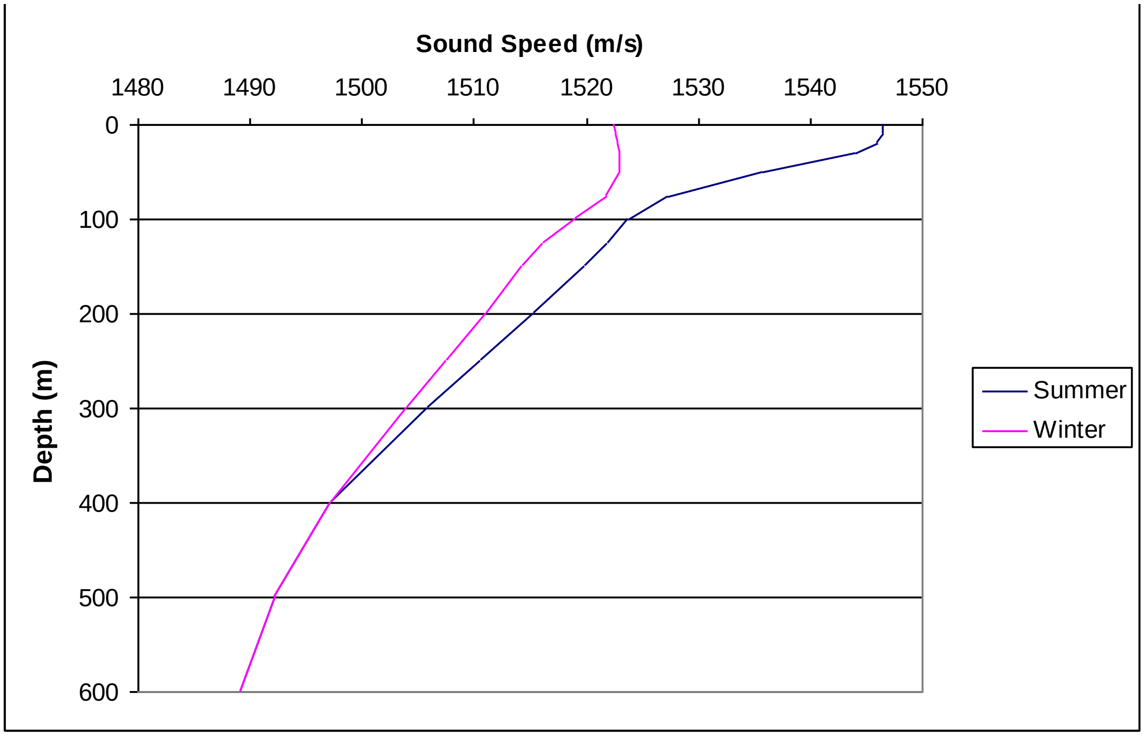

Figure B-1. Winter and Summer SVPs in the Q-20 Study Area

The two HFBL classes represented in the Q-20 Study Area are low-loss bottom (Class 2, typically found in shallow water) and high-loss bottom (Class 8). The distribution presented in **Table B-2** indicates that the high-loss bottom dominates.

Table B-2. Distribution of Sound Speed Provinces in the Q-20 Study Area

HFBL Class	Frequency of Occurrence (%)
2	28.97
8	71.03

The variation in sound speed profiles among the three provinces is quite minimal; indeed, due to the tropical location even the seasonal variability is quite small. This is illustrated in **Figure B-1**, which displays the upper 1,000 m (3,281 ft) of the winter and summer profiles.

The three LFBL provinces represented in the Q-20 Study Area have densities ranging from coarse sand to clayey silt. Their distribution is identified in **Table B-3**.

Table B-3. Distribution of LFBL Classes in the Q-20 Study Area

HFBL Class	Frequency of Occurrence (%)
Coarse Sand	66.39
Fine Sand	7.27
Clayey Silt	26.34

Table B-4. Distribution of Environmental Provinces in the Q-20 Study Area

Environmental Province	Water Depth (m) (ft)	HFBL Class	LFBL Province	Sediment Thickness (sec)	Frequency of Occurrence (%)
1	20 (66)	2	0	0.2	12.48
2	40 (131)	2	0	0.2	14.44
3	80 (262)	2	– 49*	0.57	0.46
4	320 (1050)	2	0	0.95	4.54
5	640 (2100)	2	– 49*	0.2	4.37
6	40 (131)	2	– 49*	0.2	2.36
7	80 (262)	2	13	0.2	12.13
8	160 (525)	2	13	0.2	14.20
9	320 (1050)	2	13	0.2	0.01
10	40 (131)	8	– 49*	0.2	0.08
11	80 (262)	8	0	0.2	1.62
12	160 (525)	8	0	0.2	9.43
13	320 (1050)	8	0	0.2	17.83
14	640 (2100)	8	0	0.2	0.01

HFBL = High-Frequency Bottom Loss; LFBL = Low-Frequency Bottom Loss; m = meters; ft = feet; sec = seconds; GOM = Gulf of Mexico

* Negative numbers indicate provinces that were developed as part of the Shallow-Water Upgrade to the LFBL database. These provinces are primarily limited to water depths 50-800 m (164-2,625 ft) in the GOM, but do not necessarily cover all such areas.

The logic for consolidating the environmental provinces focuses upon water depth, using bottom type as secondary differentiating factors, as depicted in **Table B-4**. The first consideration is to ensure that all eight bathymetry provinces are represented. Environmental provinces that occur in less than one percent of the Q-20 Study Area are consolidated with similar provinces (using water depth first and then HFBL as the rules for consolidation). Next, any remaining small province that has a reasonable proxy (that is, the same water depth and HFBL province) is consolidated with its comparable province. This results in the following mapping of raw environmental provinces into an initial subset in **Table B-5**.

Table B-5. Initial Subset of Provinces

Raw Province	Subset Province
3	7
6	2
9	4
10	2
14	5

The resulting distribution of the eleven environmental provinces used to model the narrowband sources in the Q-20 Study Area modeling is described in **Table B-6**.

1 **Table B-6. Distribution of Environmental Provinces in the Q-20 Study Area**

Environmental Province	Water Depth (m) (ft)	HFBL Class	LFBL Province	Sediment Thickness (sec)	Frequency of Occurrence (%)
1	20 (66)	2	0	0.2	12.48
2	40 (131)	2	0	0.	16.88
4	320 (1,050)	2	0	0.95	4.55
5	640 (2,100)	2	– 49*	0.2	4.38
7	80 (262)	2	13	0.2	12.59
8	160 (525)	2	13	0.2	14.20
11	80 (262)	8	0	0.2	1.62
12	160 (525)	8	0	0.2	9.43
13	320 (1,050)	8	0	0.2	17.83

HFBL = High-Frequency Bottom Loss; LFBL = Low-Frequency Bottom Loss; m = meter(s); ft = foot/feet; sec = second(s); GOM = Gulf of Mexico

* Negative numbers indicate provinces that were developed as part of the Shallow-Water Upgrade to the LFBL database. These provinces are primarily limited to bottom depths of 50-800 m (164-2,625 ft) in the GOM, but do not necessarily cover all such areas.

Appendix C – Definitions and Metrics for Acoustic Quantities

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

°C	degrees Celsius
°F	degrees Fahrenheit
ρ	fluid density
ρc	impedance
µPa	micropascal(s)
c	sound speed
c_w	speed of sound in water
dB	decibel(s)
dB re 1 µPa	decibel(s) referenced to 1 micropascal
dB re 1 µPa-m	decibel(s) referenced to 1 micropascal at 1 meter
dB re 1 μPa^2-s	decibel(s) referenced to 1 micropascal squared second
EL	energy flux density level
ft	foot/feet
ft^3	cubic foot/feet
ft/s	foot/feet per second
g/cm^3	gram per cubic centimeter
hr	hour(s)
in^3	cubic inch(es)
J	Joule(s)
J/m^2	Joule(s) per square meter
kg/m^3	kilogram(s) per cubic meter
kW-hr	kilowatt hour(s)
kHz	Kilohertz
Km	kilometer(s)
kPa	Kilopascal(s)
kWs	Kilowatt Second(s)
lb	pound(s)
M	meter(s)
m/sec	meter(s) per second(s)
N/m^2	Newton(s) per square meter
nmi	nautical mile(s)
oz	ounce(s)
p	Pressure
Pa	Pascal(s)
p_o	reference pressure
p_{rms}	root mean square pressure
psf	pound(s) per square foot/feet
psi	pound(s) per square inch(es)
PTS	permanent threshold shift
Q-20	AN/AQS-20A Mine Reconnaissance Sonar System
sec	second(s)
SI	source intensity
SL	sound level
SPL	sound pressure level
t	duration of signal
TTS	temporary threshold shift
W/m^2	watt(s) per square meter
Ws	watt second(s)

DEFINITIONS AND METRICS FOR ACOUSTIC QUANTITIES

This appendix provides reference materials on some of the more important metrics and units used in the report. It is intended to provide basic information, with references to further information.

C.1 Some Fundamental Definitions of Acoustics

Sound and Acoustics

Paraphrasing Beranek (1986), sound is defined as a disturbance propagated through an elastic medium, causing a change in pressure or a displacement of particles.

Sound is produced when an elastic medium is set into motion, often by a vibrating object within the medium. As the object vibrates, its motion is transmitted to adjacent –particles” of the medium. The motion of these particles is transmitted to adjacent particles, and so on. The result is a mechanical disturbance (the –sound wave”) that moves away from the source and propagates at a medium-dependent speed (the –sound speed”). As the sound wave travels through the medium, the individual particles of the medium oscillate about their static positions but do not propagate with the sound wave. As the particles of the medium move back and forth they create small changes, or perturbations, about the static values of the medium density, pressure, and temperature.

Density

For a static, homogeneous volume of matter, density is the mass per unit volume. In seawater, the average density is about 1,026 kilograms per cubic meter (kg/m^3) (2,262 pounds [lbs] per 35.3 cubic feet [ft^3]), or 1.026 gram per cubic centimeter (g/cm^3) (0.036 ounces (oz) per 0.061 cubic inch [in^3]). In air, density varies substantially with altitude and with time. A typical value at sea level and 20 degrees Celsius (°C) (68 degrees Fahrenheit [°F]) is 1.21 kg/m^3 (2.67 lbs per 0.061 in^3) or 0.00121 g/cm^3 (4.27e-5 oz per 0.061 in^3).

Pressure

Pressure (in mechanics) is a type of stress that is exerted uniformly in all directions; its measure is the force exerted per unit area (Lapedes 1978).

In a fluid (gas or liquid), pressure at a point is defined as follows. For an arbitrarily small area containing the point, the pressure is the normal force applied to the small area divided by the size of the small area.

Static Pressure (in acoustics) is, at a point in a fluid (gas or liquid), the pressure that would exist if there were no sound waves present (Beranek 1986).

Because pressure is a force applied to a unit area, it does not necessarily generate energy. Pressure is a scalar quantity; there is no direction associated with pressure, though a pressure wave may have a direction of propagation. Pressure has units of force/area. The source intensity

(SI) derived unit of pressure is the Pascal (Pa) defined as one newton per square meter (N/m^2). Alternative units are many (pounds per square feet [psf], bars, inches of mercury, etc.); some are listed at **Section C.4** of this appendix.

Acoustic Pressure

Without limiting the discussion to small amplitude or linear waves, acoustic pressure is defined as the residual pressure over the “average” static pressure caused by a disturbance. As such, the “average” acoustic pressure is zero. Here the “average” is usually taken over time.

Mean-Square Pressure is usually defined as the short-term time average of the squared pressure:

$$\frac{1}{T}\int_{\tau}^{\tau+T} p^2(t)dt \quad ,$$

where *T* is on the order of several periods of the lowest frequency component of the time series.

Root Mean Square (RMS) Pressure is the square root of the mean-square pressure.

Impedance

In general impedance measures the ratio of force amplitude to velocity amplitude. For plane waves, the ratio is ρc, where ρ is the fluid density and *c* the sound speed.

Equivalent Plane Wave Intensity

As noted by Bartberger (1965), it is general practice to measure (and model) pressure (p) or rms pressure (p_{rms}), and then infer an intensity from the formula for plane waves in the direction of propagation:

$$\text{Intensity} = (p_{rms})^2/\rho c.$$

Such an inferred intensity should properly be labeled as the equivalent plane-wave intensity in the propagation direction.

Energy Flux Density

Sound energy can be described by the sound energy flux density (EFD), which is the sound power flow per unit area, or the time integral of instantaneous intensity. For plane waves,

$$EFD = \frac{1}{\rho c}\int_{0}^{T} p^2(t)dt,$$

where ρc is the impedance and *t* is the duration of the signal. Units are Joule(s) per square meter (J/m^2). Note that EFD is the time-averaged squared pressure multiplied by the averaging time.

C.2 Definitions Related to Sound Sources, Signals, and Effects

Source Intensity

Source intensity, $I(\theta,\phi)$, is the intensity of the projected signal referred to a point at unit distance from the source in the direction (θ,ϕ). (θ,ϕ) is usually unstated; in that case, it is assumed that propagation is in the direction of the axis of the main lobe of the projector‘s beam pattern.

Source Power

For an omni-directional source, the power radiated by the projector at range *r* is $I_r(4\pi r^2)$ where I_r is the radiated intensity at range *r* (in the far field). If intensity has SI units of watts per square meter (W/m^2), then the power has units of *W*. The result can be extrapolated to a unit reference distance if either I_1 is known or $I_r = I_1/r^2$. Then the source power at unit distance is $4\pi I_1$, where I_1 is the intensity (any direction) at unit distance in units of power/area.

Pure Tone Signal or Wave (related: Continuous Wave, CW, Monochromatic Wave, Unmodulated Signal)

Each term means a single-frequency wave or signal, but perhaps limited in time (gated). The actual bandwidth of the signal will depend on duration and context.

Narrowband Signal

Narrowband is a non-precise term. It is used to indicate that the signal can be treated as a single frequency carrier signal, which is made to vary (is modulated) by a second signal whose bandwidth is smaller than the carrier frequency. In dealing with sonars, a bandwidth less than about 30 percent of center frequency is often spoken of as narrowband.

Hearing Threshold

“The threshold of hearing is defined as the sound pressure at which one, listening with both ears in a free field to a signal of waning level, can still just hear the sound, or if the signal is being increased from a level below the threshold, can just sense it” (Magrab, 1975, p. 29).

“A threshold of audibility for a specified signal is the minimum effective sound pressure of that signal that is capable of evoking an auditory sensation (in the absence of noise) in a specified fraction of trials” (Beranek, 1986, p. 394).

Temporary (Hearing) Threshold Shift

“The diminution, following exposure to noise, of the ability to detect weak auditory signals is termed temporary threshold shift (TTS), if the decrease in sensitivity eventually disappears…” (Magrab, 1975, p. 35).

Permanent (Hearing) Threshold Shift

“The diminution, following exposure to noise, of the ability to detect weak auditory signals is termed TTS, if the decrease in sensitivity eventually disappears, and noise-induced permanent threshold shift (PTS) if it does not” (Magrab, 1975, p. 35).

C.3 Decibels and Sound Levels

Decibel

Because practical applications of acoustic power and energy involve wide dynamic ranges (e.g., from 1 to 1,000,000,000,000), it is common practice to use the logarithm of such quantities. The use of a logarithmic scale compresses the range of numerical values that must be used. For a given quantity *Q*, define the decibel (dB) as:

$$10 \, log \, (Q/Q_0) \text{ dB re } Q_0$$

where Q_0 is a reference quantity and *log* is the base-10 logarithm.

When a numeric value is presented in dB, it is important to also specify the numeric value and units of the reference quantity. Normally the numeric value is given, followed by the text “re”, meaning “with reference to”, and the numeric value and unit of the reference quantity (Harris, 1998). For example, a pressure of 1 Pa, expressed in decibels with a reference of 1 microPascal, is written 120 dB re 1 μPa.

The word “level” usually indicates dB quantity (e.g., *sound pressure level* or *spectrum level*). Some specific examples for this document follow.

Sound Pressure Level

For pressure *p*, the sound pressure level (SPL) is defined as follows:

$$\text{SPL} = 10 \log (p^2/p_0{}^2) \text{ dB re } 1 \, p_0{}^2 ,$$

where p_0 is the reference pressure (usually 1 micropascal [μPa] for underwater acoustics and 20 μPa for in-air acoustics). The convention is to state the reference as p_0 (with the square implicit).

For a pressure of 100 μPa, the SPL would be

$$10 \log [(100 \, \mu\text{Pa})^2 / (1 \, \mu\text{Pa})^2] \text{ dB re } 1 \, \mu\text{Pa}$$

$$= 40 \text{ dB re } 1 \, \mu\text{Pa}$$

This is about the lowest level that a dolphin can hear in water.

Source Level

Refer to source intensity above. Define source level as SL(θ,ϕ) = 10 log[I(θ,ϕ)/I_0], where I_o is the reference intensity (usually that of a plane wave of rms pressure 1 μPa). The reference pressure and reference distance must be specified. When SL does not depend on direction, then the source is said to be omnidirectional*;* otherwise it is directive*.*

Intensity Level

It is nearly universal practice to use SPL in place of intensity level. This makes sense as long as impedance is constant. In that case, intensity is proportional to short-term-average, squared pressure, with proportionality constant equal to the reciprocal of the impedance.

When the impedance differs significantly in space or time (as in noise propagation from air into water), the intensity level must specify the medium change and/or the changes in impedance.

Intensity Levels in Water and in Air as Functions of Pressure and SPL

Unlike pressure, the metrics for intensity depend on the acoustic impedance of the medium. Thus, for example, under the assumption of plane waves, the same pressure (first three columns) causes different intensities in water and in air, as shown in **Table C-1**:

Table C-1 Intensity Levels as Functions of Pressure and SPL

Pressure (rms)	SPL (re 1 μPa)	SPL (re 20 μPa)	Intensity in Water (W/m^2)	Intensity in Air (W/m^2)
1 μPa = 10^{-5} dyn/cm^2	0 dB	-26 dB	6.7 10^{-19}	2.4 10^{-15}
20 μPa = 0.0002 μbar	26 dB	0 dB	2.7 10^{-16}	9.6 10^{-13}
1.2 10^9 μPa = 1.2 kPa	181.8 dB	155.8 dB	1	3600
1 psi = 6.9 10^9 μPa	196.8 dB	170.8 dB	31.8	1.1 10^5
1.77 10^{10} μPa	205 dB	179.0 dB	252.6	8.7 10^5
3.2 10^{10} μPa = 66.7 psf	210 dB	184 dB	660.7	2.4 10^6
3.2 10^{12} μPa = 3200 kPa	250 dB	224 dB	6.6 10^6	2.4 10^{10}

rms = root mean square; SPL = sound pressure level; W/m^3 = watts per square meter; psi = pounds per square inch; μPa = micropascals; kPa = kilopascals; dB = decibels; psf = pounds per square foot

Energy (Flux Density) Level (EL) Referred to $Pressure^2$ Time

Note that the abbreviation ―EL" is not in general usage, but is used here for convenience.

Just as the usual reference for intensity level is pressure (and not intensity itself), the reference often (but not always) used for EL is pressure^2 time. This makes sense when the impedance is constant. Some examples of conversions follow:

Suppose the integral of the plane-wave pressure-squared time is 1 μPa^2-s. Since impedance for water is 1.5 10^{12} μPa(s/m), the EFD is then

$$(1\ \mu Pa^2\text{-s})/(1.5\ 10^{12}\ \mu Pa(s/m)) = 6.66\ 10^{-13}\ \mu Pa\text{-m} = 6.66\ 10^{-19}\ J/m^2$$

Thus an EL of 0 dB (re 1 μPa^2-s) corresponds to an EFD of 6.66 10^{-19} J/m^2 (in water).

It follows that thresholds of interest for impacts on marine life have values in water as follows:

190 dB (re 1 μPa^2-s) = 10^{19} x 6.66 10^{-19} J/m^2 = 6.7 J/m^2
195 dB (re 1 μPa^2-s) = 21.2 J/m^2
200 dB (re 1 μPa^2-s) = 66.7 J/m^2
205 dB (re 1 μPa^2-s) = 210.6 J/m^2
215 dB (re 1 μPa^2-s) = 2106.1 J/m^2

Given that 1 J = 1 Ws, notice that these energies are small. Applied to an area the size of a person, 215 dB would yield about 2000 J, or about 2 kWs or about .0006 kW-hr.

C.4 Some Constants and Conversion Formulas

Speed of Sound in Water (c_w)

The speed of sound in water varies no more than 3 percent over geographic area, depth and season. For rough estimates of impedance and travel time, nominal values of 1,500 m/sec and 5,000 feet per second (ft/s) are often used.

Typical Density and Sound Speed of Sea Water

Water Density (4°C) = $\rho_w \approx 1\ g/cm^3 = 10^3\ kg/m^3 \approx 1.94\ slug/ft^3 \approx 62.43\ lb\ (mass)/ft^3$

Sound Speed = $c_w \approx 1500\ m/s = 1.5\ 10^5\ cm/s \approx 4920\ ft/s \approx 59040\ in/s$

Characteristic Impedance of Water

$$\rho_w c_w \approx 1.5\ 10^6\ kg/s\ m^2 = 1.5\ 10^6\ rayl = 1.5\ 10^5\ g/s\ cm^2$$
$$= 1.5\ 10^{12}\ \mu Pa\ (s/m) = 1.5\ 10^5\ (dyn/cm^2)(s/cm) \approx 9544.8\ slugs/ft^2\ s$$
$$\approx 3.072\ 10^5\ lb(mass)/ft^2\ s$$

<u>Length</u>
1 nmi = 1.85325 km
1 m = 3.2808 ft

<u>Speed</u>
1 knot = 0.514791 m/sec = 1.85325 km/hr
1 m/sec= 3.2808 ft/s = 196.85 ft/min
1 m/sec = 1.94254 knots

<u>Pressure</u>
1 Pa = 1 N/m^2 = 1 J/m^3 = 1 kg/m s^2
1 Pa = 10^6 μ Pa = 10 dyn/cm^2 = 10 μbar
1 μPa = 10^{-5} dyn/cm^2 = 1.4504·10^{-10} psi
1 kPa = 1000 Pa = 10^9 μPa = 0.145 psi = 20.88 psf

<u>Power</u>
1 W = 1 J/s = 1 Nm/s = 1 kg m^2/s^2
1 W = 10^7 erg/s

<u>Energy (Work)</u>
1 J = 1 N m = 1 kg m^2/s^2
1 J= 10^7 g cm^2/s^2 = 1 W s
1 erg = 1 g cm^2/s^2 = 10^{-7} J
1 kW hr = (3.6) 10^6 J

<u>Acoustic Intensity</u>
1 W/m^2= 1 Pa (m/sec) = 10^6 μPa (m/sec)
1 W/m^2= 1 J/(s m^2) = 1 N/m s
1 psi in/s = 175 W/m^2 = 1.75 10^8 μPa (m/sec)
1 lb/ft s = 14.596 J/m^{2}s = 14.596 W/m^2
1 W/m^2 = 10^7 erg/m^{2}s = 10^3 erg/cm^{2}s

<u>Acoustic Energy Flux Density</u>
1 J/m^2 = 1 N/m = 1 Pa m = 10^6 μPa m = 1 W s/m^2
1 J/m^2 = 5.7 10^{-3} psi in = 6.8 10^{-2} psf ft
1 J/cm^2 = 10^4 J/m^2 = 10^7 erg/cm^2
1 psi in = 175 J/m^2 = 1.75 10^8 μPa m

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